Quarterly Publication
ISSN 3572 - 2383

Global Journal of Environmental Science and Management

Volume 8, Number 2, Spring 2022

Global Journal of Environmental Science and Management (GJESM)

(QUARTERLY PUBLICATION)

OPEN ACCESS

Editorial Contact Information
No. 2, Unit 213, Kouhestan Deadend,
Janpour Street, Darabad Square,
Tehran, Iran
Phone: +9821-26105110-11
Email: *gjesm.publication@gmail.com*
editor@gjesm.net

Website: https://www.gjesm.net/

Publication Center
GJESM Publisher
publisher@gjesm.net

Editorial Board

Publication authorization is certified by the Ministry of Culture and Islamic Guidance; No. 93/3629; 14 May 2014
Scientific-Research grade is accredited by the Ministry of Science, Research and Technology; No. 3/18/59975; 20 June 2015

Let s work together to publish the knowledge and science to serve better the environment

Circulation: 500

***p*ISSN 2383 - 3572** **eISSN 2383 - 3866**

Aims and Scope

Global Journal of Environmental Science and Management (GJESM) is an international scholarly refereed research journal which aims to promote the theory and practice of environmental science and management. A broad outline of the journal's scope includes; peer reviewed original research articles, case and technical reports, reviews and analyses papers, short communications and notes to the editor, in interdisciplinary information on the practice and status of research in environmental science and management, both natural and man-made. The main aspects of research areas include, but are not exclusive to; environmental chemistry and biology, environments pollution control and monitoring, transport and fate of pollutants in the environment, concentrations and dispersion and trace of wastes in air, water, and soil, point and non-point sources pollution, heavy metals and organic compounds in the environment, atmospheric pollutants and trace gases, solid and hazardous waste management; soil biodegradation and bioremediation of contaminated sites; environmental impact assessment, industrial ecology, ecological and human risk assessment; improved energy management and auditing efficiency and environmental standards and criteria.

Vision and Mission

Global Journal of Environmental Science and Management (GJESM) publishes original. Peer-reviewed and technical environmental articles serve those environmental science and management through the on time quarterly publication with reliable information. GJESM is an integral partner with the scientific and technical communities, delivering superior information products and services that foster communication, build insights and enables individual and collective advancement in environmental research. Providing environmental science and management information to the general public with descriptions of contemporary advances in environmental issues to be used in improving environmental protection and management.

Abstracting and Indexing

Web of Science (ESCI); Scopus; Scimago Journal Rank (SJR); ProQuest (Agricultural and Environmental Science + Natural Science Collection + Ulrichsweb); Chemical Abstract (CAS); CABI Abstract; Global Health Abstract; Agricola; Committee on Publication Ethics (COPE); PubMed-NCBI; DOAJ; Open J-Gate; Google Scholar; Academia.edu; Geomar; WorldCat; Academic Resource Index; Environmental XPRT; Information Matrix for the Analysis of Journals (MIAR); Bibliothek Humburg; ScienceMedia; JournalTOCs; MSRT; ISC; RICeST; SID; Civilica; Magiran.

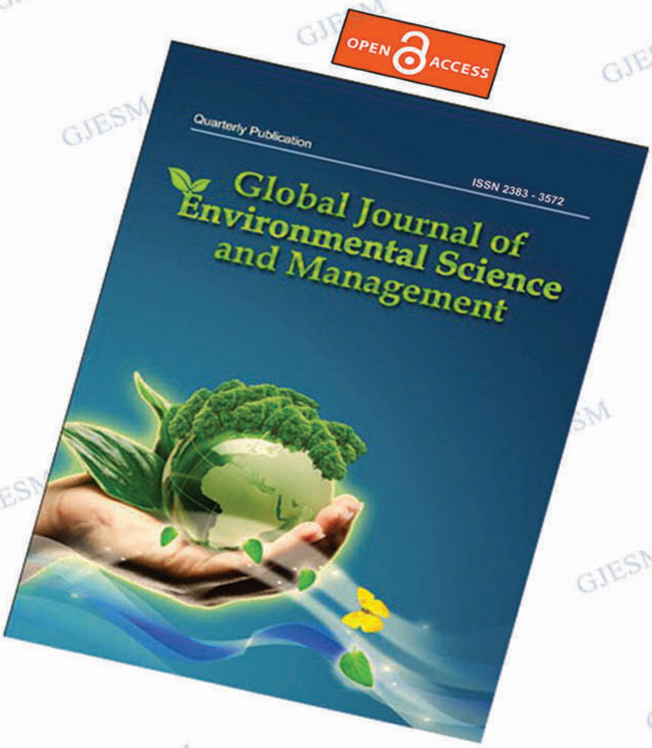
Global
Journal of Environmental Science and Management (GJESM)

Editor-in-Chief
Professor J. Nouri

pISSN 2383 - 3572
eISSN 2383 - 3866

QUARTERLY FULL OPEN ACCESS PEER REVIEWED PUBLICATION

Journal Abbreviation: Global J. Environ. Sci. Manage.



CALL FOR PAPERS

Publication benefits in
Global Journal of Environmental
Science and Management

- *Quarterly Publication journal*
- *Online submission and reviewing*
- *Online status inquiry*
- *Double blind peer reviewing*
- *Rapid evaluation and publication*
- *Immediate publication on the net*
- *Open access to all PDF full text of published articles*
- *No pay charge for publication*
- *Indexed and cited in well-known databases; particularly* Web of Science and Scopus

www.gjesm.net
www.gjesm.org

editor@gjesm.net
global.jesm@gmail.com
gjesm.publication@gmail.com

Tel.: +9821 2610 5110
Fax: +9821 2610 5111

CONTENTS

Volume 8, Number 2, Spring 2022

COVERING LETTER

Subject: **Submission of manuscript**

Dear Editor,

I would like to submit the following manuscript for possible evaluation

Manuscript Title:

Running Title (Short title):

Main Subjects:

Name and address of corresponding author:

Telephone #

Fax #

Email:

I affirm that the manuscript has been prepared in accordance with Global Journal of Environmental Science and Management guide for authors.

I have read the manuscript and I hereby affirm that the content of this manuscript or a major portion thereof has not been published in a refereed journal, and it is not being submitted fully or partially for publication elsewhere. The manuscript has been read and approved by all listed authors.

The source(s) of financial support of study (if any):

Type of Manuscript (check one):

- ☐ Original research paper
- ☐ Case report
- ☐ Research note
- ☐ Short communication
- ☐ Review paper

Name:

Corresponding Author Signature:

Date:

Global J. Environ. Sci. Manage. 8(2): 151-168, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Community behavior for mathematical model of coronavirus disease 2019 (COVID-19)

M. Ramli[1,*], M. Mukramati[1], M. Ikhwan[2] H. Hafnani[1]

[1]*Department of Mathematics, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia*

[2]*Graduate School of Mathematics and Applied Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia*

ARTICLE INFO

Article History:
Received 13 May 2021
Revised 24 July 2021
Accepted 26 August 2021

Keywords:
Basic reproduction number
Coronavirus disease 2019 (COVID-19)
Equilibrium point
Mask
Physical distancing

ABSTRACT

BACKGROUND AND OBJECTIVES: The spread of COVID-19 is very fast because it is transmitted from human to human. Non-pharmaceutical control is one of the important actions in reducing the spread of COVID-19, such as the use of masks and physical distancing. This study aims to model COVID-19 by incorporating people's habits as a non-pharmaceutical preventive measure. The model formed emphasizes the importance of preventing with masks and physical distancing. The implication of this action is that the infected population is decreasing, resulting in less interaction between the susceptible and the infected. In this case, the virus has not vanished from the community, but the use of masks in certain populations or subpopulations is lower than before, which can reduce mask waste in the environment

METHODS: This study expands on a previous MERS-CoV research model using the susceptible-exposed-infected-quarantine-recovery model by incorporating behavioral control, specifically the use of masks and physical distancing as preventive measures. The susceptible population that interacts with the carrier/exposed and infected population is used to calculate mask use. The susceptible population was divided into two subpopulations based on their willingness to wear masks. The following breakthrough is the application of the same system to the infected population, which is required to wear masks at all times during their self-isolation period. The model-generated equation system is a nonlinear system of differential equations. The developed model is examined by determining the equilibrium point and the basic reproduction number.

FINDINGS: The model resulted an asymptotically stable disease-free equilibrium and endemic equilibrium. The disease-free stability is only examined if the compliance with physical distancing exceeds 0.55 and the compliance with the use of distancing exceeds 0.55. This compliance condition resulted in a decrease in basic reproduction number ranging from 0.48 to 0.07. The endemic stability is only investigated if compliance with physical distancing is 0.1 and compliance with use of distancing is 0.2. The endemic condition can arise if masks and physical separation are not used. Physical distancing compliance and mask use have values less than 0.1 and 0.2, respectively

CONCLUSION: The analysis of the equilibrium points and basic reproduction numbers, show that increasing compliance in carrying out the health protocol measures of physical distancing and mask use causes a decrease in the spread of COVID-19, so that the disease will disappear over time. Meanwhile, ignoring health protocols has an effect on the long existence of the virus in the community.

DOI: 10.22034/gjesm.2022.02.01

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
36	4	4

*Corresponding Author:
Email: *marwan.math@unsyiah.ac.id*
Phone: +62 813-9766-8376
ORCID: 0000-0003-1225-9063

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

The world is currently dealing with a pandemic of a mysterious pheunomia disease known as Coronavirus Disease 2019 (COVID-19), which was discovered in December 2019 in Wuhan, Hubei province, China. COVID-19 has rapidly spread to all other countries around the world (Harapan *et al.*, 2020; WHO, 2021a). COVID-19 spreads quickly because the virus is transmitted from person to person via droplets that come out when talking, coughing, or sneezing, as well as direct contact with infected individuals (Eikenberry *et al.*, 2020). Based on this, the best way to limit the spread of COVID-19 cases is to avoid direct contact between humans (Soewono, 2020). Several steps have been taken to reduce human-to-human contact and prevent the spread of the COVID-19 virus. Lock downs (staying at home) have been imposed by governments all over the world as the primary and most effective means of reducing human contact. Other measures include travel restrictions (Wilder-Smith and Freedman, 2020), hand hygiene (washing hands) (Lin *et al.*, 2020), isolation, physical distancing (Chintalapudi *et al.*, 2020), avoiding public places or crowds, closing schools and offices, and wearing face masks (Li and De Clercq, 2020). Lock down activities (staying at home) can help to reduce the spread of COVID-19, but it will cause the economy to fall and a crisis to occur. As a result, governments in various countries that have implemented lockdown measures have been forced to lift the restrictions and allow people to resume their normal activities while still adhering to health protocols. Community behavior should adhere to applicable health protocols, such as avoiding public places or crowds (Garnett *et al.*, 2021), physical distancing (Sasmita *et al.*, 2020), hand hygiene (washing hands), and wearing face masks (Tran *et al.*, 2020). A person who has been exposed to COVID-19 will not develop symptoms right away because the severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2) virus has an incubation period after entering the human body. The SARS-Cov-2 virus has an average incubation period of 5.1 to 5.8 days, and symptoms appear after 11.5 to 15.6 days. If a person becomes infected with the virus, he or she must self-isolate for 14 days due to the virus's incubation period (Laeur *et al.*, 2020). Infected patients' initial symptoms, which range from flu and cough to chronic phase, can result in shortness of breath, acute complications, and even death (Phan *et al.*, 2020). According to (WHO, 2021a), 85% of positive cases infected with COVID-19 have mild symptoms or do not cause any symptoms at all, but they can still transmit the virus to others. According to the most recent WHO announcement (WHO, 2021b), the SARS-Cov-2 virus, which causes COVID-19 disease, can spread through the air produced by infected individuals' aerosol production. According to Arslan *et al.* (2020), droplets that come out of infected individuals within a certain distance range (1 m) can enter the mucosal surface, so that face-to-face conversation, coughing, sneezing, and breathing can cause the spread of droplets from the respiratory tract. The droplets will combine to form an aerosol, which will spread over a long distance (> 1 m) and last for a long time in the environment. The SARS-Cov-2 virus can also survive in aerosols for 3 hours and is even more stable when attached to plastic (72 hours), steel surfaces (48 hours), copper (4 hours), and cardboard (24 hours) (Doremalen *et al.*, 2020). As a result, WHO (2020a) stated that one of the steps to prevent the spread of COVID-19 is to use masks, particularly in public places where physical distancing measures are not possible. However, the use of masks must be part of a comprehensive COVID-19 prevention strategy that includes other health protocols. The use of masks is widely believed to prevent droplets from escaping from infected individuals and carriers. Based on this, it makes sense to recommend the use of masks for vulnerable individuals in order to avoid infection (MacIntyre *et al.*, 2021). Masks serve a dual purpose: if worn by susceptible individuals, they provide protection against infectious or non-infectious diseases transmitted by infected individuals, and if worn by infected individuals, they provide source control against disease transmission or do not transmit disease to other individuals (Lo *et al*. 2021; Bagepally *et al.*, 2021). Surgical masks reduce *P. Aeruginosa*-infected aerosols produced by coughing by more than 80% in cystic fibrosis patients (Driessche *et al.*, 2015). According to the findings of Stockwell *et al.* (2018), N95 masks outperform surgical (medical) masks. Eikenberry *et al.* (2020) estimate that the efficiency of cloth masks is between 20% and 80%, and possibly higher (well made and tightly fitted and made of good material). For surgical masks, the percentage ranges from 70% to 90%, while for N95 masks, the percentage ranges from 95% to 100%. Because non-medical masks are more commonly used than other types of masks by the general public, understanding the characteristics of non-media masks that are suitable for use to protect themselves from COVID-19 is critical. According to the WHO (2020b), non-medical masks should have three layers: 1) an innermost layer of a hydrophilic material (such as cotton or cotton blends); 2) an outer layer of a hydrophobic material (such as polypropylene, polyester, or a combination of both) that can limit contamination from outside penetrating the wearer's nose and mouth; 3) a hydrophobic middle layer made of a synthetic non-woven material such as polypropylene or cotton lining that can improve filtration or retain droplets. As time passes, countries around the world continue to struggle against COVID-19, and governments continue to encourage their citizens to wear masks when visiting public places or crowds in order to be protected. This has resulted in the widespread use of masks all over the world (Lyu *et al.*, 2020). Each month, the WHO estimates that nearly 89 million procedural masks will be required to control COVID-19 (WHO, 2021a). According to a press conference study on the Control Mechanism of the State Council of China in 2020, approximately 468.9 tonnes of medical waste are generated every day as a result of COVID-19. In Jakarta, Indonesia, however, it was discovered that the amount of medical waste had reached 12,740 tons approximately 60 days after people were first infected with the corona virus (Kojima *et al.*, 2020). The use of masks is indeed critical in order to protect indiviuals from COVID-19, but the increased use of masks has resulted in an increase in mask production. As a result, new environmental challenges emerge, such as the growing accumulation of medical mask waste. If the virus can be eradicated in the community, the use of masks can be reduced, potentially reducing mask waste in the environment. This study is based on the development of a mathematical model by adding community behavior as a non-pharmaceutical preventive measure (using masks and physical distancing) as well as having quarantine classes as a place to treat diseases that can minimize the spread of COVID-19. In this study, the susceptible-exposed-infected-quaratine-recovery (SEIQR) model was used by separating the susceptible and infected population into two subpopulations, respectively. There are susceptible subpopulation not using masks (S_1), the susceptible subpopulation using masks (S_2), the infection subpopulation not using masks (I_1) and the infection subpopulation using masks (I_2). The addition of a quarantine population to the model is the same as that done by Mandal *et al.* (2020). Based on the motivation above, this study aims to model COVID-19 by including community behavior (adherence to using masks and physical distancing) in the SEIQR model as a non-pharmaceutical preventive measure. This study is simulated at the Modeling and Simulation Laboratory, Department of Mathematics, Syiah Kuala University, Indonesia in 2021.

MATERIALS AND METHODS

This study expands on the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) distribution model developed by Manaqib *et al.* (2019), in which the MERS-CoV model is an SEIR type model that divides the population into four populations: susceptible, exposed, infected, and recovered. To create the SEIQR model, the SEIR model was modified by incorporating a new population class, quarantine (Q). Several non-pharmaceutical controls, such as mask use and physical distancing, were also added to reduce the spread of COVID-19. Each susceptible and infected population is subdivided into two subpopulations. As a result, the SEIQR's five populations are divided into two susceptible subpopulations, one exposed population, two infected subpopulations, one quarantine population, and one recovery population. The total population at time t is denoted as $N(t)$, and there are seven population/subpopulations: susceptible individuals who do not use masks ($S_1(t)$), susceptible individuals who do use masks ($(S_2(t)$), exposed individuals ($(E(t)$), infected individuals who do not use masks ($I_1(t)$), infected individuals who use masks ($I_2(t)$), quarantine individuals ($Q(t)$), and recovery individuals ($R(t)$). With the total population studied is defined using Eq. 1.

$$N(t)=S_1(t)+S_2(t)+E(t)+ \\ I_1(t)+I_2(t)+Q(t)+R(t) \quad (1)$$

The birth and death rates of individuals in the subpopulation are assumed to be equal in this model (μ). Newborns will be included in the subpopulations of susceptible individuals who do not use masks S_1. In Susceptible S_2 and infected I_2 who use masks, all of whom are considered uninfected and COVID-19 free. If susceptible S_2 and infected I_2 people who wear masks stop wearing them, they will be included in the subpopulation of susceptible S_1 and infected I_1 people who did not wear masks, and vice versa. Furthermore, if susceptible S_1 and infected I_1 individuals do not take physical distance measures, they have the potential to become infected and infect others, making them the exposed *E*. Individuals in the quarantine subpopulation Q have been determined to be unable to transmit the disease and are receiving treatment. Individuals who have been exposed to COVID-19 carry the SARS-Cov-2 virus but have not transmitted it. Individuals who have been exposed E and infected I_1, I_2 can then be identified as having a SARS-CoV2 virus in their bodies using rapid tests, antigens, and swabs, and they are added to the quarantine individual sub-population Q. Quarantine individuals are people who have tested positive for COVID-19 via rapid, antigen, or swab tests, and quarantine facilities are places of care for people who have tested positive for COVID-19 via rapid, antigen, or swab tests. If any quarantined individuals recover from the disease, they will be added to the recovered sub-population R. Individuals infected I_1, I_2 can recover naturally without disease treatment and are classified as part of the recovered subpopulation *R*. The recovery population *R* can be re-infected, but not to population *I*. The re-infected path is *R* to *S* with the number regulated by the reinfected parameter. Death occurs only naturally in each populations/subpopulations. Based on this, a mathematical model diagram of the spread of COVID-19 and the Eq. 1 are obtained in Fig. 1.

The non-linear differential equation of Fig. 1 is defined using Eqs. 2 to 8.

$$\frac{dS_1}{dt} = \mu N + \kappa_1 R + u_2 S_2 - u_1 S_1 - \beta(1-\varepsilon) S_1 I_1 - \mu S_1 \qquad (2)$$

$$\frac{dS_2}{dt} = \kappa_2 R + u_1 S_1 - u_2 S_2 - \mu S_2 \qquad (3)$$

$$\frac{dE}{dt} = \beta(1-\varepsilon) S_1 I_1 - \delta E - \alpha E - \mu E \qquad (4)$$

$$\frac{dI_1}{dt} = \delta E + u_2 I_2 - u_1 I_1 - \sigma I_1 - \eta I_1 - \mu I_1 \qquad (5)$$

$$\frac{dI_2}{dt} = u_1 I_1 - u_2 I_2 - \sigma I_2 - \eta I_2 - \mu I_2 \qquad (6)$$

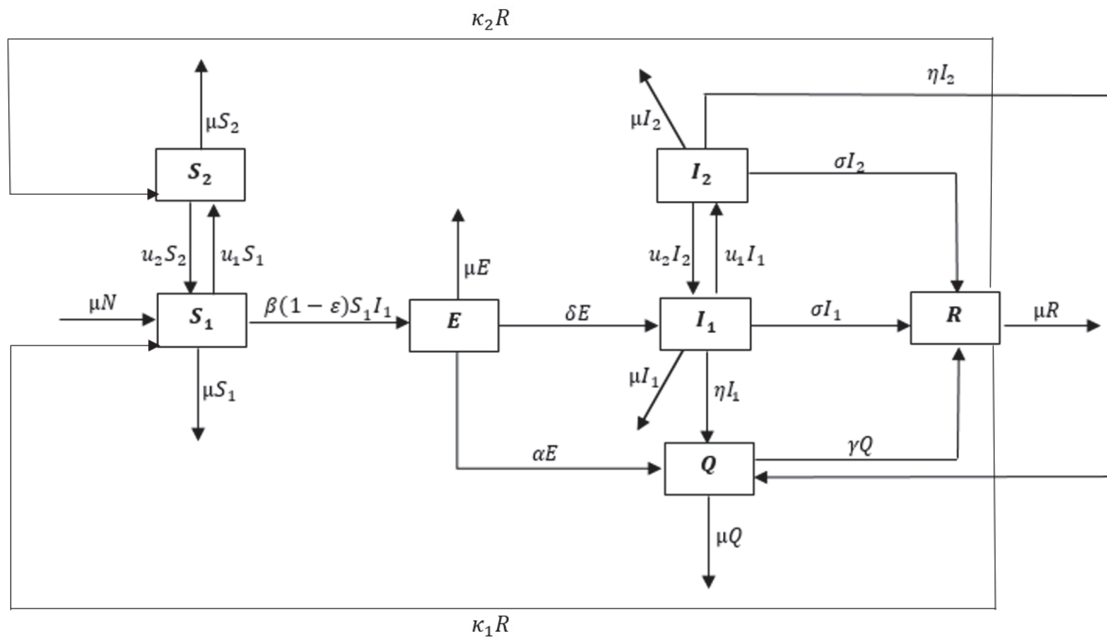


Fig. 1: Diagram of the process of spreading COVID-19 with the use of masks and physical distancing

$$\frac{dQ}{dt} = \alpha E + \eta I_1 + \eta I_2 - \gamma Q - \mu Q \quad (7)$$

$$\frac{dR}{dt} = \sigma I_1 + \sigma I_2 + \gamma Q - (\kappa_1 + \kappa_2 + \mu) R \quad (8)$$

The parameter $\beta(1-\varepsilon)$ in Eqs. 2 and 4 quantifies the extent to which susceptible individuals S_1 will be included in the exposed subpopulation E due to a lack of physical distancing measures. The level of transmission of COVID-19 disease is denoted by β, and $0 < \varepsilon < 1$ is the proportion of people who physically distance themselves from others. The parameter δ represents the number of people who have been exposed to the SARS-CoV2 virus during its incubation period and are included in the subpopulation of infected people who are not wearing a mask, whereas the parameter α represents the number of people who have had a positive rapid, antigen, or swab test and are included in the quarantine subpopulation to receive treatment. η is the proportion of infected people who receive disease treatment and are included in the quarantine subpopulation. In Eqs. 2, 3, 5 and 6, $0 < u_1 + u_2 < 1$ is the level of individuals who use masks and do not use masks. Susceptible S_1 and infected I_1 individuals who begin implementing the health protocol using masks will be included in the subpopulation of susceptible S_2 and infected I_2 individuals as u_1. In turn, susceptible S_2 and infected I_2 individuals who begin to discontinue the use of masks in the health protocol will be included in the subpopulation of susceptible S_1 and infected I_1 individuals as u_2. Furthermore, parameter γ in Eq. 7 denotes infected and exposed individuals who recovered by receiving treatment in the quarantine subpopulation and were then included in the cured subpopulation R, whereas infected individuals who recovered naturally without receiving treatment were included in the cured subpopulation R as much as σ (Eq. 8). Eqs. 2 to 8 can be simplified by forming the proportion of the number of individuals in a subpopulation with the total population, which is expressed using Eq. 9.

$$s_1 = \frac{S_1}{N}, s_2 = \frac{S_2}{N}, e = \frac{E}{N}, i_1 = \frac{I_1}{N}, \\ i_2 = \frac{I_2}{N}, q = \frac{Q}{N}, r = \frac{R}{N} \quad (9)$$

Where, Eq. 9 is substituted into Eqs. 2 to 8, the Eqs. 10 to 16 are obtained.

$$\frac{ds_1}{dt} = \mu + \kappa_1 r + u_2 s_2 - u_1 s_1 \\ -\beta(1-\varepsilon) s_1 i_1 - \mu s_1 \quad (10)$$

$$\frac{ds_2}{dt} = \kappa_2 r + u_1 s_1 - u_2 s_2 - \mu s_2 \quad (11)$$

$$\frac{de}{dt} = \beta(1-\varepsilon) s_1 i_1 - \delta e - \alpha e - \mu e \quad (12)$$

$$\frac{di_1}{dt} = \delta e + u_2 i_2 - u_1 i_1 - \sigma i_1 - \eta i_1 - \mu i_1 \quad (13)$$

$$\frac{di_2}{dt} = u_1 i_1 - u_2 i_2 - \sigma i_2 - \eta i_2 - \mu i_2 \quad (14)$$

$$\frac{dq}{dt} = \alpha e + \eta i_1 + \eta i_2 - \gamma q - \mu q \quad (15)$$

$$\frac{dr}{dt} = \sigma i_1 + \sigma i_2 + \gamma q - (\kappa_1 + \kappa_2 + \mu) r \quad (16)$$

The symbols of variables and parameters used in the model are summarized in Tables 1 and 2.

The parameter values used in this study were derived from publicly available COVID-19 data as well as literature sources such as journals, articles, and so on. The parameter values were set to be $\delta = 0.3$ from exposed to infected individuals (Mandal *et al.,* 2020). Individuals who have been exposed to COVID-19 will not immediately show symptoms, because the COVID-19 virus will experience an incubation period. Some studies estimate that if someone is exposed to COVID-19, they must isolate themselves for 14 days, where the average incubation period of the virus is 5.1 to 5.6 days and some start showing symptoms on days 11.5 to 15.6 (Laeur, 2020). Parameter value of recovered individuals after quarantine $\eta = 1/14$ (Tang *et al.,* 2020). Furthermore, the parameters of exposed individuals that were included in the quarantine subpopulation $\alpha = 0.1326$ (Resmawan *et al.*, 2021). Individuals infected with COVID-19 have a healing process against the disease by $\sigma = 0.25$ (Mandal *et al.*, 2020). Given that the average time for infected

Table 1: COVID-19 spread model variable symbol

Symbol	Explanation
N	Total population in the system
S_1	Number of subpopulations of susceptible individuals not wearing masks
S_2	Number of subpopulations of susceptible individuals using masks
E	Number of individual subpopulations exposed
I_1	Number of subpopulations of infected individuals not wearing masks
I_2	Number of subpopulations of infected individuals wearing masks
Q	Number of quarantined individual subpopulations
R	Number of subpopulations of recovered individuals

Table 2: COVID-19 spread model parameters

Symbol	Explanation	Value	Source
μ	The birth or death rate of individuals in the population	0.002116268	Determined (Sasmita *et al.*, 2020)
ε	*physical distancing*	(0.1, 0.55, 0.9)	Assumption
u_1	Mask usage rate	(0.2, 0.55, 0.88)	Assumption
u_2	The rate of not/stopping using a mask	(0.8, 0.45, 0.12)	Assumption
β	Disease transmission rate	0.75	Determined (Zhu and Zhu, 2021)
α	The rate of individual exposed to quarantine individual	0.1326	Determined (Resmawan *et al.,* 2021)
δ	The rate of individual is exposed to an infected individual	0.3	Determined (Mandal *et al.,* 2020)
η	The rate of infected individuals being quarantined individuals	0.025	Determined (Eikenberry *et al.*, 2020; Ferguson *et al.*, 2020)
σ	The rate of infected individual recover without treatment	0.25	Determined (Mandal *et al.,* 2020)
γ	The rate of quarantine individual recover with treatment	0.07142857142	Determined (Tang *et al*., 2020)
κ_1	The rate of recovered individual back to susceptible not wearing masks	1/120	Determined $\kappa_1 + \kappa_2 = 1/60$ (Batistela *et al.*, 2021; Dwomoh *et al.*, 2021)
κ_2	The rate of recovered individual back to susceptible wearing masks	1/120	

individuals is 7 days before dyspnea (difficulty breathing), 9 days before sepsis (complications due to life-threatening infection), and a range of 1-10 days before receiving treatment, $\gamma = 0.025$ is determined (Eikenberry *et al.*, 2020; Ferguson *et al.*, 2020; Eubank *et al.*, 2020). The rate of transmission of COVID-19 disease varies greatly due to the actions taken to reduce COVID-19. The lower the level of action taken, the higher the transmission rate; we set the parameter value $\beta = 0.75$ where no preventive measures were taken so that the rate of transmission was high; the value of this parameter is taken from Zhu and Zhu (2021). Individual birth and death rates are regarded as equal. Then, for the parameter values of physical distancing measures and mask use, there are several variations caused by the possibility of individuals in the population performing these actions: $\varepsilon = [0.1, 0.55, 0.9]$, $u_1 = [0.2, 0.55, 0.88]$, and $u_2 = [0.8, 0.45, 0.12]$.

Figure illustration

The study describes the impact of compliance with COVID-19 disease control policies such as the use of masks and physical distancing on the spread of COVID-19. This illustration involves three important parameters in COVID-19 prevention measures, $\varepsilon, u_1,$

and u_2 with the values of the three parameters being different based on the data obtained as described previously. This illustration depicts the amount of spread of COVID-19 in a population over time (in day). The illustrations performed on this model include only for asymptotically stable conditions. The illustration is obtained by substituting the parameters in Table 2, initial values of stated variables, and the parameter values $\varepsilon, u_1,$ and u_2 that have been set to Eqs. 10 to 16. Initial values were obtained from Indonesia's COVID-19 conditions on June 22, 2021 (Satgas, 2021), there are $s_1(0)+s_2(0)=269451481$, $e(0)=124918$, $i_1(0)+i_2(0)=13668$, $q(0)=4958$, and $r(0)=8375$.

RESULTS AND DISCUSSION

Equilibrium points

The equilibrium point is the point where each state variable does not change in value, marked by the first derivative of each variable equal to 0 (Safitri *et al.*, 2019). The equilibrium value is obtained from every first derivative of the SEIRQ variable with the condition that it must be equal to 0. Eqs. 10 to 16 have two equilibrium points. One of the equilibrium points is the disease-free equilibrium point, where the infection will disappear from the system (infected i_1 and i_2 are disappear). The point is obtained using Eq. 17.

$$E_0\left(s_1^*, s_2^*, 0, 0, 0, 0, 0\right) \quad (17)$$

Where, $s_1^* = \frac{\mu+u_2}{\mu+u_1+u_2}$ and $s_2^* = \frac{u_1}{\mu+u_1+u_2}$. Another equilibrium point is the point where the infection will continue to exist in the system which is called the endemic equilibrium point. The point is obtained using Eq. 18.

$$E_1\left(s_1^*, s_2^*, e^*, i_1^*, i_2^*, q^*, r^*\right) \quad (18)$$

Where, $s_1^* = \frac{\mu+\kappa_1 r^* + u_2 s_2^*}{\mu+u_1+\beta(1-\varepsilon)i_1^*}$, $s_2^* = \frac{\kappa_1 r^* + u_1 s_1^*}{\mu+u_2}$,

$e^* = \frac{\beta(1-\varepsilon)s_1^* i_1^*}{\delta+\alpha+\mu}$, $i_1^* = \frac{\delta e^* + u_2 i_2^*}{\sigma+\eta+u_1+\mu}$, $i_2^* = \frac{u_1 i_1^*}{\sigma+\eta+u_2+\mu}$,

$q^* = \frac{\alpha e^* + \eta\left(i_1^* + i_2^*\right)}{\gamma+\mu}$, and $r^* = \frac{\sigma\left(i_1^*+i_2^*\right)+\gamma q^*}{\kappa_1+\kappa_2+\mu}$.

The asterisk in each state variable is referred to as the optimal value obtained from the first derivative which is equated with 0.

Basic reproductive number

The basic reproduction number is one of the most important parameters in epidemiological models, and it is useful in determining the nature of disease that occurs in a population. According to Driessche and Watmough (2002), the basic reproduction number is the expected value of the number of infections per unit time caused by one infected individual case that occurs in a population at a given time. R_0 represents the basic reproduction number. R_0 can be calculated in a variety of ways, but we will use the next generation matrix. The subpopulations that will be used are those that cause disease spread (infection), namely the exposed subpopulation (E), the infected subpopulation that is not wearing a mask (I_1), the infected subpopulation that is wearing a mask (I_2), and the quarantine subpopulation (Q).

$$\frac{de}{dt} = \beta(1-\varepsilon)s_1 i_1 - \delta e - \alpha e - \mu e \quad (19)$$

$$\frac{di_1}{dt} = \delta e + u_2 i_2 - u_1 i_1 - \sigma i_1 - \eta i_1 - \mu i_1 \quad (20)$$

$$\frac{di_2}{dt} = u_1 i_1 - u_2 i_2 - \sigma i_2 - \eta i_2 - \mu i_2 \quad (21)$$

$$\frac{dq}{dt} = \alpha e + \eta i_1 + \eta i_2 - \gamma q - \mu q \quad (22)$$

Eqs. 19 to 22 can be written as $x' = \varphi(x) - \zeta(x)$, where φ is the new infection rate and ζ is the infection transition rate. Thus, the Eq. 23 is obtained.

$$x' = \begin{pmatrix} e \\ i_1 \\ i_2 \\ q \end{pmatrix}, \quad \varphi(x) = \begin{pmatrix} \beta(1-\varepsilon)s_1 i_1 \\ 0 \\ 0 \\ 0 \end{pmatrix},$$

$$\zeta(x) = \begin{pmatrix} e(\delta+\alpha+\mu) \\ -\delta e - u_2 i_2 + i_1(\sigma+\eta+u_1+\mu) \\ -u_1 i_1 + i_2(\sigma+\eta+u_2+\mu) \\ -\alpha e - \eta i_1 - \eta i_2 + q(\gamma+\mu) \end{pmatrix} \quad (23)$$

Substitute the disease-free equilibrium point Eq. 17, so that the Jacobian matrix of φ and ζ is obtained as Eq. 24.

$$F=\begin{bmatrix} 0 & \frac{\beta(1-\varepsilon)(\mu+u_2)}{\mu+u_1+u_2} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \quad (24)$$

$$V=\begin{bmatrix} \delta+\alpha+\mu & 0 & 0 & 0 \\ -\delta & \sigma+\eta+u_1+\mu & -u_2 & 0 \\ 0 & -u_1 & \sigma+\eta+u_2+\mu & 0 \\ -\alpha & -\eta & -\eta & \gamma+\mu \end{bmatrix}$$

The spectral radius of the matrix $K=FV^{-1}$ is the basic reproduction number (R_0). Thus, the Eq. 25 is obtained.

$$R_0=\frac{\beta(1-\varepsilon)(\mu+u_2)(\sigma+\eta+u_2+\mu)\delta}{(\mu+u_1+u_2)(\delta+\alpha+\mu)(\eta+\mu+\sigma)(\eta+\mu+\sigma+u_1+u_2)} \quad (25)$$

Stability analysis

In this section, a stability analysis will be carried out using the eigenvalues of the Jacobian matrix from the equilibrium point contained in the model. Eqs. 10 to 16 were tested for stability by substituting the disease-free equilibrium point and the endemic equilibrium point. Eqs. 10 to 16 are linearized using the Jacobian matrix using Eq. 26.

$$J(E)=\begin{bmatrix} u_1-\beta(1-\varepsilon)i_1-\mu & u_2 & 0 & -\beta(1-\varepsilon)s_1 & 0 & 0 & \kappa_1 \\ u_1 & -u_2-\mu & 0 & 0 & 0 & 0 & \kappa_2 \\ \beta(1-\varepsilon)i_1 & 0 & -\delta-\alpha-\mu & \beta(1-\varepsilon)s_1 & 0 & 0 & 0 \\ 0 & 0 & \delta & -u_1-\sigma-\eta-\mu & u_2 & 0 & 0 \\ 0 & 0 & 0 & u_1 & -u_2-\sigma-\eta-\mu & 0 & 0 \\ 0 & 0 & \alpha & \eta & \eta & -\gamma-\mu & 0 \\ 0 & 0 & 0 & \sigma & \sigma & \gamma & -\kappa_1-\kappa_2-\mu \end{bmatrix} \quad (26)$$

Substitute the parameter values in Table 2 and Eq. 17 into the $J(E)$ matrix. The eigenvalue matrix $J(E)$ has a non-zero solution if and only if $det(J(E)-\lambda I)$ is called the characteristic equation. Then by substituting the parameter values contained in Table 2 to Eq. 26, then the R_0 value and the eigenvalues for the disease-free equilibrium point are obtained as in Table 3.

Based on the value of R_0, it is obtained the value of $R_0>1$ and $R_0<1$. On the first R_0, $R_0>1$ obtained because the individual level is vulnerable to physical distancing measures of 0.1, individuals who use masks 0.2 and individuals who stop/ do not use masks 0.8 so that the disease spreads into an epidemic. On the second R_0, $R_0<1$ obtained because the level of individuals who are vulnerable to physical distancing measures is 0.55, individuals who use masks are 0.55 and individuals who stop/do not use masks are 0.45 so that the disease will disappear within a certain time. On the last R_0, $R_0<1$ obtained because the level of individuals who are vulnerable to physical distancing measures, individuals who use masks are 0.88 and individuals who stop/do not use masks are 0.12 so that the disease will disappear within a certain time. Therefore, the value of R_0 is very dependent on the parameters for controlling and preventing COVID-19 disease, namely physical distancing parameters, using masks, and stopping/not using masks. The more individuals who follow health protocols such as physical distancing measures and the use of masks and the fewer individuals who stop/not use masks, the smaller the R_0 value generated so that the disease will quickly disappear. Next, substitute the parameter values contained in Table 2 and Eq. 18 to $J(E)$ matrix. The eigenvalues of the endemic equilibrium points are shown in Table 4.

Simulation with several parameters

We illustrate the impact of the level of physical distancing measures at 0.1, individuals wearing masks at 0.2 and individuals stopping/not using masks at 0.8 as shown in Fig. 2.

The illustration uses a percentage of the total population N, so the overall results are expressed in percent. Fig. 2(a) shows that the rate of the subpopulation of vulnerable individuals not wearing masks continued to decline initially to 78%. The subpopulation of individuals who tend to use masks also decreased by 19.5%. The decrease occurs

Table 3: Eigenvalues and R_0 for the disease-free equilibrium point

1.	$\varepsilon = 0{,}1. u_1 = 0{,}2, u_2 = 0{,}8$	
	Eigenvalue	
	$\lambda_1 = -0.0000 + 0.0000i$	$\lambda_5 = +0.0257 + 0.0000i$
	$\lambda_2 = -1.0000 + 0.0000i$	$\lambda_6 = -0.0000 + 0.0000i$
	$\lambda_3 = -1.3175 + 0.0000i$	$\lambda_7 = -0.0715 + 0.0000i$
	$\lambda_4 = -0.6884 + 0.0000i$	*Unstable*
	R_0	
	$R_0 = 1.283142917$	
2.	$\varepsilon = 0{,}55. u_1 = 0{,}55, u_2 = 0{,}45$	
	Eigenvalue	
	$\lambda_1 = -1.0000 + 0.0000i$	$\lambda_5 = -0.1834 + 0.0000i$
	$\lambda_2 = -0.0000 + 0.0000i$	$\lambda_6 = -0.0000 + 0.0000i$
	$\lambda_3 = -1.3044 + 0.0000i$	$\lambda_7 = -0.0715 + 0.0000i$
	$\lambda_4 = -0.4924 + 0.0000i$	*Asymptotically stable*
	R_0	
	$R_0 = 0.4868007714$	
3.	$\varepsilon = 0{,}9. u_1 = 0{,}88, u_2 = 0{,}12$	
	Eigenvalue	
	$\lambda_1 = -1.0000 + 0.0000i$	$\lambda_5 = -0.2729 + 0.0000i$
	$\lambda_2 = -0.0000 + 0.0000i$	$\lambda_6 = -0.0000 + 0.0000i$
	$\lambda_3 = -1.2778 + 0.0000i$	$\lambda_7 = -0.0715 + 0.0000i$
	$\lambda_4 = -0.4293 + 0.0000i$	*Asymptotically stable*
	R_0	
	$R_0 = 0.07074610245$	

Table 4: The eigenvalues of the endemic equilibrium point

1.	$\varepsilon = 0{,}1. u_1 = 0{,}2, u_2 = 0{,}8$	
	Eigenvalue	
	$\lambda_1 = -0.0000 + 0.0000i$	$\lambda_5 = -0.0000 + 0.0010i$
	$\lambda_2 = -1.3113 + 0.0000i$	$\lambda_6 = -0.0000 + 0.0010i$
	$\lambda_3 = -0.6688 + 0.0000i$	$\lambda_7 = -0.0715 + 0.0000i$
	$\lambda_4 = -0.0000 + 0.0000i$	*Asymptotically stable*
2.	$\varepsilon = 0{,}55. u_1 = 0{,}55, u_2 = 0{,}45$	
	Eigenvalue	
	$\lambda_1 = -1.0000 + 0.0000i$	$\lambda_5 = -0.0000 + 0.0000i$
	$\lambda_2 = -1.4035 + 0.0000i$	$\lambda_6 = -0.0024 + 0.0000i$
	$\lambda_3 = -0.5766 + 0.0000i$	$\lambda_7 = -0.0715 + 0.0000i$
	$\lambda_4 = +0.0024 + 0.0000i$	*Unstable*
3.	$\varepsilon = 0{,}9. u_1 = 0{,}88, u_2 = 0{,}12$	
	Eigenvalue	
	$\lambda_1 = -0.9999 + 0.0000i$	$\lambda_5 = -0.0000 + 0.0000i$
	$\lambda_2 = -1.5770 + 0.0000i$	$\lambda_6 = -0.0030 + 0.0000i$
	$\lambda_3 = -0.4030 + 0.0000i$	$\lambda_7 = -0.0715 + 0.0000i$
	$\lambda_4 = +00031 + 0.0000i$	*Unstable*

because of the movement between subpopulations, so that the number of susceptible subpopulations decreases drastically without significant input from population R. The susceptible subpopulations that do not use masks experience a greater decrease than the susceptible subpopulations that do not use

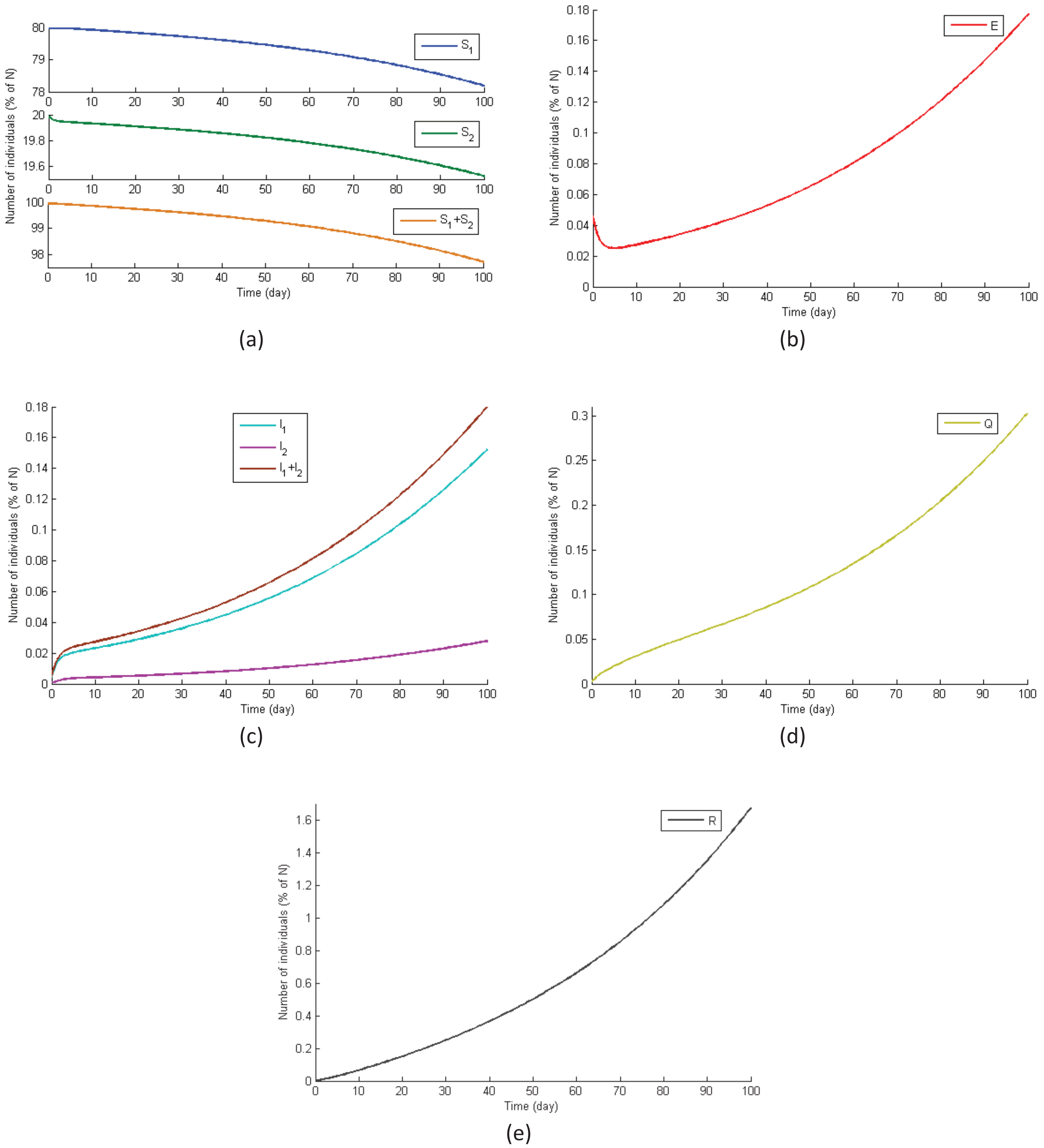


Fig. 2: The subpopulation of the spread of COVID-19 with $\varepsilon = 0.1, u_1 = 0.2$, $u_2 = 0.8$

masks, this is because the level of individuals who stop/do not use masks masks is 0.8, while the level of individuals who use masks is 0.2. The decline was exacerbated by the level of individuals taking physical distancing measures, which was only 0.1 so that the number of exposed individuals increased. In Fig. 2(b), the rate of the exposed population increased sharply by 0.18%, several times from the previous position. The graph had decreased due to the interaction of S1 and S2 that did not go to E. The increase was caused by the rate of individuals taking physical distancing measures of 0.1 and the displacement of the subpopulation into infected individuals due to the incubation period of the virus and quarantine individuals after being tested positive for COVID-19 through rapid, antigen, or swab tests. Fig. 2(c) shows the rate of the infected subpopulation not wearing a mask increased by 0.16%. The subpopulation of infected individuals who use masks also increases but the number is very small compared to those without masks. The increase occurred due to the movement between infected subpopulations so that the number of subpopulations increased in each subpopulation. This is because the level of individuals who stop/do not use masks is 0.8 while the level of individuals who use masks is 0.2. The input from exposed individuals is quite large, on the other hand the output to quarantined individuals is moderate. The decline was not very noticeable as there was very little movement of infected individuals receiving COVID-19 treatment and infected individuals who had recovered naturally from COVID-19 illness. Fig. 2(d) shows the rate at which the subpopulation of quarantined individuals increased by 0.3%. The increase in the karatina subpopulation was caused by the number of infected individuals who carried out the Swab Test or Rapid Test and the number of infected individuals who received treatment for COVID-19. The subpopulation decline was not seen as significant due to the large input of infected individuals. In Fig. 2(e), the rate of individual subpopulation recovering increased to 1.7%. The increase in the subpopulation was caused by the displacement of the subpopulation of infected individuals I_1 and I_2 who recovered naturally from COVID-19 disease and the displacement of the quarantine subpopulation Q who had recovered from COVID-19 disease with treatment. This means that the disease will continue to exist and cause infection in the population. The study tries to illustrate the impact of the level of physical distancing measures by 0.55, individuals using masks at 0.55 and individuals stopping/not using masks at 0.45 as shown in Fig. 3. Fig. 3(a) shows that the level of susceptible subpopulations that do not use masks continues to increase, while the subpopulation of susceptible individuals who use masks decreases. The number of increases in S1 is not significant because the number of S2 is still larger, the implication is that the number of susceptible populations continues to increase. This positive trend was due to input from the recovered population, whereas the exposed population did not have a large transition. This is due to the interaction of S1 and S2 in a positive trend, while the susceptible to infected interaction is limited by the physical distancing parameter. Fig. 3(b) shows that the rate of the exposed population has decreased very significantly to close to 0.001% and the graph will move towards a point and be stable at that point until $t=\infty$. The decline was caused by the movement of the population to infected individuals due to the incubation period of the virus and quarantined individuals after being tested positive for COVID-19 through rapid tests, antigens, or swabs. In Fig. 3(c), the rate of the infected subpopulation that does not wear a mask has decreased very significantly, approaching 0.001% and the graph will move towards a point and be stable at that point until $t=\infty$. The subpopulation of infected individuals wearing masks experienced rapid changes where the graph dropped to 0.001% and the graph went to a point and was stable at that point until $t=\infty$. The decrease and increase occurred due to movement between subpopulations so that the number of subpopulations increased and decreased in each subpopulation. This is because the level of individuals who stop/do not use masks is 0.45 while the level of individuals who use masks is 0.55. The decline also occurred due to the movement of infected individuals who received COVID-19 treatment and infected individuals who had recovered naturally from COVID-19 disease. Fig. 3(d). In Fig. 3(d), the rate of the subpopulation of quarantined individuals changes rapidly where the graph drops to near 0% and towards a point and stabilizes at that point until $t=\infty$. The increase in the subpopulation was caused by the number of exposed individuals who did the Swab Test or Rapid Test and the number of infected individuals who received treatment for COVID-19 disease, while the decrease in the subpopulation was due to quarantined individuals who had recovered. COVID-19 disease. In Fig. 3(e),

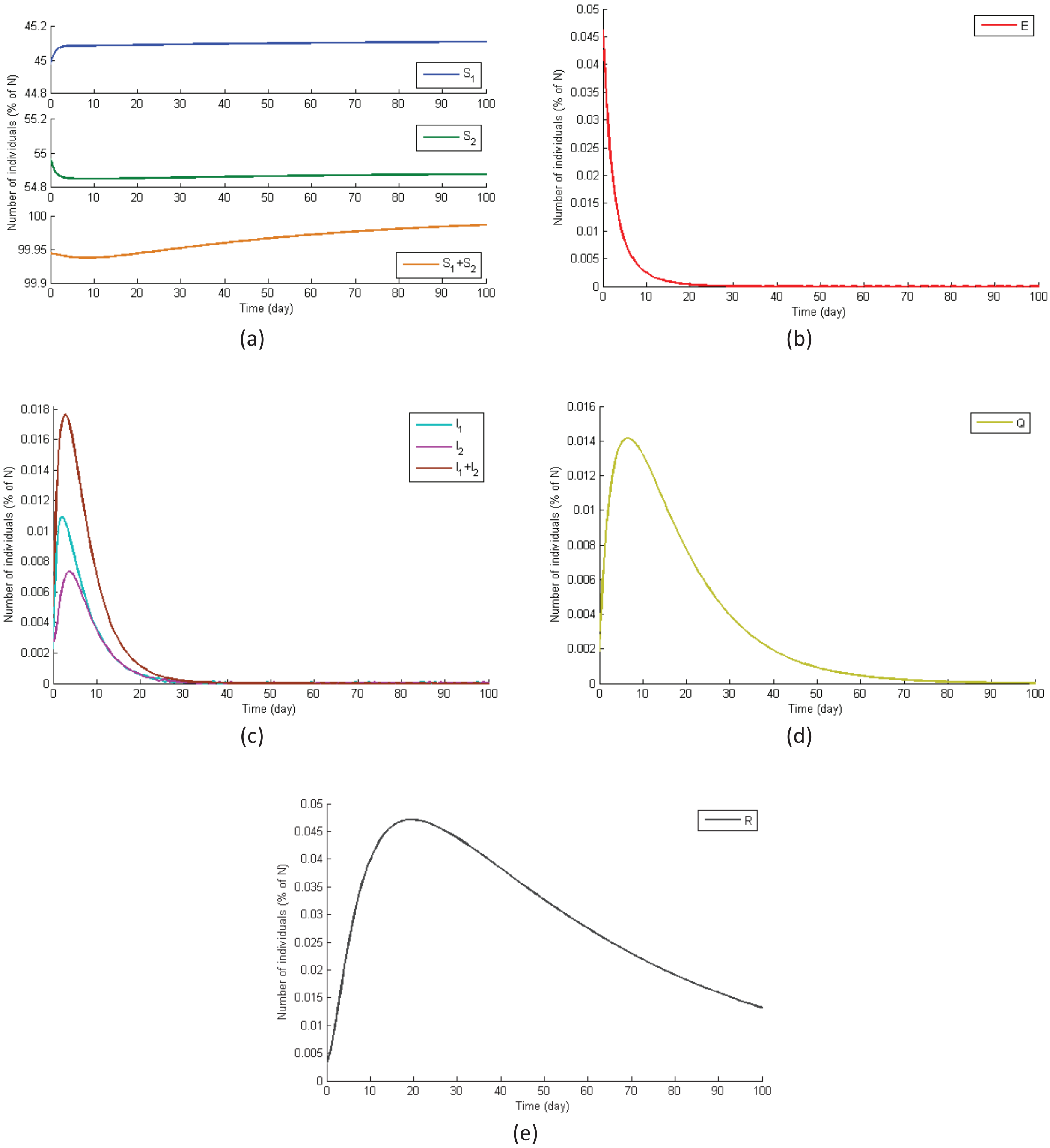


Fig. 3: The subpopulation of the spread of COVID-19 with $\varepsilon = 0.55, u_1 = 0.55, u_2 = 0.45$

the rate of individual subpopulations recovering increased to 0.046%. Then the graph begins to descend towards a point and stabilizes at that point until t= ∞. The increase in the subpopulation was caused by the displacement of the subpopulation of infected individuals I_1 and I_2 who recovered naturally

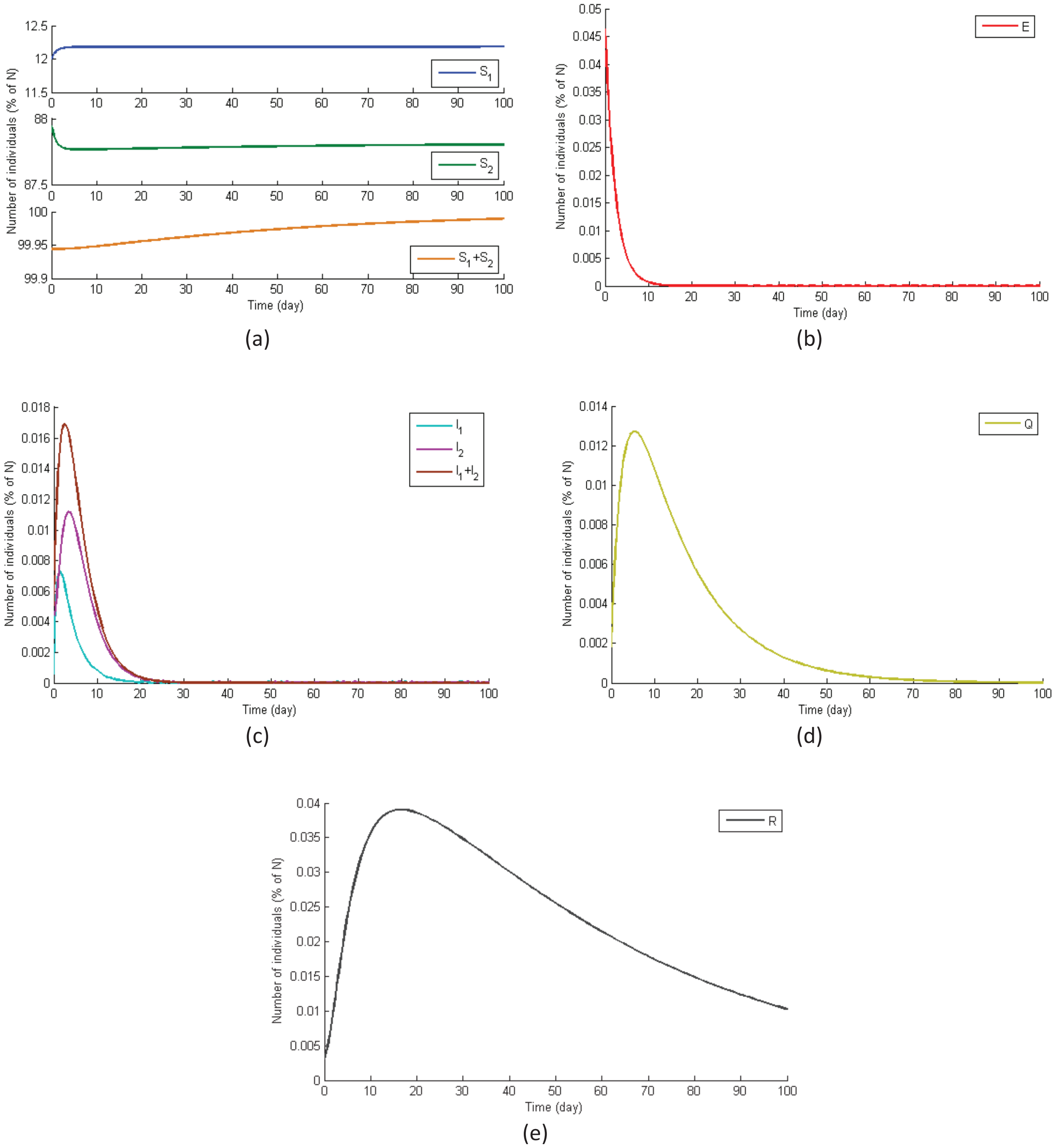


Fig. 4: The subpopulation spread of COVID-19 with $\varepsilon = 0.9, u_1 = 0.88$, $u_2 = 0.12$

from COVID-19 disease and the displacement of the quarantine subpopulation Q who had recovered from COVID-19 disease with treatment. This means that the disease does not spread the disease to the population and the disease will disappear over time.

The simulation shows the impact of the level of physical distancing measures is 0.9, individuals who use masks are 0.88 and individuals who stop/do not use masks are 0.12 as in Fig. 4. In the simulation with these parameters, the resulting shapes and transitions are the same as the simulations in the level of physical distancing measures by 0.55, individuals using masks at 0.55 and individuals stopping/not using masks at 0.45.

Figs. 3 and 4 have the same shape and show the stability of the simulation. Fig. 4(a) has a different starting point, while the shape of the curve continues to increase the susceptible population. This happens because the designed optimistic formula has succeeded in avoiding individuals from being in other populations/subpopulations. Figs. 4(b) and 4(c) only change in the momentum of the increase and decrease in the number of individuals. The same thing happened to the quarantine and recovery population in Figs. 4(d) and 4(e). From the simulations that have been carried out, the shape of the curve for each case can be different if it has not reached the peak point in the exposed population, infected population, and quarantine population. It takes a very long time to break up the peak of the disease. With optimistic parameters of more than 0.55 physical distancing and the use of masks, a peak curve has emerged and stability is obtained. Individuals are concentrated in the susceptible population/subpopulation and recovered population. By maintaining this number and implementing longer compliance, individuals in the exposed, infected, and quarantined populations are depleted to the recovered population. Parameters that play a role in preventing infection in the susceptible population are u_1 and u_2. These two parameters exclude all individuals into the masked susceptibility subpopulation because the assumption is made that this subpopulation cannot be infected. Looking at the simulations in Figs. 3 and 4, a significant parameter is physical distancing. This parameter plays a role in accelerating and slowing the transition of susceptible individuals to other populations. When the parameter is increased, peak momentum is achieved faster, and vice versa. This parameter affects the exposed population, infected subpopulation, quarantine population, and a small part of the recovered population. Based on the illustration results, it can be seen that the more individuals who take physical distancing measures, use masks and the fewer individuals who stop/do not use masks, the spread of COVID-19 will be smaller so that in a certain time the disease will disappear. COVID-19 disease control measures do not only focus on physical distancing and the use of masks, but this is one of the most important steps taken as stated by WHO. There are many other precautions that can minimize the spread. The more preventive measures are taken, the faster the disease will disappear, one of which is if the detection/tracking of individuals who have been infected and exposed to COVID-19 is increased, the individual will receive treatment faster so that fewer people will contract the disease.

CONCLUSION

This study proposes a mathematical model of COVID-19 spread that takes into account people's behavior and compliance. The use of masks and physical distancing are among the behaviors under consideration. This behavior divides the susceptible population into two subpopulations: those who use a mask and those who do not use a mask. The same holds true for the infected population. Using a mask, the value of the compliance parameter is set between 0 and 1. The physical distancing compliance parameter, which ranges from 0 to 1, does not divide the population. The analysis was performed for two different equilibrium points: disease-free equilibrium and endemic equilibrium. The equilibrium point is obtained from the position where there is no change in the number of individuals in the population. Disease-free equilibrium means that there is no disease in the population, while endemic equilibrium is that there are infected subpopulations in the population. For both equilibrium points, the stability criterion is asymptotically stable. Disease-free conditions are met and maintained if compliance with masks and physical distance exceeds 55%. Based on the stability of the disease endemic balance point, this condition will become endemic in an area/community if mask compliance is less than 20% and physical distance from crowds is not maintained. The basic reproduction rate has a significant impact on the presence or absence of an endemic in a population. The model illustration shows that if the rate of people wearing masks is at least 55% and the rate of people taking physical distance measures is at least 55%, the COVID-19 disease will be eradicated from the population within a certain time frame. The spread of COVID-19 will be significantly reduced if the awareness level of people wearing masks is increased to 88% and the level of people taking physical distancing measures is increased to 90%. As a result, the disease is vanishing from the population at a faster rate. The measures are intended to increase by 55%-88%the masked subpopulation of susceptible and infected people. This policy must be implemented because it demonstrates a positive trend of disease-free status in a relatively short period of time. Physical distancing adherence has increased from 55% to 90%, indicating a positive trend toward COVID-19 extinction. Mask pollution can be dealt with quickly based on the time it takes to be disease-free. Policy decisions involving masks for specific populations, on the other hand, should be reconsidered. It can be researched using pharmaceutical solutions that do not generate a lot of medical waste. The long-term solution to eradicating COVID-19 is to include other parameters, such as those for increasing and decreasing the number of wards, outpatient solutions, and parameters related to the internet of things (IoT). COVID-19 must be eradicated as soon as possible in order to reduce the environmental impact of mask waste.

AUTHOR CONTRIBUTIONS

M. Ramli performed the literature review, running the model, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. M. Mukramati performed the literature review, running the model, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. M. Ikhwan performed the literature review, prepared numerical code, prepared the manuscript text, and manuscript edition. H. Hafnani performed the literature review, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. All authors agreed on the final version of the manuscript.

ACKNOWLEDGEMENT

The authors would like to thank the editors and anonymous referees who provided fruitful and crucial feedback on our manuscript.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

α	The rate of individual exposed to quarantine individual
β	Disease transmission rate
COVID-19	Coronavirus Disease 2019
δ	The rate of individual is exposed to an infected individual

det	Determinant
ε	*physical distancing*
η	The rate of infected individuals being quarantined individuals
E	Number of individual subpopulations exposed
E_0	Disease-free equilibrium point
E_1	Endemic equilibrium point
Eq. / Eqs.	Equation / equations
Fig.	Figure
γ	The rate of quarantine individuals recovers with treatment
	Identity matrix
I_1	Number of subpopulations of infected individuals not wearing masks
I_2	Number of subpopulations of infected individuals wearing masks
J	Jacobian matrix
K	Spectral radius matrix
λ	Eigenvalue
κ_1	The rate of recovered individual back to susceptible not wearing masks
κ_2	The rate of recovered individual back to susceptible wearing masks
μ	The birth or death rate of individuals in the population
M	meter
MERS-CoV	Middle East Respiratory Syndrome Coronavirus
N	Total population in the system
N95	Not resistant to oil with 95% particle filtered
%	Percent
Q	Number of quarantined individual subpopulations
R	Number of subpopulations of recovered individuals
σ	The rate of infected individuals recovers without treatment
S	Number of subpopulations of susceptible individuals

	Number of subpopulations of susceptible individuals not wearing masks
S_2	Number of subpopulations of susceptible individuals using masks
SARS-Cov2	Severe acute respiratory syndrome coronavirus 2
SEIQR	susceptible-exposed-infected-quaratine-recovery
SEIR	susceptible-exposed-infected-recovery
T	Time
u_1	Mask usage rate
u_2	The rate of not/stopping using a mask
φ	The new infection rate
WHO	World Health Organization
ζ	The infection transition rate
x	State variable

REFERENCES

Arslan, M.; Xu, B.; El-Din, M.G., (2020). Transmission of SARS-CoV-2 via fecal-oral and aerosols–borne routes: Environmental dynamics and implications for wastewater management in underprivileged societies. Sci. Total Environ., 743: 140709 (**7 pages**).

Batistela, C.M.; Correa, D.P.F.; Bueno, A.M.; Piqueira, J.B.C., (2021). SIRSi compartmental model for COVID-19 pandemic with immunity loss. Chaos Solit. Fractals, 142: 110338 (**12 pages**).

Bagepally, B.S.; Haridoss, M.; Natarajan, M.; Jeyashree, K.; Ponnaiah, M., (2021). Cost-effectiveness of surgical mask, N-95 respirator, hand-hygiene and surgical mask with hand hygiene in the prevention of COVID-19: Cost effectiveness analysis from Indian context. Clin. Epidemiol. Global Health. 10: 100702 (**8 pages**).

Chintalapudi, N.; Battineni, G.; Amenta, F., (2020). COVID-19 virus outbreak forecasting of registered and recovered cases after sixty day lockdown in Italy: A data driven model approach. J. Microbiol. Immunol. Infect., 53(3): 396–403 (**8 pages**).

Driessche, K.V.; Hens, N.; Tilley, P.; Quon, B.S.; Chilvers, M.A.; de Groot, R.; Cotton, M.F.; Marais, B.J.; Spreet, D.P.; Zlosnik, J.E., (2015). Surgical masks reduce airborne spread of Pseudomonas aeruginosa in colonized patients with cysticbrosis. Am. J. Respir. Crit. Care Med., 192(7): 897-899 (**3 pages**).

Driessche, P.; Watmough, J., (2002). Reproduction numbers and sub-threshold endemic equilibria for compartmental models of disease transmission. Math. Biosci., 180(1–2): 29–48 (**20 pages**).

Doremalen, N.; Bushmaker, T.; Morris, D.H.; Holbrook, M.G.; Gamble, A.; Williamson, B.N.; Tamin, A.; Harcourt, J.L.;

Thornburg, N.J.; Gerber, S.I.; Lloyd-Smith, J.O.; de Wit, E.; Munster, V.J., (2020). Aerosol and surface stability of HCoV-19 (SARS-CoV-2) compared to SARS-CoV-1. N. Engl. J. Med., 382(16): 1564–1567 **(4 pages).**

Dwomoh, D.; Iddi, S.; Adu, B.; Aheto, J.M.; Sedzro, K.M.; Fobil, J.; Bosomprah, S., (2021). Mathematical modeling of COVID-19 infection dynamics in Ghana: Impact evaluation of integrated government and individual level interventions. Infect. Dis. Model., 6: 381–397 (**17 pages**).

Eikenberry, S.E.; Mancuso, M.; Iboi, E.; Phan, T.; Eikenberry, K.; Kuang, Y.; Kostelich, E.; Gumel, A.B., (2020). To mask or not to mask: Modeling the potential for face mask use by the general public to curtail the COVID-19 pandemic. Infect. Dis. Model., 5: 293–308 (**16 pages**).

Eubank, S.; Eckstrand, I.; Lewis, B.; Venkatramanan, S.; Marathe, M.; Barrett, C.L., (2020). Commentary on Ferguson, et al., “Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand”. Bull. Math. Biol., 82: 52 (**7 pages**).

Ferguson, N.; Laydon, D.; Nedjati-Gilani, G.; Imai, N.; Ainslie, K.; Baguelin, M.; Bhatia, S.; Boonyasiri, A.; Cucunuba Perez, Z.; Cuomo-Dannenburg, G.; Dighe, A.; Dorigatti, I.; Fu, H.; Gaythorpe, K.; Green, W.; Hamlet, A.; Hinsley, W.; Okell, L.; Van Elsland, S.; Thompson, H.; Verity, R.; Volz, E.; Wang, H.; Wang, Y.; Walker, P.; Walters, C.; Winskill, P.; Whittaker, C.; Donnelly, C.; Riley, S.; Ghani, A., (2020). Impact of nonpharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand. Report, Imperial College London. UK.

Garnett, C.; Jackson, S.; Oldham, M.; Brown, J.; Steptoe, A.; Fancourt, D., (2021). Factors associated with drinking behaviour during COVID-19 social distancing and lockdown among adults in the UK. Drug Alcohol Depend., 219: 108461 (**8 pages**).

Harapan, H.; Itoh, N.; Yufika, A.; Winardi, W.; Keam, S.; Te, H.; Megawati, D.; Hayati, Z.; Wagner, A.L.; Mudatsir, M., (2020). Coronavirus disease 2019 (COVID-19): A literature review. J. Infect. Public Health, 13(5): 667–673 (**7 pages**).

Kojima, M.; Iwasaki, F.; Johannes, H.P.; Edita, E.P., (2020). Strengthening waste management policies to mitigate the COVID-19 pandemic. Econ. Res. Instit., 5: 1-4 (**4 pages**).

Li, G.; De Clercq, E., (2020). Therapeutic options for the 2019 novel coronavirus (2019-nCoV). Nat. Rev. Drug Discov., 19(3): 149–150 (**2 pages**).

Lin, Y.H.; Liu, C.H.; Chiu, Y.C., (2020). Google searches for the keywords of “wash hands” predict the speed of national spread of COVID-19 outbreak among 21 countries. Brain Behav. Immun., 87: 30–32 (**3 pages**).

Lo, S.; Lin, C.; Hung, C.; He, J.; Lu, P., (2021). The impact of universal face masking and enhanced hand hygiene for COVID-19 disease prevention on the incidence of hospital-acquired infections in a Taiwanese hospital. Int. J. Infect. Dis., 104: 15-18 (**4 pages**).

Lyu, W.; Wehby, G.L., (2020). Community use of face masks and COVID-19: Evidence from a natural experiment of state mandates in the US. Health Aff., 39(8): 1419-1425 (**7 pages**).

MacIntyre, C.R.; Nguyen, P.; Chughtai, A.A.; Trent, M.; Gerber, B.; Steinhofel, K.; Seale, H., (2021). Mask use, risk-mitigation behaviours and pandemic fatigue during the COVID-19 pandemic in five cities in Australia, the UK and USA: A cross-sectional survey. Int. J. Infect. Dis., 106: 199-207 (**9 pages**).

Manaqib, M.; Fauziah, I.; Mujiyanti, M., (2019). Mathematical model for MERS-COV disease transmission with medical mask usage and vaccination. In Prime, 1(2): 97–109 (**13 pages**).

Mandal, M.; Jana, S.; Nandi, S.K.; Khatua, A.; Adak, S.; Kar, T.K., (2020). A model based study on the dynamics of COVID-19: Prediction and control. Chaos Solit. Fractals, 136: 109889 (**12 pages**).

Phan, L.T.; Nguyen, T.V.; Luong, Q.C.; Nguyen, T.V.; Nguyen, H.T.; Le, H.Q.; Nguyen, T.T.; Cao, T.M.; Pham, Q.D., (2020). Importation and human-to-human transmission of a novel coronavirus in Vietnam. N. Engl. J. Med., 382(9): 872-874 (**3 pages**).

Resmawan, R.; Nuha, A.R.; Yahya, L., (2021). Analisis dinamik model transmisi COVID-19 dengan melibatkan intervensi karantina. Jambura J. Math., 3(1): 66–79 (**14 pages**).

Safitri, E.; Tarmizi, T.; Ramli, M.; Wahyuni, S.; Ikhwan, M., (2019). Model of virus therapy and chemotherapy for cancer. IOP Conf. Ser.: Earth Environ. Sci., 364: 012029 (**6 pages**).

Sasmita, N.R.; Ikhwan, M.; Suyanto, S.; Chongsuvivatwong, V., (2020). Optimal control on a mathematical model to pattern the progression of coronavirus disease 2019 (COVID-19) in Indonesia. Global Health Res. Policy, 5: 38 (**12 pages**).

Satgas, (2021). Pasien Sembuh Terus Meningkat Mencapai 1.810.136 Orang.

Soewono, E., (2020). On the analysis of Covid-19 transmission in Wuhan, Diamond Princess and Jakarta-cluster. Commun. Biomath. Sci., 3(1): 9-18 (**10 pages**).

Stockwell, R.E.; Wood, M.E.; He, C.; Sherrard, L.J.; Ballard, E.L.; Kidd, T.J.; Johnson, G.R.; Knibbs, L.D.; Morawska, L.; Bell, S.C., (2018). Face masks reduce the release of Pseudomonas aeruginosa cough aerosols when worn for clinically relevant periods. Am. J. Respir. Crit. Care Med., 198(10): 1339-1342 (**4 pages**).

Tang, B.; Bragazzi, N.L.; Li, Q.; Tang, S.; Xiao, Y.; Wu, J., (2020). An updated estimation of the risk of transmission of the novel coronavirus (2019-nCov). Infect. Dis. Model., 5: 248–255 (**8 pages**).

Tran, T.T.; Pham, L.T.; Ngo, Q.X., (2020). Forecasting epidemic spread of SARS-CoV-2 using ARIMA model (case study: Iran). Global J. Environ. Sci. Manage., 6: 1–10 (**10 pages**).

WHO, (2020a). Transmission of SARS-CoV-2: implications for infection prevention precautions. Jenewa, Swiss. World Health Organization.

WHO, (2020b). Advice on the use of masks in the context of COVID-19. Jenewa, Swiss. World Health Organization.

WHO, (2021a). Coronavirus disease (COVID-19) pandemic. World Health Organization.

WHO, (2021b). Corona Virus Disease (COVID-19) Dashboard. World Health Organization.

Wilder-Smith, A.; Freedman, D.O., (2020). Isolation, quarantine, social distancing and community containment: Pivotal role for old-style public health measures in the novel coronavirus (2019-nCoV) outbreak. J. Travel Med., 27(2): 1–4 (**4 pages**).

Zhu, C.C.; Zhu, J., (2021). Dynamic analysis of a delayed COVID-19 epidemic with home quarantine in temporal-spatial heterogeneous via global exponential attractor method. Chaos Solit. Fractals, 143: 110546 (**15 pages**).

AUTHOR (S) BIOSKETCHES

Ramli, M., Ph.D., Professor, Department of Mathematics, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia.
Email: *marwan.math@unsyiah.ac.id*
ORCID: 0000-0003-1225-9063

Mukramati, M., M.Sc. Student, Assistant Professor, Department of Mathematics, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia.
Email: *mukramatimuhammad50@gmail.com*
ORCID: 0000-0002-4125-6948

Ikhwan, M., Ph.D., Candidate, Assistant Professor, Graduate School of Mathematics and Applied Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia.
Email: *m.ikhwan@mhs.unsyiah.ac.id*
ORCID: 0000-0002-8162-1479

Hafnani, H., M.Sc., Associate Professor, Department of Mathematics, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia.
Email: *hafnani@unsyiah.ac.id*
ORCID: 0000-0003-0741-8904

HOW TO CITE THIS ARTICLE

Ramli, M.; Mukramati, M.; Ikhwan, M.; Hafnani, H., (2022). Community behavior for mathematical model of coronavirus disease 2019 (COVID-19). Global J. Environ. Sci. Manage., 8(2): 151-168.

DOI: 10.22034/gjesm.2022.02.01

url: https://www.gjesm.net/article_245815.html

Global J. Environ. Sci. Manage. 8(2): 169-182, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Hydro-mechanical behavior of two clayey soils in presence of household waste leachates

H.F. Yonli[1,2,*], B. François[3], D.Y.K. Toguyeni[1,4], A. Pantet[5]

[1] Laboratoire de Physique et de Chimie de l'Environnement, Université Joseph KI-Zerbo, BP 7021 Ouagadougou 03, Burkina Faso

[2] Ecole Supérieure d'Ingénierie, Université de Fada N'Gourma, BP 46 Fada N'Gourma, Burkina Faso

[3] Building Architecture and Town Planning Department, Université Libre de Bruxelles, Avenue F.D. Roosevelt 50, CP 194/2, 1050 Bruxelles, Belgique

[4] Ecole Polytechnique de Ouagadougou, 08 BP 143 Ouagadougou 08, Burkina Faso

[5] UMR 6294 CNRS, Laboratoire Ondes et Milieux Complexes, Normandie Université, Unihavre, 53 rue Prony, 76600 Le Havre, France

ARTICLE INFO

Article History:
Received 08 June 2021
Revised 29 July 2021
Accepted 06 September 2021

Keywords:
Bottom liner
Compressibility
Hydraulic conductivity
Leachate
Shear

ABSTRACT

BACKGROUND AND OBJECTIVES: In landfills, containment is provided by natural or artificial clayey materials known for their low permeability and for their pollutant retention capacity. However, the properties of these media are modified by leachates, whose migration they are supposed to limit. This study aims to reconsider the criteria for choosing suitable materials to make a bottom liner through both their long term hydraulic and mechanical performances.

METHODS: Two fine materials sampled in Burkina Faso (West Africa) have been characterized in order to compare their hydro-mechanical behavior in the presence of household waste leachates. The first material is classified as an inorganic clay of low to medium plasticity according to Casagrande plasticity diagram, it is mainly kaolinitic with some traces amounts of smectites. The second one is classified clayey sand of low to medium plasticity, the predominant mineral clay being kaolinite. Hydro-mechanical tests were performed on both sampled materials to judge the sealing properties of these materials, as well as the characteristics of deformation and rupture which have an important effect to ensure the durability of a bottom liner. All these tests were performed first with distilled water then with leachates as interstitial fluids in order to understand the modification of the hydro-mechanical properties of the clayey soils.

FINDINGS: Leachate contamination always alters hydraulic properties of the materials. However, between the two soils, the most clayey and the most impervious (soils from Nouna) undergo the deeper weathering. Indeed, hydraulic conductivity of these soils in contact with a synthetic leachate increases from $1.71x10^{-10}$ to $1.51x10^{-9}$ m/s. In contrast to soils from Boudry, these soils also undergo very significant settlements over the long term with compressibility indexes varying from 0.164 to 0.225. For both soils, the shear strength increases showing that, from this point view, the leachate work in the sense of of the bottom liner stability. For soils from Nouna, the effective cohesion increases from 3 to 21 kPa with a slight decrease of friction angle; for soils from Boudry a slight increase of cohesion is noticed while friction angle increases from 34 to 37°.

CONCLUSION: This comparative study is of practical use to environmental geotechnics professionals because it shows that the choice in designing a bottom liner must be a compromise between long term hydraulic and mechanical behaviors of soils. It is also important to know the nature of the flows to contain in order to ensure the durability of the structure.

DOI: 10.22034/gjesm.2022.02.02

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
40	7	7

*Corresponding Author:
Email: *fabienyonli@yahoo.fr*
Phone: +226 7140 9576
ORCID: 0000-0002-4981-4705

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Due to the evolution of its demography as well as its consumption, Burkina Faso (West Africa) is experiencing a situation of high waste production currently estimated at 500 000 tons per year for its capital Ouagadougou. As in many developing countries, waste storage has migrated from uncontrolled dumping to landfills of several ha. The construction of a landfill requires phases of earthworks to define a main excavation which will be divided in several cells. These cells will be filled with waste and covered with a clayey cap liner when full in order to isolate waste. Before the installation of this cover, the rainwater percolates through the waste and is temporarily loaded to produce leachate. Leachate quality is the result of the waste composition, water budget, biological, chemical, and physical conditions in the landfill body (Erhig and Stegmann, 2018), its composition varies significantly among landfills depending on waste composition, waste age and landfilling technology (Christensen *et al*, 2001). Familiarly called "garbage juice" (Jambeck, 2007), leachate of household and similar waste has a potentiel impact on land, soils and groundwater (Wdowczyk and Szymańska-Pulikowska, 2021; Ullah *et al.,* 2018; Azizi *et al.,* 2016). These leachates must be drained by a granular material and a network of flexible pipelines before being pumped out for treatment. Despite the presence of this Leachate Collection and Removal System (LCRS), soil and groundwater protection must also be ensured by a geological barrier known as bottom liner which covers the slope and the bottom of the excavation. The bottom liners must limit the infiltration of pollutants and various authors such as Widomski *et al.* (2018) agree that it ensures the long-term safety of the site. Very often, adequate geological conditions are not satisfied and techniques of strengthening and soil treatment are implemented. The design of landfills is mainly based on a criteria related to hydraulic flow of leachate through the sealing barriers. The most stringent national and international regulations define a threshold value of 10^{-9} m/s for hydraulic conductivity (also called permeability) over a thickness of at least 1 m on the bottom and 0.5 m on the slopes (Wagner, 2013). In addition, mechanical properties such as shear strength, low compressibility, low shrinkage-swelling are required for the design (Abdellah *et al.*, 2020). Indeed, the geometry of the slopes is determined so as to ensure a sufficient coefficient of stability (Abramson *et al.*, 2002). Vertical deformations of the liner, called settlements, will occur during the exploitation of the landfill. Settlements are linked to compressibility, which similar to the hydraulic conductivity, is one of the most important properties of the liner material (Mishra *et al.*, 2010). The assessment of the settlements caused by the overloads represented by the weight of the waste accumulated over several meters vertical deformations must be verified (Dutta and Mishra, 2016) as well as the risk of failure of the landfill that may occur during the phases of construction, operation and closure of the landfill (Townsend *et al.*, 2015). All this requires the determination of the appropriate geotechnical parameters of the bottom liners. As stated above, hydraulic conductivity is the parameter used to judge of the sealing potential of the bottom liner. In soil mechanics, stability analyzes are based on the determination of cohesion and angle of friction (parameters relating to shear strength). Recompression and compression indexes are used to predict settlements. Hydro-mechanical tests are carried out to measure such parameters in order to judge the use of these local clayey materials as perennial impervious barriers. However some major concerns are not sufficiently addressed. For instance there is no regulatory specification about how to measure hydraulic conductivity (Ait Saadi, 2003) of a bottom liner. Yet, many authors such as Benson *et al.* (2018) have well established that this parameter often increase when soils suitable for liners experience leachate leakage. Also note that according to established normative procedures tests are often conducted with distilled water whereas some authors have noticed changes on the long term mechanical behavior due to the leachate impact (Cuisinier *et al.*, 2014). Sometimes the behavior can be quite unpredictable and leachate can improve or alter mechanical properties of the liner. Indeed Dutta and Mishra (2016) noticed a decrease in compressibility index of bentonites in presence of salt solutions. Naeini *et al.* (2016) showed that interaction of inorganic clay with bentonite increased shear strength of the liner. Otherwise Gratchev and Towhata (2016) noticed an increase of compressibility indexes of Kansai clay with acidic solutions, meaning an increase in settlements. Another concern is the fact that most impervious clays do not always have the best mechanical properties. Few works have highlighted the considerations described above through a comparison between two clayey materials solicited by the same leachate. This approach makes it easier to understand the criteria for choosing suitable clayey material to make a bottom liner. The study highlights the importance of a compromise between hydraulic and mechanical performances. It also highliths the importance of the representativeness of the type of fluid used for the determination of the geotechnical parameters. In summary, the study offers to environmental geotechnics professionals a reflection on how to judge the performance of clay barriers on the long term. In this study, the hydro-mechanical performances of two clayey materials, sampled in Burkina Faso (West Africa) and their evolution when they are in presence of household waste leachates are examined. The study was conducted in Burkina Faso between 2018 and 2020.

MATERIALS AND METHODS

The methodological approach consists first of all, in selecting two soils which have different mineralogical properties, both potentially suitable as bottom liners, and testing their hydro-mechanical properties in a defined reference condition. This reference condition, simulated by saturation with distilled water, aims to describe the behavior of a landfill when it is not yet solicited by the chemical action of the leachates. The hydro-mechanical properties are then assessed with two types of leachates in order to understand the modification of the behavior of the bottom liner during the operation of a landfill, including leachate leakage, deformation and risks of failure of the bottom liner. The discussion which follows will focus on the modification of properties according to the mineralogical nature of the liner and according to the type of leachate. It is oriented towards the selection criteria to consider in the choice of suitable clayey soils to make bottom liners. Fig. 1 presents the overall methodology of the characterization of the studied clayey soils.

Choice and identification of soils

In this study, two soils were collected in Burkina Faso. The first one is natural and comes from Nouna located 284 km northwest of the capital Ouagadougou. In this zone, the geological conditions indicate a cover of aeolian sands, clays and alluvium constituting young sediments on old lands. The sampling area is located in a vast plain flooded in places and covered with weeds in the winter season. When sampled, the soil is in the form of hardened blocks. Soils from Nouna are gray and hard when dry. They are moistened when black, they are soft and they smell as organic matter in decomposition. The sampling area is X = 406,327 and Y = 1,405,498 (UTM ZONE 30P). The second one comes from Boudry located 100.5 km east of Ouagadougou (X = 749,953 and Y = 1,353,945 UTM ZONE 30P). These soils from Boudry are generally shallow and not very fertile, of the ferruginous tropical type, vulnerable to the action of erosion and runoff. The sampling area is located

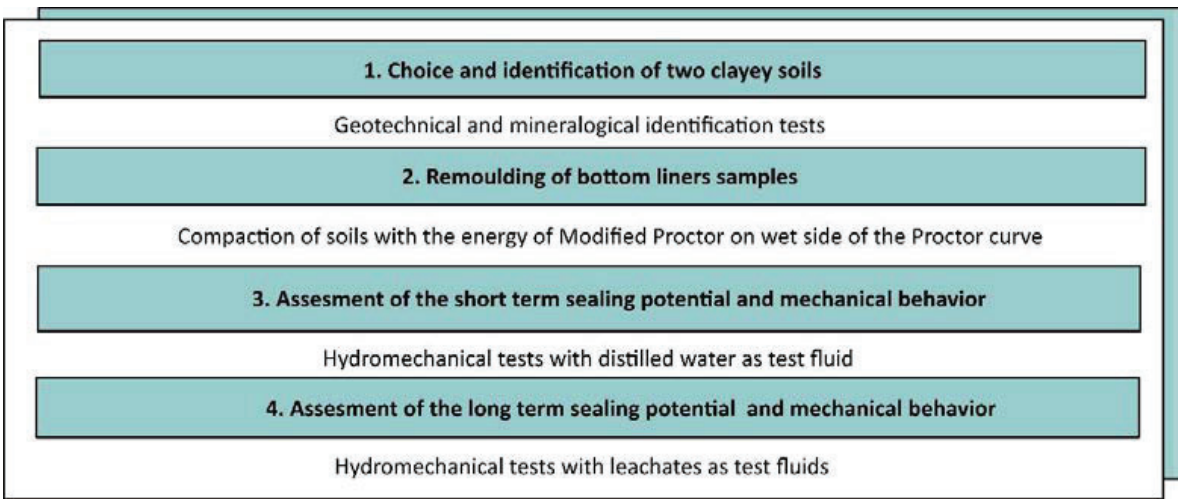


Fig. 1: Methodology of characterization of the hydro-mechanical behavior of the two clayey soils

Table 1: Geotechnical identification parameters of the studied soils

Soils	Fine fraction (≤ 80 µm) [%]	Clay fraction (≤ 2 µm) [%]	Liquidity limit w_l [%]	Plasticity limit w_p[%]	Plasticity index PI[%]	Organic matter content [%]	Optimum water content w_{OPM} [%]	Maximum dry unit weight γ_{dmax} [kN/m^3]
Nouna	95	74	44	22	22	10.8	16.30	16.53
Boudry	47.6	22.5	42	20	22	3.9	9.20	19.91

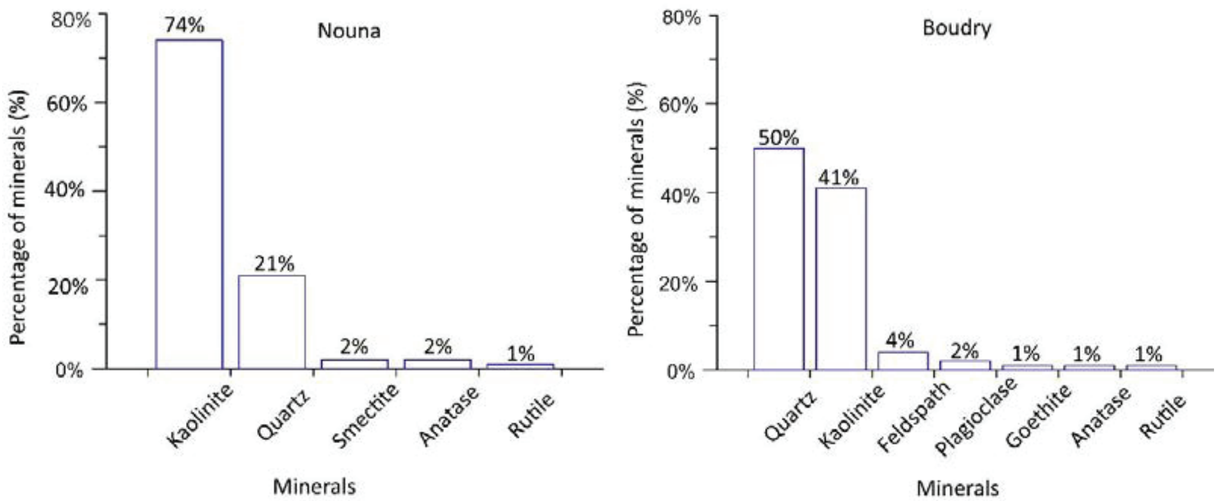


Fig. 2: Mineralogical composition of the fine fraction of the studied soils

on a large, sparsely treed plain. The reddish surface of the soil is sandy-silty. When sampled, the soil is in the form of hardened blocks. The walls remain vertical. The soil is completely dry, light brown to yellow with gravel or nodules. Soils were collected by hand digging of 75 cm deep hole. These samples were brought to the laboratory after a first on-site quartering operation. These samples of about 100 kg of soil were air-dried in the laboratory and broken up by hand. By a second quartering operation, several homogeneous batches were made, which will serve as test samples as well as for the production of test specimens. Identification tests (mineralogy by X-Ray diffraction over the infra 80 µm, particle size analysis using sieve analysis and sedimentometry, Atterberg limits, and determination of organic matter by calcination according to NF standards (AFNOR, 1992; 1996; 1998; 2002) and modified Proctor tests were carried out on these soils in order to determine their nature parameters of and compaction characteristics. The results of the geotechnical identification are shown in Table 1. The semi-quantitative mineralogical composition of the powders, which can be obtained by XRD analysis, is shown in Fig. 2. This mineralogical analysis were carried out on air-dried and glycol saturated preparations from the fine fraction of the soils. The diffractograms analysis was carried out according to Rietveld method.

The geotechnical identification tests essentially indicate clayey materials; the results of the mineralogy confirm that the fine fraction is mainly clayey respectively 76% for soils from Nouna and 41% for soils from Boudry. XRD results from oriented preparations and glycol-saturated oriented preparations reveals that the predominant mineral is kaolinite (74% of kaolinite and 2% of smectites for soils from Nouna, 41% of kaolinite for soils from Boudry). The results also report a significant amount of organic matter. In the Casagrande diagram, these materials are described as medium inorganic clays (CL), however the soil from Boudry are rather clayey sand (SC-CL). Their PI values are relatively high and thus make them promising from the point of view of their sealing potential.

Table 2: Composition by category of waste for Ouagadougou landfill (Haro *et al.*, 2018)

Category of waste	Percentage composition of waste fraction	
	Rainy season	Dry season
Fermentable waste	23.86	19.94
Paper	1.65	2.37
Cardboard	4.49	5.19
Composites	1.53	2.28
Textiles	5.41	4.32
Sanitary textiles	1.69	1.94
Plastics	11.13	12.1
Non-classified combustibles	3.46	2.81
Glass	1.14	3
Metals	2.89	1.71
Non-classified incombustibles	4.27	5.12
Special wastes	0.22	1.14
Fine materials	38.27	38.08

Table 3: Chemical composition (major ions) of the synthetic leachate

Ionic species	Ca^{2+}	Cl^-	Cu^{2+}	K^+	Mg^{2+}	Na^+	NH_4^+	SO_4^{2-}
Concentrations (mol/L)	0,014	0,07	7.10^{-4}	0,017	0,002	0,035	0,003	0,009
Concentrations (mg/L)	570,2	2475,8	5	673,5	50	793,2	50	834,9

Choice of leachates

Two types of leachates have been used in this study. The first one is natural and has been collected from the leachate storage and treatment ponds from the drainage system of Ouagadougou landfill. The values of BOD_5/COD highlight a large amount of organic matter. The pH value of the leachate is representative of a basic leachate with a pH of 7.68. The low electrical conductivity value of 1182 µs/cm shows that the salinity and at the same time the ionic strength of this leachate are not important. More details about its composition figured in Vianney *et al.* (2017). The composition by category of waste of Ouagadougou landfills are given in Table 2.

The second leachate is synthetic and has been formulated to be as close as possible of a young leachate from a household landfill in an acidogenesis phase. The formulation of this leachate has been described by Yonli *et al.* (2017). It has a relatively high biodegradable organic load consisting mainly of VFAs (Volatile Fatty Acids) and it is also loaded with heavy metals. Concentrations of chemical species (Table 3) are selected to stay within the usual ranges found in landfills and described by Christensen *et al.* (2001). The pH of the synthetic leachate is acidic with the value of 5.07 and an electrical conductivity of 12,560 µs/cm highlighting a high value of ionic strength.

Thus, there are two leachates, the synthetic one is potentially more aggressive. The formulation of synthetic leachates is a practice used in several studies. It has the advantage of guaranteeing control of the chemical composition and of discussing the modifications induced by the chemical species present by varying their concentration or by considering their actions in isolation.

Assessment of hydraulic conductivity by means of filtration tests on the two materials

The hydraulic behavior of the soils was assessed by means of API (American Petroleum Institute) type filtration tests. The method is well documented and consists of subjecting a suspension of soil and solvent to a pressure of 690 kPa (Sherwood, 1997; Benna-Zayani *et al.*, 2001; Pantet and Monnet, 2007 ; Rosin-Paumier *et al.*, 2011). The applied pressure forces the liquid to flow while the solid part called cake is retained on a filter paper. The kinetics of filtration are related to the hydraulic properties of the cake as well as the chemical composition of the filtered liquid. Although Darcy's law was developed for grainy soils (sands and gravels), to this day, it is still used, for cohesive soils (clays and silts). Application to fine soils assumes a sufficiently high hydraulic gradient so as not to observe deviations from Darcy's law. This condition is fulfilled within the framework of this study, given the high pressure value applied to the clay suspensions. From Darcy's law, it is established that the cumulative volume of filtrate V(m^3) is expressed as a linear relation as a function of the square root of time t(s) using Eq. 1.

$$V^2=2.K.S^2.P.t/(\mu.b) \quad (1)$$

Where, K is the desired intrinsic permeability (m^2) of the material, S the surface of the sample (m^2), P the pressure (Pa), μ the viscosity of the water (Pa.s^{-1}) and b = cS/V_f the specific volume of the cake deposited per unit volume, c the cake thickness (m), V_f is the final volume at the end of filtration (m^3). The coefficient of permeability or hydraulic conductivity k(m/s) is thereafter obtained by Eq. 2.

$$k = \rho.g.K/\mu \quad (2)$$

Where, ρ is the bulk density of water (kg/m), g is the acceleration due to gravity (m^2/s)

The suspensions dosed at 100 g/L are prepared with distilled water (which serves as a reference situation) then in the presence of the leachates (natural leachate and synthetic leachate) at the same dosage. The void ratio of the cake is calculated after determining its dry density ρ_d using Eq. 3.

$$e = \rho_s/\rho_d-1 \quad (3)$$

Where, ρ_s is the density of the solid particles assumed equal to 2.65 g/cm^3.

The advantage of the filtration tests method lies in its rapidity since it makes it possible to avoid the saturation period required before permeability falling head tests. Although the void index is not the same in both tests, filtration tests and permeability falling head tests lead to the same orders of magnitude of the hydraulic conductivity.

Assessment of mechanical behavior of soils from Nouna

The various mechanical parameters were determined by conducting tests on compacted samples of soils from Nouna and Boudry under drained conditions with water as saturating fluid and then with leachates. Conditions of compaction and conditions of drainage are identical in both cases. To ensure a low permeability, the samples have been remoulded by compaction with the energy of Modified Proctor on wet side of the Proctor curve (at w_{OPM}+3%).

Assessment of compressibility

The deformation properties of the soils were assessed by means of oedometric tests, applying a loading stage every 24 hours. In this approach, the consolidation phenomenon involded, implies a strong coupling between the mechanical compressibility of the soil skeleton and the drainage of the interstitial fluid and supposes a saturation of the soil. The samples of soils tested in this study were allowed to swell almost freely during a saturation phase, the sample is only subjected to a vertical stress corresponding to the weight of the piston (3 kPa). Then, the loads applied to the sample were increased, step by step, up to 483 kPa, with three loading/unloading cycles. The value of 483 kPa corresponds to the order of magnitude of the stresses caused by the weight of the waste in the landfills in Burkina Faso. The deformation parameters were calculated from the compressibility curve e-logσ'_v where e is the soil void ratio and σ'_v is the corresponding applied effective vertical stress. The compression and recompression indexes C_c and C_r are important because they allow to calculate the settlement (vertical deformation of the bottom liner). In the case of excessive settlements and especially differential settlements, the clayey bottom liner may be damaged.

Assessment of shear strength

The shear strength is measured by means of direct shear test, using a shear test appartus equipped with an automated acquisition device. It is assumed that, in landfills, the application of loads related to the weight of waste leads to the consolidation of the soil through the dissipation of interstitial pressures. This is why, tests conducted with different loads were carried out under saturated conditions with a sufficiently slow speed (of 0.02 mm/mn), in order to measure the effective characteristics. The shear stress at the rupture obeys Coulomb's law, using Eq. 4.

$$\tau = C' + \sigma'_v.tan\phi' \quad (4)$$

Where, C' is the effective cohesion and ϕ' the effective angle of internal friction.

Table 4: Hydraulic conductivities of studied soils obtained with distilled water

Soils	Nouna	Boudry
Hydraulic conductivity k(m/s)	1.71×10^{-10}	1.01×10^{-9}
Void ratio e	1.11	0.90

Table 5: Influence of the leachate on hydraulic conductivities of studied soils

Test fluids	Hydraulic conductivities k(m/s)	
	Nouna	Boudry
Distilled water	1.71×10^{-10}	1.01×10^{-9}
Natural leachate	3.51×10^{-10}	2.70×10^{-9}
Synthetic leachate	1.18×10^{-9}	7.72×10^{-9}

RESULTS AND DISCUSSION

Filtration tests with water and leachate

The results of filtration tests carried out on suspensions dosed at 100 g/L with soils from Nouna and Boudry are presented below. Table 4 also presents the characteristic values of the cake obtained.

These results show that the soil from Nouna has a hydraulic conductivity at saturation less than 10^{-9} m/s, confirming the possibility of being used as a bottom liner. The soil from Boudry however has a value of hydraulic conductivity of 1.01×10^{-9} m/s. This value of hydraulic conductivity is at the limit of the acceptable threshold. It appears otherwise that even with trace amounts, smectites are very necessary to obtain an optimal sealing. Indeed, the permeability of clay materials is highly dependent on the mineralogical composition of the clay compounds, the texture, its water content and its state of consolidation (Marcoën *et al.*, 2000). The results of the filtration tests with the synthetic leachate (Table 5) showed an important increase in the hydraulic conductivity k of the soils from of Nouna, which varies from 1.71×10^{-10} m/s to 1.18×10^{-9} m/s, i.e. k almost multiplied by 10; it results in the decrease in their sealing potential. Concerning the soils from Boudry, the increase with this leachate is slightly less significant. The less impervious material appears to undergo the deeper alteration. The degradation of the sealing potential with leachates is a phenomenon highlighted by many authors. For example Badv and Omidi (2007) who studied the effect of a synthetic leachate rich in calcium (4000 mg/l concentration) on the hydraulic conductivity of a clayey sand found an increase in the hydraulic conductivity of 20%. Wang *et al.* (2019) used a natural leachate (stabilized inorganic hazardous waste leachate) to conduct hydraulic conductivity tests on bentonites and also noticed an increase in the hydraulic conductivity. The phenomenon of degradation of the sealing potential deserves further investigation, because many parameters are involved such as the composition of the leachate and its concentration. The natural leachate has a very slight impact on the permeability of the materials. This result is in agreement with the nature of the leachate: the synthetic leachate formulated has a very high ionic strength compared to that of the natural leachate. This indicates that the mineral pollutant load of the landfill leachate is not so high. Setz *et al.* (2017) noticed that solutions having high ionic strength or predominantly divalent cations lead to larger pores and higher hydraulic conductivity.

Influence of leachates on compressibility

Compressibility of soils from Nouna

The results of œdometric tests conducted on soils from Nouna are given in Table 6. They show that although compacted (with an initial void ratio e of 0.65 and an initial density (saturated density) g_{sat} of 18.92 kN/m^3 compared to the value e of 1.11 and g_{sat} of 13.42 kN/m^3 obtained by filtration), the soils from Nouna have values of compression and recompression indexes which characterize compressible soils. Despite the low percentage of smectites of 2%, the swelling of the soils from Nouna (part "AB" of the curve) appears to be very important. Indeed, according to Tabani (1999) and Xu *et al.* (2003), the amount of swelling clay is one of the first factors which condition the swelling of clayey soils. Tabini (1999) found a swelling rate of 6.3% for a soil having a percentage of bentonite of 10% under a pressure of 5 kPa. Nouna clay, for its part, has a swelling rate of 12.05% under a pressure of 3 kPa. Nevertheless, many

Table 6: Influence of leachate on the parameters of the mechanical behavior of the soil from Nouna

Test fluids	Initial specific weight γ_{sat} (kN/m^3)	Deformabilty properties		Preconsolidation pressure $\sigma'_p(kPa)$
		Recompression index C_r	Compression index C_c	
Distilled water	18.92	0.049	0.164	55
Natural leachate	18.83	0.054	0.148	55
Synthetic leachate	19.37	0.095	0.225	50

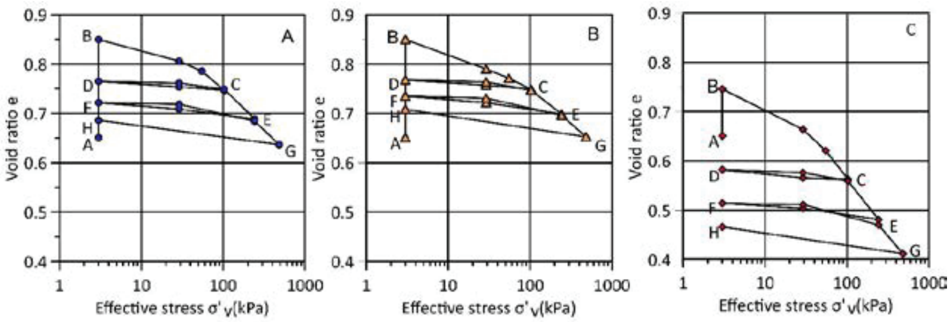


Fig. 3: Compressibility curves obtained for soils from Nouna (A. Distilled water; B. Natural leachate; C. Synthetic leachate)

authors agree that the initial state of the soil (water content and dry density) and other structural effects, seasonal influence and even test conditions may have an influence on the swelling rate (Chrétien, 2010). All else being equal, the mechanical behavior of Nouna clay is also modified under the influence of leachates. Results are summarized in Table 6 and on Fig. 3. The compressibility curves e-logσ'_v seem quite similar for distilled water (Fig. 3A) and natural leachate (Fig. 3B). Thus, it appears that the natural leachate having a weak ionic strength has few interactions with the soil. On the other hand, the impact of the synthetic leachate is very noticeable (Fig. 3C). This raises the question of the representability of leachate as a test fluid. Let's remember that the synthetic leachate is formulated to be as close as possible to a leachate of household landfill in its early stages of maturation. The swelling of Nouna is partially inhibited. Indeed, the cations contained in this solution diffuse through the layer space of the clay resulting in a reduction of repulsive forces between the clay particles (Yonli *et al.*, 2017). The compression index undergoes a significant increase from 0.164 to 0.225 and it is necessary to consider in the design of the bottom liner as it will lead to higher settlements. Gratchev and Towhata (2009) made this same observation. The authors noted that the compressibility of Ariake clay leached with acidic fluids increased because of the dissolution of ferric oxide between the clay aggregates.

In order to know the contribution of each group of chemical species contained in the synthetic leachate (VFA, major mineral ions, heavy metals) in the increase of the compressibility, œdometric tests were also performed with each one of them. The results shown in Fig. 4 reveal that while major mineral ions and heavy metals cause a decrease in compressibility (decrease in Cc), for acetic acid, the opposite occurs. It is therefore the reaction of VFA with some compounds of the soils from Nouna which contributes to such an increase in the settlements.

Compressibility of soils from Boudry

The results obtained for the soils from Boudry (Table 7 and Fig. 5) well illustrate the role of mineralogy on the modification of the mechanical properties of soils. Swelling is not affected by both leachates. Unlike soils from Nouna, the compressibility of soils from Boudry decreases because the settlements become less important. Thus, if permeability is altered by leachates regardless of the type of clay, it is not the same way for compressibility. This observation leads us to reflect on the criteria for choosing suitable clayey soils to make bottom liners. Shouldn't it be the result of a compromise between hydraulic and mechanical

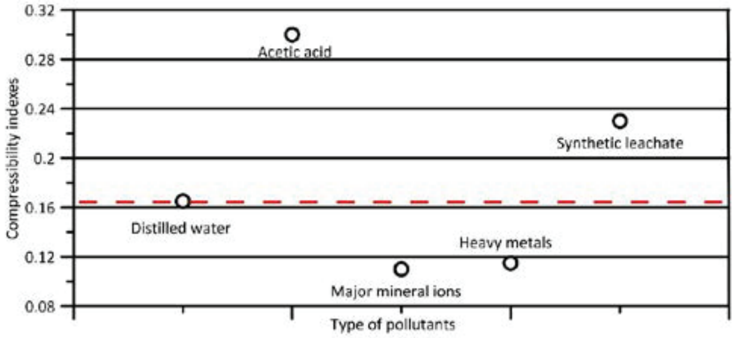


Fig. 4: Influence of the type of pollutants contained in the synthetic leachate on the compressibility of Nouna clay, comparison with distilled water

Table 7: Influence of leachate on the parameters of the mechanical behavior of the soils from Boudry

Test fluids	Initial specific weight γ_{sat} (kN/m^3)	Deformabilty properties		Preconsolidation pressure $\sigma'_p(kPa)$
		Recompression index C_r	Compression index C_c	
Distilled water	20.21	0.007	0.109	50
Synthetic leachate	20.10	0.007	0.075	50
Real leachate	20.25	0.001	0.067	50

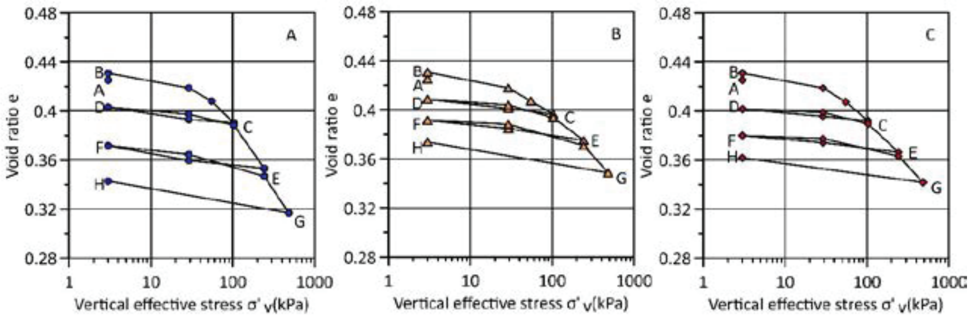


Fig. 5: Compressibility curves obtained for soils from Boudry (A. Distilled water; B. Real leachate; C. Synthetic leachate)

performance which takes into account the composition of the leachate? The answer to this question would obviously involves the choice of the representability of the test fluid as leachate. According to some authors such as Dutta and Mishra (2016), the decrease of compression index may be the result of the orientation of clay particles becoming more flocculated and resisting to settlements. Litterature also suggests that the effect of diffuse double layer on the compressibility of soils is less pronounced for kaolinitic soils compared to soils containing smectites (Mitchell and Soga, 2005). This statement is in agreement with the results of this study.

Influence of leachates on shear strength

Shear strength of soils from Nouna

The effective cohesion C' and the effective angle of internal friction Φ' (measured at a state of compacity identical to the case of the oedometric tests) and determined from the Mohr relation, are respectively 3 kPa and 28° for tests with distilled water. The low value of cohesion and the relatively high value of the angle of friction are consistent with the state of saturation of the clay. Since the real leachate did not significantly alter the compressibility of Nouna, only synthetic leachate (compared with distilled water) was used to conduct shear tests. The results of shear tests with the synthetic leachate as a saturating fluid reveal that the soil experiences an increase in shear strength (Fig. 6). The shear strength is modified with only an increase in the soil cohesion at 21 kPa. The value of the angle of internal friction is not affected. The observation of this phenomenon could find an explanation in the theory of the diffuse double layer. Leachate highly concentrated in electrolytes would cause a change in the organization of particles. From a morphological point of view, the leachate favors an increase in the number of sheets per aggregate and consequently a decrease in the number of aggregates with equal dry matter quantity. All this shows that the soil migrates towards a more cohesive state. Some authors have pointed out that it is precisely aggregates which generate the shear resistance (Derriche *et al.*, 1997).

Shear strength of soils from Boudry

The intrinsic curves of soils from Boudry, on the other hand, show that the increase in shear strength induced by the synthetic leachate is due both to the cohesion of the soil as well as to its internal friction angle (Fig. 7). However, the increase in cohesion is less significant than that of the soils from Nouna: it goes from 19 kPa to 23 kPa, i.e. an increase of 21%. This finding is in agreement with œdometric tests which have shown that the influence of the leachate on the swelling and therefore on the diffuse double layer is negligible because of the mineralogy of the soils from Boudry, whose clay fraction mainly contains kaolinite. The slight increase in the internal friction angle, which goes from 34 ° to 37 °, may be due to the action of the synthetic leachate on the geometry of the grains of sand contained in soils from Boudry.

Some authors have also found similar results, they notice an increase in shear strength of clayey soils in contact with leachate. Indeed Naieni *et al.* (2017) studied the effect of leachate's components on undrained shear strength of clay-bentonite liners. They noticed that by addition of soluble salts of single-valence cations and leachate provided from them up to 2%, the undrained shear strength of clay-bentonite liners increased. However, they also

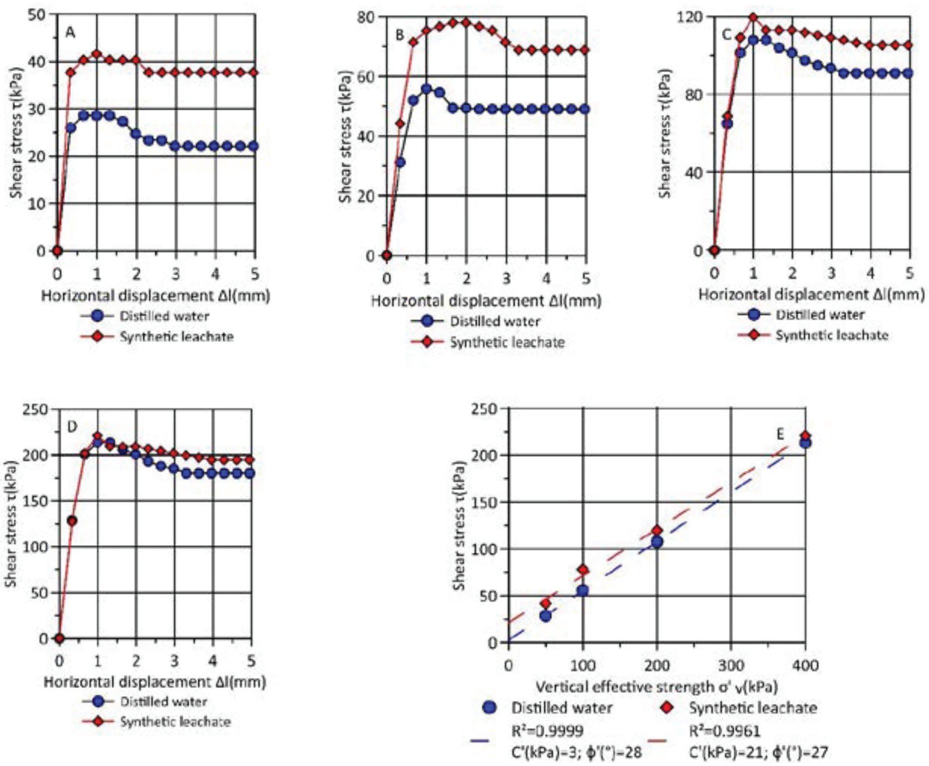


Fig. 6: Influence of synthetic leachate on the shear strength of soils from Nouna (A. Stress strain curve σ'_v = 50 kPa ; B. Stress strain curve σ'_v = 100 kPa ; C. Stress strain curve σ'_v = 200 kPa ; D. Stress strain curve σ'_v = 400 kPa E. Failure envelope)

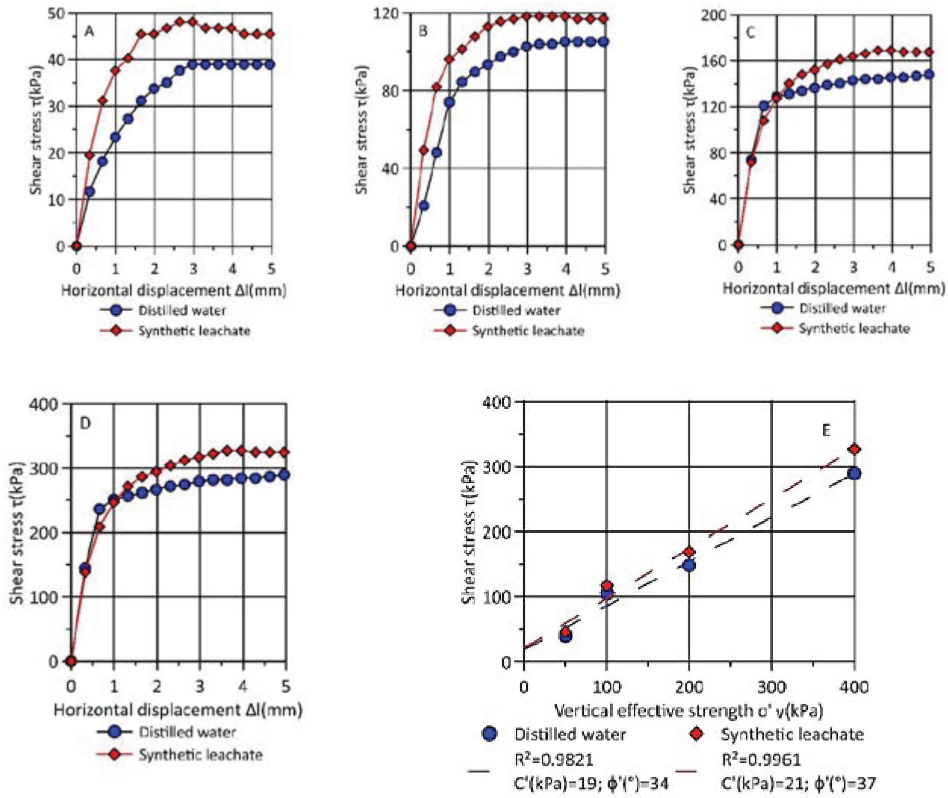


Fig. 7: Influence of synthetic leachate on the shear strength of soils from Boudr (A. Stress strain curve σ'_v = 50 kPa ; B. Stress strain curve σ'_v = 100 kPa ; C. Stress strain curve σ'_{v*} = 200 kPa ; D. Stress strain curve σ'_v = 400 kPa E. Failure envelope)

pointed out, shear strength decrease with further increase in contaminants. Sunil *et al.* (2009) noticed that even in lateritic soils used as landfill foundation, the contamination by municipal solid waste leachate lead to changes in the shear strength characteristics. The effective cohesion increases while the effective friction angle decreases.

The results of all the hydro-mechanical tests in this study show that while leachates are always detrimental to the sealing of a bottom liner, it is not necessarily the case for its mechanical behavior. This should draw attention to the fact that designing a bottom liner is a complex process that requires extensive investigations.

CONCLUSION

This study consisted to assess the modification of the long-term hydro-mechanical behavior of two clayey soils in presence of household waste leachate. It allowed to reconsider the criteria of choice of suitable clayey soils for a use as bottom liners. Contamination by leachate always alters the hydraulic properties of soils. However, between the two soils studied, the most clayey and the most impermeable (soils from Nouna) undergo the deeper alteration. Furthermore, whatever the soils considered, the leachate with the greatest ionic strength is also the most aggressive in terms of degradation of the sealing properties. The study emphasizes that the choice of the clayey soils as bottom liners should results from a compromise between long term hydraulic and mechanical performance. Indeed, soils from Boudry (mainly containing quartz and kaolinite), which are the less impermeable of both materials, experience an improvement of their deformation properties meaning that settlements decrease. On the contrary a bottom liner made from soils from Nouna, would experience very significant settlements over the long term because of the influence of volatile fatty acids contained in the synthetic leachate. The influence of the synthetic leachate on the shear strength characteristics shows that it always improves the stability of the bottom liner. In this case, a short-term design of the liner, is better from a safety point of view. This result requires further investigation by carrying out the same tests with other clayey soils and other leachates as research perspectives. The question of the representativeness of the leachate for carrying out a long-term characterization is also raised. The natural leachate of lower ionic strength has less impact on the hydro-mechanical behavior of the studied soils as evidenced by the values of hydraulic conductivities and those of the compression and recompression indexes. The conclusions of this comparative study of the hydro-mechanical properties of two clayey soils are of practical use to professionals in the field of environmental geotechnics. The importance of the surface properties with respect to leachate is well demonstrated. On the long term, leachate production, linked to the decomposition of waste, can lead to a loss of hydraulic performance and a modification of the mechanical characteristics of the bottom liners.

AUTHOR CONTRIBUTIONS

H.F. Yonli performed the literature review, compiled and interpreted the data, prepared and edited the manuscript. B. François interpreted the data and prepared the manuscript. D.Y.K. Toguyeni and A. Pantet performed the elaboration of the research problem.

ACKNOWLEDGMENTS

The authors would like to thank the national laboratory for building and public works in Burkina Faso, where a lot of geotechnical tests were carried out in the framework of this study. Special thanks go to the members of the technical management team on the date on which this work was carried out, in particular the technical director Mr. Kalsibiri Kaboré.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

API	American Petroleum Institute
b	Specific volume of the cake
BOD_5	Biologic Oxygen Demand
c	Cake thickness
C'	Effective cohesion
C_c	Compression index
Ca^{2+}	Calcium ion
CL	Inorganic clay of low to medium plasticity
Cl^-	Chloride ion
COD	Chemical Oxygen Demand
Cu^{2+}	Copper ion
C_r	Recompression index
cm	Centimeter
cm^3	Cubic centimeter
e	Void ratio
g	Gram
i.e.	That is to say
k	Hydraulic conductivity
K	Intrinsic permeability
K^+	Potassium ion
kg	Kilogram
km	Kilometer
kN	Kilonewton
kPa	Kilopascal

g	Acceleration due to gravity
L	Liter
LCRS	Leachate Collection and Removal System
m	Meter
m^2	Square meter
m^3	Cubic meter
mg	Milligram
Mg^{2+}	Magnesium ion
mn	Minute
mol	Mole
P	Pressure
Pa	Pascal
Na^+	Sodium ion
NH_4^+	Ammonium ion
PI	Plasticity index
pH	Potential hydrogen
s	Second
S	Surface of the sample
SC-CL	Clayey sand of low to medium plasticity
SO_4^{2-}	Sulfate ion
t	Time
UTM	Universal Mercator Transverse
V	Cumulative volume of filtrate
V_f	Final volume at the end of filtration
VFA	Volatile Fatty Acids
X	X coordinate
XRD	X Rays Diffraction
Y	Y coordinate
wl	Liquidity limit
w_{OPM}	Optimum water content
w_p	Plasticity limit
ρ	Bulk density of water
ρ_d	Dry density
ρ_s	Density of the solid particles
Φ'	Effective angle of internal friction
μ	Viscosity of water
μm	Micrometer
μS	Microsiemens
γ_{dmax}	Maximum dry unit weight
γ_{sat}	Saturated density
σ'_v	Effective vertical stress
σ'_p	Preconsolidation pressure
%	Per cent
°	Degree

REFERENCES

Abdellah, D.; Gueddouda M.K.; Goual, I.; Souli, H.; Ghembaza, M.S., (2020). Effect of landfill leachate on the hydromechanical behavior of bentonite-geomaterials mixture. Constr. Build. Mater., 234: 1-15 **(15 pages)**.

Abramson, L.W.; Lee, T.S.; Sharma, S.; Boyce, G.M., (2002). Slope stability and stabilization methods. Wiley, New York **(736 pages)**.

AFNOR, (1992). NF P94-057: Soils recognition and testing-particle size analysis—sedimentation method. Association Française de Normalisation, Paris, France **(17 pages)**.

AFNOR, (1996). NF P94-056: Soils recognition and testing-particle size analysis—dry sieving method after washing. Ocia. Association Française de Normalisation, Paris, France **(15 pages)**.

AFNOR, (1998). XP P94-047: Soils recognition and testing - Determination of matter organic content of a material. Association Française de Normalisation, Paris, France **(6 pages)**.

AFNOR, (2002). NF P94-051: Soils recognition and testing-determination of atterberg limits-liquidity limit at the cup-plastic limit rolling. Association Française de Normalisation, Paris, France **(15 pages).**

Ait Saadi, L., (2003) Methodology to control the homogeneity and permeability of clayey liners. PhD Thesis, National Institute of Applied Sciences of Lyon **(294 pages)**.

Azizi, A.; Malakmohamadi, B.; Jafari, H.R., (2016). Land use and land cover spatiotemporal dynamic pattern and predicting changes using integrated CA-Markov model. Global J. Environ. Sci. Manage., 2(3): 223-234 **(12 pages).**

Badv, K.; Omidi, A., (2007). Effect of synthetic leachate on the hydraulic conductivity of clayey soil in Urmia city landfill site. Iran. J. Sci. Technol. Trans. Civ. Eng., 31(5): 535-545 **(11 pages).**

Benna-Zayani, M.; Kbir-Ariguib, N.; Clinard, C.; Bergaya, F., (2001). Static filtration of purified sodium bentonite clay suspensions, effect of clay content. Appl. Clay Sci., 19: 103–120 **(18 pages)**.

Benson, C.H.; Chen, J.N.; Edil T.B., Likos, W.J., (2018). Hydraulic conductivity of compacted soil liners permeated with coal combustion product leachates. J. Geotech. Geoenviron. Eng., 144 (4): 3-15 **(13 pages).**

Chrétien, M., (2010). Understanding of shrinkage-swelling mechanisms clay soils: experimental site approach and disaster analysis on individual constructions. Ph.D. thesis, The University of Grenoble, France **(372 pages)**.

Christensen, T.; Kjeldsen, P.; Bjerg, P., (2001). Biogeochemistry of landfill leachate plumes. Appl. Geochem., 16 : 659–718 **(60 pages)**.

Cuisinier, O.; Deneele, D.; Masrouri, F.; Abdallah. A.; Conil, N., (2014). Impact of high-pH fluid circulation on long term hydromechanical behaviour and microstructure of compacted clay from the laboratory of Meuse-Haute Marne (France). Appl. Clay Sci., 88–89: 1–9 **(9 pages)**.

Derriche, Z.; Bouzid, F. ; Tas, M.; (1997). Analysis of the shear strength of a swelling clay. XIVth Conf. Int. Mech. Ground Humburg. 271-274 **(4 pages)**.

Dutta, J.; Mishra, A.K., (2016). Consolidation behaviour of bentonites in the presence of salt solutions. Appl. Clay Sci., 120 : 61-69 **(9 pages).**

Ehrig, H.-J.; Steigmann, R., (2018). Leachate quality. Solid waste landfilling : 511-539 **(29 pages).**

Gratchev, I.; Towhata, I., (2009). Effects of acidic contamination on the geotechnical properties of marine soils in Japan. In proceedings of the International Offshore and Polar Engineering Conference. 151-155 **(5 pages)**.

Haro, K.; Ouarma, I.; Nana, B.; Bere, A.; Koulidiati, J., (2018). Characterization and potential recovery of household solid waste in the city of Ouagadougou (Burkina Faso). J. Environ. Prot. Ecol., 9: 309-324 **(16 pages).**

Jambeck, J.-R.; Andino, J.M., (2007). Garbage Juice: Waste Management and Leachate Generation. J. Chem. Educ., 240A-240B **(2 pages).**

Marcoën, J.; Thorez, J.; Monjoie, A.; Tessier, D.; Schroëder, C., (2000). Handbook on natural materials for engineered clay liners for landfills and rehabilitation of waste disposals in the walloon region. Office wallon des déchets.

Mishra, A.K.; Ohtsubo, M.; Li, L.Y.; Higashi, T., (2010). Influence of the bentonite on the consolidation

behaviour of soil–bentonite mixtures. Carbonates Evaporites. 25: 43–49 **(7 pages).**

Mitchell, J.; Soga, K., (2005). Fundamentals of soil behavior. John Wiley and Sons **(592 pages).**

Naeini, S.A.; Gholampoor, N.; Jahanfar, M.A., (2017). Effect of leachate's components on undrained shear strength of clay-bentonite liners, Eur. J. Environ. Civ. Eng.: 395-408 **(14 pages).**

Pantet, A.; Monnet, P., (2007). Liquid–solid transition of kaolinite suspensions. Mech. Mater., 39(9): 819-833 **(15 pages)**.

Rosin-Paumier, S.; Touze, N.; Pantet, A., (2011). Impact of a synthetic leachate on permittivity of GCLs measured by filter press and oedopermeameter tests. Geotext. Geomembr., 29: 211-221 **(11 pages)**.

Setz, M.C.; Tian, K.; Benson, C.H.; Bradshaw, S.L., (2017). Effect of ammonium on the hydraulic conductivity of geosynthetic clay liners. Geotext. Geomembr. 45(6): 665-673 **(9 pages).**

Sherwood, J.D., (1997). Initial and final stages of compressible filtercake compaction. AIChE J., 43: 1488-1493 **(6 pages)**.

Sunil, B.M.; Shrihari, S.; Nayak S., (2009). Shear strength characteristics and chemical characteristics of leachate-contaminated lateritic soil. Eng. Geol., 106: 20-25 **(6 pages).**

Tabani, P., (1999). Water transfer in deformable soils. PhD thesis, National Polytechnic Institute of Lorraine, France **(173 pages)**.

Townsend, T.G.; Powell, J.; Jain, P.; Xu, Q.; Tolaymat, T.; Thimothy, G., (2015). Sustainable practices for landfill design and operation. New York: Springer Science + Business Media **(483 pages)**.

Ullah, K.A.; Jiang, J.; Wang, P., (2018). Land use impacts on surface water quality by statistical approaches. Global J. Environ. Sci. Manage., 4(2): 231-250 (**20 pages**).

Vianney, J.; Martine, K.; Ouattara, Y.; Guinko, S.; Sawadogo, S., (2017). Evaluation of the quality of household waste leachate treated by settling ponds at the Ouagadougou waste treatment and valorization center. J. Environ. Prot., 8: 1567-1582 **(16 pages)**.

Wagner, J.F., (2013). Clay liners and waste disposal. In Handbook of Clay Science. Develop. Clay Sci., 5: 663–676 **(14 pages)**.

Wdowczyk, A.; Szymańska-Pulikowska A., (2021). Analysis of the possibility of conducting a comprehensive assessment of landfill leachate contamination using physicochemical indicators and toxicity test. Ecotoxicol. Environ. Saf., 221:1-12 **(12 pages).**

Wang, B.; Xu J.; Chen, B.; Dong, X.; Dou, T., (2019). Hydraulic conductivity of geosynthetic clay liners to inorganic waste leachate. Appl. Clay Sci., 168: 224-248 **(25 pages)**.

Widomski, M.K.; Stępniewski, W.; Musz-Pomorska, A., (2018). Clays of different plasticity as materials for landfill liners in rural systems of sustainable waste management. Sustainability. 10: 2489: 1-15 **(15 pages)**.

Xu, Y.F.; Matsuoka, H.; Sun, D.A., (2003). Swelling characteristics of fractal-textured bentonite and its mixtures. Appl. Clay Sci., 22: 197-209 **(13 pages)**.

Yonli, H.F.; Toguyeni, D.Y.K.; Sougoti, M., (2017). Study of the influence of a young synthetic leachate on the hydromechanical properties of a swelling clay. J. Environ. Sci. Eng., B 6: 569-581 **(13 pages)**.

AUTHOR (S) BIOSKETCHES

Yonli, H.F., Ph.D., Assistant Professor, [1]Laboratoire de Physique et de Chimie de l'Environnement, Université Joseph KI-Zerbo, BP 7021 Ouagadougou 03, Burkina Faso. [2]Ecole Supérieure d'Ingénierie, Université de Fada N'Gourma, BP 46 Fada N'Gourma, Burkina Faso.
Email: *fabienyonli@yahoo.fr*
ORCID: **0000-0002-4981-4705**

François, B., Ph.D., Professor, Building Architecture and Town Planning Department, Université Libre de Bruxelles, Avenue F.D. Roosevelt 50, CP 194/2, 1050 Bruxelles, Belgique.
Email: *bertrand.francois@ulb.be*
ORCID: **0000-0001-5075-1222**

Toguyeni, D.Y.K., Ph.D., Professor, [1]Laboratoire de Physique et de Chimie de l'Environnement, Université Joseph KI-Zerbo, BP 7021 Ouagadougou 03, Burkina Faso. [2]Ecole Polytechnique de Ouagadougou, 08 BP 143 Ouagadougou 08, Burkina Faso.
Email: *togyen@gmail.com*
ORCID: **0000-0001-5306-6095**

Pantet, A., Ph.D., Professor, UMR 6294 CNRS, Laboratoire Ondes et Milieux Complexes (LOMC), Normandie Université, UNIHAVRE, 53 rue Prony, 76600 Le Havre, France.
Email: *anne.pantet@univ-lehavre.fr*
ORCID: **0000-0002-8776-5182**

HOW TO CITE THIS ARTICLE

Yonli, H.F.; François, B.; Toguyeni, D.Y.K.; Pantet, A., (2022). Hydro-mechanical behavior of two clayey soils in presence of household waste leachates. Global J. Environ. Sci. Manage., 8(2): 169-182.

DOI: 10.22034/gjesm.2022.02.02

url: https://www.gjesm.net/article_246026.html

Global J. Environ. Sci. Manage. 8(2): 183-196, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH ARTICLE

Microplastic abundance and distribution in surface water and sediment collected from the coastal area

N.D., Takarina[1,*], A.I.S., Purwiyanto[2], A.A., Rasud[1], A.A., Arifin[1], Y., Suteja[3]

[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, Indonesia

[2] Marine Science Department, Faculty of Mathematics and Natural Sciences, Sriwijaya University, Palembang, Indonesia

[3] Marine Science Department, Marine Science and Fisheries Faculty, Udayana University, Bali, Indonesia

ARTICLE INFO

Article History:
Received 07 June 2021
Revised 19 August 2021
Accepted 22 September 2021

Keywords:
Fiber
Estuary
Jakarta Bay
Plastic
Polyethylene

ABSTRACT

BACKGROUND AND OBJECTIVES: Rapid development has increased the microplastics discharges into marine environments, including coastal waters at Jakarta Bay, Indonesia. This study is proposed to assess microplastics abundance and distribution in surface water and sediment from coastal water at Jakarta Bay.
METHODS: The samples were collected from 12 locations representing Ancol, Muara Baru, and Muara Angke- Muara Karang. Samples of water and sediment were extracted to obtain the microplastics. The microplastics were identified based on their morphology (shape) and numbered for their abundance. The polymer of microplastics was determined using Raman Spectrophotometer.
FINDINGS: The results showed that microplastics were successfully identified and counted in water and sediment samples at all collection points. The number of microplastics was 1532 particles in the water sample and 1419 particles in the sediment sample. The shape of microplastics observed in the water and sediment samples were fibers, films, fragments, and pellets. Among those, fiber and film were the most dominant microplastic detected both in surface water and sediment in all locations. Three polymers, namely polyethylene, polypropylene, and polystyrene, were detected in the microplastic samples. These findings prove that microplastics with their various types are capable contaminate the aquatic environment.
CONCLUSION: The most common microplastics shapes in sediment were fiber (55.7%) > film (31.1%) > fragment (9.9%) > pellet (3.2%) and for the surface water were film (53.5%) > fiber (33.9%) > fragment (7.8%) > pellet (4.7%). The abundance of microplastics in the sediment (166.8 particles/kg, 95%CI: 148.0-185.0) was significantly higher ($p < 0.05$) than in surface water (70.9 particles/L, 95%CI: 55.6-86.2). The abundance of microplastics was significantly different among locations ($p < 0.05$, $F = 2.115$), with microplastics in sediments were higher in Ancol, and Muara Angke - Muara Karang have the highest microplastics in surface water. These results can provide valuable information on which parts of the Jakarta Bay areas should be prioritized first regarding microplastics management.

DOI: 10.22034/gjesm.2022.02.03

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
58	5	4

*Corresponding Author:
Email: *noverita.dian@sci.ui.ac.id*
Phone: +62-21727 0163
ORCID: 0000-0003-1766-7445

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

The use of plastics as a crucial component in modern society worldwide is increasing (Andrady and Neal, 2009). Plastics are employed because they are not only versatile, lightweight, strong, and sturdy but also inexpensive; hence, they have been applied in many industries. In recent years, the rate of plastics production in the world has risen from 0.5 million to 288 million tons between 1950 and 2012 (Plastics Europe, 2013). In 2016, the rate increased by 4% and reached 360 million tons in 2018 (Plastics Europe, 2019). Marine environments in Indonesia are also threatened by plastic debris, with an assumption that about 10% of plastics would end up in seas (Van Cauwenberghe *et al.*, 2015). In total, Indonesia is the second-largest country after China that discharged plastic waste into the ocean. The amount is about 0.48 – 1.29 MMT (Purba *et al.*, 2019). According to Hastuti *et al.*, (2014), about 165,000 tons of plastics debris annually pollute Indonesia's marine environment. Due to the fragmentation process, larger plastic and litter become small particles. Some of them are scrubbers in cosmetics and abrasive beads used to clean the ships (Browne *et al.*, 2007). Microplastics are plastic particles with a diameter of <5 mm (GESAMP, 2015). Based on the origin of the waste, microplastics are divided into two types, namely primary microplastics and secondary microplastics. Primary microplastics are microplastic particles derived from small particles with a size of <5 mm. In general, primary microplastics are also derived from chemical waste such as soap, called 'Scrubbers'. Scrubbers sizes ranging from 2-5mm impact filter-feeding organisms (Fendall and Sewell 2009). Secondary microplastics are particles derived from large, degraded plastic particles (Browne *et al.*, 2011). Microplastics threaten marine ecosystems, not only on the photosynthesis process in algae (Della Torre *et al.*, 2014) but also on the reproduction and hatching in certain organisms (Sussarellu *et al.*, 2016). Microplastics can accumulate in the bodies of animals such as fish, shellfish, and others. (Oehlmann *et al.*, 2019). Sources of microplastic pollution can come from a point or scattered sources. Siegfried *et al.* (2017) stated that microplastics come from a source from land-based and sea-based sources. Microplastics in household waste or industrial waste are discharged to a wastewater treatment plant (WWTP) or discharged without treatment into adjacent water bodies such as rivers. Disposal of this household waste is a potential entry point for microplastics because it can come from overflowing combined sewers. The discharge stream will lead to rivers, which are important pathways for microplastic waste generated from land to reach the marine environment (Lebreton *et al.*, 2017). Sources of microplastic pollution originating from scattered sources are waste sources without a specific point of disposal. Plastic is easier to enter the aquatic environment due to currents, rainfall, or wind (Siegfried *et al.*, 2017). Study about microplastics pollution on surface waters of marine environments in Indonesia's has been reported quite a lot, such as in the Jeneberang Estuary, South Sulawesi (Wicaksono *et al.*, 2020), coastal area of Nusa Penida, Bali, and coastal water of Bentar, East Java (Germanov *et al.*, 2019), Benoa Bay estuary, Bali (Suteja *et al.*, 2021), and Musi River estuary, South Sumatera (Purwiyanto *et al.*, 2020). Some studies also reported the existence of microplastics in sediments, such as in Sumatra west coast (Cordova and Wahyudi, 2016), Banten Bay (Falahudin *et al.*, 2020), and Muara Angke, Jakarta (Cordova *et al.*, 2021). Jakarta Bay is one of the plastic contributors, even the highest to marine environments in Indonesia. This condition becomes very threatening and needs attention. Wastewater with various pollutants enters flowing river waters (Suteja and Purwiyanto, 2018) and carries the water to Jakarta Bay, thus worsening the condition of waters in Jakarta Bay (Kunzmann, *et al.*, 2018). Heavy pollution in the Jakarta Bay area reached a high level where dissolved oxygen levels exceeded the quality standard, causing mass fish deaths on the north coast of Jakarta in 2004 (Sachoemar and Wahjono, 2007). Mass mortality of fish occurred repeatedly after, including in 2005 and 2007 (Anugrahini and Adi, 2018). Based on Cordova and Nurhati (2019), among wastes that enter Jakarta Bay, plastic waste accounts for 59 percent of abundance and 37 percent of weight. Dwiyitno *et al.* (2020) confirmed that plastic debris in Jakarta Bay ranged from 7,400 to 10,300 items/ km^2. That plastic debris is the potential source for contributing to the microplastics abundance in Jakarta Bay. The investigation on microplastics in the riverbed near Jakarta Bay has been reported by Manalu *et al.* (2017). As the riverbed is part of the river channeling to the coastal water, there might be a chance that microplastics can be carried through water flow. This number can be higher or even lower. Research conducted by Manalu *et al*. (2017) was lack with data on microplastics in water. According to Efadeswarni *et al*. (2019), microplastics were also detected in the digestive tract of several fishes collected in Jakarta Bay. The area of Jakarta Bay, especially in Muara Angke, was known to be an aquaculture area for mussel *Perna viridis*, which is marketed and consumed by locals or visitors (Irnidayanti, 2021). As the mussels live in the aquatic environment, understanding the existence of microplastics in their habitat is necessary. Related to food security, the contamination of food sources by microplastics in the environment could harm the consumer's health. Further, information about microplastics distribution is urgently required to develop efficient and effective microplastics management, especially in Jakarta Bay that receives high plastic discharges. The objectives of this study are 1) to determine the microplastics based on their shape (morphotype), 2) to determine the abundance and distribution of microplastics, and 3) to determine the polymer type of microplastics found on surface water and sediment in coastal water of Jakarta Bay. This study was conducted in 2020.

MATERIALS AND METHODS

Study area

The sampling site location was in the water of Jakarta Bay, Indonesia. Jakarta Bay covers 595 km^2 with a coastline of 149 km and a water depth of 15 meters. As the estuary of thirteen rivers, the condition of Jakarta Bay is influenced by the flow of waste carried by these rivers. The numbers of sampling site were 12 sites to represent Ancol (1-3), Muara Baru (4-6), Muara Angke (7-9), Muara Karang (10-12) as illustrated in Fig. 1. Ancol was dominated by vegetation, industrial and fishery activities in the central, and a combination of settlement and marine port in the Muara Angke - Muara Karang (Putri *et al.*, 2019). Coastal development, growing urbanization, and industrialization have increased pollution and sedimentation rates in the bay. Sediments in the inner part of Jakarta Bay were greyishly dominated by sand and clay, and shell fragments were also found. While in the outer part of the bay, the sediments were clayey sand and contained shell fragments. Lubis *et al.*, (2007) have estimated that the sedimentation rates in Jakarta Bay ranging from 0.074 cm/y to 0.852 cm/y. The climate observed in Jakarta Bay is tropical monsoon. This climate is characterized by a rainy season in October to March and a dry season in April – September (Dsikowitzky *et al.*, 2016). In the rainy season, Jakarta Bay also has high input of pollutants (ammonium and nitrate) (Suteja, 2016). The water in the bay of Jakarta has a counterclockwise movement and originates from the eastern part (van der Wulp *et al.*, 2016). The temperature range at Jakarta Bay is low and high at the nearshore within a range of 30 – 32 ^{o}C (Ladwig *et al.*, 2016). Salinity in Jakarta varies depending on the distance from river-mouth to the open sea (Huhn *et al.*, 2016). Chlorophyll-a decreased further away from river-mouth, in line with nitrogen and phosphate content (Damar *et al.*, 2020). Several types of demersal (*Argyrosomus amoyensis*, *Siganus guttatus*) and pelagic (*Rastrelliger kanagurta*, *Ilisha elongata*) fishes were also found in Jakarta Bay (Dwiyitno *et al.*, 2016). Several types of plankton (*Skeletonema costatum*, *Prorocentrum micans*) were recorded to have bloomed in Jakarta Bay (Ladwig *et al.*, 2016).

Surface water and sediment samplings

Surface water and sediment sampling activities were conducted two days on 3 and 10 August 2020, covering 12 sampling sites of Jakarta Bay during daytime starting 08.00 AM to 12.00 PM. A plankton net mounted with a 350 µm mesh size (net length 0.6 m, round opening diameter 16 cm) was used. Plankton net was towed horizontally to sample microplastics in surface water (Manbohi *et al.*, 2021). After the sampling in water was completed, the plankton net was lifted and flushed using surrounding water to limit potential microplastic contamination. Distilled water is also used to clean the inner part of 1 L high-density polyethylene bottle (Li *et al.*, 2021). Samples of sediment were taken using Stainless Steel Van Veen Grab with 15 – 30 cm wide and 5 L capacity (Manalu *et al.*, 2017). Amounts of 600 – 880 gram sediment were used (Li *et al.*, 2021). The sediment samples were then put into a high-density polyethylene bottle. During the field activity and transport, samples were kept in an iced box. In each sampling point, samples were collected with three replication. Each sample was then composited. The total samples collected were 24 samples consisting of 12 water samples and 12 sediment samples.

Isolation of microplastics

The microplastics in samples were separated

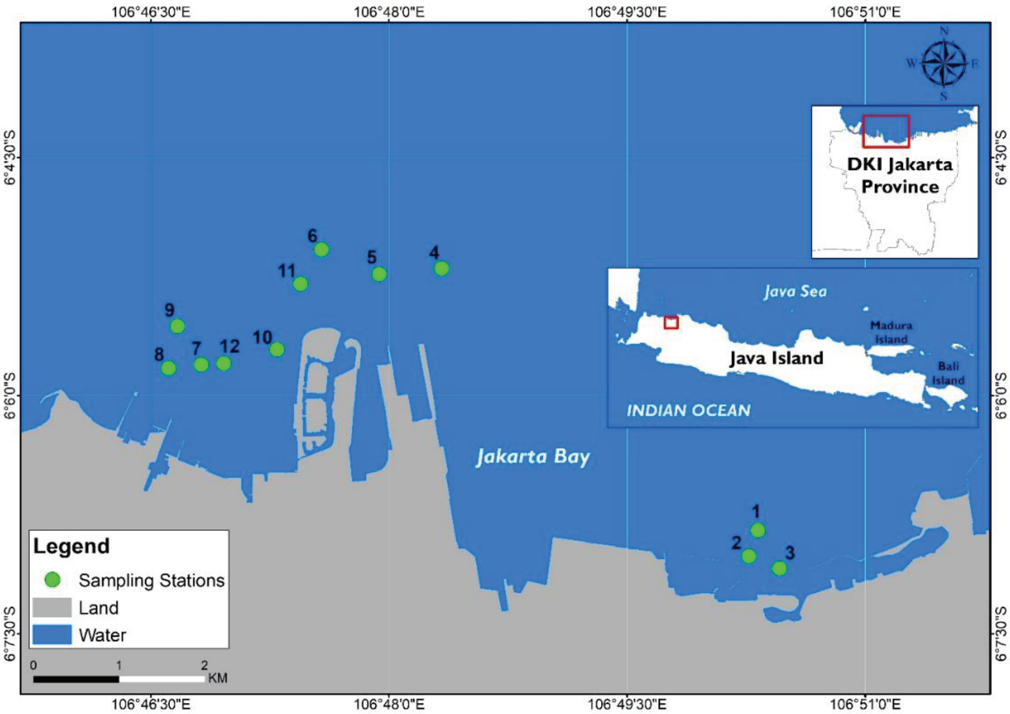


Fig. 1: Geographic location of the study area and sampling stations in Jakarta Bay, Indonesia

using the floating method based on the factor of densities differences. The water sample was filtered on test sieve analysis (ABM, with American Society for Testing and Materials E-11; aperture 200 mm; mesh no. 10) on the first layer and 500 µm (ABM, with American Society for Testing and Materials E-11; aperture 500 µm; mesh no. 35) on the layer below. The samples (filtered water) were shifted in beaker glass. Microplastics extraction of water samples was carried out by mixing the water sample into a measuring cup containing saturated NaCl solution with a ratio of 1:3 water volume (mL). The filtered water sample was around 500 mL then poured with NaCl Solution to make the microplastics float by the factor of densities. Samples were suspended using NaCl solution for 24 h to separate the sample from the remaining impurities, minimize the washing process, and increase the density of water samples (Nuelle *et al.*, 2014). After 24 h, microplastics floated at the surface, and heavier material was drained from the sample. 40 mL of the surface water sample was filtered on Whattman filter paper (cellulose nitrate 0.47 nm pore size 0.45 µ) adjusted with a vacuum pump (Millipore, 17 kPa). The filtered paper was placed into a Petri-dish for further identification. Sediment samples were dried at 40 °C for at least 48 h to obtain dry weight. Each dried sediment sample weighed around 50 g and then put into 1 L glass beaker and added with a saturated NaCl solution with a volume of 200 mL (density 1.20 g/cm^3) (Peng *et al.*, 2017). The suspension was stirred for two minutes and then allowed to stand until the sediment and impurities settled to the bottom of the measuring cup and left 24 h to extract microplastics by floating densities. After 24 h, 40 mL from the surface of the solution was filtered on Whattman paper using a vacuum pump (Millipore, 17 kPa). A vacuum pump (Millipore) filtration unit helps the filtration process in a shorter time. Samples from the filter paper were stored in Petri-dish for further identification.

Identification of microplastics

The identification of microplastics was performed visually using an Olympus CX21 microscope at magnification of 10x4 or 10x10. Indomicro View software was installed on the computer connected to the microscope and support better sample photographs. Visual identification of microplastics is grouped into four shapes, namely film, fiber, fragments, and pellets (Hidalgo-Ruz *et al.*, 2012). The samples of water and sediment at each location were taken and identified which has the most dominant shape as a representative sample for polymer analysis. Microplastics polymer analysis using the Micro-Raman Spectroscopic method was carried out using a Senterra II Compact Raman Microscope coupled with an optical microscope with a graft of 1200 lines/mm with a magnification of 20x and 50x. Each microplastics sample was excited with a 532 nm visible diode 1 laser and 785 nm - 60 mW near-infrared focused onto the sample for 10 - 60 seconds. Raman's spectrum was recorded as line measurements (N4 points) on different parts of the particle focused on avoiding dirt contamination. All spectra with a frequency resolution of 35/cm and a range of 400 – 4000/cm were analyzed using OPUS 7.5 software (Liu *et al.*, 2021). The obtained Raman spectra were then compared to the reference polymer plastic spectrum (Alam *et al*., 2019).

Quality control

For preventing contamination during the whole procedures of the microplastics analysis, precaution and quality control are applied. This procedure aims to make sure the microplastics data gained from this study is accurate. The distilled water was used to clean all equipment (Suteja *et al.*, 2021). The cotton-based gloves were chosen to avoid cross-contamination. During sampling, the plankton net was attached to the side of the boat to reduce contamination. All equipment used for laboratory purposes are sterile and made from non-plastics materials (Falahudin *et al.*, 2020).

Statistical analysis

PAST software was used to perform statistical analysis. The abundance of microplastics was expressed in the form of average values and confidence intervals visualized in box plots. The abundance of microplastics in surface water was recorded as the number of particles of microplastics per liter of seawater (particles/L). The abundance of microplastics in sediments was noted as the number of microplastic particles per kilogram of sediment (particles/kg). To observe variations between sampling sites, medium (sediment and water), and microplastic shapes (fiber, film, fragment, pellet), the t-test and 1 way ANOVA test were performed. The microplastic abundance in sediment and surface water from 12 sites was recorded for its geographical coordinate. The distribution map of microplastic was created using QGIS.

RESULTS AND DISCUSSION

Microplastics abundance and distribution

The 1532 microplastics particles were identified in surface water while a lesser number of 1419 microplastics were detected sediments from 12 sampling sites, with mean abundance varied from 55.8 to 86.6 particles/L in water and from 152.4 to 188.9 particles/L per kg dry weight in sediment. Sampling sites on Jakarta Bay were divided into 3 groups, namely the east group including three sites along the Jakarta shorelines (sites 1–3), the central group including four sites (4, 5, 6, 10, 11), and the west group (sites 7, 8, 9, 12). The East group represents microplastic discharges from vegetation-based sources, the central group represents microplastic discharges from industrial and fishery activities, and the west group represents microplastic discharges from settlement and marine port-based sources. Fibers, fragments, films and pellets are microplastic shapes found in this study (Fig. 2)

Among microplastic shapes, the mean abundance of the highest shapes of microplastic in sediment was fiber. While on the surface water, the mean abundance of the highest shapes of microplastic shapes was film (Fig. 3).

Table 1 summarized the Anova one-way result for abundance between morphotypes, while Table 2 showed the result based on location and Table 3 based on medium (water and sediment). All the results showed a significant difference ($p < 0.05$). This indicates there is a difference in the abundance of microplastic in terms of morphotype, location, and medium. The predominant shape of microplastics found in surface water was films, with an average proportion of 40 – 70 % (Fig. 4). Films were high in sites 4, 6, 8, 9 and covering Muara Angke - Muara Karang with maximum abundances equal to 181.3 particles/L. The second highest shape of microplastic abundance (107.1 particles/L) in surface water was fiber. The high abundance was also observed in the Muara Angke - Muara Karang, mainly in sites 12 and 10. Conversely, fragment microplastic was lower in Muara Angke - Muara Karang, and the highest

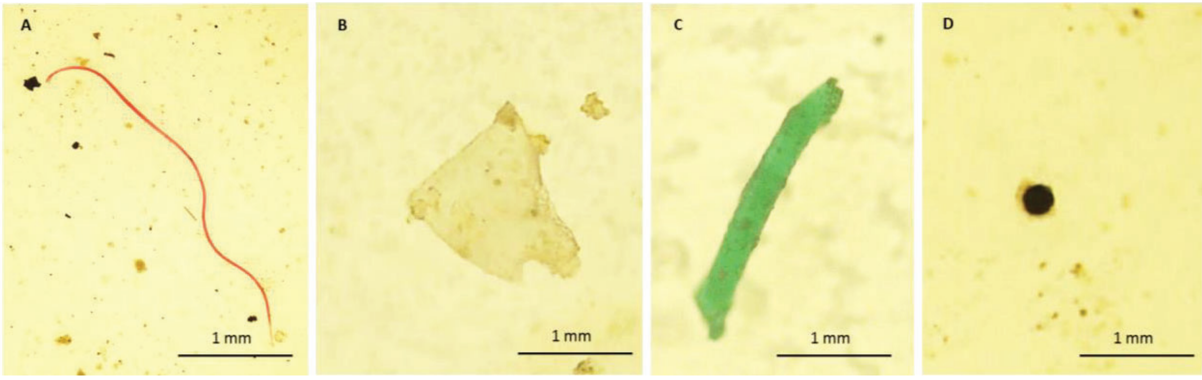


Fig. 2: Microplastics shape found in selected sample, a) fiber, b) film, c) fragment, d) pellet

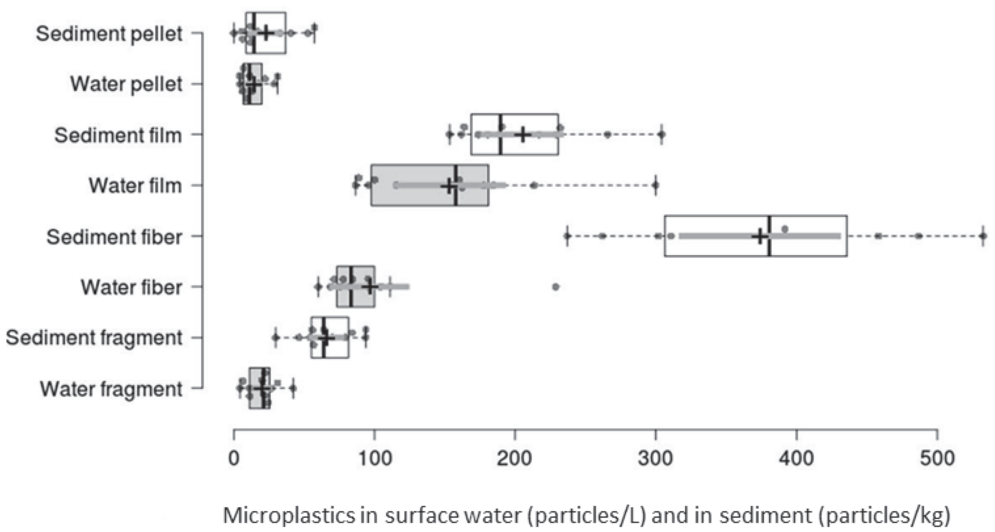


Fig. 3: Average and 95% Confidence Interval of microplastic abundance in Jakarta Bay Surface water and sediment

abundance was observed in the surface water in Ancol (27.4 particles/L) in particular sites 1 and 2. Pellet was a less common microplastic with an average proportion below 10%. Pellet abundance showed increasing trends to Muara Angke - Muara Karang with the highest abundance (15.5 particles/L) in site 6.

The abundance of microplastic in sediment observed was higher compared to the microplastic in surface water. The distribution and abundance of microplastics in sediment are showed in Fig. 5. Ancol has maximum abundances of fibers (416.9 particles/kg). Film was the second high microplastic in sediment with the highest abundance of 201.4 particles/kg in central parts covering sites 6, 8, and 11. Fragment microplastic was lower in Muara Angke - Muara Karang, and the highest abundance was observed in the sediments in Muara Baru and Ancol (78.5 particles/kg) in particular sites 2 and 4. Pellet was less common microplastic in sediments with an increasing trend to Ancol with the highest abundance of 42.8 particles/kg in site 3.

Jakarta Bay provides not only spaces for residential but also industrial activities on its shore and even in terms of ecological on spawning and feeding grounds for pelagic organisms in surface water and benthic mollusc in sediment (Cappenberg, 2017). At the same time, the surface water and sediment of Jakarta Bay were threatened by microplastics pollution based on the result of this study. The surface water of Jakarta

Tabel 1: Anova one way between morphotype

Summary	Sum of sqrs	df	Mean square	F	p (same)
Between groups	230641	3	76880,3	67,91	0,00
Within groups	104156	92	1132,13	Permutation p (n=99999)	
Total	334797	95	0,00		
Components of variance (only for random effects):					
Var(group)	3156,17	Var(error):	1132,13	ICC:	0,735996
Omega-2	0,6765				
Levene´s test for homogeneity of variance, from means	p (same):	0,00			
Levene´s test, from medians	p (same):	0,00			
Welch F test in the case of unequal variances: F=75,51, df=46,57, p=6,568E-18					

Tabel 2: Anova one way between location

Summary	Sum of sqrs	df	Mean square	F	p (same)
Between groups	245986	15	16399,1	14,77	0,00
Within groups	88810,4	80	1110,13	Permutation p (n=99999)	
Total	334797	95	0,00		
Components of variance (only for random effects)					
Var(group)	2548,16	Var(error):	1110,13	ICC:	0,696544
Omega 2	0,6827				
Levene´s test for homogeneity of variance, from means	p (same)	0,00			
Levene´s test, from medians	p (same)	0,00			
Welch F test in the case of unequal variances: F=24,44, df=29,38, p=1,387E-12					

Tabel 3: Anova one way between medium

Summary	Sum of sqrs	df	Mean square	F	p (same)
Between groups	270775	7	38682,2	53,17	0,00
Within groups	64021,8	88	727,52	Permutation p (n=99999)	
Total:	334797	95	0,00		
Components of variance (only for random effects)					
Var(group)	3162,89	Var (error)	727,52	ICC	0,812996
Omega 2	0,7918				
Levene´s test for homogeneity of variance, from means	p (same)	0,00			
Levene´s test, from medians	p (same)	0,00			
Welch F test in the case of unequal variances: F=55,52, df=37,16, p=9,48E-18					

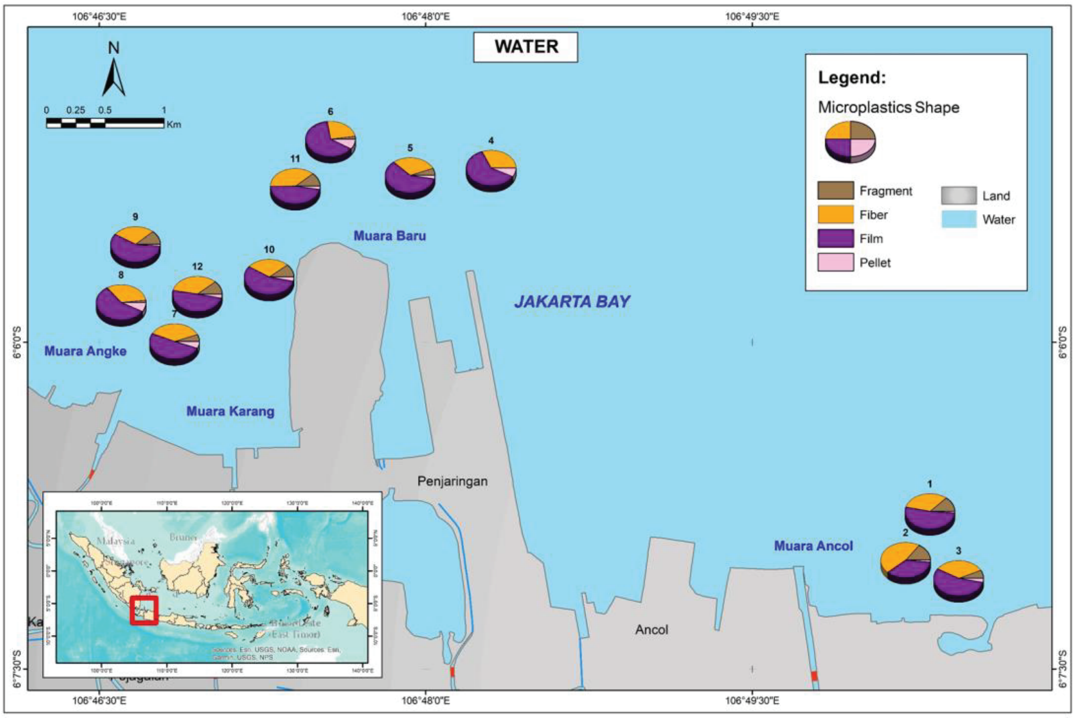


Fig. 4: Distribution and abundance (particles/L) of microplastic in Jakarta Bay surface water

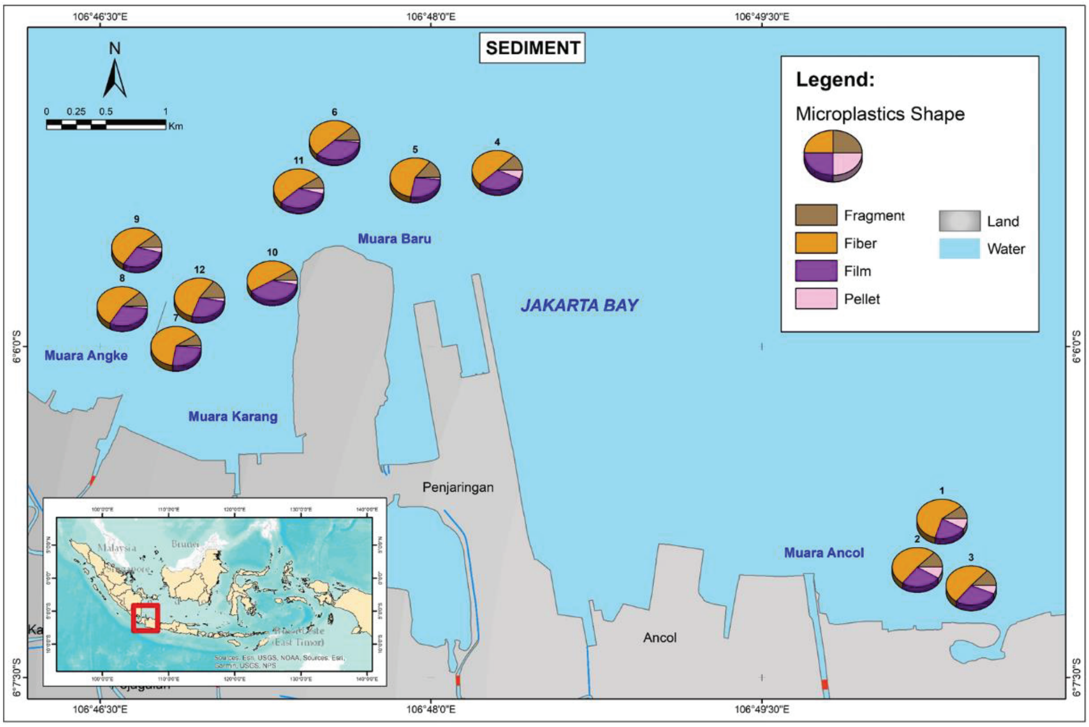


Fig. 5: Distribution and abundance (particles/kg/dry weight) of microplastic in Jakarta Bay sediment

Bay contains an average of 70.9 ± 27.1 particles/L. Its recorded microplastic abundance was higher compared to intact Benoa Bay, Bali-Indonesia (0.002 particles/L) (Suteja *et al.*, 2021), in Shanghai (27.84 ± 11.81 particles/L) (Zhang *et al.*, 2019), and Yellow River Bay (497 particles/L) (Han *et al.*, 2020). Microplastics abundance in sediment in this study (166.9 particles/kg) was 6 folds greater than microplastic in the sediment of the intact bay (28.1 ± 10.28 particles/kg) (Cordova *et al.*, 2021), whereas it is comparable to the microplastic from Banten Bay (267 ± 98 particles/kg) (Falahudin *et al.*, 2020) that also has been surrounded by settlement and industrial activities. Interestingly, in Jakarta Bay, the abundance and shape distribution of microplastic in surface water was contradicted the abundance of microplastic in sediments. In surface waters, microplastic abundance trends were increasing from Ancol to Muara Angke - Muara Karang. In contrast, microplastic abundance trends in sediment were opposite trends. High microplastic in surface water in Muara Angke - Muara Karang was correlated with low microplastic abundance in sediment in this part. A possible explanation for this is that microplastic particles from sediments experience sediment resuspension from the bottom. It causes the microplastics to rejoin the water column (Lambert and Wagner, 2018). As a result of this resuspension, microplastic abundance in sediment was lower than in surface water. This resuspension is influenced by nearshore circulation, offshore tides, and sedimentation rates. Another cause is related to the sedimentation rate. Radjawane and Riandini (2009) explained that the sedimentation rate in Ancol was lower than in Muara Angke - Muara Karang, which explains the higher microplastic abundance in this part. As can be seen in Ancol, the presence of a layer of microplastic in sediment aligns with the relatively low sedimentation rates (Martin *et al.*, 2017). The abundance of microplastic in found sediment in particular inshore of Ancol because those microplastics trapped into the vortex, eventually settling on the sediment instead of flushing out to the offshore (Claessens *et al.*, 2011). Film and fiber were microplastic shapes with the highest abundances, and both were high in surface water of Muara Angke - Muara Karang and Muara Baru, where fishery activities and settlements dominated the land use. Films in sediment in central parts were also observed high. There is Muara Angke fishery port in those location, with an average of 275 ships visiting this port every month. The presence of films in high quantity was in agreement with Yona *et al.*, (2019) that film high abundances were related to the presence of the fish landing area nearby. Li *et al.*, (2020) reported that the presence of an aquaculture market nearby might accumulate microplastics within marine environments. Fibers were also related to the fishing activities as mostly local fishermen use plastic fishing nets. Zhu *et al.*, (2018) observed a high abundance of fibers in the North Yellow Sea due to constant use of plastic fishing and nets and ropes as the main fishing tools. The settlements in Muara Angke - Muara Karang of the bay were also contributing to the fiber abundances. Besides originating from fishing activities, fiber microplastics are widely used originated from clothing from nearby settlements. Fragments were higher in surface water and sediment in the exact location in Ancol near site 3. High abundances of fragments in the precise location were related to the presence of a river nearby. The riverbank of this area was dominated by combinations of industrial and residential land uses. The high fragment shape in an aquatic environment indicates that microplastics are produced from waste originating from population activities either through rivers or landfills. The fragment is a microplastic shape formed from macroplastic fragmentation due to weather, mechanical processes, and the domestic waste discharges from nearby settlements. In this study, pellets have the lowest abundance compare to other shapes. This type of microplastic is known as the primary material for making plastics produced directly from factories and industries (Sulistyo *et al.,* 2020) and is used to produce of larger plastic products (Espiritu *et al.,* 2019). The absences of plastic factories near the sampling sites may explain the low abundance of pellets compared to other microplastics. Microplastics abundance in sediment tend to be higher than abundances in surface water can be seen in fragment and film microplastics. Fragment abundances in Ancol in the sediment of site 3 were 3 folds greater than in water. The same condition can be seen from film abundance in the sediment of Muara Angke - Muara Karang that 16% higher than film abundance in surface water. Higher microplastic in sediment was in agreement with the microplastic accumulation and sea bottom as a sink for plastic debris. The accumulation and sinking

Table 4: Microplastic polimer

Sample	Ancol			Muara Baru			Muara Angke			Muara Karang		
	1	2	3	4	5	6	7	8	9	10	11	12
Surface water	PE	PE	PE	PE	PE	PE	PE	PP	PP	PE	PE	PE
Sediment	PP	PP	PS	PP	PE	PE	PE	PP	PP	PE	PS	PP

of plastic debris are related to plastic's buoyancy (Woodall *et al*., 2014). Fragment and film have less buoyancy and sinking fast. In contrast, fibers and pellets were more buoyant and stayed longer at the surface water (Chubarenko *et al*., 2016). It explains why fiber and pellet abundances in Muara Angke - Muara Karang were high in surface water, and in contrast, the fiber and pellet abundance in sediment were low. The study location is 1-2 km from the mainland. This location is considered as nearshore where freshwater input is still influential. Currents in this area are generally high at low tide, especially those close to river mouths. At low tide, the current is influenced by flood discharge, especially during the rainy season. Currents in Jakarta Bay move from east to west (Yayah Surya *et al*., 2019). It may explain that the Muara Karang and Muara Angke areas have the highest abundance of microplastics in surface water. In this study, where most inputs from freshwater affect the sampling site, we assume that any municipal or industrial waste carried by the flow also contributes to the source of microplastics. Based on the study of Hidayaturrahman and Lee (2019), microplastics were detected in municipal and industrial wastewater treatment. In addition, Liu *et al.* (2019) found that microplastic detected industrial, agricultural, and municipal waste on wastewater treatment. Unfortunately, Jakarta municipality is a lack wastewater treatment. Wastewater generated from both residents and industry runs to surface water. It is estimated that 1,3 million people in slum areas drop their waste into the river without treatment (Luo *et al.*, 2019). Alam *et al.* (2019) reported that microplastics were detected in river waters near slum areas in Majalaya. Ancol waters are the estuary of the Ciliwung river, while the waters of Muara Baru are one of the estuaries of the Krukut river. Ancol is located close to artificial beach tourism activities.

Microplastic polymer

Microplastic polymers in surface water and sediment in this study are shown in Table 4. Two polymers, polyethylene and polypropylene were detected in surface water. The most common type of polymer was found in all locations was polyethylene. Polypropylene in surface water was only detected at points 8 and 9 of Muara Angke. The detected polymers in sedimentary microplastics consisted of polyethylene, polypropylene, and polystyrene. Polypropylene and polyethylene were detected more in the sediment at the sampling site compared to polystyrene.

The polymers were found during this study can come from the waste that enters the waters of Jakarta Bay which is dominated by plastic bags and merchandise packaging (Manalu *et al.*, 2017). All the polymers found have a lower density than water and cause microplastics to float on the water surface so that they are easy to detect. Microplastics with concentrated colors an initialed as identification of polyethylene polymers that are widely found in surface waters. Polyethylene is the main material for creating plastic bags and containers (GESAMP, 2015).

CONCLUSION

This study succeeded in identifying microplastics in Jakarta Bay in number about 2900 particles of microplastics. The microplastics found in both surface water and sediment are fibers, films, fragments and pellets. There are three forms of polymers detected in microplastics in Jakarta Bay, namely polyethylene, polypropylene and polystyrene. Microplastic fibers and film forms were the most dominant based on their abundance, both in surface water and in sediments. In this study, the pattern seen is in sediment, fiber > film, in surface water, film> fiber. When viewed from the type of polymer, polyethylene is the most dominant polymer compared to other polymers in microplastics detected in surface water and sediment. This indicates that the degraded and accumulated microplastics in surface waters and sediments in Jakarta Bay originate from plastics made from these polymers that produce microplastic fibers and films through specific degradation mechanisms. Based on distribution, the highest microplastic abundance in surface water was found in the Muara Angke - Muara Karang following the presence of industrial, settlement, and fishery activities. These anthropogenic activities have contributed to the particular microplastic shapes, including fibers and films. The presence of a river with its riverbank dominated by combinations of residential and industrial have also contributed to the discharges of fragment microplastics in the bay. By comparing the microplastic both in surface water and sediment, it can be seen that some microplastic can stay longer at the surface, and some were sinking to the bottom. The existence of differences in the character of microplastics in both shape and polymer indirectly helps control contaminants in the aquatic environment. Microplastics abundances both in sediment and surface water were higher near inshore areas than offshore areas. Referring to the results of this study, in managing microplastic in Jakarta Bay and considering the abundance distributions, management of surface water should be prioritized in Muara Angke - Muara Karang while management of sediment should be maximized in Ancol. With these findings, the amount of microplastics is higher than in previous studies, indicating the increasing number. We might assume that this increasing number may be related to land-based activities and sea-based activities. As a further recommendation, the study can be expanded to detect marine microplastics in each municipal and industrial waste so the contributed number can be accurately determined.

AUTHOR CONTRIBUTIONS

N.D. Takarina performed the conception and design, drafting manuscript, obtaining funding, supervision. A.I.S. Purwiyanto analysed and interpreted data, critical revision of the manuscript for important intellectual content. A.A. Rasud administrated the technical, material support, drafting of the manuscript and statistical analysis. A.A. Arifin administrated technical, material support, statistical analysis. Y. Suteja performed the acquisition of data, supervise, analyisis and interpretated data, and also critical revision of the manuscript for important intellectual content

ACKNOWLEDGEMENT

This study was supported by funding of PUTI Grants scheme Q2 with contract number [NKB-4244/UN2.RST/HKP.05.00/2020].

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
$C_6H_7O_2(ONO_2)_3$	Cellulose nitrate
cm/y	Centimeters per year
/cm	Reciprocal centimeter
GESAMP	Group of experts for scientific aspects of marine protection
g/cm^3	Gram per cubic centimeter, unit of density
h	Hour
HDPE	High-density polyethylene (kind of plastic polymer)

items/km^2	Items per square kilometer
kg	Kilogram
km	Kilometer
km^2	Square kilometer
kPa	Kilopascal, unit of pressure
L	Liter
m	Meter
mL	Milliliter
mm	Millimeter
MMT	Million metric ton
mW	Mega watt
NaCl	Sodium chloride
nm	Nanometer
particles/kg	Particles per kilogram
particles/L	Particles per liter
PAST	Paleontological statistics
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
QGIS	Quantum geographic information system
WWTP	Wastewater treatment plant
µ	Micron
µm	Micrometer
%	Percent
^{o}C	Degree of Celcius

REFERENCES

Alam, F.C.; Sembiring, E.; Muntalif, B. E.; Suendo, V., (2019). Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). Chemosphere, 224: 637-645 **(9 pages).**

Andrady, A.L.; Neal, M.A., (2009). Applications and societal benefits of plastics. Philos. Trans. R. Soc. Lond. B. Biol. Sci., 364(1526): 1977–1984 **(8 pages).**

Anugrahini, T.; Adi, I.R., (2018). Fishermen's adaptation to aquatic environment changes

in Jakarta Bay, in: Adi, I.R., Achwan, R. (Eds.), Competition and cooperation in social and political sciences. Routledge, London.

Browne, M.A.; Galloway, T.; Thompson, R., (2007). Microplastic--an emerging contaminant of potential concern? Integr. Environ. Assess. Manage., 3(4): 559–561 **(3 pages).**

Browne, M.A.; Crump, P.; Niven, S.J.; Teuten, E.; Tonkin, A.; Galloway, T.; Thompson, R., (2011) Accumulation of microplastic on shorelines worldwide: sources and sinks. Environ. Sci. Technol., 45(21):9175-9179 **(5 pages).**

Cappenberg, H.A.W., (2017). The composition of species and structure of benthic mollusc of Jakarta Bay. Oceanol. Limnol. Indones., 2(3): 65-79 **(15 pages).**

Chubarenko, I.; Bagaev, A.; Zobkov, M.; Esiukova E., (2016). On some physical and dynamical properties of microplastic particles in marine environment. Mar. Pollut. Bull., 108(1-2): 105–112 **(8 pages).**

Claessens, M.; De Meester, S.; Van Landuyt, L.; De Clerck, K.; Janssen, C.R., (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Mar. Pollut. Bull., 62(10): 2199–2204 **(5 pages).**

Cordova, M.R.; Wahyudi, A.J., (2016). Microplastic in the deep-sea sediment of Southwestern Sumatran waters. Mar. Res. Indones., 41(1): 27–35 **(9 pages).**

Cordova, M.R.; Nurhati, I.S., (2019). Major sources and monthly variations in the release of land-derived marine debris from the Greater Jakarta area, Indonesia. Sci. Rep. 9: 18730 **(8 pages).**

Cordova, M.R.; Ulumuddin, Y.I.; Purbonegoro, T.; Shiomoto, A., (2021). Characterization of microplastics in mangrove sediment of Muara Angke Wildlife Reserve, Indonesia. Mar. Pollut. Bull., 163: 112012 **(8 pages).**

Damar, A.; Colijn, F.; Hesse, K.-J.; Adrianto, L.; Yonvitner; Fahrudin, A.; Kurniawan, F.; Prismayanti, A.D.; Rahayu, S.M.; Rudianto, B.Y.; Ramli, A. (2020). Phytoplankton Biomass Dynamics in Tropical Coastal Waters of Jakarta Bay, Indonesia in the Period between 2001 and 2019. J. Mar. Sci. Eng., 8: 674 **(17 pages).**

Della Torre, C.; Bergami, E.; Salvati, A.; Faleri, C.; Cirino, P.; Dawson, K.A.; Corsi, I., (2014). Accumulation and embryotoxicity of polystyrene nanoparticles at early stage of development of sea urchin embryos *Paracentrotus lividus*. Environ. Sci. Technol., 48(20):12302-12311 **(10 pages).**

Dwiyitno; Dsikowitzky, L.; Nordhaus, I.; Andarwulan, N.; Irianto, H.E.; Lioe, H.N.; Ariyani, F.; Kleinertz, S.; Schwarzbauer, J., (2016). Accumulation patterns of lipophilic organic contaminants in surface sediments and in economic important mussel and fish species from Jakarta Bay, Indonesia. Mar. Pollut. Bull., 110(2): 767-777 **(11 pages).**

Dwiyitno; Andayani, F.; Anissah, U.; Januar, H.I.; Wibowo, S., (2020). Concentration and characteristic of floating plastic debris in Jakarta Bay: A preliminary study. Squalen Bull. of Mar. and Fish. Postharvest Biotech., 15(3): 109-117 **(9 pages).**

Dsikowitzky, L.; Sträter, M.; Dwiyitno; Ariyani, F.; Irianto, H.E.; Schwarzbauer, J., (2016). First comprehensive screening of lipophilic organic contaminants in surface waters of the megacity Jakarta, Indonesia. Mar. Pollut. Bull., 110(2): 654-664 **(11 pages).**

Efadeswarni; Andriantoro; Azizah, N.; Saragih, G.S., (2019). Microplastics in digestive tracts of fishes from Jakarta Bay, In International Conference on the Improvement of Environmental Quality (ICIEQ) 2019. Bogor, Indonesia 29 August. IOP Conf. Ser.: Earth Environ. Sci., 407: 012008 **(6 pages).**

Espiritu, E.Q.; Dayrit, S.A.S.N.; Coronel, A.S.O.; Paz, N.A.C; Ronquillo, P.I.L.; Castillo, V.C.G.; Enriquez, E.P., (2019). Assessment of quantity and quality of microplastics in the sediments, waters, oysters, and selected fish species in key sites along the bombong estuary and the coastal waters of Ticalan in San Juan, Batangas. Philipp. J. Sci., 148(4): 789-801 **(13 pages).**

Falahudin, D.; Cordova, M.R.; Sun, X.; Yogaswara, D.; Wulandari, I.; Hindarti, D.; Arifin, Z., (2020). The first occurrence, spatial distribution and characteristics of microplastic particles in sediments from Banten Bay, Indonesia. Sci. Total Environ., 705: 135304 **(pages 10).**

Fendall, L.S.; Sewell, M.A., (2009). Contributing to marine pollution by washing your face: microplastics in facial cleansers. Mar. Pollut. Bull., 58(8):1225–1228 **(4 pages).**

Germanov, E.S.; Marshall, A.D.; Hendrawan, I.G.; Admiraal, R.; Rohner, C.A.; Argeswara, J.; Wulandari, R.; Himawan, M.R.; Loneragan, N.R., (2019). Microplastics on the menu: plastics pollute Indonesian manta ray and whale shark feeding grounds. Front. Mar. Sci., 6: 679 **(21 pages).**

GESAMP, (2015). Sources, fate and effects of microplastics in the marine environment: a global assessment, Kershaw, P. J., ed. (IMO/FAO/ UNESCOIOC/ UNIDO/WMO/ IAEA/UN/ UNEP/ UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP.

Han, M.; Niu, X.; Tang, M.; Zhang, B.T.; Wang, G.; Yue, W.; Kong, X.; Zhu, J., (2020). Distribution of microplastics in surface water of the lower Yellow River near estuary. Sci. Total Environ., 707:135601 **(9 pages).**

Hastuti, A.R.; Yulianda, F.; Wardianto, Y., (2014). Distribusi spasial sampah laut di ekosistem mangrove Pantai Indah Kapuk, Jakarta. Bonoworo Wetlands, 4(2): 94-107 **(14 pages).**

Hidayaturrahman, H.; Lee, T.-G., (2019). A study on characteristics of microplastic in wastewater of South Korea: Identification, quantification, and fate of microplastics during treatment process. Mar. Pollut. Bull., 146: 696-702 **(7 pages).**

Huhn, M.; Hattich, G.S.I.; Zamani, N.P.; von Juterzenka, K.; Lenz, M., (2016). Tolerance to stress differs between Asian green mussels Perna viridis from the impacted Jakarta Bay and from natural habitats along the coast of West Java. Mar. Pollut. Bull., 110(2): 757-766 **(10 pages).**

Irnidayanti, Y., (2021). Toxicological analysis of gonad development in green mussels (*Perna viridis*) in Jakarta Bay, Indonesia. Pak. J. Biol. Sci., 24: 394-400 **(8 pages)**.

Kunzmann, A.; Arifin, Z.; Baum, G., (2018). Pollution of coastal areas of Jakarta bay: water quality and biological responses. Mar. Res. Indonesia, 43(1): 37–51 **(15 pages).**

Ladwig, N.; Hesse, K.-J.; van der Wulp, S.A.; Damar, A.; Koch, D., (2016). Pressure on oxygen levels of Jakarta Bay. Mar. Pollut. Bull., 110(2): 665-674 **(10 pages).**

Lambert, S.; Wagner, M., (2018) Microplastics are contaminants of emerging concern in freshwater environments: an overview, in: Wagner, M., Lambert, S., (Eds), Freshwater microplastics. The handbook of environmental chemistry, vol 58. Springer.

Lebreton, L.C.M.; van der Zwet, J.; Damsteeg, J.-W.; Slat, B.; Andrady, A.; Reisser, J., (2017). River plastic emissions to the world's oceans. Nat. Commun., 8: 15611 **(10 pages).**

Li, Y.; Lu, Z.; Zheng, H.; Chen, C., (2020). Microplastics in surface water and sediments of Chongming Island in the Yangtze Estuary, China. Environ. Sci. Eur. 32: 15 **(pages).**

Liu, X.; Yuan, W.; Di, M.; Li, Z.; Wang, J., (2019). Transfer and fate of microplastics during the conventional activated sludge process in one wastewater treatment plant of China. Chem. Eng. J., 362: 176-182 **(7 pages).**

Liu, R-p.; Dong, Y.; Quan, G.-q.; Zhu, H.; Xu, Y.-N.; Elwardany, R.M.; (2021). Microplastic pollution in surface water and sediments of Qinghai-Tibet Plateau: Current status and causes. China Geol., 4(1), 178-184 **(7 pages).**

Lubis, A.A.; Aliyanta, B.; Menry, Y., (2007). Estimation of sediment accumulation rate in Jakarta bay using natural radionuclide unsupported 210pb. Indo. J. Chem., 7(3): 309-313 **(5 pages).**

Luo, P.; Kang, S.; Apip; Zhou, M.; Lyu, J.; Aisyah, S.; Binaya, M.; Regmi, R. K.; Nover, D., (2019). Water quality trend assessment in Jakarta: A rapidly growing Asian megacity. PloS One. 14(7): e0219009 **(17 pages).**

Manalu, A.A.; Hariyadi, S.; Wardiatno, Y., (2017). Microplastics abundance in coastal sediments of Jakarta Bay, Indonesia. AACL Bioflux, 10: 1164-1173 **(10 pages).**

Martin, J.; Lusher, A.; Thompson, R.C.; Morley, A., (2017). The deposition and accumulation of microplastics in marine sediments and bottom water from the Irish continental shelf. Sci. Rep. 7: 10772 **(9 pages).**

Oehlmann, J.; Schulte-Oehlmann, U.; Kloas, W.; Jagnytsch, O.; Lutz, I.; Kusk, K.O.; Wollenberger, L.; Santos, E.M.; Paull, G.C.; Van Look, K.J.W.; Tyler, C.R., (2019). A critical analysis of the biological impacts of plasticizers on wildlife. Philos. Trans. R. Soc. London, Ser. B., 364:2047-2062 **(16 pages).**

Peng, G.; Zhu, B.; Yang, D.; Su, L.; Shi, H.; Li, D., (2017). Microplastics in sediments of the Changjiang Estuary, China. Environ. Pollut., 225: 283-290 **(8 pages).**

Plastics Europe, (2013). Plastics-The Facts 2013.

Plastics Europe, (2019). Plastics – the Facts 2019.

Purba, N.P.; Handyman, D.I.W.; Pribadi, T.D.; Syakti, A.D.; Pranowo, W.S.; Harvey, A., Ihsan, Y.N., (2019). Marine debris in Indonesia: A review of research and status. Mar. Pollut. Bull., 146: 134-144 **(11 pages).**

Purwiyanto, A.I.S.; Suteja, Y.; Trisno; Ningrum, P.S.; Putri, W.A.E.; Rozirwan; Agustriani, F.; Fauziyah; Cordova, M.R.; Koropitan, A.F., (2020). Concentration and adsorption of Pb and Cu in microplastics: Case study in aquatic environment. Mar. Pollut. Bull., 158: 1-9 **(9 pages).**

Putri, R.F.; Wibirama, S.; Giyarsih, S.R.; Pradana, A.; Kusmiati, Y., (2019). Landuse change monitoring and population density analysis of Penjaringan, Cengkareng, and Cakung Urban Area in Jakarta Province. E3S Web Conf., 76: 03004 **(6 pages).**

Radjawane, I.M.; Riandini, F., (2009). Numerical simulation of cohesive sediment transport in Jakarta Bay. IJReSES, 6: 65-76 **(12 pages).**

Sachoemar, S.I.; Wahjono, H.D., (2007). Kondisi pencemaran lingkungan perairan di Teluk Jakarta. J.Air Indones., 3(1): 1-14 **(14 pages).**

Siegfried, M.; Koelmans, A.A.; Besseling, E.; Kroeze, C., (2017). Export of microplastics from land to sea. A modelling approach. Water Res., 127: 249–257 **(9 pages).**

Sulistyo, E.N.; Rahmawati, S.; Putri, R. A.; Arya, N.; Eryan, Y.E., (2020). Identification of the existence and type of microplastic in code river fish, special region of Yogyakarta. Eksakta, 1(1): 85-91 **(7 pages).**

Sussarellu, R.; Suquet, M.; Thomas, Y.; Lambert, C.; Fabioux, C.; Pernet, M.E.J.; Le Goïc, N.; Quillien, V.; Mingant, C.; Epelboin, Y.; Corporeau, C.; Guyomarch, J.; Robbens, J.; Paul-Pont, I.; Soudant, P.; Huvet, A., (2016). Oyster reproduction is affected by exposure to polystyrene microplastics. PNAS, 113(9): 2430–2435 **(6 pages).**

Suteja, Y., (2016). Beban pencemar dan kapasitas asimilasi amonium dan nitrat saat pucak musim barat di Teluk Jakarta. J. Mar. Aquat. Sci., 2(1): 16-22 **(7 pages).**

Suteja, Y.; Purwiyanto, A.I.S, (2018). Nitrate and phosphate from rivers as mitigation of eutrophication in Benoa bay, Bali-Indonesia. IOP Conf. Ser.: Earth Environ. Sci. 162 (1): p. 012021 **(9 pages).**

Suteja, Y.; Atmadipoera, A.S.; Riani, E.; Nurjaya, I.W.; Nugroho, D.; Cordova, M.R., (2021). Spatial and temporal distribution of microplastic in surface water of tropical estuary: Case study in Benoa Bay, Bali, Indonesia. Mar. Pollut. Bull., 163: 111979 **(14 pages).**

Van Cauwenberghe, L.; Claessens, M.; Vandegehuchte, M.B.; Janssen, C.R., (2015). Microplastics are taken up by mussels (*Mytilus edulis*) and lugworms (*Arenicola marina*) living in natural habitats. Environ. Pollut., 199: 10–17 **(8 pages).**

van der Wulp, S.A.; Damar, A.; Ladwig, N.; Hesse, K.-J., (2016). Numerical simulations of river discharges, nutrient flux and nutrient dispersal in Jakarta Bay, Indonesia. Mar. Pollut. Bull. 110(2): 675-685 **(11 pages).**

Wicaksono, E.A.; Tahir, A.; Werorilangi, S., (2020). Preliminary study on microplastic pollution in surface-water at Tallo and Jeneberang Estuary, Makassar, Indonesia. AACL Bioflux, 13: 902-909 **(8 pages).**

Woodall, L.C.; Sanchez-Vidal, A.; Canals, M.; Paterson, G.L.J.; Coppock, R.; Sleight, V.; Calafat, A.; Rogers, A.D.; Narayanaswamy, B.E.; Thomps, R.C., (2014). The deep sea is a major sink for microplastic debris. R. Soc. Open Sci., 1: 140317 **(8 pages).**

Yahya Surya, M.; He, Z.; Xia, Y.; Li, L. (2019). Impacts of sea level rise and river discharge on the hydrodynamics characteristics of Jakarta Bay (Indonesia). Water, 11: 1384 **(18 pages).**

Yona, D.; Sari, S.; Iranawati, F.; Bachri, S.; Ayuningtyas, W.C., (2019). Microplastics in the surface sediments from the eastern waters of Java Sea, Indonesia. F1000Research, 8: 98 **(14 pages).**

Zhang, J.; Zhang, C.; Deng, Y.; Wang, R.; Ma, E.; Wang, J.; Bai, J.; Wu, J.; Zhou, Y., (2019). Microplastics in the surface water of small-scale estuaries in Shanghai. Mar. Pollut. Bull., 149: 110569 **(6 pages).**

Zhu, L.; Bai, H.; Chen, B.; Sun, X.; Qu, K.; Xia, B., (2018). Microplastic pollution in North Yellow Sea, China: Observations on occurrence, distribution and identification. Sci .Total. Environ., 636: 20–29 **(10 pages).**

AUTHOR (S) BIOSKETCHES

Takarina, N.D., Ph.D., Associate Professor, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, Indonesia.
Email: *noverita.dian@sci.ui.ac.id*
ORCID: 0000-0003-1766-7445

Purwiyanto, A.I.S., Ph.D. Candidate, Assistant Professor, Marine Science Department, Faculty of Mathematics and Natural Sciences, Sriwijaya University, Palembang, Indonesia.
Email: *anna_is_purwiyanto@unsri.ac.id*
ORCID: 0000-0002-9148-1713

Rasud, A.A., B.Sc., Instructor**,** Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, Indonesia.
ayuameliarasud@gmail.com
ORCID: 0000-0002-9088-9987

Arifin, A.A., B.Sc., Instructor, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, Indonesia.
anggitoabimanyu16@gmail.com
ORCID: 0000-0001-6970-408X

Suteja, Y., Ph.D. Candidate, Assistant Professor, Marine Science Department, Marine Science and Fisheries Faculty, Udayana University, Jl, Raya Kampus Universitas Udayana, Bukit Jimbaran, Bali, Indonesia.
yuliantosuteja@unud.ac.id
ORCID: 0000-0002-7824-5177

HOW TO CITE THIS ARTICLE

Takarina, N.D.; Purwiyanto, A.I.S.; Rasud, A.A.; Arifin, A.A.; Suteja, Y., (2022). Microplastic abundance and distribution in surface water and sediment collected from the coastal area. Global J. Environ. Sci. Manage., 8(2): 183-196.

DOI: 10.22034/gjesm.2022.02.02

url: https://www.gjesm.net/article_246329.html

Global J. Environ. Sci. Manage. 8(2): 197-208, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH ARTICLE

Carbon footprint and cost analysis of a bicycle lane in a municipality

J. Prasara-A[1,*], A. Bridhikitti[2]

[1] *Energy and Environment for Sustainable Development Research and Training Center, Faculty of Environment and Resource Studies, Mahasarakham University, Mahasarakham, Thailand*

[2] *Environmental Engineering and Disaster Management Program, School of Interdisciplinary Studies, Mahidol University Kanchanaburi Campus, Lumsum Sub-District, Saiyok District, Kanchanaburi, Thailand*

ARTICLE INFO

Article History:
Received 31 July 2021
Revised 07 October 2021
Accepted 16 November 2021

Keywords:
Bicycle lane
Carbon footprint
Cycling
Life cycle assessment
Life cycle costing

ABSTRACT

BACKGROUND AND OBJECTIVES: Cycling has been widely promoted as an alternative mode of transport to help the reduction of environmental impact and improve users' health. Promoting cycling will help enhance the "Green City" initiative in Thailand. While several studies have addressed social issues of cyclists, the environmental impacts and economic viability of cycling infrastructure are yet unknown. Quantifying its environmental impact and the costing aspect are essential to prove that cycling would positively affect a city. This study compares the expected environmental and economic impacts before and after constructing a bicycle lane in Mahasarakham, Thailand.
METHODS: This study uses life cycle assessment and life cycle costing to assess a bicycle lane's environmental and economic viability. Life cycle assessment and life cycle costing are tools used to analyze environmental impact and cost during the life cycle of a product or service. The scope of this study covers the processing of raw material acquisition, transportation, construction, use, and disposal. The functional unit set for this study is the use of a bicycle lane for one year. The environmental impact examined is greenhouse gas emissions along the product's life cycle (the so-called "carbon footprint").
FINDINGS: According to the results, approximately 0.2 million tons of carbon dioxide equivalent of carbon footprint could have been reduced in 2020 had a bicycle lane been installed. The use phase plays the leading role in reducing carbon footprint. The reduction in environmental impacts is due to reduced fuel consumption by cars and motorcycles when bicycles are used. Even though a low rate (26%) of road users, who participated in this research, were willing to ride bikes had a bicycle lane been provided, a considerable amount of environmental impact could still have been reduced.
CONCLUSION: The carbon footprint expected to be reduced in a year is valued at about 4.7 million baht of carbon credit. In comparison, the life cycle cost of bicycle lanes for one year is approximately 3.7 million baht. Furthermore, it is anticipated that had a bicycle lane been installed since 2015, the city would have reduced overall carbon footprint emissions by more than 1.15 million tons of carbon dioxide equivalent by 2020. Therefore, the results of environmental impact and cost assessment from this study are helpful for urban environmental management.

DOI: 10.22034/gjesm.2022.02.04

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
31	6	2

*Corresponding Author:
Email: *jittima.p@msu.ac.th*
Phone: +6643 754 435
ORCID: 0000-0003-3490-6567

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Cycling has been endorsed worldwide as an alternative mode of transportation to promote the transition to a green society. Promoting bicycles has been one of Thailand's "Green City" action plan measures for 2017–2027 (Kongboon *et al.*, 2021). Mahasarakham is located in the middle of the northeastern region of Thailand and is a city that has the potential to operate a bicycle lane system. The traffic in this city is moderate, and there are several educational institutions. This situation is an excellent opportunity to promote healthy transportation means to the youth. In 2020, Mahasarakham municipality officially hosted about fifty-five thousand inhabitants (Mahasarakham Municipality, 2020). Chaowarat *et al.* (2016) studied public policy to promote a bicycle lane in Mahasarakham city. They identified different factors to address before endorsing cycling in the city. Despite the feasibility of installing a bicycle lane system based on policy and attitudes of potential bicycle lane users, the environmental aspects and economic viability of the system in Mahasarakham had not yet been studied. Mitigating climate change is the dire need of the hour. Greenhouse gas (GHG) emissions from different human activities are the primary cause of this global environmental issue. Transportation is one of the key sectors contributing to GHG in Thailand. More importantly, the country pledged in its 'Nationally Appropriate Mitigation Actions' in December 2014 to reduce its GHG emissions in the energy and transportation sectors by 7-20% on a business-as-usual basis by the year 2020 (TGGMO, 2014). More recently, Thailand pledged in COP 26 that the nation aims to reach carbon neutrality by 2050 and net-zero GHG emissions by or before 2065 (MFA, 2021). This commitment emphasizes the urgent need for the country to reduce GHGs effectively. The expected GHG emissions before and after the construction of a bicycle lane must be quantified to prove that a bicycle lane would effectively reduce GHGs and promote the "Green city" initiative. Literature reveals that much emphasis has been placed on researching cycling. However, although it has been widely researched in Western countries it has seldom been studied in Thailand. Recent research has been targeted towards health, safety, and cyclist behavioral issues. For example, Andersen *et al.* (2018) examined cycling and cycling-related injury trends in four of Denmark's largest cities to measure if changes in cycling trips and injuries were linked. Bourne *et al.* (2018) evaluated the health benefits of electrically assisted bicycles in the United Kingdom. Boufous *et al.* (2018) examined the effects of environmental factors on riders' speed in Sydney, Australia. Huemer (2018) identified factors making people ride bikes under the influence of alcohol in Germany and then designed safety measures. Mandic *et al.* (2018) examined the effects of short-term cycling training on children's cycling knowledge, confidence, and behaviors in Dunedin, New Zealand. Shrestha *et al.* (2020) assessed cyclists' exposure to particulate matters in Perth, Western Australia. Castells-Graells *et al.* (2020) studied factors affecting the risk and discomfort of cyclists in Zurich, Switzerland. In Thailand, a few studies have found factors influencing cycling attitudes to help promote cycling in cities. Singsaktrakul and Muneenam (2019) examined potential features to support tourists for cycling in Songkhla province and Ratanaburi *et al.* (2021) examined the impact of stakeholder involvement on the quality of a bicycle lane infrastructure in the capital, Bangkok. A summary of aspects considered by different recent studies is presented in Table 1.

As it is shown in Table 1 the recent literature mainly deals with cyclists' issues, and most studies have been conducted in other countries. In Thailand, there have been two recent studies of cycling, both of which examined cyclists' aspects. Although one study also investigated cycling infrastructure, only the quality of a bicycle lane was considered. The environmental and cost factors have not yet been examined. To prove that a bicycle lane provision would positively impact society, ecological and economic changes need to be measured. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are tools used to assess the environmental impacts and costs during the life cycle of a product/service (Klöpffer and Grahl, 2014). These tools are well-known to support decision-making as they can help prevent shifting problems from one stage to another in the life cycle of a product/service. This study uses LCA and LCC to examine the life cycle greenhouse gas (GHG) emissions (in other terms, "Carbon footprint") and the costs of a bicycle lane system in a municipality. The carbon footprint accounts for different GHGs which may be emitted, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), throughout a

Table 1: Summary of examined issues of cycling for different recent studies

Country	Subjects		References
	Cyclist	Infrastructure	
Denmark	Cycling-related injuries	-	Andersen *et al.* (2018)
United Kingdom	Health benefits	-	Bourne *et al.* (2018)
Australia	Factors on speed	-	Boufous *et al.* (2018)
Germany	Behaviors under the influence of alcohol	-	Huemer (2018)
New Zealand	Effects of training on children's cycling skills	-	Mandic *et al.* (2018)
Thailand	Features to support tourists for cycling	-	Singsaktrakul and Muneenam (2019)
Australia	Exposure to particulate matters	-	Shrestha *et al.* (2020)
Switzerland	Risk and discomfort	-	Castells-Graells *et al.* (2020)
Thailand	Stakeholder involvement	Quality of a bicycle lane	Ratanaburi et al. (2021)

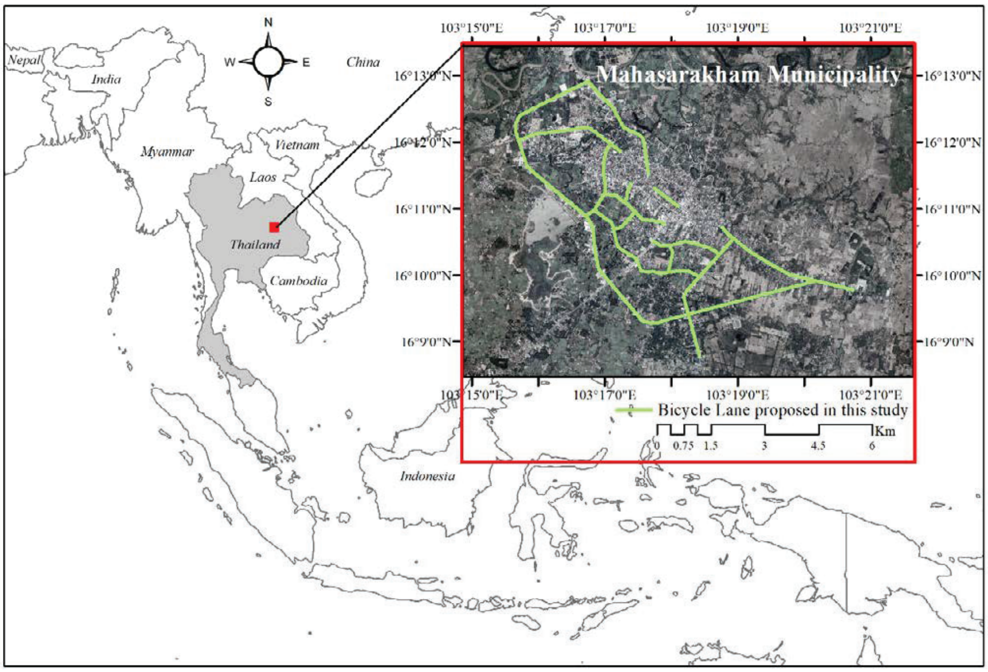


Fig. 1: Geographic location of the study area in Mahasarakham municipality in Thailand

product's life cycle (CSS, 2021). These are sometimes called "life cycle greenhouse gases". The life cycle stages considered for this study include; material acquisition, transportation, construction, use, and disposal. The results are expected to be used as supporting information for policymakers. The study compares the expected carbon footprints before and after installing a bicycle lane system and the cost involved during its life cycle. This study was carried out in Mahasarakham city, Thailand, from 2015 to 2020.

MATERIALS AND METHODS

The main goal of this study is to compare the carbon footprints and costs before and after constructing a bicycle lane in Mahasarakham municipality, Mahasarakham, Thailand. The geographic location of the study area is presented in Fig. 1. Mahasarakham city is located in the middle of the northeastern region of Thailand. This study is based on the bicycle lane construction plan designed by the Faculty of Architecture, Urban Design, and Creative Arts, Mahasarakham University, Thailand. The bicycle lane network design which covers approximately 32 km is illustrated in Fig. 1.

This study hypothesizes that a bicycle lane provision would help reduce the carbon footprint which could be used to offset the cost of constructing a bicycle lane. The carbon footprint and life cycle cost incurred before and after installing a bicycle lane must be calculated to prove this hypothesis. The tools used to assess the carbon footprints were life cycle assessment and life cycle costing for life cycle costs.

Life cycle assessment

This LCA study was conducted following the framework of ISO 14067: 2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification (IOS, 2018). Following the guidelines, there were four main stages, i.e., goal and scope definition, inventory analysis, life cycle impact assessment and interpretation.

Goal and scope definition

This study aims to determine whether installing a bicycle lane in Mahasarakham city will help reduce life cycle GHG emissions and to quantify those emissions. The analysis compares the expected total GHG emissions before and after installing a bicycle lane in the city. The system boundary of this study covers the processes of; raw material acquisition, transportation, construction, use, and disposal. The functional unit set for this study is the use of a bicycle lane for one year. The assessment covers the year 2015 to 2020.

Life cycle inventory (LCI) analysis

Life cycle inventory (LCI) is defined as the inputs (energy, resources, and materials used) and outputs (emissions) examined in each life cycle stage of the bicycle lane. The aforementioned data was required for the impact assessment. Therefore, the LCI data was calculated considering the functional unit set (using a bicycle lane for one year). The LCI data were obtained from different sources and were computed using spreadsheets. The details of LCI data analysis for each life cycle stage of the bicycle lane are described as follows.

Raw material acquisition

The LCI data for all raw materials used in the life cycle of the bicycle lane studied was obtained from existing databases (TGGMO, 2021a).

Transportation

LCI data for this stage refers to transportation information of raw materials and bicycle lane construction. These data were acquired by interviewing a road construction contractor.

Construction

Since the bicycle lane had not yet been constructed in Mahasarakham, LCI data for this stage were obtained from secondary data such as the bicycle lane construction plan designed by the Faculty of Architecture, Urban Design and Creative Arts, Mahasarakham University, Thailand and Siam Traffic (2021). The main activities included in the plan were road markings on the designed bicycle lane system and construction facilities (road signs and bicycle parking). Note that the construction of facilities is excluded from this study since facilities are long-lived during the use phase. Therefore, their impacts are considered less significant for the functional unit set of this study (use of a bicycle lane for one year).

Use

LCI data for this stage was obtained by comparing LCI data on the use of vehicles on the existing roads before construction with that expected after installing a bicycle lane. The transportation volume data obtained from 1,447 road user surveys were used in this stage to determine whether bicycles would have been preferred had a bicycle lane been installed. The transportation volume assessment was conducted in December 2015. The transportation volume counting was done thrice a day during rush hours between 8.00-9.00 am, 12.00-1.00 pm, and 5.00-6.00 pm on weekdays and weekends. Note that future transportation volumes of future roads were assumed to have transportation volumes similar to that of the existing roads. The average daily transportation volumes were estimated using the parameters suggested in SPU, (2012). Finally, the average yearly transportation volumes were calculated using the average daily transportation volumes (weekdays and weekends), assuming that there are 260 weekdays and 105 days during weekends in a year. The final LCI results of this stage were the LCI data obtained by comparing the transportation volume expected after and before the bicycle lane installation, using Eq. 1.

$$LCI_u = LCI_{ua} - LCI_{ub} \quad (1)$$

Where LCI_u is the LCI data for the use phase of the bicycle lane, LCI_{ua} is the LCI data for the use phase of the road after having a bicycle lane installed, LCI_{ub} is the LCI data for the use phase of the road before having a bicycle lane installed.

If the results are negative, it signifies a reduction in energy consumption, resources, and materials. In addition, a decrease in GHG emissions from the year 2016 to 2020 was estimated using data from the year 2015 and numbers of vehicles registered in Mahasarakham city for different years from the NSO, (2020).

Disposal

LCI data for this stage included energy used and emissions during the removal of the bicycle lane. These data were acquired by interviewing a road construction contractor. In this case, it is a disposal of road markings with a functional life of two years.

Life cycle impact assessment

The life cycle GHG emission (carbon footprint) assessment was calculated by multiplying emissions factors by LCI data obtained from the previous stage, using Eq. 2.

$$CF = LCI_1EF_1 + LCI_2EF_2 + ... + LCI_kEF_k \quad (2)$$

Where CF is the carbon footprint in the unit of kgCO_2eq, LCI_i (1, 2, 3 ... k) is the LCI data (unit differs depending on the type of LCI), EF_i (1, 2, 3 ... k) is the emission factors in the unit of kgCO2eq/unit of LCI data. Thus, an emission factor is a constant showing global warming potential for each LCI. The emission factors used in this study were from EPA, (2021) and TGGMO, (2021a).

Interpretation

This stage is to tackle the goal of the LCA study using the impacts analyzed from the previous step. This study aims to determine whether installing a bicycle lane in Mahasarakham city can help reduce the carbon footprints and to quantify them, using Eq. 3.

$$CF_t = CF_a - CF_b \quad (3)$$

CF_t is the total carbon footprint of the bicycle lane, CF_a is the carbon footprint after a bicycle lane construction, CF_b is the carbon footprint before a bicycle lane construction.

If the total carbon footprint is negative, it implies that the bicycle lane positively affects the municipality, and its installation can help reduce the carbon footprint of the city.

Life cycle costing

Life cycle costs were calculated from raw materials, transportation, construction, use, and disposal processes (Klöpffer and Grahl, 2014). The calculation for the life cycle cost in this study is shown in Eq. 4.

$$C_l = C_r + C_t + C_c + C_u + C_d \quad (4)$$

Where C_l is the life cycle cost of the bicycle lane, C_r is the cost of raw materials, C_t is the cost of transportation, C_c is the cost of construction, C_u is the cost of use phase, C_d is the cost of disposal phase.

As mentioned before, a bicycle lane system has not yet been installed in Mahasarakham city, and the costs were obtained from secondary data (Bicycle lane construction plan designed by the Faculty of Architecture, Urban Design and Creative Arts, Mahasarakham University, Thailand and Siam Traffic (2021)). Therefore, all costs were adjusted for 2020 using Consumer Price Indices from BT, (2020). In addition, the value of potential carbon credits obtained from greenhouse gas reduction was calculated using carbon credit prices from TGGMO, (2021b).

RESULTS AND DISCUSSION

Environmental impacts

The difference in expected values of the environmental impacts before and after the installation of the bicycle lane is shown in Fig. 2. These are the total carbon footprint of the bicycle lane (in different life cycle stages) calculated using Eq. 3. Based on the functional unit set for this study (using a bicycle lane for one year), the results presented in Fig. 2 were calculated yearly. This yearly calculation is because the GHGs are not influenced by time during construction and disposal phases. However, GHGs for the use phase of bicycle lane is influenced by the number of registered vehicles, which changes every

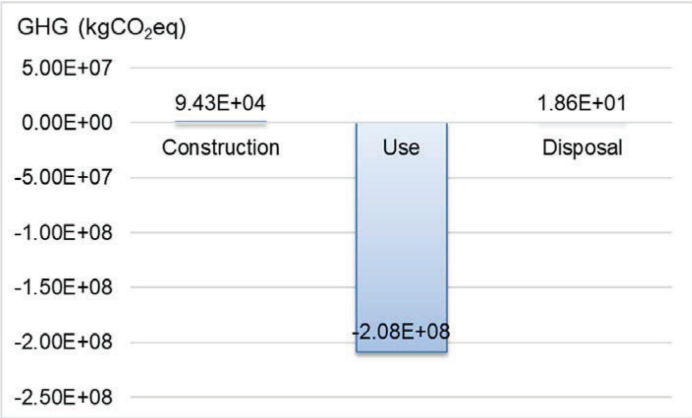


Fig. 2: Total life cycle GHG emissions in different stages for one year

Table 2: Number of vehicles before and after installing a bicycle lane in 1 year

Percentage of frequency for using bicycles	Fraction of vehicle users not using bicycles	Motorcycle	Gasoline car	Pickup truck
		Number	Number	Number
Usual		343,649,990	160,554,265	191,156,425
95-100 (97.5)	0.025	429,562	120,416	143,367
72.5-95 (85)	0.15	4,639,275	722,494	1,720,408
50-72.5 (60)	0.4	21,993,599	8,991,039	18,351,017
0-49 (25)	0.75	64,434,373	30,103,925	35,841,830
Never (0)	1	154,642,496	88,304,846	80,285,699
Vehicles remaining on the road		246,139,305	128,242,719	136,342,320
Vehicles reduced after installing the bicycle lane		97,510,685	32,311,546	54,814,105

year. From this stance, the year 2020 is presented in Fig. 2 as it provides the most recent data available from NSO (2020). The total GHGs of a bicycle lane from 2015 to 2020 are presented later in Fig. 4.

The negative results signify that the installation of a bicycle lane can help reduce GHG emissions. In 2020, the amount of GHGs decreased by around 0.2 million tons of carbon dioxide equivalent, influenced by the decrease in the number of vehicles on the road. This decrease in cars/motorcycles will help save fossil fuels, limit burning emissions, and reduce carbon footprint. The primary process which plays an essential role in reducing the impacts is the use phase which accounts for nearly 100 % of the total reduced effects. A similar reduction during the use phase was found by Mrkajic *et al.* (2015), where the installation of a bicycle lane system led to GHG reduction in Novi Sad city, Serbia. In other road infrastructure LCA studies, such as asphalt pavements (Barbieri *et al.*, 2021), it was also found that the use phase is highly significant in reducing emissions. Another LCA study on asphalt pavements by Araújo *et al*. (2014), found that carbon footprint reduction in the use phase of asphalt pavements was due to the decrease in fuel consumption and exhaust emissions from vehicles on the roads. Other minor sources contributing to the carbon footprint of the bicycle lane were GHG emissions from raw materials acquisition and pollutions emitted during the construction and disposal phases. The willingness of road users to opt for bicycles had a bicycle lane been provided is a critical factor in helping reduce the environmental impacts. The difference in the number of vehicles before and expected after installation of a bicycle lane in 2015 is shown in Table 2. These results were calculated using transportation volumes and the percentage of road users willing to use bicycles if the bicycle lane was provided. Overall, the number of vehicles was expected to decrease after installing a bicycle lane by approximately 26% of the usual number. Motorcycles occupy a significant portion (about 53%) amongst the number of vehicles reduced.

Fig. 3 presents the potential GHG reduction from different types of vehicles in additional years during

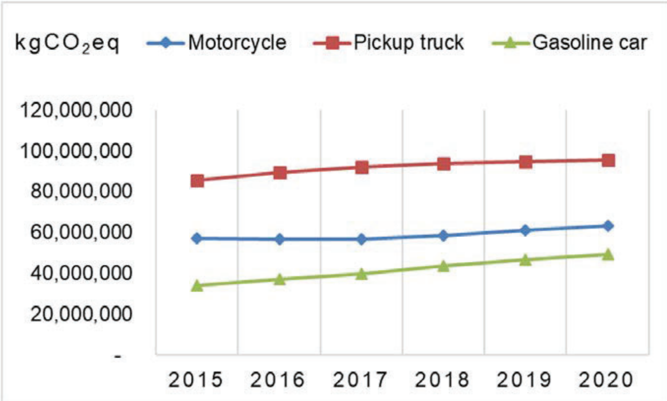


Fig. 3: Carbon footprint reduction by different types of vehicles in the use phase of a bicycle lane

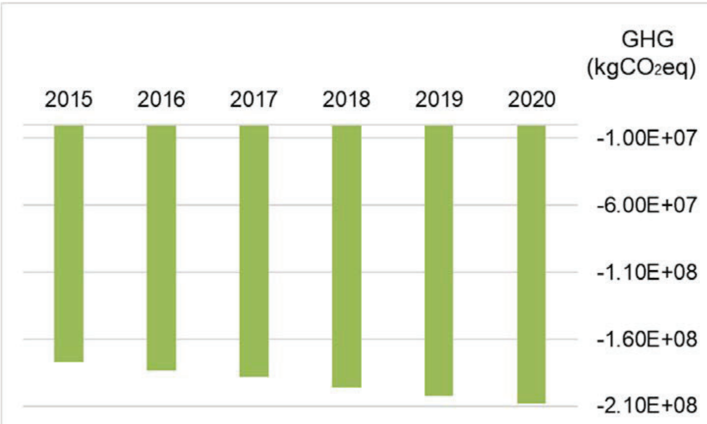


Fig. 4: Total carbon footprint of a bicycle lane for different years

the use phase of the bicycle lane. It is seen that the amount of GHG reduction by pickup trucks is the highest among other types of vehicles. Compared to other vehicles, the expected number of motorcycles reduced after installing the bicycle lane was considerably high (Table 2). Fortunately, since the emission factor for motorcycles is lower than other vehicles, this results in a lower carbon footprint than that of pickup trucks. Another reason that pickup trucks play a dominant role in reducing the carbon footprint is because they use diesel fuel, whereas motorcycles and gasoline cars are fueled by gasoline. Therefore, the emission factor for diesel-fueled vehicles is higher than those using gasoline (EPA, 2021), leading to a higher carbon footprint value. A study by Chang and Huang, (2021) also found that the carbon footprint of diesel-fueled buses is higher than buses using other fuels. On the other hand, gasoline cars showed the least GHG emission reduction since they have the lowest expected reduction after the bicycle lane installation (Table 2). When considering the carbon footprint reduction across the years examined, all vehicles showed an increasing trend. This increase was due to the increase in the number of vehicles registered in Mahasarakham city every year (NSO, 2020).

Fig. 4 shows the total life cycle GHG emissions of a bicycle lane used from 2015 to 2020. These results include the carbon footprints of all life cycle stages considered; construction, use, and disposal phases for all the years investigated. It is seen that a bicycle lane has an increasing trend in carbon footprint reduction in later years. The results in Fig. 4 imply that had a bicycle lane been installed since 2015, the city could have reduced a total GHG of more than 1.15 million tons of carbon dioxide equivalent by 2020.

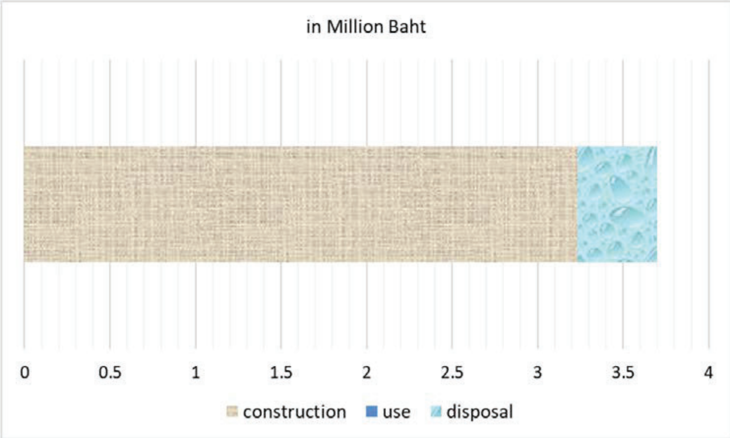


Fig. 5: Life cycle costing in different stages in the year 2020

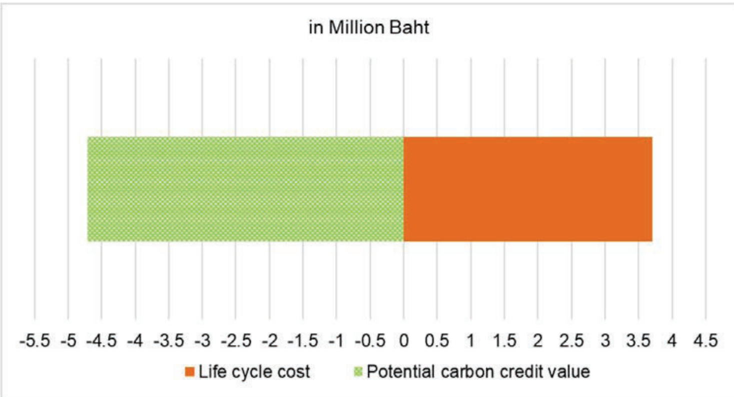


Fig. 6: Potential value of carbon credit compared to life cycle cost in the year 2020

Costing

Costs of each life cycle stage in one year of operating the bicycle lane system in Mahasarakham city are presented in Fig. 5. Based on the functional unit set for this study (use of a bicycle lane for one year), the life cycle cost illustrated in Fig. 4 was calculated yearly. Data for the year 2020 were used in the analysis as it is the most recent data available at the time the study was undertaken. Most of the cost incurred was during the construction stage (about 87%). Therefore, the potential value of carbon credit gained by avoiding GHG emissions was reduced by bicycle lane installation. As shown in Fig. 6, the estimated carbon credit was higher than the one-year life cycle cost of installing the bicycle lane. The potential carbon credit is valued at around 4.7 million baht, while the life cycle cost is approximately 3.7 million baht. The results imply that installing a bicycle lane system could help offset all the life cycle costs by gaining the value of carbon credits of GHG reduction during its life cycle. Moreover, there is also a surplus carbon credit of about 1 million baht remaining after subtracting the total life cycle cost from full carbon credits. This credit signifies that GHG emission could have been avoided in 2020 had a bicycle lane been installed, and 1.27-fold economic benefits would have been garnered. Likewise, Maizlish *et al.* (2017) also proved that cycling helps reduce GHG emissions and provides health co-benefits for cyclists.

Despite the low rate of road users willing to use bicycles even with provision of a bicycle lane, the results still showed positive environmental and economic impacts. A bicycle lane system investment could earn the added ecological and economic benefits if the municipality promotes bicycles. However, survey results revealed that most road users were unwilling to use bicycles because of safety concerns, weather conditions, and convenience. These issues were also reported in a study about bicycle lane infrastructure in another Thai city (Ratanaburi *et al*., 2021). For sustainable use of the bicycle lane, these issues should be addressed. In addition to global warming, other environmental impacts of a bicycle lane should also be considered. A study conducted by Robinah *et al.* (2022) found that apart from climate change, particulate matter formation is one of the significant issues of road infrastructure equipment. Therefore, it is suggested that further research should investigate other impact categories of a bicycle lane installation.

CONCLUSION

For Thailand to find effective ways to help reduce the GHGs, it will be necessary to target transportation, which is one of the major sectors contributing large amounts of GHGs. Cycling, therefore, is being promoted with the hope of lessening GHGs. While much research has been conducted on the cyclists' aspects, literature examining the bicycle lane infrastructure is limited. Moreover, to prove that a bicycle lane could help reduce GHGs, it is essential to quantify its environmental and economic impacts. This study compares the expected life cycle GHG emissions and costs before and after installing a bicycle lane using LCA and LCC in Mahasarakham, Thailand. The results reveal that using the bicycle lane for one year can help reduce carbon footprint by about 0.2 million tons of carbon dioxide equivalent in 2020. Although only 26% of the vehicle users were willing to use bicycles had a bicycle lane been provided, a modest carbon footprint reduction could still be achieved. Considering the potential of a bicycle lane installation to progressively reduce entire life cycle GHGs in successive years from 2015 to 2020, the bicycle lane was found to have an increased tendency to reduce carbon footprint. This reduction was due to an increasing trend in the number of vehicles every year. Moreover, it is estimated that had a bicycle lane been established in 2015, the city could have reduced the total carbon footprint by more than 1.15 million tons of carbon dioxide equivalent by 2020. The use phase plays a dominant role in reducing environmental impacts. This reduction is the result of decreased fuel usage by vehicles. Considering the various types of automobiles studied, the amount of GHG reduction achieved by pickup trucks was the highest. Pickup trucks play a significant role in carbon emission reduction because they run on diesel fuel, whereas motorcycles and gasoline cars run on gasoline. This reduction is due to the high emission factor of diesel compared to gasoline, thereby resulting in a significant carbon footprint reduction. The reduction in GHG emissions could help offset the total life cycle cost as well. The total carbon credits gained by installing a bicycle lane in Mahasarakham is about 4.7 MB, while the whole life cycle cost in 2020 is approximately 3.7 MB. This credit implies that having a bicycle lane installed in the municipality would provide economic benefits valued 1.27-fold of the total life cycle cost. The findings from this study prove that provision of a bicycle lane reduces GHGs and could be instrumental in the transition to a low-carbon society. In addition, the findings could be used as a guide for other cities to conduct similar studies. Moreover, the results from this study could be used as supporting information to help formulate measures to reduce GHGs in the transportation sector of the city. Based on the results of this study, it is highly recommended that a bicycle lane be constructed to help with GHG reduction in the city. The sooner the bicycle lane is provided, significant GHG reduction could be achieved. In order to promote a sustainable bicycle lane system, safety and convenience issues should be addressed as well. Moreover, it is suggested that other impact categories of a bicycle lane should also be studied in the future.

AUTHOR CONTRIBUTIONS

J. Prasara-A performed the literature review, research design, analyzed and interpreted the data, prepared the manuscript text and manuscript editing. A. Bridhikitti helped in the research design and manuscript editing.

ACKNOWLEDGEMENT

This work was supported by the Higher Education Research Promotion (HERP) program and Mahasarakham University [Contract No. 5808021/2558]. The authors would like to gratefully acknowledge Methee Piriyakarnnon from the Faculty of Architecture, Urban Design, and Creative Arts, Mahasarakham University, for providing the bicycle lane construction plan designed for use in the analysis. In addition, thank to all respected anonymous supporters for providing valuable inputs for this study. Alice Padmini Albert from the Faculty of Environment and Resource Studies, Mahasarakham University, is also gratefully acknowledged for English language support. Also thank to Adrian Plant (Mahasarakham University) for English language support in the final proof editing.

CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

ABBREVIATIONS

%	Percent
am	Before noon
BT	Bank of Thailand
C_c	Cost of construction
C_d	Cost of disposal phase
CF	Carbon footprint
CF_a	Carbon footprint after a bicycle lane construction
CF_b	Carbon footprint before a bicycle lane construction
CF_t	Total carbon footprint of the bicycle lane
CH_4	Methane
C_l	Life cycle cost of the bicycle lane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COP 26	26th session of the Conference of the Parties
C_r	Cost of raw materials
CSS	Center for Sustainable Systems
C_t	Cost of transportation
C_u	Cost of the use phase
EF	Emission factor
EPA	Environmental Protection Agency
Eq.	Equation
Fig.	Figure
GHG	Greenhouse gas
IOS	International Organization for Standardization
ISO	International Organization for Standardization
$kgCO_2eq$	kilogram of carbon dioxide equivalent
km	kilometer
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory
LCI_u	LCI data for the use phase of the bicycle lane
LCI_{ua}	LCI data for the use phase of the road after having a bicycle lane installed
LCI_{ub}	LCI data for the use phase of the road before having a bicycle lane installed
MFA	Ministry of Foreign Affairs
N_2O	Nitrous oxide
MB	Million Baht

Mt	Million ton
NSO	National Statistical Office
pm	After noon
SPU	Strategic Planning Unit
t	Ton
TGGMO	Thailand Greenhouse Gas Management Organization

REFERENCES

Andersen, L.B.; Riiser, A.; Rutter, H.; Goenkad, S.; Nordengen, S.; K. Solbraa, A., (2018). Trends in cycling and cycle related injuries and a calculation of prevented morbidity and mortality. J. Transp. Heal., 9: 217–225 **(9 pages).**

Araújo, J.P.C.; Oliveira, J.R.M.; Silva, H.M.R.D., (2014). The importance of the use phase on the LCA of environmentally friendly solutions for asphalt road pavements. Transp. Res., Part D Transp. Environ., 32: 97–110 **(14 pages).**

BT, (2020). Key economic indicators. Bank of Thailand.

Barbieri, D.M.; Lou, B.; Wang, F.; Hoff, I.; Wu, S.; Li, J.; Run Vignisdottir, H; André Bohne, R.; Anastasio, S.; Kristensen, T., (2021). Assessment of carbon dioxide emissions during production, construction and use stages of asphalt pavements. Transp. Res. Interdiscip. Perspect. 11: 100436 **(11 pages).**

Boufous, S.; Hatfield, J.; Grzebieta, R., (2018). The impact of environmental factors on cycling speed on shared paths. Accid. Anal. Prev., 110: 171–176 **(6 pages).**

Bourne, J.E.; Sauchelli, S.; Perry, R.; Page, A.; Leary, S.; England, C.; Cooper, A.R., (2018). Health benefits of electrically-assisted cycling: a systematic review. Int. J. Behav. Nutr. Phys. Act., 15: 116 **(15 pages).**

Castells-Graells, D.; Salahub, C.; Pournaras, E., (2020). On cycling risk and discomfort: urban safety mapping and bike route recommendations. Computing. 102: 1259–1274 **(16 pages).**

Chang, C.-C.; Huang, P.-C., (2021). Carbon footprint of different fuels used in public transportation in Taiwan: a life cycle assessment. Environ. Dev. Sustain, **(15 pages).**

Chaowarat, P.; Piriyakarnnon, M.; Sawangchaeng, S.; Natephra, W., (2016). Public Policy of Cycling Promotion in Mahasarakham City. In the 4th International Conference on Magsaysay Awardees: Good Governance and Transformative Leadership in Asia. College of Politics and Governance (COPAG), Mahasarakham University, Mahasarakham, Thailand 31 May.

CSS, (2021). Carbon footprint factsheet. Center for Sustainable Systems, University of Michigan, USA.

DRR, (2012). Normal maintenance manual. Department of Rural Roads, Ministry of Transport, Bangkok, Thailand.

EPA, (2021). Emission factors for greenhouse gas Inventories. Environmental Protection Agency.

Huemer, A.K., (2018). Cycling under the influence of alcohol in Germany. Transp. Res. Part F Traffic. Psychol. Behav., 56: 408–419 **(12 pages).**

IOS, (2018). ISO 14067: 2018 greenhouse gases — carbon footprint of products — requirements and guidelines for quantification. International Organization for Standardization.

Klöpffer, W.; Grahl, B., (2014). Life cycle assessment (LCA): a guide to best practice. Wiley-VCH Verlag GmbH and Co. KGaA, Weinheim, Germany.

Kongboon, R.; Gheewala, S.H.; Sampattagul, S., (2021). Empowering a sustainable city using self-assessment of environmental performance on EcoCitOpia platform. Sustainability. 13: 7743 **(17pages).**

Mahasarakham Municipality, (2020). Mahasarakham municipality's history.

Maizlish, N.; Linesch, N.J.; Woodcock, J., (2017). Health and greenhouse gas mitigation benefits of ambitious expansion of cycling, walking, and transit in California. J. Transp. Health. 6: 490–500 **(11pages).**

Mandic, S.; Flaherty, C.; Pocock, T.; Kek, C.C.; McArthur, S.; Ergler, C.; Chillón, P.; Bengoechea, E.G., (2018). Effects of cycle skills training on children's cycling-related knowledge, confidence and behaviours. J. Transp. Heal., 8: 271–282 **(12 pages).**

MFA, (2021). The Prime Minister participated in the World Leaders Summit during the 26th United Nations Framework Convention on Climate Change Conference of the Parties (UNFCCC COP26) in Glasgow, United Kingdom. Ministry of Foreign Affairs.

Mrkajic, V.; Vukelic , D.; Mihajlov, A., (2015). Reduction of CO_2 emission and non-environmental co-benefits of bicycle infrastructure provision: the case of the University of Novi Sad, Serbia. Renew. Sustain. Energy. Rev., 49: 232–242 **(11 pages).**

NSO, (2020). Number of vehicles registered by types of vehicle, regions and provinces. National Statistical Office.

Ratanaburi, N.; Alade, T.; Saçli, F., (2021). Effects of stakeholder participation on the quality of bicycle infrastructure. A case of Rattanakosin bicycle lane, Bangkok, Thailand. Case. Stud. Transp. Policy. 9: 637–650 **(14 pages).**

Robinah, N.; Safiki, A.; Thomas, O.; Annette, B., (2022). Impact of road infrastructure equipment on the environment and surroundings. Global J. Environ. Sci. Manage., 8(2): 1-14 **(14 pages).**

Shrestha, A.; Mullins, B.; Zhao, Y.; Selvel, L.A.; Rumchev, K., (2020). Exposure to air pollutants among cyclists: a comparison of different cycling routes in Perth, Western Australia. Air. Qual. Atmos. Heal., 13: 1023–1034 **(12 pages).**

Siam Traffic, (2021). Road marking material use guidelines. Siam Traffic Co., Ltd.

Singsaktrakul, P.; Muneenam, U., (2019). Cycling Tourism Situation in Songkhla Special Economic Zone. Humanities, Social Sciences, and Arts, 12(2): 890–909 **(20 pages).**

SPU, (2012). Project appraisal guidelines. National Roads Authority, Dublin.

TGGMO, (2014). NAMA (Nationally Appropriate Mitigation Action). Thailand Greenhouse Gas Management Organization.

TGGMO, (2021a). Emission factor. Thailand Greenhouse Gas Management Organization.

TGGMO, (2021b). Carbon credit prices. Thailand Greenhouse Gas Management Organization.

AUTHOR (S) BIOSKETCHES

Prasara-A., J., Ph.D., Associate Professor, Energy and Environment for Sustainable Development Research and Training Center, Faculty of Environment and Resource Studies, Mahasarakham University, Mahasarakham, Thailand.
Email: *jittima.p@msu.ac.th*
ORCID: 0000-0003-3490-6567

Bridhikitti, A., Ph.D., Assistant Professor, Environmental Engineering and Disaster Management Program, School of Interdisciplinary Studies, Mahidol University Kanchanaburi Campus, Lumsum Sub-District, Saiyok District, Kanchanaburi, Thailand.
Email: *arika.bri@mahidol.edu*
ORCID: 0000-0003-3356-0015

HOW TO CITE THIS ARTICLE

Prasara-A, J.; Bridhikitti, A., (2022). Carbon footprint and cost analysis of a bicycle lane in a municipality. Global J. Environ. Sci. Manage., 8(2): 197-208.

DOI: 10.22034/gjesm.2022.02.04

url: https://www.gjesm.net/article_247328.html

Global J. Environ. Sci. Manage. 8(2): 209-224, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Community empowerment of waste management in the urban environment: More attention on waste issues through formal and informal educations

A. Brotosusilo[1,*], D. Utari[2], H.A. Negoro[3], A. Firdaus[4], R.A. Velentina[1]

[1] *Faculty of Law, Universitas Indonesia, Depok, West Java, Indonesia*

[2] *Faculty of Health Science, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia*

[3] *Department of Economic, Faculty of Economics and Business, Universitas Indonesia, Indonesia*

[4] *School of Environmental Science, Universitas Indonesia, Indonesia*

ARTICLE INFO

Article History:
Received ***
Revised ***
Accepted ***

Keywords:
Awareness
Behavior
Education
Littering
Logistic regression
Waste management

ABSTRACT

BACKGROUND AND OBJECTIVES: Indonesia's economic growth is estimated to be driven by high levels of consumption which lead to large amounts of waste. Education is required to raise environmental awareness among the population as it is one of the ways to overcome the waste issue, especially in urban areas, which are the engines of economic growth. This study aims to determine whether the higher levels of education have a greater impact on citizens regarding environmental concerns such as littering.

METHODS: The study took logistics regression on the primary data survey from 7 cities (Jakarta, Jambi, Muaro Jambi, Ambon, Padang, Surabaya, and Tasikmalaya) in Indonesia during 2019-2021. The survey includes 563 observations on the household level, involving a total of 2,349 respondents. The logistic regression predicts the likelihood of urban citizens to litter, given their socio-economic backgrounds and existing littering behavior and environmental awareness.

FINDINGS: This study found that education did not affect decreasing the value of littering behavior as expected since it is estimated that an increase of 1 year in school will increase the probability of littering by 0.0189. Formal education is not enough to decrease the probability of littering behavior on the individual level. In contrast, informal education taught on keeping a clean environment matters is better than conventional formal education. Besides that, having self-initiative on environmental caring and good habits from childhood will decrease the probability of littering on an individual level. An individual has a self-initiative, the probability of littering will be 0.1732 times lower than those who do not have self-initiative. This study also found that per capita income and per capita expenditure in big cities in Indonesia ranged between USD 156,903 and USD 116,857. These economic factors affect the behavior of citizens not to litter. The per capita expenditure increasing by USD 1 per person per day will decrease the probability of littering by-0.0468. However, these factors are not enough to minimize the littering behavior since the disposal place availability becomes another keys factor in decreasing littering behavior on urban citizens.

CONCLUSION: The government should also focus on building citizens' behavior regarding waste management awareness especially building good habits since childhood and individual initiative, simultaneously implementing the programs to reduce waste production.

DOI: 10.22034/gjesm.2022.02.05

NUMBER OF REFERENCES
52

NUMBER OF FIGURES
3

NUMBER OF TABLES
3

*Corresponding Author:
Email: *broto.susilo@ui.ac.id*
Phone: +6281 2100 85080
ORCID: 0000-0001-7072-0263

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Indonesia is listed in the top 5 of the most populous countries in the globe, resulting in bigger various economic activities compared to its peers in the Association of Southeast Asian Nations (ASEAN) region. In the real sector, big economic activities will be followed by waste production. The waste itself takes part in the economy in the middle phase: as value-added, delivery, or packaging. After the output produced has been absorbed by the economy (consumed by economic agents), the residue of what-so-called value-added, delivery, or packaging will turn into a new phase: a waste. Waste is defined as the residue of real economic activities within a period. Indonesia, as the world's biggest archipelago, has agglomerated structure of economic activities. Both production and consumption activities are concentrated in the urban environment, and this study tried to explain what might cause a waste problem that comes from Indonesia's biggest economic growth contributor households. Cities are synonymous with high density and waste management problems (Brotosusilo and Handayani, 2020). The increase in the world's population living in urban areas indicates the possibility of an increase in the volume of waste which will eventually become a pressure for cities (World Bank, 2018). Increased income and consumerism also affect the high amount of waste produced in cities. Suleman *et al.* (2015) describe that the rapid increase in living standards and technology leads to higher solid waste production. Households in urban areas have a lower probability of burying or burning waste but piles of garbage in public places are more common, which has an impact on the environment and citizens (Adzawla *et al.,* 2019). The discovery of piles of waste can be found in the streets or halted and public places, most of which are in the form of leftover food or beverage packaging. Littering behavior is also known to be influenced by spatially based attributes. It means that areas with lots of drink shops, empty buildings, or areas close to roads will have a higher tendency to litter than housing with green and well-maintained spaces (Weaver, 2015). Humans interact with nature, and this can affect ecosystem, economic, and cultural resilience on local and regional scales (Folke and Gunderson, 2002). The littering of waste can shake the resilience of the ecosystem. Waste littering is caused by a lack of environmental awareness (Eastman *et al.,* 2013). The development of study shows that this plastic waste will not only interfere with aesthetics but can also have an impact on health. There is some evidence found related to the impact of littering, both in the terrestrial and aquatic environment (Jefferson, 2019). Waste management to achieve the Sustainable Development Goals (SDGs) by reducing waste generation through the reuse, reduce, and recycle (3R). There have been many previous studies exploring household behavior in waste management. Human behavior can be regulated by prevailing social norms. When littering is not reprimanded, it will lead to littering by other individuals. Individuals tend to adopt behavior adapted from socio-spatial contexts (Cialdini *et al.,* 1990). Some policies regarding the payment of plastic bags have been made (Mcllgorm *et al.,* 2011). It aims to minimize the use of waste. However, the policies made are not going well in Indonesia. The presence of piles of waste on the road, river, or sea has attracted a lot of attention. The waste problem does not only come from within the country; there are reports of waste exports from developed countries to developing countries (World Bank, 2018). The enforcement of regulations is accused of being the cause of littering behavior because the existing sanctions are not strictly enforced (Kedzierski *et al.,* 2020). Several approaches are taken to solve the problem of waste littering, either through technical approaches or social knowledge. The constraint is that it is impossible to tackle waste using only one approach. It is necessary to combine approaches because of the complex waste problem. The problems that occur come from the amount of waste itself and its littering behavior. Differences in waste management in cities of Indonesia are caused by differences in people's understanding of a healthy and clean environment. Ignorance of waste is also the cause (Brotosusilo and Handayani, 2020). Improper waste management behavior is still being carried out, burning waste is still very common to destroy waste (Hilburn, 2015). Therefore, awareness about waste disposal and the action of identifying human behavior harms the environment should be more improved as it facilitates behavior change (McNicholas and Cotton, 2019). Several studies state that the factor that influences littering is the level of education. Efforts can be made by providing education to maintain environmental sustainability (Eastman *et al.,* 2013; Bahri *et al.,* 2020). In making decisions and in acting so as not to have harmed the environment, it is influenced by the level of education (Dodds and Holmes, 2018). Waste can be prevented and controlled through collaborative education and policy enforcement (Ten-Brink *et al.,* 2009). Environmental education must pay attention to the media used in both formal and informal education. The use of this media has the aim of enriching intellectual work tools (Cuc, 2014). Alexander *et al.* (2009) mentioned that the obstacle in pro-environmental behavior is knowledge where individuals with less education will litter more. Formal education plays a role in the proper level of waste management. From the household side, the socio-economic variables that may cause households' behavior in littering were explored. The key variables explored will relate to education and prior knowledge of urban citizens**.** This study may fill the gap on how urban citizens in Indonesia show unique behavior in littering. This environmental behavior occurs when there is a role for self-interest and pro-social motives. Pro-social behavior will create a moral value as a feeling of strong obligation that wanted to be involved in pro-environmental behavior. Social norms are in the form of behavior patterns, beliefs**,** and practices of pro-environmental behavior. Strong norms will prevent littering (Bator *et al.,* 2010). An order that is enforced, not just order because of the rules, can influence someone to be willing to follow the norm (Keizer *et al.,* 2013). Restoration or enforcement of social norms may be able to spread pro-social behavior to other**s.** Disrespect decreases in association with sanctions the stronger variable is cues that convey explicit attention to norms (Keizer *et al.,* 2013). One effort that shows results is that it is not enough to maintain cleanliness, individuals need examples or role models. Perform cleaning when there are people in the area so they can emulate them. In developing moral norms, cognitive prerequisites are needed in the form of awareness and knowledge of environmental problems (Bamberg and Moser, 2007). Bamberg and Moser (2007) conducted a meta-analysis of the factors that influence pro-environmental behavior. The determinant factor for proliferative behavior is intention. The intention is defined as a summary of the interaction of cognitive skills, action knowledge, action strategies**,** and problems with behavioral variables, attitude, control, and responsibility. Waste disposal depends on the socio-economic status and location of the settlement (Alhassan *et al.,* 2020). Education is one of the most important factors in reshaping and improving human behavior, including the littering behavior of urban citizens. This study focused on how education matters to urban citizens' behavior to create a clean and healthy living. Environmental attitudes are related to feelings, expansion of the physical environment, environmental services/products (Leonidou *et al.,* 2015). Environmental problems originating from waste are caused by littering behavior (Bator *et al.,* 2010) will carry out the behavior of littering if in the area he has seen or discovered the existence of waste scattered before (Schultz *et al.,* 2011). The scattered waste means that the surrounding community tolerates the behavior of littering (Weaver, 2015) when there is an irregularity in the behavior of throwing waste. It will be difficult to rebuild the order of littering of waste in the area. This does not necessarily encourage individuals to litter but behavior control also plays a role in individual initiatives not to litter. Socio-economic factors influence household decisions in solid waste disposal. It was found that education, gender, and age had a significant effect on the choice of waste littering (Adzawla *et al.,* 2019). The characteristics and location of a household also influence how household waste is littered of. Waste littering is divided into several systems, namely house to house (HtH), communal, informal waste collector (INF) systems**,** and illegal disposal. Waste littering in the HtH system **i**s littering where households litter their waste in the trash in front of the house, and cleaners from the city government collect the samples. Citizens who litter waste according to this system are influenced by gender after age, income, household size, work sector, and homeownership status (Alhassan *et al.,* 2020). A communal waste-littering system occurs when a landfill is provided for citizens in one area. When littering waste**,** the citizens have to collect the waste in a communal container where the cleaning staff will collect the trash in the communal place, instead of one house to another. When households do not entrust their waste littering to the city government, they will call informal waste workers called Informal waste collectors (INF). The waste produced by the household is purchased by INF so that the household

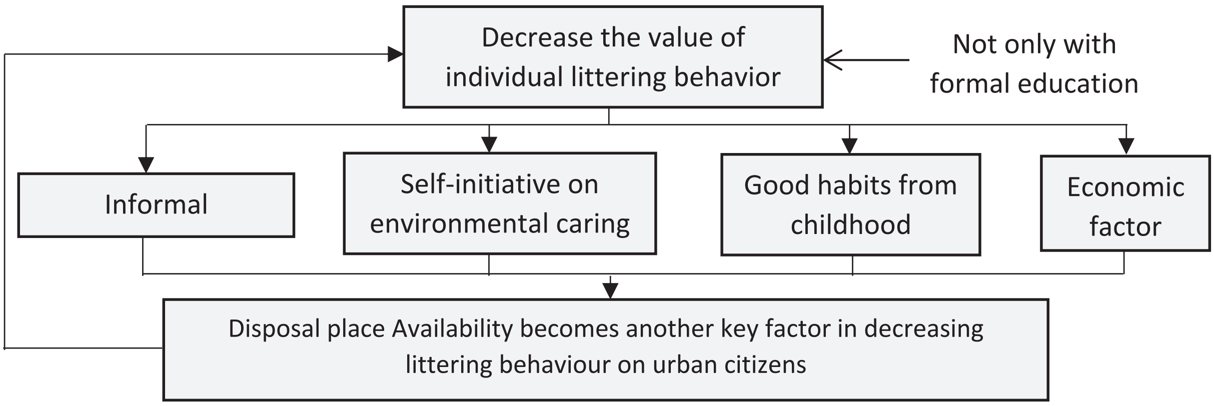


Fig. 1: Framework concept to decrease the value of individual littering behaviour

will get additional income from waste production paid for by INF. This study tried to analyze is if the higher education of citizens will have more impact on the attention in the environment, focusing on the waste littering awareness as in Ningrum and Herdiansyah (2018). This awareness is a new aspect considering that people's awareness of their environment is quite low as found in many studies. Based on this, the study is focused on waste littering awareness considers that most people dispose of waste by burning it. The survey was conducted in 7 cities (Jakarta, Jambi, Muaro Jambi, Ambon, Padang, Surabaya, and Tasikmalaya) in Indonesia during 2019-2021.

MATERIALS AND METHODS

Data description and collection

The data used was primary data. This primary data was obtained through a survey with more than 2000 respondents. The survey includes 563 observations on the household level. The households contain a various number of family members, with a total of 2,349 respondents on the individual level. The questionnaire used consists of 2 main sections: household (Adzawla *et al.,* 2019) and individual section. The household section profiles the data of respondents' entire household data, including the members and their education levels, age, and marital status (Al-Khatib *et al.,* 2019). The household section consists of 3 subsections and is filled by the household's representatives. The individual section consists of 4 subsections that profile different aspects of individual littering behavior (Alexander *et al.,* 2009; Brotosusilo and Handayani, 2020). These individual subsections are filled individually by household members. The survey has been conducted on the most populous cities in big provinces (by populations) in Indonesia. The provinces that were observed are the Special Administrative Region of Jakarta, Jambi, West Java, East Java, Maluku, and West Sumatera. The cities were observed in this survey are all administrative sub-regions in Jakarta, Jambi, Muaro Jambi, Ambon, Padang, Surabaya, and Tasikmalaya. The study was conducted in 2019-2020 and qualitative research was carried out in 2021 under the conditions of the Covid-19 pandemic so that it was carried out taking into account strict health protocols. The survey itself took more than 3 sessions to break down many aspects of littering behavior. Multiple sessions on the questionnaire were used for general socio-economic profiling (such are incomes, expenditures, and educations of each family member) while the rest phases cover specific aspects of waste-handling behavior. The framework concept could be seen in Fig. 1.

All sessions on the questioner consist of more than 80 questions to enlarge research possibilities. This study will not explain all of the survey results. This study focuses on what factors might cause an individual to litter. In other words, this study used 4th phase of the survey. The sampling method used in this survey was random purposive sampling**.** The random households were taken from intended locations that have waste management problems with a high amount of populations. After the households have been chosen, the other family members were asked about their behavior in littering. Hence, the data of waste-handling behavior within the same family might differ from each other.

Economic modeling and regression method

The dependent variable is where the respondent throws a waste. Various places to throw waste are mentioned on the survey; hence, it has been converted the multiple choices into a dummy variable. The (dependent) dummy variable is called 'litter', which the value of 1 means the respondent threw waste to places other than the trash bin. Littering has been defined as an individual decision to throw waste in an incorrect place or littering space. With a dummy variable for litter as the dependent variable, this study examined how other variables might affect the probability of an individual throwing waste to the incorrect place. This survey defined incorrect places as any other places than a trash bin, a final littering site (FDS), and any other spaces allocated as the littering site. In the case of Indonesia that has been summed on the survey, the places where not supposed to be thrown a waste are rivers, roadsides, drainages, and house yards. The results will show the interpretation in a detailed explanation. This study, as previously mentioned, will focus on the education and prior knowledge of respondents as the main factors influencing their likelihood of littering. The regression model is specified as Eq. 1.

$$p = \frac{1}{1+e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_7 X_7 + \varepsilon)}} \qquad (1)$$

Where;

p = Probability of littering

e = exponential number

$\beta_0 - \beta_9$ = coefficient parameters

X_1 = Education level (years)

X_2 = Expenditure per Capita/day (United States Dollar (USD)

X_3 = Dummy of Educated enough (environmental education exposure) to keep clean the environment (1= Yes)

X_4 = Dummy of Self-initiative of keep clean (1 = Yes, I have)

X_5 = Dummy of Good Habit (not to litter since childhood; 1=Yes)

X_6 = Dummy of Trash Bin Unavailability (1 = not available)

X_7 = Income per capita/day (USD)

ε = Error terms

Seven independent variables (X1 to X7), are proposed where three of them are continuous (education level, expenditure, and income per capita). Another variable used is the socio-economic profiling variable, and the rest four variables are dummies. Data education levels are stated in years of formal education that existed in Indonesia, which consists of elementary school (6 years), junior high school (3 years), senior high school (3 years), and bachelor (4 years). Expenditure (X2) and income (X7) per capita per day collected are stated in Rupiah but have been converted to USD as of the time the data were collected. Those 3 variables are the socio-economic profiling variables that have been used to profile the respondent's economic status and behavior, according to their wealth and formal education attained. The dummy variables used are dummy of educated enough to keep clean the environment, self-initiative to keep the environment clean, good habit (not to litter) since childhood, and trash bin availability. The dummy variable of educated is found to be enough to keep clean the environment. It means that the respondents have obtained an informal method of education in the form of social advice to not litter, slogans, warnings, local officers' instruction, and announcements, and citizens' local meetings held to conduct environmental cleansing. The dummy variable of self-initiative of keep clean is profiling variables whether the respondents are caring enough to their living environment, and have some initiative to clean up when it's dirty. The dummy variable of good habits since childhood is a profiling variable. It will determine whether the respondent has had a good environmental habit (not littering) since childhood. These questions are included in the survey since childhood exposure to good habits could shape an individual's habits in the future. The dummy variable of trash bin unavailability is the dummy variable to profile whether there is a trash bin near the respondents' living environment. This variable is to cover the possibility of littering behavior due to lack of waste-handling infrastructure (external factors) rather than the behavioral (internal) factors, or socioeconomic factors.

RESULTS AND DISCUSSION

Waste issues

Every year, waste production in Indonesia increases. In 2019, Indonesia generated 64 million tons of waste (Kompas, 2020). Organic waste accounts for 60% of total waste produced, with plastic waste accounting for 15%. Waste originating from land also affects the waters, which becomes plastic waste deposition in rivers and the sea (Carpenter and Wolverton, 2017). It is proven by World Bank data from 2018, 87 cities along Indonesia's coast contributed waste to the sea, which was estimated to be around 1.27 million tons (Permana, 2019). This number of wastes is because of the increase in both production and consumption (Fig. 2). These are concentrated in the urban environment making cities in Indonesia are surrounded by waste management problems. Based on this number of wastes produced, it is expected that Indonesia's economic growth will be fueled by high levels of consumption, which results in large amounts of waste.

Urban waste in the urban environment is an expansion caused by a population explosion due to both birth mortality and urbanization. The increase in the volume of global waste has increased higher than the increasing urbanization (Hoomweg and Bhada-Tata, 2012). According to Weaver (2015), urban citizens have more potential to litter. Contrary to the opinion of others, urban people litter less than rural areas (Finnie, 1973). Urban households are more environmentally friendly than rural ones (Fransson and Garling, 1999). Those who live in rural environments tend to litter more than their urban counterparts (Schultz *et al.*, 2011). The increase in the amount of waste will cause the problem of the amount of waste in the final processing site (TPA) to become uncontrollable (McNicholas and Cotton, 2019). The problem of waste is still often neglected compared to pollution and heavy metal contamination because waste is considered to only provide aesthetic problems while contamination causes health problems (Finnie, 1973). The percentage of waste types that are mostly

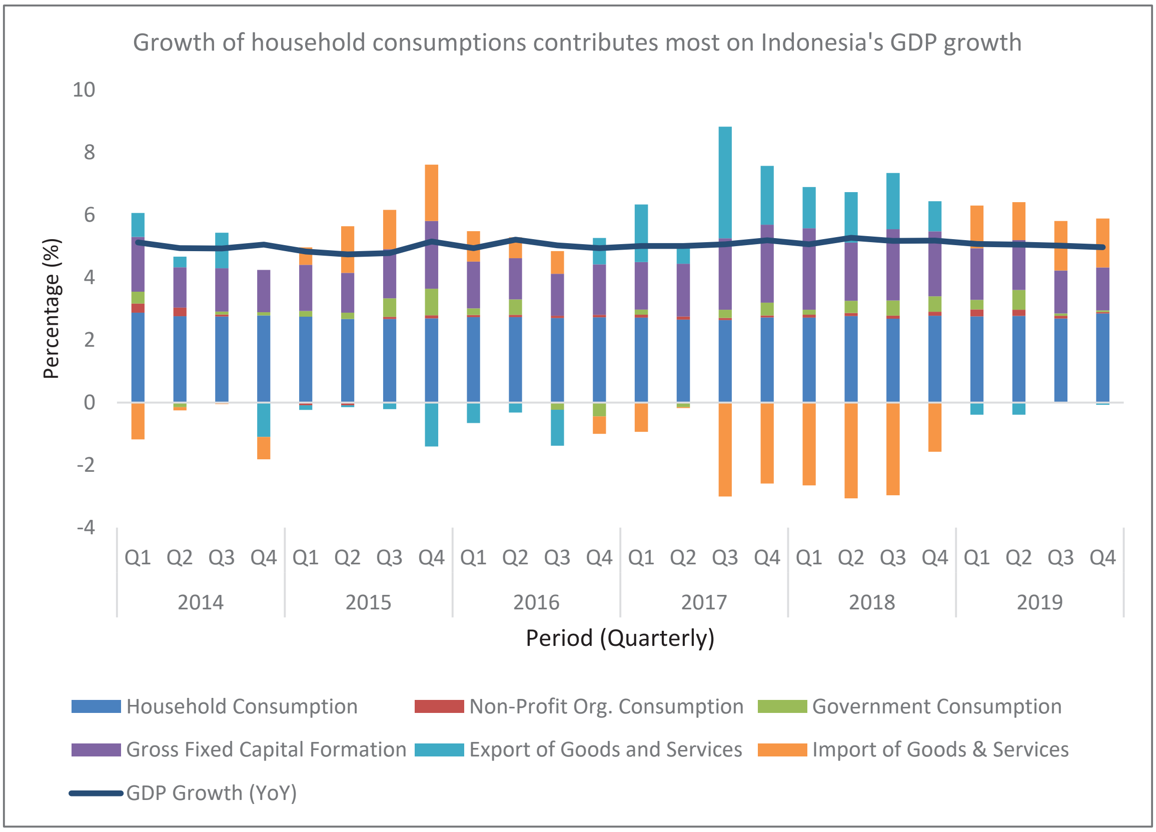


Fig. 2: Contribution to gross domestic product (GDP) growth by expenditure accounts (BPS, 2020)

Table 1: Summary statistics of income and expenditure per capita

Province	West Java	Jakarta	Jambi	West Sumatera	Maluku	East Java	Total
Income per capita (IDR)							
Mean	96,852	146,842	156,402	156,564	255,424	125,317	156,903
S.D.	37,804	60,924	88,833	106,482	185,680	31,752	104,109
Frequency	27	95	88	97	59	100	466
Expenditure per Capita (IDR)							
Mean	119,630	102,737	103,385	100,673	178,571	102,172	116,857
S.D.	70,791	43,958	51,291	38,916	123,483	34,054	72,049
Frequency	27	95	96	99	91	99	507

produced are plastic and metal waste. Plastic waste comes from grocery bags, containers, polystyrene cups; while metal waste originates from beverage and food cans, perfume containers, glass; and organic waste comes from the cooking residue (McIlgorm *et al.,* 2011). Solid waste is divided into biodegradable and non-biodegradable (Hoomweg and Bhada-Tata, 2012). One of the most produced and dangerous waste is plastic (Jefferson, 2019), this is because most of the plastics used are single-use plastics; even though there are plastics that can be recycled, only a few percent are recycled. Plastic waste is common or dominating, where this waste comes from grocery bags, beverage packaging, and aluminum (Carpenter and Wolverton, 2017). The increase in the amount of plastic waste occurred due to a shift in packaging from traditional to plastic materials (Kedzierski *et al.,* 2020). The relatively easy manufacturing process and more affordable prices are the reasons for the use of plastic as food wrappers. There have been efforts to reduce plastic waste by prohibiting the use of plastics and replacing them with more biodegradable paper bags. It is necessary to have an understanding which is not only related to waste, but also its impact on health as a way to improve waste management so that the littering behavior can be reduced (Brotosusilo and Handayani, 2020). The correlation between environmental attitudes and responsible behavior towards the environment shows a positive relationship (Fransson and Garling, 1999). It should be noted that there is a difference between ecological attitudes and ecological behavior. Attitude is stated by the existence of the intention of the perpetrator. This intention comes from the perception that whether the activity provides benefits while the behavior is the final behavior pattern carried out by the perpetrator (Fraj and Marinez, 2006). Human behavior connects cognition (social and psychological) and human action, namely social and biophysical (Alessa *et al.,* 2003). Factors that influence environmental responsibility include attitudes, knowledge, and norms (Fransson and Garling, 1999). Pro-environmental behavior may be affected by individual awareness, environmental education, and social norms (Dodds and Holmes, 2018). Environmental behavior is essential in waste management as it aims to minimize risks for the next generation (Bamberg and Moser, 2007).

Summary statistics

The summary statistics of the respondents are grouped by the province. The summary statistics show that samples in Maluku have the highest income per capita, followed by West Sumatera, Jambi, Jakarta, East Java, and West Java. Respondents in Maluku also have the most expenditure per capita compared to the other provinces sampled. The table of summary statistics of income and expenditure per capita is stated in Table 1.

Probability to litter not in place

In logistic regression, there are two ways of interpretation: marginal effect and odds ratio. The possible estimations have been tested, where the last estimate includes the dummy of the province recorded. Yet, due to low data variability in 1 province, there come 3 best possible estimations explaining the impact of education and prior knowledge on littering behavior. This study will use both continuous and dummy variables collected from the survey to provide a deeper understanding of littering behavior. Regression estimation stated

Table 2: Regression result, dummy variables are interpreted through odds ratio

	(1)	(2)	(3)
	Estimation1	Estimation 2	Estimation 3
Variables	Probability of littering	Probability of littering	Probability of littering
Education Level (Years)	0.0252	0.0332*	0.0189
	(0.0183)	(0.0190)	(0.0184)
Expenditure per Capita/day (United States Dollar (USD))	-0.0283**	-0.0294*	-0.0468***
	(0.0139)	(0.0174)	(0.0159)
Educated enough to keep clean the environment (1= Yes)	0.1151***	0.1097***	0.1269***
	(0.0180)	(0.0177)	(0.0202)
Self-initiative of keep clean (1 = Yes, I have)	0.1421***	0.1372***	0.1732***
	(0.0225)	(0.0224)	(0.0287)
Good Habit (not to litter since childhood; 1=Yes)	0.2891***	0.2638***	0.3040***
	(0.0632)	(0.0582)	(0.0665)
Trash Bin Unavailability (1 = not available)			3.056***
			(0.8000)
Income per Capita/day (USD)		-0.00453	
		(0.0121)	
Constant	1.509***	1.671***	1.426***
	(0.245)	(0.258)	(0.253)
Pseudo R-Square	0.4259	0.4343	0.4349
Observations	1,996	1,820	1,996

Standard errors (S.D.) in parentheses; *** p<0.01, ** p<0.05, * p<0.1

with left alignment interpreted through marginal effect, while the right alignment shows coefficient parameters for dummy variables. The logistic regression result is stated in Table 2.

Based on Table 1, education level has a positive and non-significant effect on the probability of an individual to litter not in place. According to the results above, more other variables significantly affected the likelihood of littering. In this case, the higher level of education – approximated from the long years of schooling– increases the likelihood of littering, but it is not statistically significant. For example, on estimation 3, an increase of 1 year in school will increase the probability of littering by 0.0189 and is not significant (may decrease the likelihood of littering at some points, does not always increase). Education level itself might be not sufficient to explain the probability of littering since formal education material might vary, depending on the institution where the education is taken. With the summary point regarding the littering individual behavior (Table 3), it is stated that education plays a role in pro-environmental behavior, namely throwing waste in its place.

Lack of knowledge is a determining factor for environmental awareness (Fransson and Garling, 1999). Environmental behavior or responsibility results from environmental concern. To encourage the behavior of protecting the environment from waste, it is necessary to transfer knowledge in environmental education (Wichels *et al.,* 2016). Low environmental education is blamed for the low responsibility behavior towards the environment (Fransson and Garling, 1999). The utilization of natural resources by humans that causes environmental damage requires more awareness and knowledge from the community itself regarding the impact of their behavior to optimize environmental sustainability. Increased knowledge is associated with increased responsible behavior (Gunderson *et al.,* 2000). Environmental behavior is based on individual perceptions and attitudes towards environmental problems. This perception will lead to responsible behavior that can be formed through the provision of environmental education. Lack of knowledge causes environmental awareness and responsible behavior towards the environment to weaken (Alessa *et al.,* 2003). According to action theory, it analyzes that constraints-opportunities will interact with knowledge which will influence individual motives in influencing the implementation of pro-environmental behavior (Bamberg and Moser, 2007). In other study, waste management through recycling is also associated with knowledge (Hilburn, 2015). Differences in knowledge can indicate gaps in recycling participation between individuals. Waste

Table 3: Summary point with the individual littering behavior

No	Variables	Summary point
1	Education	a. As a determinant of environmental awareness b. Increased responsibility behavior c. Influencing the implementation of pro-environmental behavior d. More educated people are more likely to recycle e. Improving household waste management decisions
2	Environmental Caring	a. A clean and healthy lifestyle that encourages waste littering in its proper place. b. A sense of comfort motivates initiatives to practice waste separation behavior. c. Varying levels of sensitivity to nature as a result of social norms, prevalent social norms, infrastructure, and regulations
3	Good Habits	a. Higher levels of income and education are also associated with strong environmental management practices. b. Increasing personal awareness of pro-environmental behavior as a resource for maintaining cleanliness.
4	Economic Factors	a. The education campaign provided affects not only behavior change, which will indirectly increase income through recycling behavior. b. Households with higher incomes and spending habits lead more clean and healthy lives.

management by prioritizing recycling can be done by combining the factors of public education and available recycling facilities. Knowledge about the impact of inappropriate waste management will be formed from the education given. Education has a contribution to waste management, when the head of the household has a higher level of formal education the probability is higher to littering of waste in its place rather than littering it illegally. In addition to routine information dissemination, valid and persuasive messages, facilities provision, and leading actor's role at the community (Ruliana *et al.,* 2019), providing education on waste management is also effective way to encourage waste separation. Intensification in waste management education can be taken as the method to encourage management in the form of 3R (reduce, reuse, and recycle) (Alhassan *et al.,* 2020). Those who are educated are more likely to participate in recycling in California (Saphores *et al.,* 2006). Education on waste management is important in improving household decisions in waste management, whether it will be dumped in its place or disposed of by illegal disposal - burning, open littering, and landfilling (Azizi *et al.,* 2016). Through formal education, understanding the community's need for a healthy and hygienic environment can also be improved. Individuals know the impact of illegal waste littering, the impact of burning waste, hoarding inorganic-organic waste, or allowing it to pile up in public places. Households with a high level of education can be ensured that their waste management is collected and closed properly (Adzawla *et al.,* 2019). Informal education through campaigns is also accused of being an environmental management strategy through anti-waste campaigns, monitoring, and education in one community (Carpenter and Wolverton, 2017). The education campaign provided not only affects behavior change which will indirectly increase income through recycling behavior (Varotto and Spagnolli, 2017). It is stated that environmental damage due to littering, in general, is caused by a lack of knowledge. And provide advice on the need for providing knowledge in formal education from an early age. However, based on the results of this study, the level of education does not provide significant results in encouraging pro-environmental behavior. Pro-environmental behavior is formed due to personal interests and pro-social motives (Bamberg and Moser, 2007). Urban and richer and more literate households tend to use urban waste collection arrangements (Kumara and Pallegedara, 2020). On the other hand, several studies have stated that one of the determinants of environmental awareness (disposing of waste in its place) is associated with improving education. It should be noted that these determinants will produce different results between individuals. Besides, the education which is given to the same individual but at different times will also produce different results (Fransson and Garling, 1999). The use of instructional media gives insignificant results (Eastman *et al.,* 2013). The use of education alone is not sufficient to support proper waste littering as may be caused by the unsuitable media used. Kollmus and Agemyeman (2002) that more education does not affect better environmental behavior. Alhassan and Muhammad (2013) also estimate that highly educated people are willing to pay a higher amount of money for better waste management. It is feared that the existence of higher education indeed requires concern for the environment, but they do not carry out their management. They prefer to pay for management by other individuals. Per capita expenditure has a negative and significant relationship to the probability of littering behavior. According to the results above, when the per capita expenditure increases by 1 USD per person per day, it will decrease the probability of littering by -0.0468 (estimation 3). The variable significance at $p<0.01$ (marked by a triple asterisk) indicates that the increase in expenditure per capita as the proxy of wealth and economic status will consistently decrease the probability of littering. This finding confirmed why the wealthy (or economically good district) showed a cleaner environment than the less wealthy districts. This finding also confirmed why a richer individual tend to not litter than to the less one. Similar results are also obtained in the variable of income per capita. For example, a 1 USD increase in income per person per day will decrease the probability of littering by -0.00453 (estimation 2). The marginal effect coefficient shows a negative effect on the probability of littering. Yet, the variable does not show a significant effect due to inconclusive answers on respondents. This result also confirmed that per capita expenditure is still a better approach to measure the economic status of the respondents. Hence on estimation 3, per capita expenditure is only used as the proxy of economic status. The social and economic status of the household influences management indicated by housing with high income is mostly located with a wider, planned and better road network. This allows households to join in the house-to-house waste collection from formal institutions (Alhassan *et al.,* 2020). Higher levels of income and education are associated with high environmental management habits as well (Viscusi *et al.,* 2013). A clean and healthy lifestyle that is associated with education correlates with a clean environment. Thus, a clean and healthy lifestyle will encourage the behavior of littering waste in its place (Brotosusilo and Handayani, 2020). Households with higher incomes and expenditures have more clean and healthy lifestyles. In addition, to maintain their lifestyle, they will carry out proper waste management so that it does not affect their environment. The careless disposal of waste identic will cause problems in a clean and healthy life. Waste is a direct or indirect source of disease (Tobing, 2005). Waste is an ideal environment for the growth of various parasites, bacteria, and pathogens. Meanwhile, waste serves as a breeding ground for a variety of vectors (disease carriers) such as rats, cockroaches, flies, and mosquitoes. Pathogens and disease vectors thrive in decomposing waste such as cans, bottles, and plastics. Waste may cause a variety of diseases, including diarrhea, dysentery, intestinal worms, malaria, elephantiasis, and dengue fever. These diseases pose a risk to humans, even cause death. In contrast to what Fransson and Garling (1999) stated, household income has a weak relationship with environmental concerns. The decision to litter is mostly related to attitudes or demographics other than income and welfare (Adzawla *et al.,* 2019). Efforts that can be made to encourage environmental behavior so that people dispose of waste in its place are by instilling personal awareness about pro-environmental behavior as an asset to maintain cleanliness (Brotosusilo and Handayani, 2020). The dummy variable in respondents who are quite educated to maintain environmental cleanliness shows a decreasing odds ratio (below one) to the possibility of littering. If an individual is educated enough to keep the environment clean, the probability of littering will be 0.1269 times smaller than if it is not (estimation 3). This dummy variable has been used to estimate the probability of littering since the education level does not answer why more educated people are expected to not litter. This variable has been created from the question of whether formal or informal respondents' educations consistently taught them to avoid littering. The decreasing of this dummy variable confirms one of several aspects on why more educated people aren't littering. It is also added the dummy variable of self-initiative on keeping cleanness of the environment.

This variable has been created whether the respondents have a self-initiative to keep the environment clean, by littering the waste in the rightful place. This dummy variable also shows decreasing odds ratio to the probability of littering behavior. For example, if an individual has a self-initiative, the probability of them littering will be 0.1732 times lower than those who do not have self-initiative (estimation 3). The result gives this study such an important mark that an initiative on good things will significantly decrease the probability of negative attitude (in this case, littering). Social norms in society are closely related to the behavior of littering. These norms determine the general behavior accepted in the region. When waste is found scattered about not in its place, this can signal the prevailing norm conditions, namely the acceptance of littering. Individual behavior is influenced by cues from the surrounding environment through norm enforcement (Schultz *et al.,* 2011). Identification of environmental cues can result in misperceptions of waste littering where enforcement of social norms must be carried out properly to spread pro-environmental perceptions and behavior habits (Weaver, 2015). Social norms are not only related to moral norms but also behavior control (Bamberg and Moser, 2007). A sense of comfort also encourages initiatives to carry out waste separation behavior (Alhassan *et al.,* 2020). Personal initiatives on waste littering related to the role of cognitive, emotional**,** and social interactions. Intention and guilt are the main factors that affect personal initiative. Feelings of guilt when engaging in non-pro-environmental behavior that harms oneself or others. Awareness has a role in environmental responsibility and directly affects the level of control behavior as an attitude of choosing pro-environmental behavior (Bamberg and Moser, 2007). Each individual has a different level of sensitivity to nature, which comes from social norms, prevailing social norms, infrastructure**,** and regulations. This factor will influence individual initiative on pro-environmental behavior (Varotto and Spagnolli, 2017). Personal initiative is an important factor in determining littering through behavior control. Inadequate waste littering facilities are not a cause for littering when the individual has the correct littering initiative. When individuals do not find trash cans, they will not litter and keep their trash and throw it away when they meet the trash can (Finnie, 1973). Initiative becomes a reason for proper waste disposal to keep the environment clean and provide an example to other individuals. Awareness becomes the initial capital to maintain environmental cleanliness which fosters individual initiatives to protect the environment (Brotosusilo and Handayani, 2020). This study tried to explain important factors which might cause a problem in waste management problem from the household side. Through primary data collection, this study explored how households litter their residues of consumption, their decision-making on littering, and their prior knowledge of environmental preservation. A massive share of consumption to GDP in Indonesia also makes this study important since the biggest cities and provinces within the country are surrounded by large waste generation (Fig. 3). The high share of consumption to GDP also makes most of the waste generated by the country come from household consumption.

Environmental management behavior may be influenced by peer and family pressure, social norm factors, social influences, knowledge, attitudes, and personal factors that affect recycling (Maki and Raimi, 2016; Varotto and Spagnolli, 2017; Wichels *et al.,* 2016). The practice of waste management consists of collection and littering. Most areas have a formal waste collection service originating from the municipality. The cleaners will collect waste in individual houses or at the communal waste collection points. This study focused on household waste management which is associated with factors that influence their behavior. It is important to find out and understand individual behavior in managing and preserving the environment (Leonidou *et al.,* 2015). Littering could be prevented by understanding human behavior (Carpenter and Wolverton, 2017). The dummy variable of good habit also shows that a good habi**t** of environmental caring by not littering will also decrease the probability of littering. The results above indicated that this dummy shows decreasing odds ratio. The example interpretation of this variable is, if an individual has had a good habit (not littering) since childhood, their probability of littering will be 0.2273 times lower than those who do not have a good habit since childhood (estimation 4). The finding of this study showed that good habits since childhood will shape people to be better **i**n society which in this case is to be the non-littering person. It is better if the habit of littering of waste is practiced since childhood before entering school (Brotosusilo and

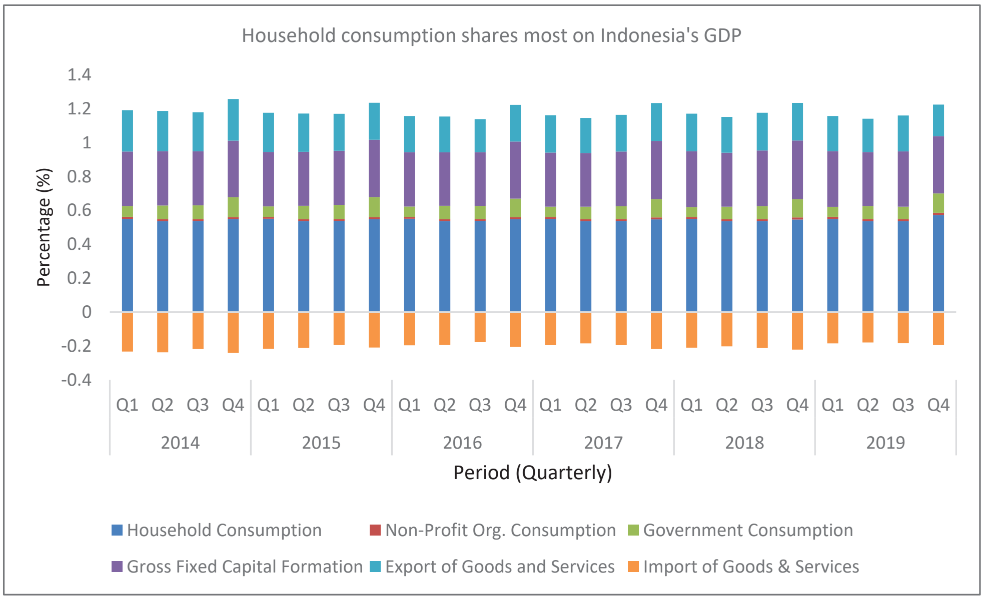


Fig. 3: Share to GDP by expenditure accounts (in decimals) (BPS, 2020)

Handayani, 2020) as one of the most important ways to teach a person about cleanliness, to keep their living environment clean. In contrast to the opinion of Cruz *et al.* (2012) which states that good habits are not significantly related to individual behavior. The pro-environmental behavior that is taught since childhood can change due to peer influence. Peers who can influence individuals to engage in anti-environmental behavior (littering) or pro-environment (littering). The presence of other people influences the decision to litter (Bator *et al.,* 2010) when there is a possibility of decreasing littering. The habit of littering waste is also associated with economy class, when in a better living environment, children will get used to maintaining cleanliness. This can be a driving force for proper littering of waste. The good habits, good economic condition, environmental education, self-initiative and good taught from the parents are not sufficient to decrease the probability of littering. A variable of trash bins unavailability confirms the statement. This dummy, according to the results above, study shows a consistent and significantly increased odds ratio, meaning that although if an individual faces no trash-bins, they will tend to litter. Their probability to litter will be 3.056 times higher (estimation 3) rather than if the trash bins are available. As mentioned by Hilburn (2015), the increase in population density that occurs in cities is a burden in waste management due to the limited infrastructure available. Availability and affordability of trash bins serve as a reminder for households in waste disposal, and associated facilities have a high impact on waste disposal (Carpenter and Wolverton, 2017). The availability and affordability of trash bins reduce the behavior of littering (Bator *et al.,* 2010). Lack of access to formal waste separation facilities and information is an obstacle to household waste separation (Alhassan *et al.,* 2020). Facilities and information can be in the form of inadequate littering sites, unclear separation information**,** and short separation times. The lowest level of littering occur when trash bins are available and a short distance away (Schultz *et al.,* 2011). Optimization of the distance of the trash bin is 20 feet, if the location of the trash bins is more than 20 feet, it will increase littering. This optimization can change depending on the type of waste that is littered. When waste-littering facilities are not available, there is one factor associated with encouraging waste properly, namely social norms (Schultz *et al.,* 2011). The implementation of social norms for waste disposal can prevent the impact of waste disposal by taking advantage of the role of the surrounding community in cleaning activities. The more that contributes, the more effective it will be to keep the environment clean. The existence of littering facilities alone is not sufficient in waste management; it needs to be synchronized with the waste transportation performance. Waste collection services influence the behavior of littering (Hilburn, 2015). When the household has littered waste in the trash bins, but the cleaning service authorities do not transport it on time, it can have an impact on the reluctance of households to a litter of waste in its place (Adzawla *et al.,* 2019). This can increase household perceptions about the ineffectiveness of littering of waste properly. Negates the benefits of correct waste collection and reduces household motivation from collecting waste. For this reason, the accuracy of transporting waste from the trash bins is also necessary so that there is no excessive accumulation of waste in the trash bins. There must be control of waste transportation by related officers in a timely and orderly manner. Availability and affordability of waste littering facilities are less effective when there is a high and diverse density of waste littering. Cleaning or transporting waste is less effective if the waste input is higher than the capacity of the available facilities (Carpenter and Wolverton, 2017). The frequency of waste collection, the mode of transportation**,** and the distance to waste collection affect the choice of household waste management (Rai *et al.,* 2019). Waste management through waste sorting must also be the concern of the relevant government. Efforts made by households to sort waste but are not supported by officers to make the same efforts will make households reluctant to separate waste again (Alhassan *et al.,* 2020). Trash cans classified as inorganic and organic can motivate the community to separate. Otherwise, when officers only mix the waste directly into the garbage truck, it may reduce the motivation for trash separation done by households. Environmental educations are suggested through formal education and family education must be the main primary methods to improve waste management. Effective waste management through sophisticated infrastructures is an enabler for the people who are already aware of the importance of waste handling. Otherwise, if people do not have enough awareness, the problem would persist since the main key drivers of waste management improvements are the people themselves. Environmental educations were found which might face some socio-economic challenges where environmental education through formal entities and families will only be effective on people who had enough income and a certain education level. In the other words, waste management on poor or low-economic class agglomerates can't be done solemnly without welfare improvement first.

CONCLUSION

This study was built by lack of people's awareness regarding waste littering that most people dispose of waste by burning it. The result shows several important pieces of evidence from citizens in some big cities in Indonesia such as Jakarta, Jambi, Muaro Jambi, Ambon, Padang, Surabaya, and Tasikmalaya during 2019-2021. Good habit (for not littering) since childhood is a supporting factor to decrease littering behavior. A person who implemented littering waste in the right place as a habit since childhood tends to not litter. To build this habit, then formal and informal education is needed. Formal and informal education on keeping the environment clean and self-initiative in environmental caring was found to decrease the likelihood of littering. Formal education taken by the respondents isn't enough to explain the key variables affecting the probability of littering. Informal education is needed and has more impact on the building of citizen's awareness. A person with self-initiative on environmental caring will not litter in incorrect places. Good economic status and condition will be followed by good behavior to not littering a waste. The place where citizens interact and growing was also the factor found that may affect citizen awareness of environmental issues. This is as reflected in the findings that districts with better economic status will tend to be cleaner than the district where less expenditure has per capita. However, good endowments on educational variables and habits are not sufficient to reduce littering if the facilities do not meet the demand. The availability of a trash bin (or littering site) is critical since its unavailability can increase the probability of littering behavior. Therefore, building citizens' awareness should be altogether with building supportive infrastructures accompanied by simultaneous education either formal or informal. From these findings, there is still a question that arises, what type of informal education is preferred and gives more impact to Indonesian citizens on builds they are awareness? This can be a recommendation for future studies.

AUTHOR CONTRIBUTIONS

A. Brotosusilo and D. Utari performed conceptualization, methodology, and literature review. H.A. Negoro performed the validation and formal analysis. A. Firdaus performed review, editing, and visualization. R.A. Velentina performed project administration. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENT

This study was funded by KEMENTERIAN RISET DAN TEKNOLOGI/BADAN RISET DAN INOVASI NASIONAL, grant number 8/E1/KP.PTNBH/2021 and grant number [NKB-067/UN2.RST/HKP.05.00/2021] Research and Development (Risbang), Universitas Indonesia. This research under supervision and technical assistance from Cluster of Interaction, Community Engagement and Social Environment, School of Environmental Science, Universitas Indonesia.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

*	p<0.1
**	p<0.05
***	p<0.01
	Calculated probability of littering
e	Exponential number
$\beta_0 - \beta_7$	Coefficient parameters
X_1	Education level (years)
X_2	Dummy if respondent educated enough to keep the environment (1=Yes)
X_3	Dummy if respondent has self-initiative to keep clean (1=Yes)
X_4	Dummy if respondent has good habit (not to litter) since childhood (1=Yes)
X_5	Dummy of trash bin unavailability (1=Unavailable)
X_6	Dummy if respondent is taught not to litter since childhood (1=Yes)
X_7	Dummy of Provinces
ε	Error terms
$	Dollar
3R	Reduce, reuse, and recycle
ASEAN	Association of Southeast Asian Nations
BPS	Statistics Indonesia
Est	Estimation
FDS	Final disposal site
Freq	Frequency
GDP	Gross Domestic Product
HtH	House to house
INF	Informal waste collector
Org	Organization
Prob	Probability
R	Correlation coefficient
SDGs	Sustainable Development Goals
S.D.	Standard deviation
TPA	Final processing site
USD	United states dollar

REFERENCES

Adzawla, W.; Tahidu, A.; Mustapha, S.; Azumah, S.B., (2019). Do socioeconomic factors influence households' solid waste disposal systems? Evidence from Ghana. Waste Manage. Res., 37(1): 51–57 **(7 pages).**

Alessa, L.; Bennett, S.M.; Kliskey, A.D., (2003). Effects of knowledge, personal attribution and perception of ecosystem health on depreciative behaviors in the intertidal zone of Pacific Rim National Park and Reserve. J. Environ. Manage., 68(2): 207–218 **(12 pages).**

Alexander, C.; Smaje, C.; Timlett, R.; Williams, I., (2009). Improving social technologies for recycling. Proc. ICE-Waste Res. Manage., 162(1): 15–28 **(14 pages).**

Alhassan, H.; Kwakwa, P.; Owusu-Sekere, E., (2020). Households' source separation behaviour and solid waste disposal options in Ghana's Millennium City. J. Environ. Manage., 259: 110055 **(10 pages).**

Alhassan, M.; Muhammad, J., (2013). Households' demand for better solid waste disposal services: case study of four communities in the New Juaben Municipality, Ghana. J. Sustainable Dev., 6: 16–25 **(10 pages).**

Al-Khatib, I.A.; Aafat, H.A.; Daoud, R.; Shwahneh, H., (2009). Enhanced solid waste management by understanding the effects of gender, income, marital status, and religious convictions on attitudes and practices related to street littering in Nablus – Palestinian territory. Waste Manage., 29: 449–455 **(7 pages).**

Azizi, A.; Malakmohamadi, B.; Jafari, H.R. (2016). Land use and land cover spatiotemporal dynamic pattern and predicting changes using integrated CA-Markov model. Global J. Environ. Sci. Manage. 2(3): 223-234 **(12 pages).**

Bahri, R.; Rachmaniyah; Darjati, (2020). Evaluation of Waste Management Facilities Through Land-Based Marine Litter Data: Case Study of Kenjeran Beach, Surabaya. J. Environ. Sci. Sustainable Dev., 3(1): 156–176 **(21 pages).**

Bamberg, S.; Moser, G., (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behavior. J. Environ. Psychol., 27: 14–25 **(12 pages).**

Bator, R.J.; Bryan, A.D.; Schultz, P.W., (2010). Who gives a hoot? Intercept surveys of litterers and disposers. Environ. Behav., 43: 295 **(21 pages).**

Brotosusilo, A.; Handayani, D., (2020). Dataset on waste management behaviors of urban citizens in large cities of Indonesia. Data Brief, 32: 106053 **(11 pages).**

BPS, (2020). Statistical yearbook of Indonesia 2020, BPS.

Carpenter, E.; Wolverton, S., (2017). Plastic litter in streams: The behavioral archaeology of a pervasive environmental problem. Appl. Geog., 84: 93–101 **(9 pages).**

Cialdini, R.; Reno, R.; Kallgren, C., (1990). A focus theory of normative conduct: Resysling the concept of norms to reduce littering in public place. J. Personality Social Psychol., 58(6): 1015–1026 **(12 pages).**

Cruz, J.E.; Emery, R.E.; Turkheimer, E., (2012). Peer network drinking predicts increased alcohol use from adolescence to early adulthood after controlling for genetic and shared environmental selection. Dev. Psychol., 48(5): 1390–1402 **(13 pages).**

Cuc, M.C., (2014). The influence of media on formal and informal education. Proc. Social Behav. Sci., 143: 68–72 **(5 pages).**

Dodds, R.; Holmes, M.R., (2018). Education and certification for beach management: Is there a difference between residents versus visitors? Ocean Coastal Manage., 160: 124–132 **(9 pages).**

Eastman, L.; Nunez, P.; Crettier, B.; Thiel, M., (2013). Identification of self-reported user behavior, education level, and preferences to reduce littering on beaches. A survey from the SE Pacific. Ocean Coastal Manage., 78: 18–24 **(7 pages).**

Finnie, W.C., (1973). Field experiments in litter control. Environ. Behav., 5(2): 123–144 **(22 pages).**

Folke, C.; Gunderson, L., (2002). A kaleidoscope of change. Conserv. Ecol., 6(1): 19: **(7 pages).**

Fraj, E.; Marinez, E., (2006). Influence of personality on ecological consumer behavior. J. Consum. Behav., 5: 167–181 **(15 pages).**

Fransson, N.; Garling, T., (1999). Environmental concern: Conceptual definitions, measurement methods, and research findings. J. Environ. Psychol., 19: 369–382 **(14 pages).**

Gunderson, K.; Barns, C.V.; Hendricks, W.W.; McAvoy, L.H., (2000). Wilderness education: An updated review of the literature and new directions for research and practice. USDA For. Serv. Proc., 4: 253–259 **(7 pages).**

Hilburn, A.M., (2015). At home or to the dump? Household garbage management and the trajectories of waste in a Rural Mexican Municipio. J. Latin Am. Geog., 14(2): 29–52 **(24 pages).**

Hoomweg, D.; Bhada-Tata, P., (2012). What a waste: A global review of solid waste management. Urban development series, knowledge papers, No. 15. World Bank, Washington, DC.

Jefferson, M., (2019). Whither plastics? Petrochemicals, plastics and sustainability in a garbage-riddled world. Energy Res. Soc. Sci., 56: 101229 **(8 pages).**

Kedzierski, M.; Frere, D.; Le maguer, G.; Bruzaud, S., (2020). Why is there plastic packaging in the natural environment? Understanding the roots of our individual plastic waste management behaviours. Sci. Total Environ., 740: 139985 **(9 pages).**

Keizer, K.; Lindenberg, S.; Steg, L., (2013). The importance of demonstratively restoring order. Plos One, 8(6): e65137 **(7 pages).**

Kollmus, A.; Agemyeman, J., (2002). Mind the gap: Why do people act environmentally and what are the barriers to proenvironmental behavior? Environ. Edu. Res., 8(3): 239–260 **(22 pages).**

Kompas, (2020). Indonesia Hasilkan 64 Juta Ton Sampah, Bisakah Kapasitas Pengelolaan Tercapai Tahun 2025? (Indonesia Produces 64 Million Tons of Waste, Can Management Capacity Be Reached By 2025?).

Kumara, A.S.; Pallegedara, A., (2020). Household waste disposal mechanisms in Sri Lanka: Nation-wide survey evidence for their trends and determinants. Waste Manage., 114(1): 62–71 **(10 pages).**

Leonidou, L.; Coudounaris, D.N.; Kvasova, O.; Christodoulides, P., (2015). Drivers and outcomes of green tourist attitudes and behavior: Sociodemographic moderating effect. Physchol. Marketing, 32(6): 635–650 **(16 pages).**

Maki, A.; Raimi, K.T., (2016). Environmental peer persuasion: How moral exporting and belief superiority relate to efforts to influence others. J. Environ. Psychol., 49: 18–29 **(12 pages).**

Mcllgorm, A.; Campbell, H.; Rule, M., (2011). The economic cost and control of marine debris damage in the Asia-Pacific region. Ocean Coastal Manage., 54: 643–651 **(9 pages).**

McNicholas, G.; Cotton, M., (2019). Stakeholder perceptions of marine plastic waste management in the United Kingdom. Ecol. Econ., 163: 77–87 **(11 pages).**

Ningrum, Z.B.; Herdiansyah, H., (2018). Environmental awareness and behavior of college students in regards to the environment in urban area. E3S Web of Conferences, 74: 10004 **(6 pages).**

Oosterhuis, F.; Papyrakis, E.; Boteler, B., (2014). Economic instruments and marine litter control. Ocean Coast. Manage., 102: 47–54 **(8 pages).**

Permana, E., (2019). Indonesia hasilkan 67 juta ton sampah pada 2019 (Indonesia produced 67 million tons of waste in 2019). Anodolu Agency.

Rai, R.K.; Bhattarai, D.; Neupane, S., (2019). Designing solid waste collection strategy in small municipalities of developing countries using choice experiment. J. Urban Manage., 8(3): 386–395 **(10 pages).**

Ruliana, V.; Soemantojo, R.W.; Asteria, D., (2019). Assessing a community-based waste separation program through examination of correlations between participation, information exposure, environmental knowledge, and environmental attitude. ASEAN J. Community Engagement, 3(1): 2 **(27 pages).**

Saphores, J.; Nixon, H.; Ogunseitan, O.A.; Shapirro, A.A., (2006). Household willingness to recycle electronic waste: An application to California. Environ. Behav., 38(2): 182–208 **(27 pages).**

Schultz, P.W.; Bator, R.J.; Large, L.B.; Bruni, C.M.; Tabanico, J.J., (2011). Littering in context: Personal and environmental predictors of littering behavior. Environ. Behav., 20(10): 1–25 **(25 pages).**

Slavin, C.; Grage, A.; Campbell, M.L., (2012). Linking social drivers of marine debris with actual marine debris on beaches. Mar. Pollut. Bull., 64: 1580–1588 **(9 pages).**

Suleman, Y.; Darko, E.; Agyemang-Duah, W., (2015). Solid waste disposal and community health implications in Ghana: Evidence from Sawaba, Asokore Mampong Municipal Assembly. J. Civ. Environ. Eng., 5(6): 202 **(6 pages).**

Ten-Brink, P.; Lutchman, I.; Bassi, S.; Speck, S.; Sheavly, S.; Register, K.; Woolaway, C., (2009). Guidelines on the use of market-based instruments to address the problem of marine litter. IEEP, Sheavly consultants.

Timlett, R.; Williams, I.D., (2011). The ISB model (infrastructure, service, behaviour): A tool for waste practitioners. Waste Manage., 31(6): 1381–1392 **(12 pages).**

Tobing, I.S.L., (2005). Dampak Sampah terhadap Kesehatan Lingkungan dan Manusia (Impact of Waste on Environmental and Human Health).

Varotto, A.; Spagnolli, A., (2017). Psychological strategies to promote household recycling. A systematic review with meta-analysis of validated field interventions. J. Environ. Psychol., 51: 168–188 **(21 pages).**

Viscusi, W.K.; Huber, J.; Bell, J.; Cecot, C., (2013). Discontinuous behavioral responses to recycling laws and plastic water bottle deposits. Am. Law Econ. Rev., 15(1): 110–155 **(46 pages).**

Weaver, R., (2015). Littering in context(s): Using a quasi-natural experiment to explore geographic influences on antisocial behavior. Appl. Geog., 57: 142–153 **(12 pages).**

Wichels, A.; Harth, B.; Gerdts, G., (2016). Linking Education and Science to Increase Awareness of Marine Plastic Litter—Distribution of Plastic Waste on Beaches of the German Bight. Fate Impact Microplastics Mar. Ecosyst., 162–163 **(8 pages).**

World Bank, (2018). What a waste: An updated look into the future of solid waste.

AUTHOR (S) BIOSKETCHES

Brotosusilo, A., Ph.D., Instructor, Faculty of Law, Universitas Indonesia, Depok, West Java, Indonesia.
Email: *broto.susilo@ui.ac.id*
ORCID: 0000-0001-7072-0263

Utari, D., Ph.D., Instructor, Faculty of Health Science, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia.
Email: *dyah.utari15@gmail.com*
ORCID: 0000-0002-6808-0209

Negoro, H.A., M.Sc., Instructor, Department of Economic, Faculty of Economics and Business, Universitas Indonesia, Indonesia.
Email: *adinegoro9@gmail.com*
ORCID: 0000-0002-2232-2217

Firdaus, A., M.Sc., Instructor, School of Environmental Science, Universitas Indonesia, Indonesia.
Email: *azharfirdaus@ui.ac.id*
ORCID: 0000-0003-3858-7743

Velentina, R.A., M.Sc., Instructor, Faculty of Law, Universitas Indonesia, Depok, West Java, Indonesia.
Email: *vnapitupulu@yahoo.com*
ORCID: 0000-0002-8772-142X

HOW TO CITE THIS ARTICLE

Brotosusilo, A.; Utari, D.; Negoro, H.A.; Firdaus, A.; Velentina, R.A., (2022). Community empowerment of waste management in the urban environment: More attention on waste issues through formal and informal educations. Global J. Environ. Sci. Manage., 8(2): 209-224.

DOI: 10.22034/gjesm.2022.02.05

url: https://www.gjesm.net/article_246468.html

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

Laboratory analysis to determine the accurate characteristics of urban food waste

A. Charkhestani , D. Yousefi Kebria*

Department of Environmental Engineering, Faculty of Civil Engineering, abol Noshirvani University of Technology, Babol, Iran

ARTICLE INFO

Article History:
Received 25 June 2021
Revised 17 October 2021
Accepted 05 November 2021

Keywords:
Accurate determination
Characterization
Comparative analysis
Heat value
Waste management

ABSTRACT

BACKGROUND AND OBJECTIVES: Although the characteristics food waste have been well studied, some of the problems associated with result reporting have not been addressed. The related data are usually reported by referring to the global statistics, using the empirical models, and performing the laboratory analysis. The aims of the current study were to analyze the municipal food waste characteristics (including physical, proximate, ultimate and heating value analysis), monitor the differences among the laboratory methods, and highlight the significant differences among the food waste characteristics more accurately.

METHODS: Sampling was performed weekly at a disposal site located in Sari, Mazandaran, Iran. Food waste was extracted from the municipal solid waste samples. Moisture content, pH, organic matter, ash content, organic carbon, carbon to nitrogen ratio, low heating value and chemical equation of the waste were determined and compared by statistical indices.

FINDINGS: The results showed no significant difference between proximate analysis and global statistics for sampling including organic matter and moisture content. In ultimate analysis, statistical investigation of the laboratory results showed that Walkley and black, Kjeldahl, and dry ashing/ion chromatography methods had more accuracy compared to determination by elemental analyzer which puts direct impact on extracted chemical equation. In addition, heating value investigation by empirical models based on proximate analysis (13.6 MJ/kg) was closer to the bomb calorimeter results (13.4 MJ/kg) in average. However, the models developed based on ultimate analysis, including Dulong, Steuer, and Scheurer-Kestner, had a lower accuracy (with higher heating value of 1.4 to 5 MJ/kg). Surveying the reliable sources highlighted the gap in extracted chemical equation and heating value of the food waste with real amount. These findings provided appropriate information about solid waste management and characterization.

CONCLUSION: Investigation of the gap among laboratory methods revealed that determination method was a key factor in accurate characterization of food waste. Thus, without using the most accurate laboratory methods, the implementation of waste management plans would face major problems.

DOI: 10.22034/gjesm.2022.02.06

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
47	2	8

*Corresponding Author:
Email: *dy.kebria@nit.ac.ir*
Phone: +981132332071
ORCID: 0000-0001-8210-6631

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Food waste (FW) contains a considerable portion of household solid waste with over 90% organic matter (OM) and 80% moisture (Meng *et al.,* 2015). FW includes fruits, vegetable scraps, and other organic discarded parts from households, institutional and industrial sources such as restaurants, school cafeterias, and canteens (Guo *et al.,* 2018). FW is mostly the kitchen waste produced by households and restaurant kitchens (Yang et al., 2013). The exponential increase in FW is regarded as a threat to the environment (Paritosh *et al.,* 2017). Adhikari *et al.* (2006) estimated that the annual amount of FW could increase from 278 to 416 million tons (2005-2025) in the Asian countries. FW accounts for 55% and 45% of the total municipal solid waste (MSW) produced in developing countries (Troschinetz and Mihelcic, 2009) and European countries, respectively (IPCC, 2006). According to the FAO, (2012) and the World Bank, (2012), approximately 1.3 billion tons of FW are generated in the food supply chain. However, a low percentage of the waste has been composted and much of it is disposed to the landfills or incinerated. EPA, (2016) estimated that FW, comprising 22% MSW, more than any other single material reached the landfills. The FW disposed at the landfill sites constitutes the largest source for emission of greenhouse gasses (Kamyab *et al.,* 2015a). In 2005, due to environmental impacts, Sweden applied a landfill prohibition on organic waste (EEA, 2013a). In addition, Germany has a ban on landfilling the unpretreated organic wastes (EEA, 2013b). Composting or energy recovery of food waste can be a sustainable solution for MSW management and may reduce the pressure on landfills (Kamyab *et al.,* 2015b). FW, as a large part of MSW, has been investigated by many researchers. According to Carmona-Cabello *et al.* (2018), FW chemical composition is the base of valorization process. Van Dooren *et al.* (2019) showed that bread (22%), dairy products (17%), vegetables (14%), fruit (12%) and meat (7%) were the main wasted food in Dutch households. Boumanchar *et al.* (2018) reported 50.5% carbon (C), 7.1% hydrogen (H), 2.1% nitrogen (N), 0.2% sulfur (S), 40.1% oxygen (O), 14.7 kJ/kg and higher heating value (HHV) as ash-free dry weight bases for FW ultimate analysis. Zhou *et al.* (2014) reviewed the physical and chemical compositions of MSW in China and found that food residue formed about 55.86% of the total MSW. They estimated the average moisture content of food residue (69.85%), ash content (20.98%), HHV (15,386 kJ/kg) as dry bases and proposed $C_{257.3}$, $H_{456.2}$, $O_{168.3}$, N_{18}, and S_1 for chemical equation. Chen *et al.* (2019) studied the FW in Taiwan and recommended $C_{333.3}$, $H_{596.6}$, $O_{183.3}$, $N_{23.3}$, and S_1 for chemical equation and 22.74 MJ/kg (dry basis) for HHV. Baawain *et al.* (2017) investigated MSW in Muscat and reported 40.5% carbon, 5.95% hydrogen, 2.39% nitrogen, 0.66% sulfur, 43.53% oxygen on dry mass for FW. However, Tchobanoglous *et al.* (1993) reported 70% moisture content, 48% carbon, 6.4% hydrogen, 2.6% nitrogen, 0.4% sulfur, 37.6% oxygen, 5% ash and 5.512 MJ/kg HHV (dry basis) as references for FW. The existence of accurate data on food waste characteristics, which has been poorly documented in Iran, is necessary in policy making and intervention strategies (van Herpen *et al.,* 2019). There are several problems for result reporting due to the complexities involved in data gathering and lack of a common ground on what is termed as FW (De Laurentiis *et al.,* 2020). Majority of the studies rely on secondary data sources which may not represent the accurate characterization of FW in the study area (Xue *et al.,* 2017) or, sometimes, the differences among the laboratory methods are not considered and investigated thoroughly by researchers. These defects have led to differences in the amount of FW reported and several inconsistencies in the characterization of FW (Adelodun *et al.,* 2021). Accordingly, the main study questions are: Which laboratory methods are more accurate in determining the important elements of FW such as organic carbon, nitrogen, sulfur, etc.? What are the differences between determining the heating value by bomb calorimeter and by empirical models? What are the differences between the chemical equation obtained from elemental analysis and secondary data sources? Such information is very important for MSW management planning (Raharjo *et al.,* 2018). Considering the inconsistencies in characterization of FW, direct characterization by different common laboratory methods is necessary to fill the knowledge and data gap in order to decide upon suitable FW management strategy. It is obvious that different factors, such as income level, consumption pattern, geographic location, source of energy, and climate, influence the waste characteristics in any region (Golhosseini and Jalili Ghazizadeh, 2021). The aim of this study was to statistically compare the common laboratory methods (namely proximate, ultimate and heating value analyses) used for the

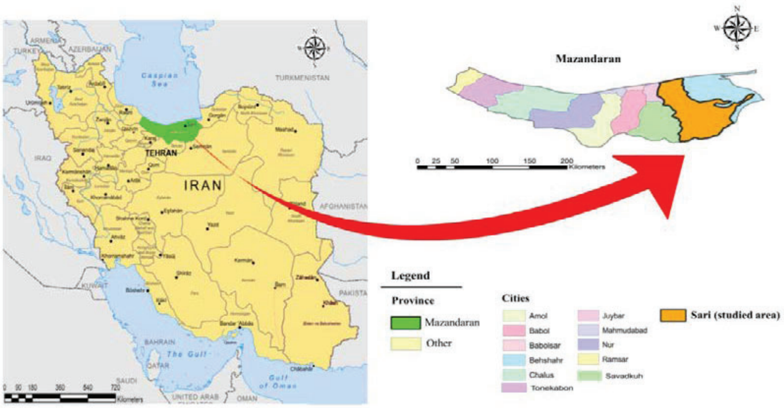


Fig. 1: Geographic location of the study area in Sari, Mazandaran Province, Iran

municipal food waste characterization in order to highlight the differences among them. Besides, comprehensive data on FW characterization in one of the Iranian cities was presented for the first time. In fact, the novelty of this work was establishing an infrastructure for laboratory characterization of FW to resolve the existing inconsistencies and present the characteristics of a region more accurately. To achieve these objectives, sampling was conducted at a disposal site located in Sari, Mazandaran province, Iran in 2021.

MATERIALS AND METHODS

The methods which were based on international standards for waste and recommended in Iran were selected for investigation. These methods had been used in various laboratories and studies to characterize the waste. Thus, their comparative analysis could provide a proper insight for choosing the most accurate method. As previously discussed, FW forms the largest fraction of waste reaching the landfills and is usually separated from other parts to recycle. Therefore, determining the accurate characteristics of FW may be helpful in making the right decision for their management.

Study area

This study was conducted in Sari, Mazandaran province, located in the north of Iran, where the summers are hot, muggy, dry, and clear and the winters are cold and partly cloudy. In this area, the annual temperature typically varies between 2 °C and 32 °C and rarely drops to -2°C or reaches 36° C (Weatherspark, 2021). Sari, as the capital city, is the largest and the most populous city of Mazandaran province. It is located between the northern slopes of the Alborz mountains and the southern coast of the Caspian Sea, and lies between latitudes of 360 33' and 47.95" N and longitudes of 530 03' and 36.32" E (Fig. 1).

Sampling and physical composition

MSW sampling was performed weekly at a disposal site located in the study area (ASTM D5231-92, 2016). The sampling plan was based on random truck sampling determined by considering the available facilities and background information on the site location. About 50 kg garbage was randomly picked up from the arrival trucks of each zone and then mixed to make approximately 1 ton MSW for physical analysis. The sample was separated into eight major categories including food waste, plastics, rubber and leather, paper and cardboard, textiles, none flammable materials, woods, and other substances. Then, the extracted FW was prepared for laboratory analysis by quartering method. The age of the samples was about 24 hours since, in Sari, the households waste is daily gathered by the MSW collection system.

Analytical methods

The moisture content was determined according to the standard test method for moisture trough the analysis of coal and coke samples with the help of an electronic oven (Memmert, UNE 400, Germany) (ASTM D3173, 2017). OM and ash content were determined by ignition loss of the oven-dried sieved sample in a muffle furnace according to the standard test method (ASTM D3174-12, 2018). In order to determine pH, each sample was mixed with water in 1:10 to make a solution and shaked at 300 rpm for 30 min (Sánchez-Monedero *et al.,* 2001). Elemental analysis including carbon, hydrogen, oxygen, nitrogen, and sulphur (CHONS) was conducted in an elemental combustion system (4010 CHONS analyzer, Costech, Italy) to obtain the weight percent of CHONS and chemical composition of food waste according to ASTM E777-17a, (2017) for carbon and hydrogen, and ASTM E775-15, (2021) and ASTM E778-15, (2021) for sulfur and nitrogen, respectively. Oxygen was measured by difference which is a common method in the laboratories with adequate instrument. Elemental analyzer instrument, through separate analysis of each element in the laboratory, makes the determination and comparison easier and provides other fundamental information on 1) Determining heating value according to chemical equation, 2) Determination of the C/N ratio as an important indicator, 3) Comparing the C and N values with the values obtained from other measuring methods, and 4) The data used to calculate the theoretical maximum biogas yields. In addition, the total organic carbon (TOC) for the assessment of the C/N ratio was determined via two different ways to compare and define the most suitable method. These two methods were 1) Dichromatometric oxidation (Walkley and Black, 1934), and 2) Applying a suitable factor of transformation to the total organic matter content (1/1.724) determined by ignition loss as 'Van Bemmelen' factor which is commonly used in soil organic matter studies (Heaton *et al.,* 2016). In addition to the elemental analyzer method, Kjeldahl method (Vapodest 30s, Gerhardt, Germany), which has been widely used to determine the nitrogen of waste, soil and compost in Iran, was used to determine the total Kjeldahl nitrogen (TKN). This method is typically used for the analysis of total sulfur and involves dry ashing followed by sulfate detection with ion chromatography (Dry ashing/IC method). The dry ashing/IC method was also applied to compare the results of the elemental analyzer method. In addition to the empirical models described in Table 1, a bomb calorimeter was used to determine the heating value of the FW samples (Chang *et al.,* 2007). Empirical models are more commonly used because they present more comparable data by relying on secondary sources instead of laboratory analyses which may not be accurate. This inconsistency has been highlighted in this study.

All the mentioned methods were also in accordance with the Iranian national standards. All the analyses were carried out in triplicate, and the deviation, averages, and correlation were investigated by the t-test and analysis of variance (ANOVA) to show the significant difference among the laboratory methods. In fact, ANOVA checks the impact of one or more factors by comparing the means of different samples, and helps to find out if there is a difference among the groups or not.

RESULTS AND DISCUSSION

The conducted laboratory analyses on MSW composition and physical and chemical properties of FW as well as heating value analysis of FW are described in the following sections.

Physical composition of MSW

Waste composition is influenced by many factors such as income level, level of economic development, cultural norms, geographical location, energy sources, and climate in any region (Golhosseini and Jalili Ghazizadeh, 2021). According to the World Bank report (2018), Iran is located in the Middle East and North Africa region (MENA) where FW is the predominant type of waste (Kaza *et al.*, 2018). Table 2 shows the extracted physical compositions of MSW in different regions of

Table 1: Heat value models based on physical, proximate and ultimate analyses

Models*	Equations	Reference
Proximate analysis:		
LHV =45B-6W	Traditional Eq.	JNMSWF, 1991
LHV =44.75B-5.85W+21.2	Bento's Eq.	JNMSWF, 1991
Ultimate analysis:		
LHV = 81C + 342.5(H-O/8) + 22.5S - 6(9H+W)	Dulong's Eq.	Wilson, 1977
LHV = 81(C-3xO/8) + 57x3xO/8 + 345(H-O/16) + 25S - 6(9H+W)	Steuer's Eq.	Wilson, 1977
LHV = 81 (C-3xO/4) + 342.5H + 22.5S + 57x3xO/4 - 6(9H+W)	Scheurer-Kestner's Eq.	Wilson, 1977

* LHV = Low heating value (Kcal/Kg); B = Combustible volatile matter (%); W = Moisture content (wt %); C = Carbon content (wt %); H = Hydrogen content (wt %); S = Sulfur content (wt %); O = Oxygen content (wt %), JNMSWF: Japan National Municipal Solid Waste Foundation.

Table 2: The mean average physical compositions of MSW in different regions (dry base wt %)

Region[1]	Paper	Woods	Rubber and leather	Plastic	Food waste	Other	Non-flammable
MENA	13	1	2	12	58	8	6
South Asia	10	1	2	8	57	15	7
East Asia and Pacific	15	2	1	12	53	12	5.6
Europe and Central Asia	18.6	1.6	1	11.5	36	21	11
Sub-Saharan Africa	10	1	-	8.6	43	30	8
Latin America and the Caribbean	13	1	1	12	52	15	7
North America	28	5.6	9	12	28	3.6	13.8
Global	17	2	2	12	44	14	9
Current study[2]	12.4	3.3	0.1	5	58.7	16.5	4

[1] All the data is according to the World Bank report (Kaza *et al.,* 2018)
[2] The data are the average of seven consecutive days sampling

the world. Obviously, weight fraction of FW has the highest percentage among other components of MSW. The results indicated a good conformity between the literature and the field study on FW generation. Thus, the secondary source showed no significant difference in determining the percentage of FW in MSW. Zhou *et al*. (2014) reported that food residue formed about 55.86% of the total MSW. However, the amounts of FW generated significantly differed depending on housing types and seasons (Adelodun *et al.,* 2021).

Physical and chemical properties of FW

Heterogeneous nature of FW, as a critical problem of using it as a resource, requires a comprehensive analysis of its physicochemical properties (Bayard *et al.,* 2018).

Proximate and ultimate analyses

Proximate analysis of FW covering its moisture content, pH, organic matter and ash was performed in triplicate, and the average values were presented (Table 3). The results were compared to the data presented in the environmental engineering book published by Kiely, (1997) as a secondary source. Moreover, ultimate analysis was used to determine the percentage of each individual element in the FW including carbon, hydrogen, oxygen, nitrogen, sulfur, and ash. For better comparison, the typical data on ultimate analysis of FW were presented according to the well-known solid waste management books written by Tchobanoglous, *et al.* (1993) and Pichtel, (2005) (Table 3). These books were employed to compare the results obtained in the current study. According to Table 3, in the proximate analysis, the results of moisture content and OM represented a high precision besides good accuracy relative to the reference (70%). Carmona-Cabello *et al.* (2020) reported a heterogeneous composition of FW with moisture content of 52.1 to 73.9%. In the ultimate analysis, the average contents of hydrogen (7.15%) and oxygen (35.17%) were close to the reference, while those of carbon (41.91%), nitrogen (1.96), sulfur (0.87%) and ash (12.94%) were far from the reference (carbon 48%, hydrogen 6.4%, nitrogen 2.6 0%, sulfur 0.4%, oxygen 37.6% and ash 5%). Baawain *et al.* (2017) investigated FW in Muscat and reported carbon, hydrogen, nitrogen, sulfur and oxygen as 40.5%, 5.95%, 2.39%, 0.66%, and 43.53%, respectively. However, Boumanchar *et al.* (2018), in their study, reported carbon, hydrogen, nitrogen, sulfur, and oxygen as 50.5%, 7.1%, 2.1%, 0.2%, and 40.1% for FW, respectively. In the present study, the coefficients of variation were higher in C, N, S, C/N, and ash than in H and O contents. This difference could be attributed to two factors: 1) the nature of FW that varied in any region (Golhosseini and Jalili Ghazizadeh, 2021), and 2) application of different measurement methods which may lead to different results. Therefore, for better investigation, the parameters, such as carbon, nitrogen, sulfur, and ash, in two or three determination methods were compared and the obtained results were analyzed using the t-test and ANOVA or other statistical indexes.

Nitrogen determination

Nitrogen determination was done using two common methods: 1) CHONS analyzer, 2) and TKN (Table 4). Using the TKN, the values were found to be in the range of 1.3% and 3.25% with an average value of 2.3% ± 0.57% (Selvam *et al.,* 2021). An independent samples t-test was also done as shown in Table 5. As can be seen in Table 6, at a confidence level of 95%, data significance (sig) parameters were higher than

Table 3: Proximate and ultimate analyses of the food waste*

n\Statistical items\Ref	Proximate analysis (wt%)				Ultimate analysis based on elemental analyzer (wt%)						
	MC_w	OM_d	A_d	pH	C	H	O	N	S	A_d	C/N
1	73	89.6	10.4	6.15	43.1	7.8	38.05	1.53	0.8	8.72	28.17
2	70.3	81.6	18.4	6.42	41.27	7.08	35.01	2.34	1	13.3	17.64
3	68	84.4	15.6	6.21	42.35	7.2	36.89	1.38	0.8	11.38	30.69
4	72.8	82.6	17.4	6.44	45.6	6.85	31.7	2.1	0.75	13	21.71
5	71.2	75.5	24.5	7.02	34.59	6.9	37.55	1.96	0.7	18.3	17.65
6	70.7	82.2	17.8	6.75	47.49	7.3	29.85	2.43	1.12	11.81	19.54
7	74.3	77.9	22.1	6.43	38.94	6.95	37.15	1.96	0.9	14.1	19.87
Ave	71.5	81.97	18.02	6.49	41.91	7.15	35.17	1.96	0.87	12.94	22.18
SD	2.09	4.53	4.53	0.30	4.27	0.33	3.19	0.39	0.14	2.94	5.20
SE	0.79	1.71	1.71	0.11	1.61	0.12	1.21	0.15	0.05	1.11	1.96
CV%	2.92	5.53	25.13	4.68	10.18	4.58	9.08	19.86	16.04	22.68	23.42
Kiely, 1997	70	83.3	16.7	-	-	-	-	-	-	-	-
Pichtel, 2005	-	-	-	-	48	6.4	37.6	2.6	0.4	5	18.46

*n: Sample's number; Ref: Reference; w: Wet basis; d: Dry basis; N: Number of samples; Ave: Average; SD: Standard deviation; SE: Standard error; CV: Coefficient of variation.

Table 4: Ash, nitrogen and sulfur determination in the samples through different laboratory methods

Component	Methods	1	2	3	4	5	6	7	Ave
Ash	CHONS analyzer	8.72	13.3	11.38	13	18.3	11.81	14.1	12.94
	Furnace	10.4	18.4	15.6	17.4	24.5	17.8	22.1	18.03
N	CHONS analyzer	1.53	2.34	1.38	2.1	1.96	2.43	1.96	1.95
	Kjeldahl	1.68	1.835	1.7	1.648	1.742	1.98	1.918	1.78
S	CHONS analyzer	0.8	1	0.8	0.75	0.7	1.08	0.9	0.86
	Ashing/IC	0.65	0.9	0.71	0.67	0.65	0.92	0.82	0.76

0.05. It meant that the variance and average of two groups were not significantly different from each other. However, the value of coefficient of variation (CV) in the Kjeldahl method was lower (7.12%) than its value in the CHONS analyzer determination (19.86%). Thus, it could be concluded that Kjeldahl method was more precise than elemental analyzer, and both methods led to lower average results compared to the mentioned references.

Sulfur determination

The results of determining the total sulfur by dry combustion method (elemental analyzer) and ashing/ion chromatography method have been shown and compared in Tables 4 and 5. Evidently, the sulfur content in the elemental method was slightly higher than its content in the Ash/IC method. However, other statistical indexes showed a perfect agreement between both methods, implying that there was no significant difference between them. Comparison of the results indicated that both methods were precise and the sulfur content of the FW was approximately twice the content mentioned in the references, which was the characteristic of the FW in the studied region.

Ash determination

Considering the waste samples in the CHONS analyzer and ash as the final residual, the ash percent of each sample was calculated (Table 4). In other methods, the ash percent was determined through sample combustion in 550 ^{0}C in a furnace for approximately 4 hours. The results have been shown in Table 5 and the variances are compared using the t-test (Table 5). Obviously, at a confidence level of 95%, sig>0.05 meant that the variances of two groups were equal, while sig. (2-tailed)<0.05 meant that the averages were not equal and significantly differed. The CV was not significantly different in furnace method and CHONS analyzer, implying that both methods were precise. It should be noted that OM also plays an

Table 5: Comparing the laboratory methods by independent samples t-test

t-test	Ash		N		S	
	CHONS analyzer	Furnace	CHONS analyzer	Kjeldahl	CHONS analyzer	Ashing/IC
Number of samples	7	7	7	7	7	7
Mean	12.9443	18.0286	1.9571	1.7861	0.86	0.76
SD	2.93619	4.53016	0.38862	0.1272	0.14	0.12
SE	1.10977	1.71224	0.14688	0.04808	0.05	0.04
%CV	22.68	25.13	19.86	7.12	14.85	14.38
Sig.*	-	0.423	0.071	-	0.728	-
Sig. (2-tailed)	-	0.028	0.29	-	0.165	-

*Significance

Table 6: Statistical analysis of carbon determination, test of homogeneity of variances, ANOVA, and multiple comparisons through different laboratory methods

Component	Methods	1	2	3	4	5	6	7	Ave
C	Elemental analyzer	43.1	41.27	42.35	45.6	34.59	47.49	38.94	41.91
	Walkley and Black	48.7	37.8	48	37	30.8	42	33.8	39.73
	Van Bemmelen	49.78	45.33	46.89	45.89	41.94	45.67	43.28	47.55

Test of homogeneity of variances (VAR00001)

Levene statistic	df1+	df2	Sig.
3.774	2	18	0.043

ANOVA (VAR00001)

	Sum of Squares	df	Mean square	F	Sig.
Among groups	227.957	2	113.978	4.763	0.022
Within groups	430.696	18	23.928		
Total	658.652	20			

Multiple comparisons (Dependent variable: (VAR00001) Games-Howell

(I) Method	(J) Method	Mean Difference (I-J)	SE	Sig.
Elemental analyzer	Walkley and Black	2.17714	3.04439	0.760
	Van Bemmelen	-5.64143*	1.89361	0.034
Walkley and Black	Elemental analyzer	-2.17714	3.04439	0.760
	Van Bemmelen	-7.81857	2.76681	0.054
Van Bemmelen	Elemental Analyzer	5.64143*	1.89361	0.034
	Walkley and Black	7.81857	2.76681	0.054

+ df: Degrees of freedom.
* The mean difference is significant at the 0.05 level.

important role in select the accurate method. Referring to Table 3, the OM determination using furnace gives both precise and accurate values for FW according to the global statistics with low SD and CV. Consequently, the ash content left over from furnace gave a more accurate value compared to the elemental analyzer method.

Total organic carbon determination

As previously mentioned, TOC was determined in three ways. TOC and total carbon as well as TKN and total nitrogen sometimes have been used ambiguously. Selvam *et al.* (2021) reported that the TOC values of FW from a canteen in Beijing ranged from 29.7% to 56.3% with an average value of 45.6% ± 9.8% which can be compared to the value obtained in the present study. Analysis of variance followed by the Games-Howell Post Hoc test was conducted for carbon determination methods according to Table 6. Results of variance homogeneity (sig=0.043<0.05) showed that variances of the three methods were not equal, and ANOVA test (sig=0.022<0.05) showed that the group means were not equal. Thus, the Post-Hock multiple comparison demonstrated that the Van Bemmelen method had a significant difference with the other two methods. CV values in the Walkley and Black method and Elemental analyzer were 10.2% and 17.2%, respectively. The results showed that organic carbon determination by the Walkley and black method was more precise compared to the other two methods. The

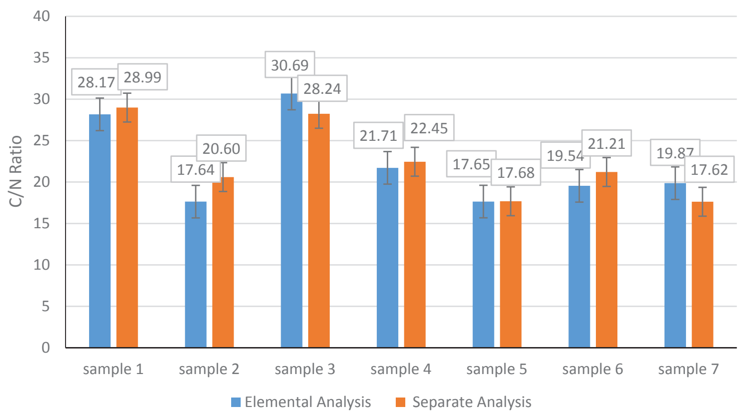


Fig. 2: Carbon to nitrogen ratio of food waste in different methods

low heating value (LHV) of the samples determined by bomb calorimeter method demonstrated that TOC determination by the Walkley and Black method led to closer results when it was used in different empirical models compared to determination of C by elemental analyzer. Thus, the Walkley and Black method was more accurate method rather than other two methods.

C/N ratio determination

Carbon to nitrogen ratio is one of the major parameters in controlling the nutrient balance in composting process (Norbu *et al,* 2005). It can help to determine the biodegradability of any biomaterial (Lü *et al.,* 2018). The C/N ratio of FW ranges from 9.3 to 24.5 with an average value of 17.3 ± 3.7 (Selvam *et al.,* 2021). For better investigation, the C/N ratios obtained from separate analysis (Walkley and Black plus Kjeldahl method) and elemental analyzer are compared (Fig. 2).

Statistical investigations showed that the average and variances were not significantly different from each other. However the CV value in a separate analysis (19.03%) was lower than its value in the elemental analyzer (21.69%). As already discussed, separate analysis of C and N was more precise and accurate. Thus, the average C/N ratio of the separate analysis (22.4), which was higher than the reference (18.46) and the average C/N ratio (14.9-16) reported by Carmona-Cabello *et al.* (2020), could be reported as an accurate amount for FW in this region (Pichtel, 2005).

Heating value

The heating value of FW was determined by a laboratory bomb calorimeter and calculated based on empirical models according the proximate and ultimate analyses results. Table 7 shows the results obtained from different samples compared to the LHV extracted from the reference (Tchobanoglous *et al*., 1993).

The models developed based on proximate analysis (Traditional: 13.64 and Bento: 13.68 MJ/kg) showed an almost better conformity (p-value <0.05) with the lab scale analysis (13.38 MJ/kg) because there was no different parameter determination methods in the proximate analysis (OM and MC). On the other hand, most of the empirical models developed based on the ultimate analysis, which had been obtained by elemental analyzer, had a significant difference (p-value <0.05) with the results of bomb calorimeter, except for the Dulong's equation which gave the closest results (14.82 MJ/kg) compared to Steuer's equation (16.71) and Scheurer-Kestner's equation (18.47 MJ/kg). Knowing that C was a key factor in LHV calculations, the average TOC obtained by the Walkley and Black method was replaced by the average TOC obtained by the elemental analyzer method, leading to more accurate results in the bomb calorimeter method in all models. This provided stronger reasons for achievement of more accurate data on FW characterization by separate analysis. In addition, the heating values of FW based on the secondary source elemental analysis (Table 2) were very far from the real amount (2.15 to 6.06 MJ/kg) (Tchobanoglous *et al*., 1993). Chen *et al.* (2019) studied the FW in Taiwan and reported 22.74 MJ/kg (dry basis) higher heating value. Zhou *et al*. (2014) reviewed the physical and chemical compositions of MSW in China and reported 15,386

Table 7: LHV based on bomb calorimeter test (MJ/kg) compare to other models (dry basis) (Tchobanoglous *et al*., 1993)

Sample No.	Model based on lab scale analysis	Models based on ultimate analysis			Models based on proximate analysis	
	Bomb calorimeter	Dulong's equation	Steuer's equation	Scheurer-Kestner's equation	Traditional equation	Bento's equation
1	11.75	15.45	17.49	19.40	15.03	15.07
2	13.07	14.59	16.47	18.22	13.59	13.64
3	14.11	14.80	16.77	18.63	14.18	14.22
4	11.15	16.28	17.99	19.57	13.72	13.77
5	12.93	11.60	13.60	15.50	12.42	12.48
6	14.74	17.88	19.50	20.98	13.70	13.75
7	15.96	13.15	15.14	17.00	12.80	12.85
Ave.	13.38	14.82	16.71	18.47	13.64	13.68
Reference	-	15.53	17.53	19.44	13.89	13.97

Table 8: Chemical equation (with water) for determination of food waste in different ways (Tchobanoglous *et al*., 1993)

N	Based on elemental analyzer	Based on the most accurate method	Reference
1	$C_{143.8}H_{1501.9}O_{697.5}N_{4.38}S_1$	$C_{162.5}H_{1501.9}O_{697.5}N_{4.8}S_1$	$C_{320.43}H_{2566.07}O_{1227.72}N_{14.88}S_1$
2	$C_{110.2}H_{1059.9}O_{491.9}N_{5.36}S_1$	$C_{100.9}H_{1059.9}O_{491.9}N_{4.2}S_1$	
3	$C_{141.3}H_{1222.9}O_{565.68}N_{3.95}S_1$	$C_{160.2}H_{1222.9}O_{565.68}N_{4.8}S_1$	
4	$C_{162.3}H_{1549}O_{720.5}N_{6.41}S_1$	$C_{131.7}H_{1549}O_{720.5}N_5S_1$	
5	$C_{131.9}H_{1559}O_{736.7}N_{6.4}S_1$	$C_{117.5}H_{1559}O_{736.7}N_{5.7}S_1$	
6	$C_{117.4}H_{1002.9}O_{453.46}N_{5.15}S_1$	$C_{103.8}H_{1002.9}O_{453.46}N_{4.42}S_1$	
7	$C_{115.5}H_{1378.5}O_{655}N_5S_1$	$C_{117.9}H_{1378.5}O_{655}N_{4.9}S_1$	
Ave.	$C_{129.9}H_{1286.2}O_{598.2}N_{5.2}S_1$	$C_{125.8}H_{1286.2}O_{598.2}N_{4.7}S_1$	

kJ/kg as dry basis for FW. It could be concluded that it was not wise to conduct waste management planning based on secondary sources and literature without a comprehensive laboratory analysis.

Chemical equation

After determining the most accurate method, the chemical fequation based on elemental analysis, the best laboratory method and the mentioned references were compared (Table 8).

Unlike heating value, the average FW chemical equation was not significantly different in the elemental analyzer and laboratory determination methods, except for in C and N contents. It was, however, significantly different from the average FW chemical equation in the references (Tchobanoglous *et al*., 1993). In addition, some researchers obtained the chemical equation of FW. For example, Chen *et al.* (2019) reported $C_{333.3}H_{596.6}O_{183.3}N_{23.3}S_1$ the chemical equation of FW in Taiwan, and Zhou *et al*., (2014) reported $C_{257.3}H4_{56.2}O_{168.3}N_{18}S_1$ as the chemical equation of FW in China. The big gaps among the chemical compositions of FW indicated the complex nature of waste in different regions. Therefore, the FW chemical equation referring to a reliable source or literature did not have a good accuracy and required a comprehensive laboratory analysis.

CONCLUSION

The FW was extracted from MSW and subjected to a comprehensive comparative laboratory analysis to determine the accurate methods and characteristics. The results showed the high precision and consistency of the physical composition of the prepared MSW (especially in the FW by 58.7%, moisture content by 71.5%, organic matter by 81.9%, oxygen by 35.1%, and hydrogen content by 7.1%) with the global statistics. Compared to the analysis of instrumental elements, carbon determination based on the Walkley and Black method, nitrogen based on Kjeldahl method, sulfur based on Ion chromatography method and ash determination using furnace had higher precisions. Investigation of the heating value presented a good conformity of the models developed based on proximate analysis, including traditional (13.64 MJ/kg) and Bento's equations (13.68 MJ/kg), with the laboratory results (13.38 MJ/kg). The models developed based on ultimate analysis, including Dulong (14.82 MJ/kg), Steuer (16.71 MJ/kg), and Scheurer-Kestner (18.47 MJ/kg), led to lower accuracies and higher LHVs (1.4 to 5 MJ/kg) compared the bomb calorimeter method (13.38 MJ/kg). For FW, the heating value extracted from the secondary data sources ranged 15.5-19.4 MJ/kg, while the real amount was 13.38 MJ/kg in average in the study area. The final chemical equation ($C_{125.8}\ H_{1286.2}\ O_{598.2}\ N_{4.7}\ S_1$) was obtained according the most accurate determination methods for the FW. However, the secondary data sources presented a different chemical equation ($C_{320.43}\ H_{2566.07}\ O_{1227.72}\ N_{14.88}\ S_1$). The results from this study could establish an infrastructure for the laboratory characterization of FW and resolve the inaccuracies and inconsistencies. It could also help in representing the characteristics for any region more accurately and implementing proper waste management plans such as composting or energy recovery. The limitations faced in this study were the existing knowledge gap for characterization of FW in Iran and the fact that FW characteristics could be influenced by many parameters. Further studies should be conducted to extend the related knowledge at regional or national level. Moreover, the characteristics of the MSW, from which the FW was extracted, and validation of leachate characteristics could be investigated in future studies.

AUTHOR CONTRIBUTIONS

A. Charkhestani performed the experiments and literature review, gathered data, compiled the data, analyzed and interpreted the data, prepared the manuscript text. D. Yousefi Kebria performed the manuscript edition.

ACKNOWLEDGEMENT

The authors would like to acknowledge Shiraz Municipality Waste Management Organization for providing a specialized laboratory of waste for performing the laboratory analyses.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

ANOVA	Analysis of variance
A_d	Ash (dry basis)
ASTM	American Society for Testing and Materials
Ave	Average
C	Carbon
CHONS	Carbon, Hydrogen, Oxygen, Nitrogen, and Sulfur
C/N	Carbon to nitrogen ratio
CV	Coefficient of variation
d	Dry basis
df	Degrees of freedom
Eq.	Equation
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
F	Frequency
FW	Food waste
H	Hydrogen

HHV	High heating value
IC	Ion chromatography
IPCC	Intergovernmental Panel on Climate Change
JNMSWF	Japan National Municipal Solid Waste Foundation
Kcal/kg	Kilocalories per kilogram
kJ/kg	Kilojoules per kilogram
LHV	Low heating value
MC	Moisture content
MJ/kg	Megajoules per kilogram
MSW	Municipal Solid Waste
MENA	Middle East and North Africa
n	Sample number
N	Nitrogen
O	Oxygen
OC	Organic carbon
OM	Organic matter
pH	Power of hydrogen
P-Value	Probability value
Ref.	Reference
rpm	Round per minute
S	Sulfur
SD	Standard deviation
SE	Standard error
Sig	Significance
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TOM	Total organic matter
w	Wet basis
Wt	Weight

REFERENCES

Adhikari, B.K.; Barrington, S.; Martinez, J., (2006). Predicted growth of world urban food waste and methane production. Waste Manage. Res., 24: 421–433 (**12 pages**).

ASTM D3173, (2017). Standard test method for moisture in the analysis sample of coal and coke. ASTM International, West Conshohocken, PA.

ASTM D3174-12, (2018). Standard test method for ash in the analysis sample of coal and coke from coal. ASTM International, West Conshohocken, PA.

ASTM D5231-92, (2016). Standard test method for determination of the composition of unprocessed municipal solid waste. ASTM International, West Conshohocken, PA.

ASTM E777-17a, (2017). Standard test method for carbon and hydrogen in the analysis sample of refuse-derived fuel. ASTM International, West Conshohocken, PA.

ASTM E775-15, (2021). Standard test method for total sulfur in the analysis sample of refuse-derived fuel. ASTM International, West Conshohocken, PA.

ASTM e778-15, (2021). Standard test methods for nitrogen in refuse-derived fuel analysis samples. ASTM International, West Conshohocken, PA.

Baawain, M.; Al-Mamun, A.; Omidvarborna, H.; Al-Amri, W., (2017). Ultimate composition analysis of municipal solid waste in Muscat. J. Clean. Prod., 148: 355–362 (**8 pages**).

Bayard, R.; Benbelkacem, H.; Gourdon, R.; Buffière, P., (2018). Characterization of selected municipal solid waste components to estimate their biodegradability. J. Environ. Manage., 216: 4-12 (**9 pages**).

Boumanchar, I.; Chhiti, Y.; M'hamdi Alaoui, F.E.; Sahibed-dine, A.; Bentiss, F.; Jama, C., Bensitel, M., (2018). Municipal solid waste higher heating value prediction from ultimate analysis using multiple regression and genetic programming techniques. Waste Manage. Res., 37: 578–589 (**12 pages**).

Carmona-Cabello, M.; Garcia, I.L.; Leiva-Candia, D.; Dorado, M.P., (2018). Valorization of food waste based on its composition through the concept of biorefinery. Curr. Opin. Green Sustain. Chem. 14: 67-79 (**13 pages**).

Carmona-Cabello, M.; García, I.L.; Sáez-Bastante, J.; Pinzi, S., Koutinas, A.A.; Dorado, M.P., (2020). Food waste from restaurant sector - characterization for biorefinery approach. Bioresour. Technol., 301: 122779 (**37 pages**).

Chang, Y.F.; Lin, C.J.; Chyan, J.M.; Chen, I.M.; Chang, J.E., (2007). Multiple regression models for the lower heating value of municipal solid waste in Taiwan. J. Environ. Manage., 85: 891–899 (**9 pages**).

Chen, W.H.; Lin, Y.Y.; Liu, H.C.; Chen, T.C.; Hung, C.H.; Chen, C.H.; Ong, H.C., (2019). A comprehensive analysis of food waste derived liquefaction bio-oil properties for industrial application. Appl. Energy., 237: 283–291 (**8 pages**).

De Laurentiis, V.; Caldeira, C.; Sala, S., (2020). No time to waste: assessing the performance of food waste prevention actions. Resour. Conserv. Recycl., 161: 104946 (**10 pages**).

EEA, (2013a). Municipal waste management in Sweden [Online]. European Environment Agency.

EEA, (2013b). Municipal waste management in Germany. European Environment Agency.

EPA, (2016). Advancing sustainable materials management: 2016 recycling economic information (REI) report methodology. United States Environmental Protection Agency.

FAO, (2012). Towards the future we want: end hunger and make the transition to sustainable agricultural and food Systems. Food and Agriculture Organization of the United Nations, Rome.

Golhosseini. Z,; Jalili Ghazizadeh. M., (2021). Municipal solid waste status in Iran; from generation to disposal. Preprint, available at Research Square., 1-17 (**17 pages**).

Guo, W.; Zhou, Y.; Zhu, N.; Hu, H.; Shen, W.; Huang, X.; Zhang, T.; Wu, P.; Li, Z., (2018). On site composting of food waste: a pilot scale case study in China. Resour. Conserv. Recycl., 132: 130–138 (**9 pages**).

Heaton, L.; Fullen, M. A.; Bhattacharyya, R., (2016). Critical analysis of the van Bemmelen conversion factor used to convert soil organic matter data to soil organic carbon data: comparative analyses in a UK loamy sand soil. Espaço Aberto., 6(1): 35-44 (**10 pages**).

IPCC, (2006). Waste generation, compositions and management data. Guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change, WMO/UNEP.

JNMSWF, (1991). Design guide for the facility of solid waste disposal. Japan National Municipal Solid Waste Foundation, Tokyo.

Pichtel, J., (2005). Waste management practices: municipal, hazardous, and industrial. CRC Press, Taylor and Francis Group.

Kamyab, H.; Lim, J.S.; Khademi, T.; Ho, W.S.; Ahmad, R.; Hashim, H.; Ho, C.S.; Keyvanfar, A.; Lee, C.T., (2015a). Greenhouse gas emission of organic waste composting: a case study of universiti teknologi Malaysia green campus flagship project. J. Teknol., 74(4): 113-117 (**5 pages**).

Kamyab, H.; Goh, R.K.Y.; Wong, J.H.; Lim, J.S.; Khademi, T.; Ho, W.S.; Ahmad, R.; Hashim, H.; Ho, C.S.; Lee, C.T., (2015b). Cost-benefit and greenhouse-gases mitigation of food waste composting: a case study in Malaysia. Chem. Eng. Trans., 45: 577-582 (**6 pages**).

Kaza, S.; Yao, L.C.; Bhada-Tata P; Van woerden, F., (2018). What a waste 2.0 : a global snapshot of solid waste management to 2050. Urban Development. World Bank, Washington, DC.

Kiely, G., (1997). Environmental engineering. McGraw-Hill, New York.

Lü, F.; Shao, L.-M.; Zhang, H.; Fu, W.-D.; Feng, S.-J.; Zhan, L.-T.; Chen, Y.-M.; He, P.-J., (2018). Application of advanced techniques for the assessment of bio-stability of biowaste derived residues: A minireview. Bioresour. Technol., 248: 122-133 (**12 pages**).

Meng, Y.; Li, S.; Yuan, H.; Zou, D.; Liu, Y.; Zhu, B.; Li, X., (2015). Effect of lipase addition on hydrolysis and biomethane production of Chinese food waste. Bioresour. Technol., 179: 452–459 (**8 pages**).

Norbu, T.; Visvanathan, C.; Basnayake, B. (2005). Pretreatment of municipal solid waste prior to landfilling. Waste Manage., 25: 997–1003 (**7 pages**).

Paritosh, K.; Kushwaha, S.K.; Yadav, M.; Pareek, N.; Chawade, A.; Vivekanand, V., (2017). Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. BioMed Res. Int., 1–19 (**19 pages**).

Raharjo, S.; Ruslinda, Y.; Bachtiar, V.S.; Regia, R.A.; Fadhil, M.; Rachman, I.; Matsumoto, T., (2018). Investigation on Municipal Solid Waste Characteristics from Commercial Sources and Their Recycling Potential in Padang City, Indonesia. IOP Conf. Ser. Mater. Sci. Eng., 288, 121-134 (**13 pages**).

Sánchez-Monedero, M.A.; Roig, A.; Paredes, C.; Bernal, M.P., (2001). Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresour. Technol., 78: 301–308 (**8 pages**).

Selvam, A.; Ilamathi, P.; Udayakumar, M.; Murugesan, K.; Banu, R.; Khanna, Y.; Wong, J., (2021) Current developments in biotechnology and Bioengineering; Food Waste Properties. Elsevier, 11–41 (**31 pages**).

Tchobanoglous, G.; Theisen, H.; Vigil, S., (1993). Integrated solid waste management engineering principles and management issues, McGraw-Hill series in water resource and environmental engineering. McGraw-Hill, New York.

Troschinetz, A.M.; Mihelcic, J.R., (2009). Sustainable recycling of municipal solid waste in developing countries. Waste Manage., 29: 915–923 (**9 pages**).

Van Dooren, C.; Janmaat, O.; Snoek, J.; Schrijnen, M., (2019). Measuring food waste in Dutch households: A synthesis of three studies. Waste Manage., 94: 153–164 (**12 pages**).

Van Herpen, E.; Van der Lans, I.A.; Holthuysen, N.; Nijenhuis-de Vries, M.; Quested, T.E., (2019). Comparing wasted apples and oranges: An assessment of methods to measure household food waste. Waste Manage., 88: 71–84 (**14 pages**).

Walkley, A.; Black, I.A., (1934). An examination of the degtjareff method determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci., 37: 29–38 (**10 pages**).

Weatherspark, (2021). Climate and average weather year round in Sari, Iran.

Wilson, D.G., (1977). Handbook of solid waste management. Van Norstrand Reinhold, New York.

World Bank, (2012). What a waste: a global review of solid waste management, Urban Development Series. World Bank, Washington, DC.

Xue, L.; Liu, G.; Parfitt, J.; Liu, X.; Van Herpen, E.; Stenmarck, Å.; O'Connor, C.; Östergren, K.; Cheng, S., (2017). Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol., 51: 6618–6633 (**16 pages**).

Yang, F.; Li, G.X.; Yang, Q.Y.; Luo, W.H., (2013). Effect of bulking agents on maturity and gaseous emissions during kitchen waste composting. Chemosphere. 93: 1393–1399 (**7 pages**).

Zhou, H.; Meng, A.; Long, Y.; Li, Q.; Zhang, Y., (2014). An overview of characteristics of municipal solid waste fuel in China: Physical, chemical composition and heating value. Renew. Sustain. Energy Rev., 36: 107–122 (**16 pages**).

AUTHOR (S) BIOSKETCHES

Charkhestani, A., Ph.D. Candidate, Department of Environmental Engineering, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran.
Email: *ali_charkhestani@yahoo.com*
ORCID: 0000-0001-8210-6631

Yousefi Kebria, D., Ph.D., Associate Professor, Department of Environmental Engineering, Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran.
Email: *dy.kebria@nit.ac.ir*
ORCID: 0000-0001-7983-1568

HOW TO CITE THIS ARTICLE

Charkhestani, A.; Yousefi Kebria, D., (2022). Laboratory analysis for determining the accurate characterizations of urban food waste. Global J. Environ. Sci. Manage., 8(2): 225-236.

DOI: 10.22034/gjesm.2022.02.06

url: https://www.gjesm.net/article_247092.html

Global J. Environ. Sci. Manage. 8(2): 237-250, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

A basis water quality monitoring plan for rehabilitation and protection

M.D. Enriquez *, R.M. Tanhueco

Gokongwei College of Engineering, De La Salle University, 524-4611 Philippines

ARTICLE INFO

Article History:
Received 22 May 2021
Revised 28 July 2021
Accepted 02 September 2021

Keywords:
Environmental analysis
Pandurucan River
Water quality analysis (WQA)
Water quality index (WQI)
Water quality management plan (WQMP)

DOI: 10.22034/gjesm.2022.02.07

ABSTRACT

BACKGROUND AND OBJECTIVES: Safeguarding water resources became a major concern in many parts of the world as it aims to provide safe and healthy water for humans. Water quality monitoring is a popular tool in ensuring water quality is safe and within the allowable limits and standards for the health of the community. To provide interventions and strategies for the rehabilitation, a water quality monitoring plan was conducted to describe the water quality and the classification of the river.
METHODS: This study conducted an environmental analysis to determine existing conditions and processes in the surrounding environment such as the land use, drainage pattern, reconnaissance survey of the river, and a key interview to describe the barangay profile and the community's water use and practices. The water quality monitoring covers the evaluation of ten water quality parameters: temperature, pH, dissolved oxygen, total dissolved solids, total suspended solids, phosphate, nitrate, oil and grease, chloride, and E. coli.
FINDINGS: Results of the study presents the water quality against the ten water quality criteria. Phosphate measured on four stations ranges between 2.40-4.50 mg/L exceeding the allowable 0.50mg/L; the oil and grease exceeds the standards 2 mg/L with measured values of 2.40-4.60 mg/L in stations 2, 3, and 4; while measured chloride in all stations prove that the water is salty with values exceeding the freshwater requirement of 250mg/L; and the measured TSS in stations 2, 3 and 4 ranges from 32.30 to 49.3 mg/L exceeds the standards of 30 mg/L. E. coli was also detected in water samples collected in all sampling stations. The computed water quality index of 39.02 described water as poor, always impaired, and threatened by the surrounding environment.
CONCLUSION: The measured concentrations for phosphate, oil/ grease, chloride, and TSS exceeds the water quality requirement suggesting that the water is contaminated. The E. coli detected in all water samples, further recommends prohibition of recreational activities to avoid accidental intakes and skin contact on the polluted water. The existing activities in the surrounding residential, commercial and agricultural areas contributed to water contamination as aggravated by the unreliable drainage system, absence of proper sanitation facilities, and collection and disposal behavior of the community. From this, a scientific basis can be drawn on how the river can be rehabilitated and protected and serve as guide for policymakers and water managers on implementing strategies to achieve sustainable water resources.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
39	5	4

*Corresponding Author:
Email: *michelle_d_enriquez@dlsu.edu.ph*
Phone: +63 9988 525342
ORCID: 0000-0002-1618-6335

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Rivers play a significant role in agriculture, human consumption and recreational activities, and industries. But population growth, climate change impacts, industrial processes, transportations emissions, agricultural and industrial wastes, urban runoff (Wei and Yang, 2010; Mohiuddin *et al.,* 2011) physical and chemical processes such as weathering and dissolution of minerals, parent rocks, and soils (Adamu *et al.,* 2011; Skordas *et.al.,* 2015; Purushothaman and Chakrapani, 2007) gradually impact the natural water ecosystem impairing the water quality (Parry *et al.*, 2007; Razzaghmanesh *et al*, 2005). It is therefore important to safeguard the water resources to ensure that water quality conforms within the acceptable limits to protect the water resources and the public health (Said *et al*., 2004; Neri *et al*. 2012; WHO, 2012). To safeguard water resources, water quality monitoring is designed to determine the physical, chemical, and biological characters of water for human health and consumption (US EPA, 2005). Moreover, water quality monitoring is designed to confirm the water quality suitable for its intended use (Azizi *et al.,* 2016). In addition, monitoring is done to determine the trends in the aquatic environment and describe how the contaminants enter and affect the natural aquatic environment (Bartram and Balance, 1996). Therefore, water quality monitoring has become an important activity in assessing and evaluating the conformity of water for drinking and recreational activities. Taal Lake in Talisay, Batangas, Philippines was declared safe for bathing, swimming, and skin diving, and aquaculture after monitoring and evaluating nine water quality parameters (Martinez and Galera, 2011). Monitoring of Mangonbangon River in Tacloban City, Philippines revealed that the river is unpolluted from the total heavy metal content (Decena *et al.,* 2018). The study conducted on Pasig River, Philippines revealed that the river is very poor and degrading from the presence of stagnant, blackish, and stinking water (Gorme *et al*, 2010). While, the monitoring and assessment of water quality conducted in Buhisan River, Cebu Philippines revealed that the mean midstream and downstream did not conform to class D surface water (Maglangit *et al*., 2014). More so, the 36 river monitoring stations in Palawan, Philippines using nine parameters and water quality index showed good to excellent water quality for agriculture, irrigation, and other purposes; while five (5) river monitoring stations showed good to excellent ratings after treatment and suited for class A (Martinico-Perez *et al*., 2019). Evaluation and assessment of water quality parameters provide direction to a water quality monitoring plan. The ten primary water quality parameters as mandated by the Department of Natural Resources-Environmental Management Bureau is used in this study for the evaluation of the water quality standards of the study area. The sample collection and method of analysis of previous studies were considered and followed to achieve the objectives of the study. To aid the water quality monitoring plan, a popular tool known as Water Quality Index (WQI) was developed. WQI was described as the most effective way to describe the quality of water (Regmi and Mishra, 2016; Akter *et al*., 2016). With the aid of WQI, descriptions such as generally moderate water quality of Lake Taihu Basin (Wu *et al*., 2018); good water quality in the upstream and midstream of the Chillan River (Debels *et al*., 2005), the average water quality of Mantayupan falls at the headwater down the river channel (Neri *et al*., 2012) and poor water quality of Pasig River in Metro Manila, Philippines (Regmi and Mishra, 2016) were used to describe the general water quality. Since the rating scores of WQI of the Canadian Council of Ministers of Environment provide a simple description of water quality, this study adopted the same methodology for the understanding of the local community. In the Philippines, RA 9275 or the Philippine Clean Water Act of 2004 defines water quality in terms of physical, chemical, biological, or radiological characteristics by which the acceptability of the water is evaluated to conform with Administrative Order: 2016-08 or the Water Quality Guidelines and General Effluents Standards of 2016 (DENR-EMB, 2016). In general, drinking water of good quality should be clear and free of harmful substances and must conform to the Philippine National Standards for Drinking Water. While recreational waters must be free from any contaminants as accidental drinking and skin contact is expected during bathing and swimming. The Department of Environment and Natural Resources identified that almost half of the classified rivers in the country did not meet the minimum standards for beneficial use as impaired by domestic, industrial, and agricultural sources; and almost 50 out of 427 rivers are considered biologically dead (Cabacungan, 2016). One of the rivers in San Jose, Occidental Mindoro is the Pandurucan River and is believed to be impaired and degrading; however, there is no substantial evidence on the water quality and no scientific study has been carried out to investigate the characteristic of water and the possible sources of contamination. This study aims to present a water quality monitoring plan to provide information on the water quality conditions of Pandurucan River. The river has a plan to be rehabilitated as a tourist destination and the information obtained from this undertaking intends to provide scientific bases to support sound decision-making for San Jose water managers and policymakers. Results of the study can provide significant proof on water quality conditions, sources of contaminants, level of pollution and understand how human activities impaired the natural water ecosystem. Specifically, this study aims to present the physical/chemical and microbial analysis of water; conduct environmental analysis considering all present situations of the surrounding areas; characterize the water quality condition using Water Quality Index; determine the significant differences between water quality at different sites and different seasons; and recommend strategies for water quality management plan of Pandurucan River, San Jose, Occidental Mindoro. The water quality monitoring covers the period of 2019 to 2020.

MATERIALS AND METHODS

Study area

Pandurucan River is located at San Jose, Occidental Mindoro covering San Roque and Labangan Poblacion on its midstream and downstream sections. The river is generally used for recreational purposes as swimming and bathing which are commonly observed and enjoyed. Four sampling stations were selected based on the drainage pattern and probable point sources and the center of commercial and residential areas. Table 1 shows the descriptions of the sampling stations.

Sampling method and data collection

One grab sample was taken every month in the four identified stations from September 2019 to February 2021. Water samples were collected simultaneously on the four sampling sites following the standard procedures recommended by Administrative Order 2016-08. In situ, water

Table 1: Description and profile of sampling station sites (PAG-ASA, 2021)

Stations	Description
Station 1: Labangan Poblacion	The station is located at 12˚ 21' 55"N 121˚04'36''E at Labangan, San Jose, Occidental Mindoro. It is located in mangrove areas with riverbanks riprapped with nearby salt farm. The station is characterized by clear water during the dry season and muddy water during the wet season while the river bed is covered with pebble stones. Under the Type A climatic conditions, average temperature in the site is 27.96ºC with rainfall amount 113.23 mm. Most of the land cover is agricultural use and generally residential and commercial areas.
Station 2: San Roque	The station is located at 12˚ 21' 54"N 121˚04'00''E of San Roque, San Jose, Occidental Mindoro. At the station is the Pandurucan Bridge with river water characterized by scattered garbage in the river banks and surrounding mangrove. The water is typically greenish to brownish and a foul smell can be observed. The river bed is covered with muddy clay. The station is also covered of Type A climate conditions with average temperature of 28.29ºC and accumulated rainfall amount during the study period of 3,634.90 mm. Most of the land cover surrounding the station is categorized as highly dense residential, residential and commercial areas.
Station 3: Market area	The station can be found in 12˚ 21' 20"N 121˚03'52'' E with visible residential houses, garbage and waste on the riversides, snail shells in the river banks with greenish to brownish water. A foul smell can also be observed. The river bed is also covered with muddy clay. The station is generally surrounded by residential areas and commercial establishments. The rainfall pattern is the same as Station 2 with an average temperature of 28.32ºC.
Station 4: Downstream-outlet	The station is situated at 12˚ 21' 01"N 121˚03'41''E of Brgy 5, San Jose, Occidental Mindoro. The station point is characterized by residential houses with garbage (diapers and plastics); a mass of soil that separates the river and the sea. There are swimming children can be seen, and the river bed is covered with a sandy bottom. The water is bluish during sunny weather. The station is considered as the outlet of the river since it faces an opening to Mindoro Strait. Average temperature in the station is 28.42ºC.

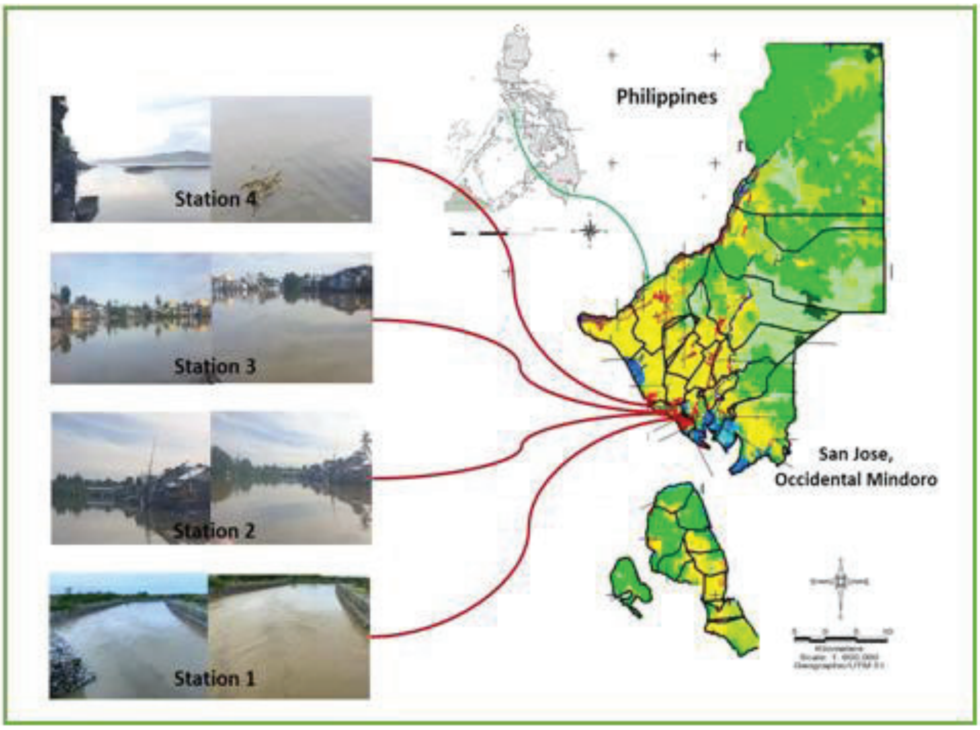


Fig. 1: Geographic location of the study sampling stations at San Jose, Occidental Mindoro, Philippines

quality analyses were done for the temperature, pH, dissolved oxygen, total dissolved solids, and total suspended solids using a multi-parameter probe; while water samples for phosphate, nitrate, chloride were collected and brought for laboratory analysis in Provincial Environmental and Natural Resource Office (ENRO)-Batangas City, Philippines. Samples for E. coli were also brought in ENRO and analyzed using the Multiple Tube Fermentation.

Environmental analysis

Walkthrough analysis was conducted to determine the prevailing conditions in the surrounding environment of the river and to describe the profile of each sampling station. Interviews with the barangay health workers were also conducted to determine the barangay health profile such as population, growth rate, death rate, number of households, and common health problems. A questionnaire with 138 respondents of San Roque and 153 respondents of Labangan was surveyed to determine the water sources and the water use of households.

Water quality index (WQI)

The study adopted the WQI of the Canadian Council of Ministers of Environment. CCME is designed to express water quality information that is easily understood by water managers and the public (CCME, 2001). The calculation of index scores can be obtained using Eq. 1 while, the WQI value for each rank is shown in Table 2.

$$\text{Water Quality Index} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (1)$$

Where;

F_1 = percentage of variables that do not meet the objectives

F_2 = percentage of individual tests that do not meet the objectives

F_3 = amount by which the objectives are not meet

Table 2. Water quality objectives used in the model for aquatic ecosystem and recreational uses (CCME, 2001)

Rank	WQI value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment, conditions very close to natural or pristine level
Very Good	89-94	Water quality is protected with a slight present of threat or impairment, conditions very close to natural or pristine level
Good	80-88	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65-79	Water quality is protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45-64	Water quality frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

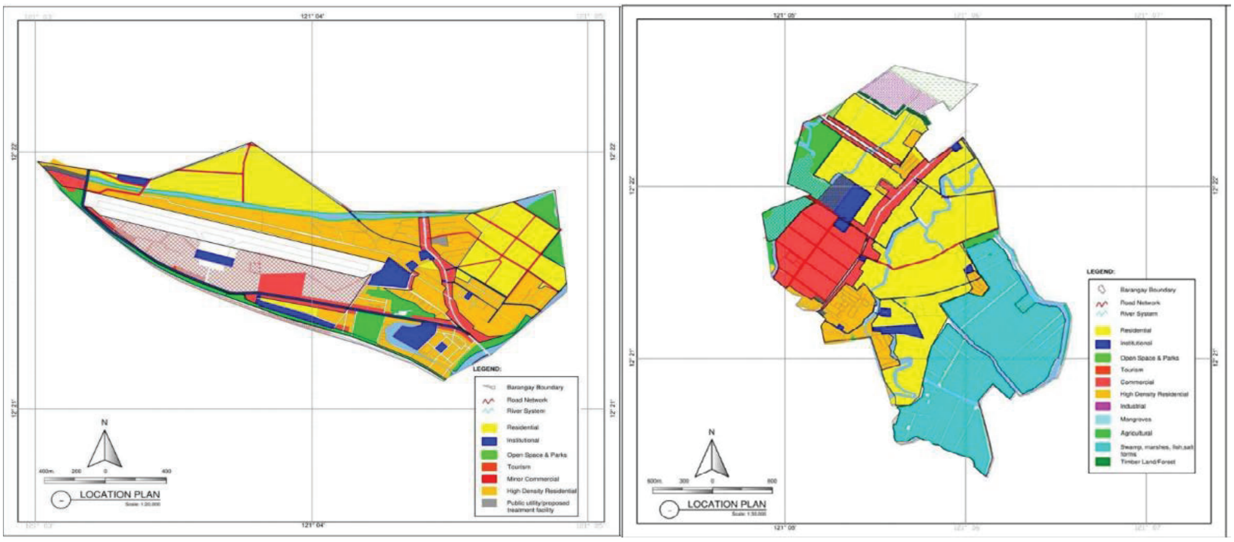


Fig. 2: General land use map of (a) San Roque (b) Labangan Poblacion (LGU San Jose, 2017)

RESULTS AND DISCUSSION

Existing environmental conditions and processes

In general, the land use pattern in San Roque is mostly covered with high-density residential: residential and minor commercial areas. Most of the commercial areas are found along the coast of Aroma Beach and San Jose Airport. The coastal barangay of San Roque is located just a kilometer away from the town of San Jose along the Pandurucan River separating it from the town (Fig. 2). The mode of transportation is mostly thru tricycles that can roam around the town via cemented roads. On the Eastern part of the area is the town proper of San Jose and Bubog: North (LGU San Jose, 2017).

The barangay has a total land area of 335.35 hectares (ha) with 15, 749 populations in 2020. The population growth rate is 1.46% and crude death rate of 4.7% in 2020. 47% of the population belongs to the age group of 15-44 years old; 15% for 45-64 years old; 11% for 10-14 years old and 5-9 years old; 4% for 65 and above; and 2% for 0-11 months. The number of households in the barangay is 3, 610 where 936 households have access to Level I and 1,577 households have Level III water system and the rest from doubtful sources. Also, only 2, 291 of the total household have provision for sanitary toilets (LGU San Jose, 2020). Labangan Poblacion has a total land area of 718.33 hectares mostly covered by residential, swamps, marshes and fish/salt farms, and high-density residential and commercial areas.

Commercial areas include educational institutions, government, and private offices, cockpit, and business establishments. The inland barangay is also a kilometer away from the town proper of San Jose. The barangay is bounded by agricultural barangays at the south; the town of San Jose at the north; Bagong Sikat at the east and the municipality of Magsaysay at the west. Barangay Labangan Poblacion has a total population of 9,744 in 2020. The population growth rate is 1.68% and crude death rate of 3.2% in 2020. 47% of the population belongs to the age group of 15-44 years old; 16% for 45-59 years old; 10% for 10-14 years old and 5-9 years old; 9% for 60 and above; 7% for 1-4 years old; and 2% for 0-11 months. The number of households in the barangay is 2,397 where 622 households have access to Level I, 1,047 households have Level III water systems and the remaining have doubtful sources. Also, only 1,522 of the total household have provision for complete basic sanitation facilities (LGU San Jose, 2020).

Water supply and water use

From the survey conducted to 138 households and 153 households in Brgy. San Roque and Labangan, the general water use is primarily for domestic purposes. 82% of the respondents showed that the major water source is being supplied by the Prime Waters while 18% uses deep wells dug in their backyard. Prime Waters is the only identified water service provider in the municipality of San Jose that uses one deep well and 15 shallow wells (16 pumping houses) as its water sources with one reservoir situated at Brgy. Labangan and has 500 cum capacity. The pumping house located at the municipal hall of San Jose supplies water in Barangays 6, 7, 8, Pag-asa, and Caminawit supported by another pumping house in Doña Consuelo Subdivision. The pumping house is located in Brgy. Bagong Sikat supplies water for the barangays and San Roque area. The distribution line is mainly composed of 150mm PVC, 100mm PVC, and 75 mm PVC. The water supply is treated using chlorination where the dosage of chlorine oxide depends on the capacity of each pump (LGU San Jose, 2020). Most of the households experience unreliable water supply and undesirable water quality. 89% of the respondents used drinking water from the refilling station as the majority complains about the water quality being compromised by the presence of corrosive particles and bad smell due to too much chlorine. The 11% fetched their drinking water from the well; stored in bottled; and the majority drank water directly without any treatment. However, 83 experienced diarrhea where 32 were taken to a health facility while the rest took home remedies.

Drainage pattern

Drainage pattern can also affect the river system as it determines contributing factors and possible sources of contamination. In general, drainage in San Jose is composed of curb type and steel grated box type. However, there are still some areas in the municipality that do not have a reliable drainage system. All existing curbs and gutters in the municipality drain water to the Pandurucan River. While those that are in the area of San Roque drain water in the Bubog River. Fig. 3 shows the drainage system in the study area.

Physical-chemical and E. coli results

Following the procedures for in situ and laboratory analysis, the following results were observed. Water samples consider the wet season and dry season from September 2019 to August 2020 (Table 3). While, Fig. 4 shows the measured concentrations of each sampling station.

Water temperature is one of the most important physical characteristics of aquatic systems as it affects the biological, physical, and chemical processes for plants and animals. As temperature increases, photosynthesis and other chemical and metabolic reactions increase providing adequate nutrients for aquatic life (FOEN, 2012). Measured water temperature in sampling sites ranges from 27.87°C to 33.8°C and is acceptable for all classes of water use and suitable for some fishes and aquatic life as the standards require 26-30ºC for recreational waters. Potential hydrogen or pH indicates the acidity or alkalinity of water with 6.5 to 8.5 as the ideal value. The measured pH in the sampling stations ranges from 7.29 to 7.89. Based on the standards, the values are good for aquatic plants like algae and some fishes. Dissolved oxygen reflects the amount of oxygen dissolved in an aqueous solution as affected by the velocity of water flow, prevailing climate, type and the number of water organisms, amount of water nutrients, and the presence of organic waste and vegetation in the water. DO

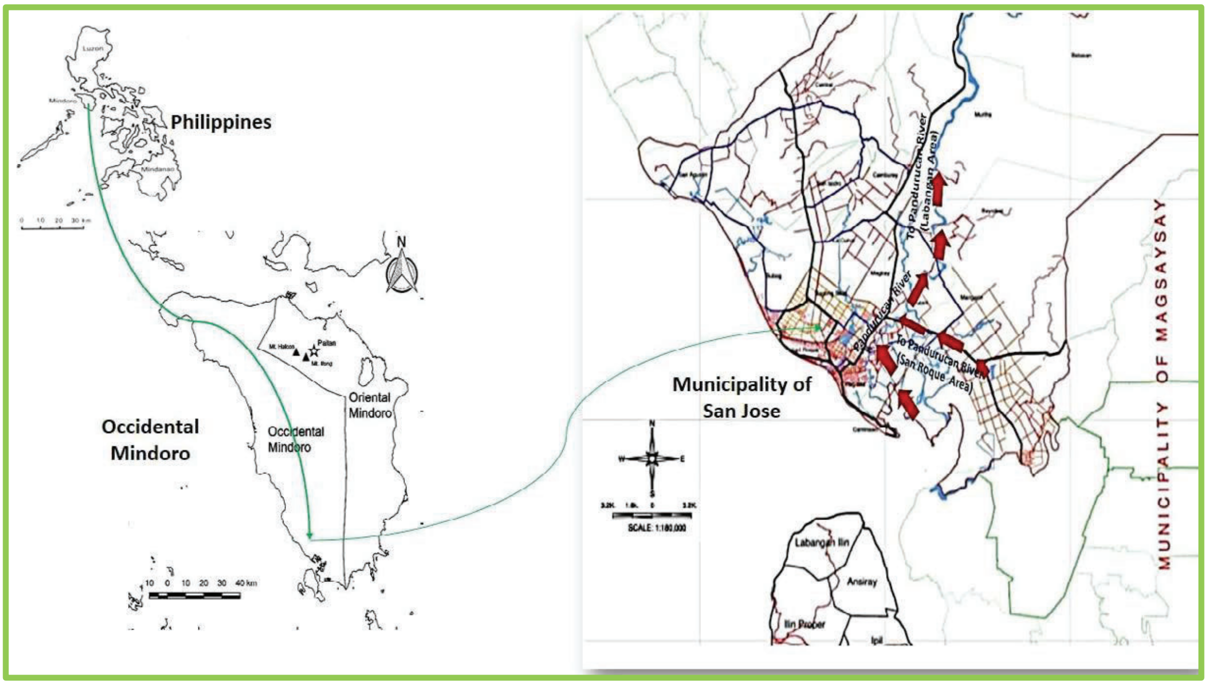


Fig. 3: Geographic location of the study area along with the existing drainage system in San Jose, Occidental Mindoro, Philippines

Table 3: Average concentrations of physical-chemical parameters

Physical-chemical parameters	Wet season				Dry season			
	1	2	3	4	1	2	3	4
Temperature (˚C)	27.87	28.53	29.49	30.61	29.64	32.04	33.3	33.8
pH (units)	7.29	7.57	7.49	7.89	7.44	7.41	7.34	7.42
Dissolved oxygen (mg/L)	6.39	3.92	3.35	3.61	6.35	2.82	2.88	3.34
Total dissolved oxygen (mg/L)	1311	1291	1355	1417	1386	1544	1562	1596
Total suspended solids (mg/L)	28.93	37.43	38.22	38.86	25.63	41.00	41.88	43.46
Phosphate (mg/L)	0.70	2.74	3.07	3.50	0.822	3.58	3.7	4.04
Oil and grease (mg/L)	1.22	2.56	2.72	3.17	1.36	2.94	2.94	4.14
Nitrate (mg/L)	0.44	2.58	2.86	3.11	0.53	3.39	3.47	3.26
Chloride (mg/L)	585.71	623.57	632.14	662.86	744.00	760.00	728.00	714.00
E. coli (MPN/100 mL)	234.71	414.86	442.86	306.57	201.80	242.20	265.4	222.00

level below 5.0 mg/L compromises aquatic life and significantly indicates poor water quality (Liu *et al.*, 2009; Li and Bishop, 2004). Measured DO in stations 2, 3, and 4 showed higher values and beyond the allowable limit. Lower DO in the sampling station is manifested by limited aquatic life with only spire snail shells and other small crustaceans are present. While DOs measured in station 1 were higher than 5.0 mg/L indicating healthy water as fishes and other crustaceans are observed in the site. Suspended solids containing much organic matter may cause putrefaction and consequently lacks dissolved oxygen. The Total suspended solids found in water may include particles of clay, silt, decaying plant and animals, wastes, and sewage caused by water turbidity, high flow rate, and velocity of runoff. Based on the water quality criteria, TSS should not exceed 30 mg/L. The measured TSS on the sampling stations except Station 1 was higher during November and December 2019. TSS tends to increase during wet seasons and decreases during dry months. While Total dissolved solids (TDS) measures the inorganic

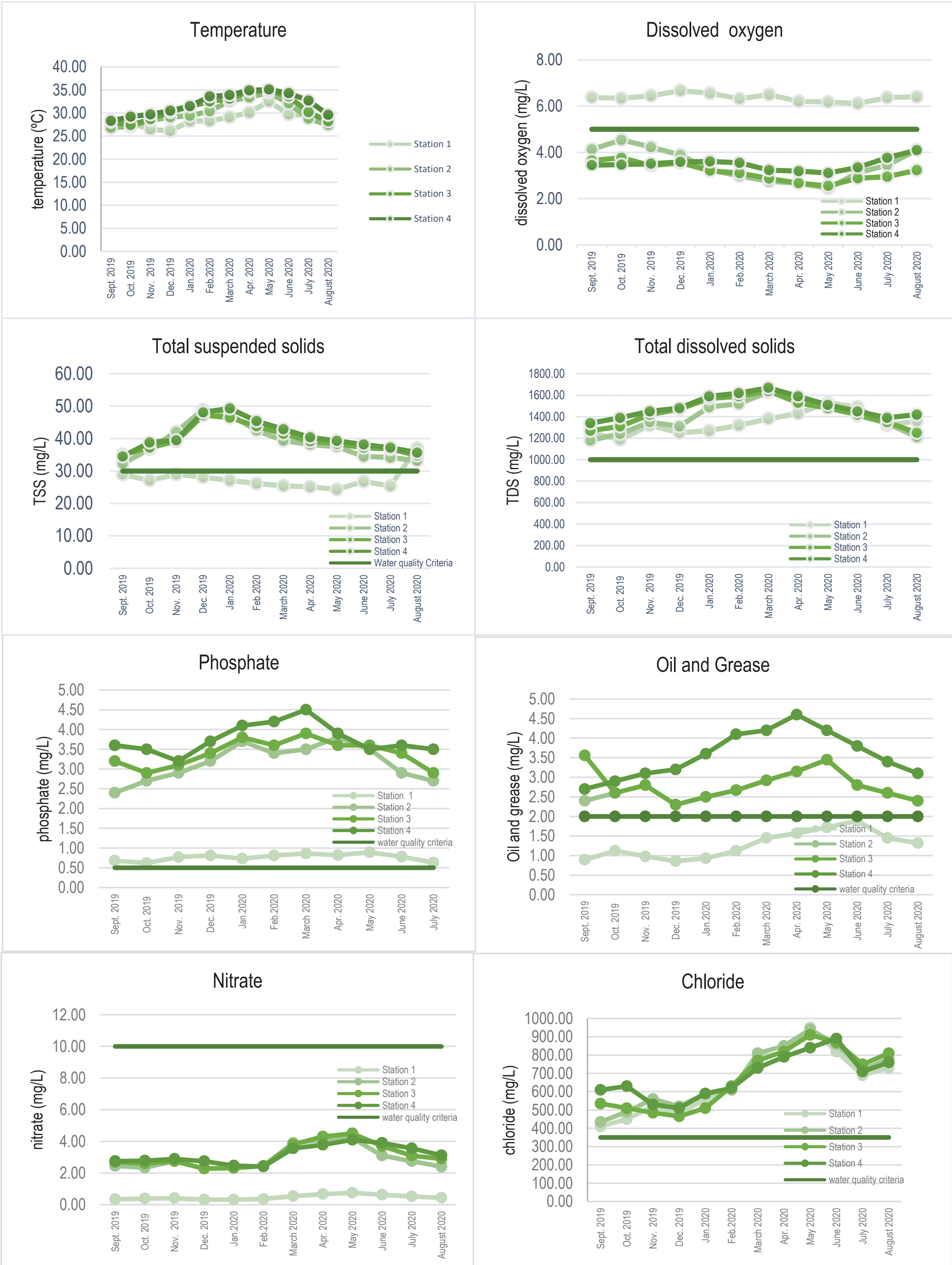


Fig. 4: Measured concentrations of physical –chemical water quality parameters in all stations

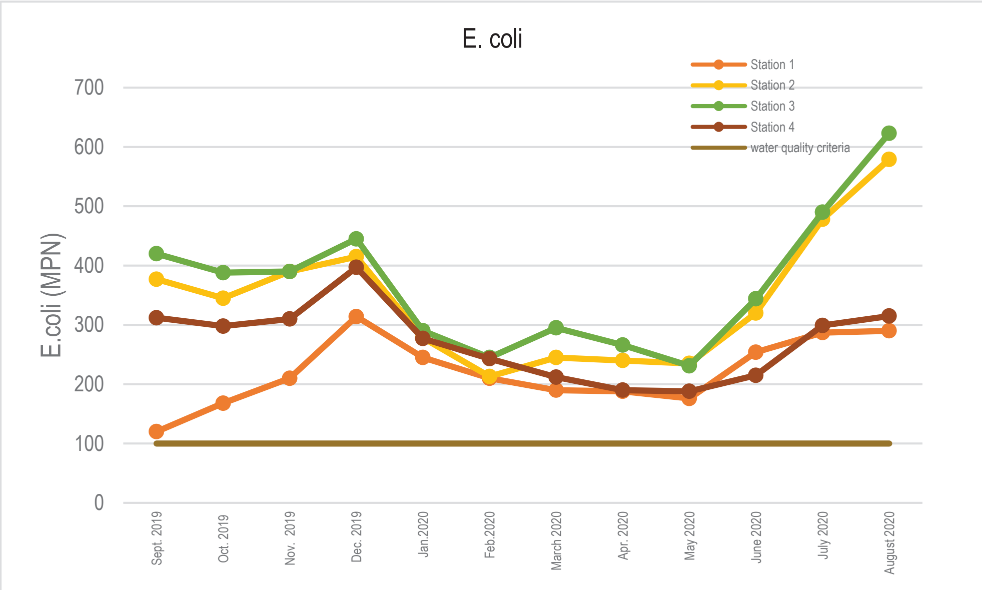


Fig. 5: Measured E. coli in the four sampling stations

salts like calcium, magnesium, and chloride dissolved in water (Bodzin, 2004). TDS affects the taste of water (WHO, 2003), and measured values must not exceed 1000 mg/L to meet the water quality criteria (DENR-EMB, 2016). The measured TSS ranges between 28.93 to 38.86 mg/L during the dry season and 25.63 to 43.46 mg/L during the wet season with only water from station 1 conforms to the water quality criteria. While the measured TDS in all stations exceed the allowable limits with higher values observed during the dry seasons. Higher phosphate can be dangerous to marine organisms causing tremendous development on aquatic bloom and lessen the amount of light in the water thus, decreasing the amount of dissolved oxygen. When algae grow quickly, they die quickly contributing to the organic waste and decomposition of bacteria. The acceptable range of phosphate concentration in river water is 0.50 mg/L (DENR-EMB, 2016). The measured phosphate in four sampling stations ranges between 0.70 to 3.5 mg/L during the wet months and 0.82 to 4.04 mg/L during the dry months. The algae are commonly observed in the river banks and with higher phosphate concentrations, limited aquatic life is observed and deprived of sufficient oxygen (Khan *et al.,* 2006). Oil and grease can damage the aquatic environment and interfere with aerobic and anaerobic biological processes. Measured concentrations for oil and grease were higher during the dry months as it ranges between 1.08 to 3.5 mg/L with water samples from Station 1 conforms to the acceptable limit of 2 mg/L. Oil films are also observed in water surfaces of stations, 2, 3, and 4 indicating the presence of contaminants (Moslem *et al.,* 2013) comprising the usability of the river system (US EPA, 1999). The allowable limit for nitrates concentration is 10 mg/L and an excessive amount may lead to algal bloom causing depletion of oxygen affecting the aquatic life (DENR-EMB, 2016). The measured concentrations of nitrate in the four sampling stations do not exceed the allowable limit but higher values were measured during March and May where agricultural activities are dominant in the surrounding environment as runoff from nitrogen fertilizers, domestic wastewater, human and animal waste are commonly observed (Wright *et al.,* 2004). Chloride is a measure of sodium and potassium content of the water samples and must be less than 350 mg/L for freshwater (DENR-EMB, 2016). High chloride in the water body indicates saltwater intrusion. All water samples in all stations exceed the normal value for the freshwater significantly describing that the water is salty.

E. coli is a common bio-indicator of water

Table 4: Computed WQI in each station

Stations	Computed WQI	Rank	Description
Station 1	60.06366	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Station 2	35.20767	Poor	
Station 3	30.64781	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.
Station 4	30.17662	Poor	
Average	39.023945	Poor	

pollution and indicator of contamination, diseases, and unsafe drinking (Ram *et al.*, 2008; Yogendra *et al.*, 2008). The E. coli is measured by the Most Probable Number per 100 mL of water sample (MPN/100 mL) and must not exceed 100MPN/100 mL for recreational uses (DENR-EMB, 2016). Results of the microbial analysis show the presence of E. coli in all water samples (Fig. 5). Higher values were measured in Station 3 particularly from November to December 2019 and from June to August 2020.

Following the mathematical framework of CCME in assessing the ambient water quality, the computed water quality index on the four sampling stations generally described that the water samples do not meet the allowable requirement of water quality. The average WQI described that the water is poor and always threatened and compromised by the surrounding environment (Table 4).

Statistical analyses

One-way ANOVA was employed to determine the significant relationship of ten water quality parameters measured in four sampling stations. The result shows a p-value of 0.232 and 0.09659 for pH and chloride. The measured concentrations on other parameters were generally similar. Stations 2 and 4 have the highest value of pH and chloride concentrations. Station 2 generally receives the pH concentrations from Station 1 as it is surrounded by salt farms and other industrial effluents. As water flow in station 2 is slower, much of the concentrations settled in the site. Station 4 is located where seawater freely intrudes the site that contributed to the increase chloride concentrations. Since the monitoring covered the wet and dry seasons, significant differences on the variation of seasons to the measured concentrations were determined using one-way ANOVA. January to May was considered as dry seasons as no rainfall was measured, while June to December was considered as wet months. Results show that pH, dissolved oxygen, total suspended solids, phosphate, oil and grease, nitrate, and E. coli vary significantly with seasons with p-values of 0.259, 0.682, 0.669, 0.603, 0.569, 0.672, and 0.0587, respectively. Measured concentrations for pH, DO and E. coli were higher during the wet seasons which can be attributed to surface runoff, septic tanks overflow, and flooding during the rainy seasons. TSS, phosphate, oil and grease, and nitrate were higher during the dry seasons and can attributed to the increased in agricultural and economic activities, farming and fishing, and agricultural wastes that were intercepted in the river system.

Proposed interventions and management plan strategies

The economic, industrial, and agricultural activities contributed to the measured concentrations of water quality parameters in Pandurucan River. The poor management of river water compromises the quality of water that limits the available benefits for San Joseños. The lack of a municipal sewage system that should collect the solid and wastewater from septic tanks; the drainage system that directly goes into the river; the indiscriminate waste disposal of the surrounding community; and the lack of concrete policies to safeguard the river are the major contributing factors that lead to the deterioration of the Pandurucan River. Reviving the river will become possible if policymakers, water managers and the community will work hand in hand on minimizing the sources of pollution. Provision for sewerage system and improvement of the drainage system must be initially considered by the local government unit to provide a proper system for the collection and disposal of garbage and wastes. Encouraging the community to practice proper garbage segregation and disposal and build septic tanks will help lessen the indiscriminate disposal of garbage into bodies of water. Cleaning activities on river beds and banks will help improve the river's flow pattern and velocity. More importantly, implementation of policies and ordinances that will promote preservation and restoration of the river water to enlighten the community to become aware, participate, and support all intervention measures.

CONCLUSION

The water quality management plan of Pandurucan River presents the physical-chemical and microbiological characteristics of the water quality standards of DAO 2016-08. From the four sampling stations, grab water samples were taken and in-situ and laboratory tests were performed to obtain the desired objectives. Four of nine physical-chemical parameters failed to meet the water quality standards: phosphate measured ranges between 2.40-4.50 mg/L exceeding the allowable 0.50mg/L; oil and grease measured were found to exceed the standards of 2 mg/L with measured values of 2.40-4.60 mg/L in stations 2, 3 and 4; while measured chloride in all stations exceeds the freshwater requirement of 250mg/L; and the measured TSS in stations 2, 3 and 4 ranging from 32.30 to 49.3 mg/L exceeds the 30mg/L standards. The detected E. coli in all sampling stations indicates the presence of contaminants in the river. The results show that river water is not safe for recreational purposes like swimming and bathing as accidental intakes and skin contact on contaminated water can cause health problems. The garbage collection and disposal of the surrounding community contributed to the sources of pollution in the river as most of the households do not have reliable sanitation facilities. The lack of a dependable drainage system in the municipality also contributed to the source of contaminants as collected water in the curb and box-type drainages drain directly in the river. These practices and activities contribute to the Poor water quality index computed in the study area. As the local government unit aims to rehabilitate the Pandurucan River to become a tourist destination, this study can serve as a framework in the water quality management plan and provide a scientific basis to establish policies and guidelines in the surrounding community. The interventions, management, and rehabilitation strategies must be first initiated by the policymakers and should involve the stakeholders, water managers, and the community in improving and protecting the water quality. As an initial undertakings in the study area; the water quality parameters; calculated WQI, sources of contaminants determined in this study will serve as input data on the study related to the fate and transport of bacteria and calculate the associated heath risk if water is ingested or accidentally taken.

AUTHOR CONTRIBUTIONS

M. Enriquez performed the experimental design, analyzed and interpreted the data, prepared the manuscript text and manuscript revision. R. Tanhueco checked the experimental design, interpretation of data, manuscript text and manuscript revision.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Science and Technology-Engineering Research and Development for Technology for the research grant (ERDT Project: RPSM 19-20 1344); the Local Government Unit of San Jose, Occidental Mindoro Philippines for the Comprehensive Land and Water Use Plan used in the study; Department of Science and Technology-San Jose, Occidental Mindoro, Philippines for the weather data; Ms. Myra Maniago and Ms. Rose Real- Barangay Health Center of Labangan Poblacion and San Roque for the barangay health profile; and the respondents of the survey for their valuable time in answering the survey.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

ABBREVIATIONS

%	Percent
ANOVA	Analysis of variance
Brgy.	Barangay
CCME	Canadian Council of Ministers and Environment
ºC	Degree Celsius
DAO	Department of Environment and Natural Resources Administrative Order
DENR-EMB	Department of Environment and Natural Resources- Environmental Management Bureau
DO	Dissolved oxygen
E. coli	Escherichia coli
ENRO	Environment and Natural Resources Office
Eq.	Equation
Fig.	Figure
ha	Hectare
LGU	Local Government Unit
mg/L	Milligrams per liter
mL	Milliliter
mm	Millimeter
MPN	Most Probable Number
OMSC	Occidental Mindoro State College
PAG-ASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
pH	Potential Hydrogen
p-value	Probability value
PVC	Polyvinyl chloride
RA 9275	Republic Act 9275
TDS	Total dissolved solids
TSS	Total suspended solids
WHO	World Health Organization
WQA	Water Quality Analysis
WQI	Water Quality Index
WQMP	Water Quality Management Plan
US EPA	United States Environmental Protection Agency

REFERENCES

Adamu C.I.; Nganje T.N.; & Edet A., (2015). Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, Southeastern Nigeria. Environ. Nanotechnol. Monit. Manage. 3: 10-21 (**12 pages**).

Akter T.; Jhohura F.T.; Akter F.; Chowdhury T.R.; Mistry S.K.; Dey D.; Barua MK.; Islam MA ; Rahman M., (2016). Water Quality Index for measuring drinking water quality in rural Bangladesh: a cross-sectional study. J Health Popul Nutr., 35(4), (**12 pages**).

Azizi, A.; Malakmohamadi, B.; Jafari, H.R., (2016). Land use and land cover spatiotemporal dynamic pattern and predicting changes using integrated CA-Markov model. Global J. Environ. Sci. Manage., 2(3): 223-234 **(12 pages).**

Bartram J.; Ballance R., (1996). Water quality monitoring- a practical guide to the design and implementation of freshwater quality studies and monitoring programs. UNEP and WHO.

Bodzin A., (2004). Phosphates in the stream. Pennsylvania, USA.

CCME, (2001). Canadian Water Quality Index 1.0 Technical report and user's manual. Canadian Council of Ministers of the Environment. Canadian Environmental Quality Guidelines Water Quality Index Technical Subcommittee, Gatineau, QC, Canada.

Debels P.; Figueroa R.; Urrutia R.; Barra R.; Nielle X., (2005). Evaluation of water quality in the Chillan River ´ (Central Chile) using physicochemical parameters and a modified water quality index. Environ. Monit. Assess., 110: 301–322 **(22 pages).**

Decena S.C.; Arguelles M.S.; Robel L.L., (2018). Assessing heavy metal contamination in surface sediments in an urban river in the Philippines. Pol. J. Environ. Stud., 27(5): 1983-1995 **(13 pages).**

DENR-EMB, (2016). Water quality guidelines and general effluents standards of 2016. Department of Environment and Natural Resources-Environmental Management Bureau.

FOEN, (2012). Indicator water temperature of surface waters.

Department of the Environment, Transport, Energy and Communications. Federal Office for the Environment.

Cabacungan G.C., (2016). Water crisis looms in Metro Manila. Philippine Daily Inquirer, Philippines.

Gorme J.B.; Maniquiz M.C.; Pum S.; Lee-Hyung K., (2010). The water quality of the Pasig River in the city of Manila, Philippines: Current Status, Management and Future Recovery. Environ. Eng. Res., 15(3): 173-179 **(7 pages).**

Khan S.; Lau S.L.; Kayhania M.M.; Stenstrom M.K., (2006). Oil and grease measurement in highway runoff sampling time and event mean concentration. J. Environ. Eng., 132: 415-422 **(8 pages)**.

Liu J.; Dong H.W.; Tang X.L., (2009). Genotoxicity of water from the Songhua River, China, in 1994– 1995 and 2002–2003: potential risks for human health. Environ. Pollut., 157(2): 357- 364 **(8 pages).**

Li B.K.; Bishop P.L., (2004). Oxidation-reduction potential changes in aeration tanks and micro profiles of activated sludge floc in medium- and low-strength wastewaters. Water Environ. Res., 76(5): 394–403 **(10 pages).**

LGU San Jose, (2017). Municipal disaster risk reduction plan 2017-2021. LGU-San Jose, Occidental Mindoro. Local Government Unit of San Jose, Occidental Mindoro.

LGU San Jose, (2020). Barangay Health Profile. LGU-San Jose, Occidental Mindoro. Local Government Unit of San Jose, Occidental Mindoro.

Maglangit F.F.; Galapate R.P.; Bensig E.O., (2014). Physicochemical-assessment of the water Quality of Buhisan River, Cebu, Philippines. Int. J. Res. Environ. Sci. Tech., 4(2): 83-87 **(5 pages).**

Martinico-Perez M.G.; Hara J.P.; Cabrestante M.P., (2019). Evaluation of Water Quality of Major Rivers in Palawan, Philippines Using Physico-Chemical Parameters and Water Quality Index. NSO.

Martinez F.B.; Galera, I.C., (2011). Monitoring and evaluation of the water quality of Taal Lake, Talisay, Batangas, Philippines. Acad. Res. Int., 1(1): 229-236 **(8 pages).**

Mohiuddin K.M.; Ogawa Y.; Zakir H.M.; Otomo K.; Shikazono N., (2011) Heavy metals contamination in water and sediments of an urban river in a developing country. J. Environ. Sci. Tech., 8 (4): 723-736 **(13 pages).**

Moslem S.; Ramezanpour Z.; Imanpour J.; Mahmoudifard A.; Rahmani T., (2013). Water quality assessment of the Zarivar Lake using physico-chemical parameters and NSF-WQI indicator, Kurdistan Province-Iran. Int. J. Adv. Biol. Biomed. Res., 1(3): 302-312 **(11 pages).**

Neri A.C.; Wee V.P.; Hoyohoy G.B., (2012). Water Quality of Mantayupan River in Barili, Cebu, Philippines. Ann. Trop. Res., 34(2): 95-111**(17 pages).**

PAG-ASA, (2021). Meteorological data of San Jose, Occidental Mindoro. Philippine Atmospheric Geophysical and Astronomical Services Administration.

Parry M.; Canziani, O.; Palutikof J.; Van Der Linden P.; Hanson C., (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Printed in USA at the University Press, New York.

Purushothaman P.; Chakrapani G.J., (2007). Heavy metals fractionation in Ganga River sediments, India. Environ. Monit. Assess., 132(1-3): 475-489 **(15 pages).**

Ram S.; Vajpayee P.; Shanker, R., (2008). Contamination of potable water distribution systems by multi antimicrobial-resistant enterohemorrhagic Escherichia coli. Environ. Health Perspect., 116 (4): 448-452 (**5 pages**).

Razzaghmanesh M.; Mohammai K.; Samani J.M.V., (2005). A river quality simulation using WASP6: case study. 9th Environmental Engineering Specialty Conference, Toronto, Ontario, Canada. 2nd-4th June.

Regmi R.K.; Binaya K.M., (2016). Use of water quality index in water quality assessment: A case study in the Metro Manila. Water and Urban Initiative Working Paper Series.

Said, A.; Steven, D.K.; Sehlke, G., (2004). Environmental assessment: An innovative index for evaluating water quality in streams. Environ. Manage., 34 (3): 406-414 **(9 pages).**

Skordas K., Kelepertzis E., Kosmidis D., Panagiotaki P., Vafidis D., (2015). Assessment of nutrients and heavy metals in the surface sediments of the artificially lake water reservoir Karla,Thessaly, Greece. Environ. Earth. Sci., 73: 4483-4493 **(11 pages).**

USEPA, (1999.) Understanding oil spills and oil spill response. United States Environmental Protection Agency.

US EPA, (2005). Designing water quality monitoring programs for watershed projects. United States Environmental Protection Agency.

Wei B.; Yang L., (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchem. J. 94: 99-107 **(9 pages).**

Wright J.; Gundry S.; Conroy R., (2004). Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. Med. Int. Health. 9(1): 106-117 **(9 pages).**

WHO, (2012). Guidelines for Drinking-water Quality, Fourth Edition, World Health Organization.

WHO, (2003). Total dissolved solids in drinking-water: Background document for development of WHO Guidelines for drinking-water quality. Originally published in guidelines for drinking-water quality, 2nd ed. Vol. 2. Health criteria and other supporting information. World Health Organization, Geneva.

Wu Z.; Wang X.; Chen Y.; Cai Y.; Deng J., (2018). Assessing river water quality using water quality index in Lake Taihu Basin, China. Sci., Total Environ. 612: 914-922 **(9 pages).**

Yogendra K.; Puttaiah E.T., (2008). Determination of water quality index and suitability of an urban water body in Shimoga Town, Karnataka. Proceedings of Taal 2007. The 12th World Lake Conference. 342-346 **(5 pages).**

AUTHOR (S) BIOSKETCHES

Enriquez, M.D., Ph.D. Candidate, Instructor, Gokongwei College of Engineering, De La Salle University, 524-4611 Philippines.
Email: *michelle_d_enriquez@dlsu.edu.ph*
ORCID: 0000-0002-1618-6335

Tanhueco, R.M., Ph.D., Professor, Gokongwei College of Engineering, De La Salle University, 524-4611 Philippines.
Email: *renan.tanhueco@dlsu.edu.ph*
ORCID: 0000-0001-5792-9871

HOW TO CITE THIS ARTICLE

Enriquez, M.D.; Tanhueco, R.M., (2022). A basis water quality monitoring plan for rehabilitation and protection. Global J. Environ. Sci. Manage., 8(2): 237-250.

DOI: 10.22034/gjesm.2022.02.07

url: https://www.gjesm.net/article_245946.html

Global J. Environ. Sci. Manage. 8(2): 251-264, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

Impact of road infrastructure equipment on the environment and surroundings

N. Robinah [1], A. Safiki [1,2,*], O. Thomas [1], B. Annette [1]

[1] *Department of Lands and Architectural Studies, Faculty of Engineering Kyambogo University, Kyambogo, Uganda*

[2] *Department of Construction Economics and Management, School of Built Environment, College of Engineering, Design, Art and Technology, Makerere University, Kampala, Uganda*

ARTICLE INFO

Article History:
Received 14 May 2021
Revised 29 July 2021
Accepted 02 September 2021

Keywords:
Effects
Emissions
Noise
Road Infrastructure equipment
Vibrations

ABSTRACT

BACKGROUND AND OBJECTIVES: The effect of infrastructure equipment is taking a toll on the health and economic well-being of residents all around the world. This is mainly because it contributes to ambient air pollution, noise, and vibration in the surroundings. The study aimed at analyzing the effects of the road infrastructure equipment on the surroundings in Uganda. The emissions of carbon dioxide, carbon monoxide, nitrogen dioxide, hydrocarbons, and particulate matter were analyzed.

METHODS: Six road infrastructure equipment were sampled consisting of an excavator, roller, grader, concrete mixer, tamper, and wheel loader, obtained from a case study project in Kampala city, Uganda. The diesel exhaust air emissions were computed and analyzed using the emissions rate equation model for non-road equipment, developed by Environmental Protection Agency. This was based on the horsepower and power rating of the equipment. Noise and vibrations levels were obtained using a sound level meter, seismometers, and accelerators, while following the National Environment Regulations.

FINDINGS: The greenhouse gas of carbon dioxide was the most predominant accounting for 84.1 percent of the total emissions. The grader was the highest emitter of this greenhouse gas, at 1,531.5 g/h, representing 37.1%. The lowest air pollutant emission was nitrogen dioxide at 1.43 g/h for the concrete mixer, representing 1.4%. Overall, the equipment emitted more greenhouse gases than air criteria pollutants at 88.8% and 11.2% respectively. The highest criteria air pollutant was particulate matter at 100.5 g/h, emitted by the grader. Most of the emissions met the standards stipulated by Environmental Protection Agency, for reducing emissions back to the environment, except particulate matter. However, the concentrations of some pollutants like carbon monoxide and nitrogen dioxide did not satisfy the limits required for ambient air quality that is safe for workers. All the equipment had noise levels way above the recommended 70.00 decibel, except for the wheel loader. Only the excavator produced vibrations higher than permissible vibration limit by 4%.

CONCLUSION: The criteria air pollutants of carbon monoxide, nitrogen dioxide, and particulate matter emitted by the equipment were all not safe to the workers. They exceeded the permissible limits of 50 ppm, 5 ppm, and 0.02 g/kW/h respectively. This partly shows why ambient air pollution had been reported in urban centers in Uganda. The study shows the need for strengthening the regulations and monitoring of the construction equipment being used, in order to protect the surroundings.

DOI: 10.22034/gjesm.2022.02.08

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
50	5	4

*Corresponding Author:
Email: *sainomugisha@kyu.ac.ug*
Phone: +256 7019 87760
ORCID: 0000-0001-7425-5442

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the “Show Article.

INTRODUCTION

In 2016, approximately 91 percent of the urban population worldwide was reported to take in air breath that is below the World Health Organization (WHO) air quality requirements of particulate matter ($PM_{2.5}$). Close to more than half of that were exposed to air pollution, 2.5 times greater than the safety standards. Approximately, 4.2 million people are said to be dying due to pollution levels of ambient air and premature lives of 0.8 million lost annually due to approximately $PM_{2.5}$ in the earth's atmosphere. In 2018, WHO reported that the effects of exposure to air pollution resulted to death of 7 million people, with the worst hit nations being developing countries.

While particulate matter was reported as the most severe in cities around the world, other ambient air pollution sources discovered included CO, NOx, and HC. Uganda has not been spared by these problems due to its average annual urbanization growth rate of 2.0%. About 16% urbanization in 2014 was reported and is predicted to reach 32% urbanization by the year 2050 (World Urbanization Trends, 2014). This urbanization is said to keep pace with an increase in construction activities. As a result, there is more utilization of construction machinery, resulting into increase d demand for petroleum products (diesel) (UBOS, 2015), which increases the air pollution emissions. This is why Matagi (2002), reported that due to increased motorized diesel consumption and resurgence of economic activities, there was increased noise pollution and dust emissions resulting in nasal and bronchial discomfort. In 2014, a survey on the air quality in Uganda's city Kampala for both particulate matter $PM_{2.5}$ and coarse particles, concentrations were obtained way above 100 µg/m^3. Carbonaceous aerosol was between 35 – 55% (Schwander *et al.,* 2014). An analysis of ambient air pollution levels and their effects on the lung function of children in Kampala city and Bwenge sub-county a low developed area, revealed that children in high ambient sites exhibited lower lung function. This was attributed to the high $PM_{2.5}$ levels in Kampala of 177.5 µg/m^3. These children suffered underweight and cough which were associated with low lung function (Kirenga *et al.,* 2018). Much as studies have been conducted worldwide to indicate this air pollution in many cities around the world, Sub-Saharan Africa has had the least studies attempting to contribute to the data needed to monitoring and regulating of ambient pollution (Schwela, 2012). In addition, Agricultural lands and human-built environment constitute the majority of changes and are increasing continuously (Azizi *et al.,* 2016). In Uganda, some attempts have been made to characterize the ambient air pollution, however, hardly any studies can be reported focusing on analyzing the likely causes of this air pollution. Worldwide, the construction industry is the third-highest pollution emission contributor after oil and gas and chemical manufacturing sectors. This equipment pollution of CO_2 makes it the third emitter per unit of energy used just after cement and steel production industries (Avetisyan *et al.,* 2011). Greenhouse gases mainly are emitted during the construction materials' production (Balasbaneh *et al.,* 2017; Akan *et al.,* 2017). The other air emission pollutants also coming from the construction equipment include CO, NOx, and PM, constituting the most common exhaust pollutants as categorized by the Environmental Protection Agency (EPA, 2017). Greenhouse gases originating from the construction industry due to diesel consumption by the construction equipment (Moretti *et al.* 2018) are seen in a multitude of studies like Marzouk *et al.,* 2017; Alzard *et al*., 2019; Fan 2017; Zhang *et al.,* 2017. The construction equipment accounted for 29% of diesel exhaust emissions only second to on-road vehicles in Oregon State in USA (DEQ, 2017). Montadka (2017), also identified dust plus emissions from diesel exhaust of construction equipment as part of the long run harmful emissions affecting the health of workers. Particle pollution was identified by Giunta *et al.* (2019) and Giunta (2020) to be emitted by this equipment. This pollution was said to produce the highest perceived and undesired effects from the construction industry to the surrounding communities. The impact of the construction equipment has even gone a long way to account for numerous disputes, like legal disputes from noise pollution (Kwon *et al.,* 2017). The equipment on the other hand has been reported to produce other harmful effects from vibrations. These result in damage to infrastructures like buildings, affect humans by causing whole body or vibration white finger, and become a nuisance for the local population in the surrounding areas (Svinkin, 2004). However, much as studies have been reported worldwide on ambient air pollution, noise and vibration effects, in Uganda, there is a lack of clear information about the sources of the high ambient air pollution levels reported in its urban centers. This is evidenced by a paucity of literature on the same, yet there is continuous high urbanization infrastructure developments ongoing. This leaves a gap for studies which can assess and establish whether the high ambient air pollution reported in its cities and towns could be from the high construction developments. This is in line with what has been recommended by other studies on the need for increased research in towns of developing nations in Sub-Saharan Africa so as to serve as useful data. This will also inform the environmental protection agencies on which sectors to focus on, while regulating and monitoring air pollution. This will quantify and predict air emissions at the scale of individual equipment, hence covering up on the limited database (Heidari *et al.,* 2015). A road infrastructure project taking place in Kampala city was taken a case study. Kampala was selected because it's characterized by a rapidly growing population and a stable growing economy with many infrastructure developments taking place. This has seen a rapid increase in vehicular traffic, which has necessitated the expansion of its road infrastructure. Kampala has a population of approximately 1.52 million, with a population density of about 7,715 persons per square kilometer. About 0.79 million live within the central business district of this city, where the case study road construction project was selected. The city has been ranked among the top fifteen fastest growing cities in the world with an annual average growth rate of 4.03% as per City Mayors Statistics (CMS, 2018). Illnesses noted as a result of exposure to high concentrations of diesel exhaust include dizziness, irritation of the eyes, nose, throat; headache; respiratory disease like asthma, and lung cancer (OSHA, 2017). These health problems are experienced by both the road construction workers and the people within the surrounding areas where this equipment is being used. Therefore, the aim of this study is to analyze the impact of road infrastructure equipment on the surroundings in terms of air pollutant emissions, noise, and vibrations on a selected road infrastructure project in Kampala city, Uganda in 2019.

MATERIALS AND METHODS

The study was a case study approach which employed a purposive sampling technique to come up with the case study project selected, following Battaglia *et al.* (2008) guide. The selected project was considered to best represent the many projects ongoing in various urban centers in Uganda. It consisted most of the non-road construction equipment that had been identified by other studies to contribute to air pollutant emissions. All the equipment taken as the sample because of the small equipment population (Israel, 1992). The hypothesis of the study was that most equipment produced high emissions above the acceptable standards. Also, it hypothesized that the noise and vibration levels produce are above the permissible levels. The data on emissions, noise, and vibration levels for the six road transportation construction equipment were obtained. Particularly this was collected from the road construction project on Namirembe road, central division, Kampala city area (Fig. 1). The project consisted activities like excavation, soil grading, loading, offloading, and compaction at the time of data collection. The construction equipment considered in the study included an excavator, grader, concrete mixer, roller, tamper, and wheel loader as indicated in Fig. 2a. Their extensive use in the ongoing projects makes them well suited to represent the construction equipment generally used in the urban centers.

Overview of the study area

Uganda's geographical location is on the coordinates of latitude $4^0$12'N and $1^0$29'S and longitude $29^0$34'E and $35^0$0'E. The population stands at 34.9 million, with 6.4 million staying in urban centers as per the 2014 population census. The road infrastructure network in the country of paved roads was reported to have risen from 3,489 km to 3,795 km between 2013 and 2014. Kampala is its capital city and is located in the central region of the country. Its geographical coordinates are $0^0$15'N and 32^0 30'E, and is about 45 km in the northern part of the equator and about 8 Km above Lake Victoria. It is 1300 m above the sea level.

Project descriptions for the case study

Namirembe road-works was the selected project, one of the many infrastructure developments taking place in the central business district of Kampala city. The project was to be built a non-motorized one-way 3.5 km road, whose construction was meant to commence in 2015 but started in November 2018.

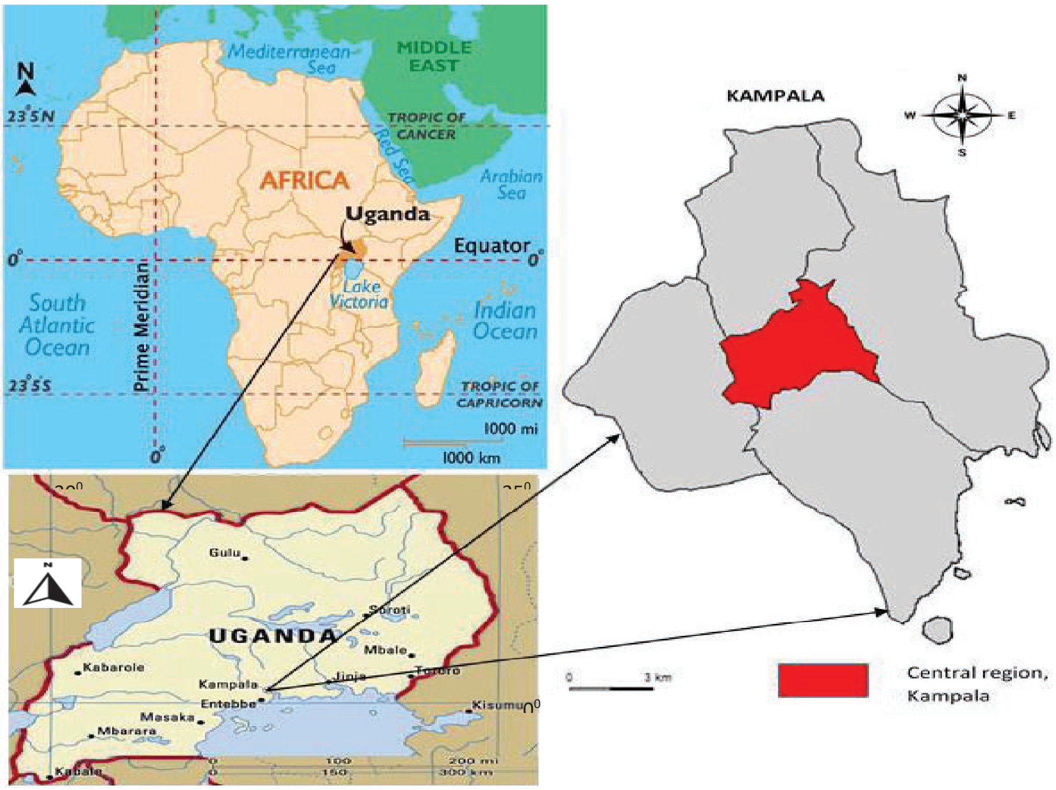


Fig. 1: Geographic location of the case study in Central region, Kampala city, Uganda

The project was a 3 billion Uganda shillings project, funded by the World Bank, and executed by M/S Stirling Engineering LTD. The project employed 3 rollers-flat and foot, 2 wheel loaders, 2 graders, 1 bulldozer, 2 excavators, 3 hand-held tampers, and 1 concrete mixer. The project employed about 60 workers both skilled and unskilled. It is part of the street construction projects, which are dealt with in categories of new construction, rehabilitation, and resurfacing in urban centers. It was also selected because it typically suited Barati and Shen (2016) conditions, and its categorization was of the projects which consist most of the top 10 construction equipment, considered as the highest contributors to NOx, CO, and PM as per (EPA, 2005).

Measurement of research data

To achieve the objectives of the study, several procedures as identified from previous studies were adopted for measuring the data required. The study centered on field data recording, modelling, observations, and participation. Field visits were made to the road construction site to obtain the required data for analysis. The Fig. 2b is a flowchart of the methodology used to obtain the air emissions, noise, and vibrations from the equipment studied. The non-road (EPA, 2008) and the off-road- California Air Resources Board (CARB, 2009) models were used to compute emissions of the sampled construction equipment. These categorize emission rates according to the type of equipment basing on horsepower/ power rating group on the measured CO_2, CO, NO_x, CH, and PM pollutants. This is different from other numerous models which use fuel consumed and coefficients attached to them, but not based on the equipment type (Ahn *et al.,* 2009). The model was based on the horsepower (hp) and power rating (kW) of the selected study sample equipment (Fig. 2a). Their emission factors and load factors were obtained from secondary data.

Emissions were calculated using Eqs. 1 and 2 to ascertain the emission rates of the respective equipment per hour. This was based on other studies' finding like Heidari and Marr (2015) who found

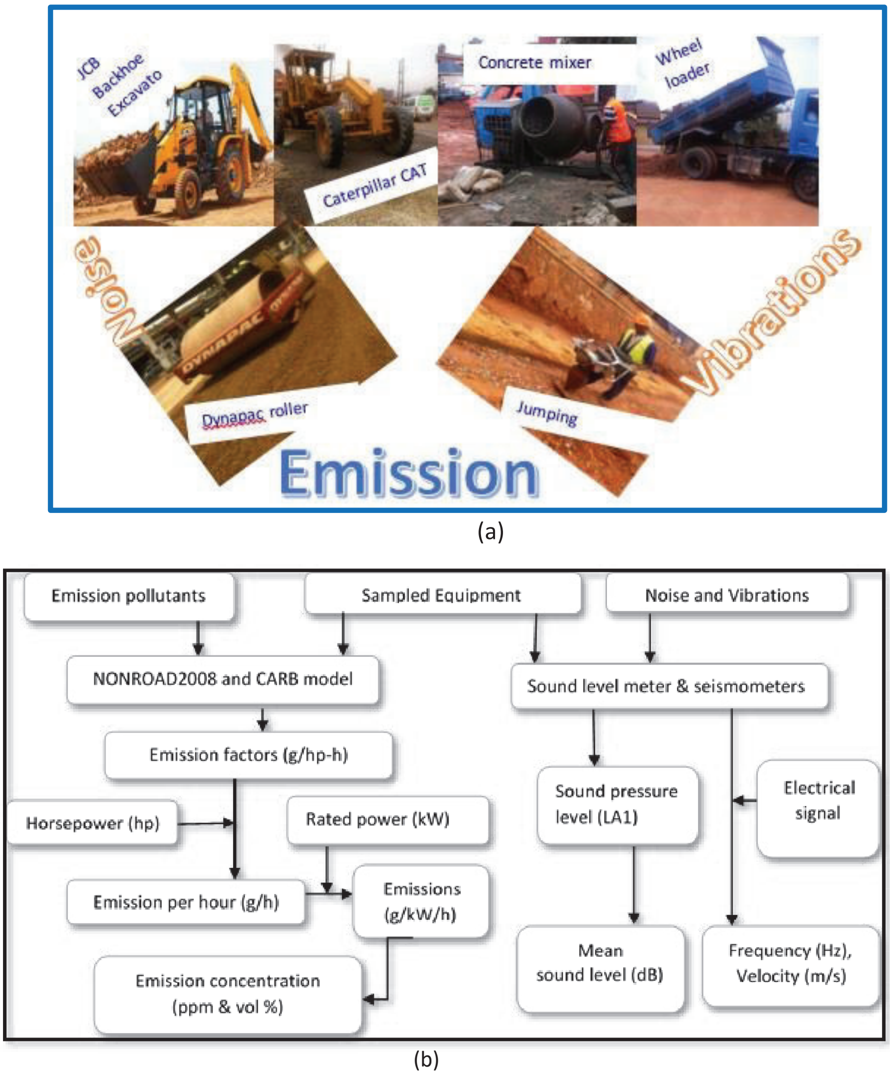


Fig. 2: The different; a) road infrastructure equipment studied; b) methods used schematic diagram

that there is much agreement between modelled emissions and real-time emissions for a number of equipment studied. The emission rates from construction equipment were calculated for the 5 air pollutants selected.

$$\text{Emissions rate}\left(g/h\right) = \text{Engine power}\left(hp\right) * \text{Emissions factor}\left(\frac{g}{hp-h}\right) * \text{load factor} \quad (1)$$

$$\text{Emissions rate}\left(g/kW/h\right) = \frac{Emission\,rate\,g/h}{\text{Power}\left(kW\right)} \quad (2)$$

The emission concentration levels for some of the air the air pollutants were determined using Eq. 3 – 5 (Pilusa *et al.,* 2012) and compared with permissible levels of exposure to employees like OSHA and EPA. This was needed so as to compare with permissible limits related to health of workers on construction sites constantly exposed to these air pollutants. Doing this ensured that emissions were conforming to the safety and health regulations for construction.

$$CO\left(\frac{g}{kW/h}\right) = 3.591\ x10^{-3}\ x\ CO\left(ppm\right) \quad (3)$$

$$NOx\left(\frac{g}{kW/h}\right) = 6.636\ x10^{-3}\ NOx\,(ppm) \quad (4)$$

$$CO_2\left(\frac{g}{kW/h}\right) = 63.470\ x\ CO_2\,(vol\ \%) \quad (5)$$

Where, ppm = concentration in parts per million and vol % = concentration in parts volume percent. The air pollutant emissions studied were grouped under criteria air pollutants (PM, CO, and NOx) and greenhouse gases (CO_2 and HC). Since the engine data of their model years was not readily available, comparison of the emissions was based only their satisfaction of tier emissions limits for tier 1 (1994 to 2000), tier 2 (2004 -2009), tier 3, and tier 4 (from 2008 to 2015). This was based on the case study project manager's disclosure that all their equipment were of models below manufacture year of 2015.

Noise pollution and vibration levels

The noise generated at the construction sites has been reported with the likelihood to affect humans' right to silence, comfort, and health of residents plus their visitors (Feng *et al.,* 2020). The noise levels from the sampled equipment was measured using a sound level meter with a microphone pointer (Mangalekar *et al.*, 2012), at a distance of approximately 1.0 meters from the equipment. The results obtained were analyzed and compared with the permissible national construction noise levels of NER (2013). Vibration is defined by the NER (2013), to mean "*movement of the body caused by mechanical rotating or revolving tools and entering the body at the feet, the seat or the fingers or the palm of the hands such as from the organ in contact with vibrating equipment*". Field visits were made to the road construction site to observe and record the respective vibration levels from the sampled construction equipment. It was done with the help of seismometers and accelerators (vibration sensors). Ground vibration was typically measured at the source with a sensor that produces an electrical signal which is proportional to the amplitude of the ground motion.

RESULTS AND DISCUSSION

The findings present results of the emissions, noise pollution, and vibration levels for each of the six sampled road infrastructure equipment.

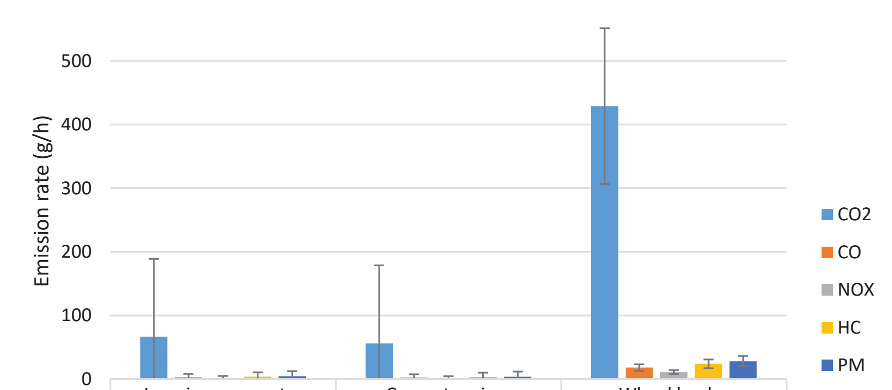
Air (diesel exhaust) emissions

The collected data from the sampled road construction equipment and their emission rates were tabulated in Table 1. Emission factors for CO_2, NO_x, and HC which were directly related to the brake-specific fuel consumption as availed with EPA publication were used.

These values were used in computing the emission rates of the equipment in grams per hour and g/kW/h. The findings reveal that the equipment sampled mostly was grouped under 50 hp, except for the roller and the grader which were between 100 – 175 hp and the excavator between 50 – 100 hp. The equipment with the highest hp was the grader at 150 hp and the concrete mixer had the lowest at 5.5 hp. This horsepower is an indicator of the level of emissions expected, because hp is directly proportional to the emissions produced as per the model used in Eq. 1. The emissions rates were computed using this hp of each construction equipment and presented in Fig. 3a and b**.** The findings on the air emissions given out by the road construction equipment sampled revealed that the grader was the highest contributor of emissions at 37.13% and lowest being the concrete mixer at 1.4% of total average emissions (Fig. 4b). The grader produced more toxic diesel emissions due to its

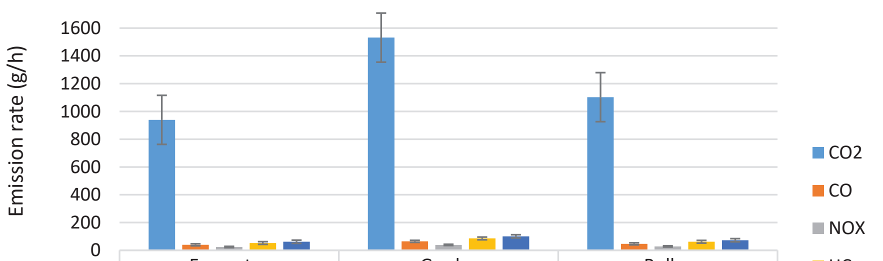
Table 1: Measured parameters for air pollutant emissions' calculation

Equipment	Rated power (kW)	Engine power (hp)	Emission factor (g/hp-h)					Load factor
			CO_2	CO	NO_x	HC	PM	
Excavator	68.8	92	10.21	0.43	0.26	0.57	0.67	1
Roller	80.5	108	10.21	0.43	0.26	0.57	0.67	1
Jumping compactor	4.8	6.5	10.21	0.43	0.26	0.57	0.67	1
Grader	111.9	150	10.21	0.43	0.26	0.57	0.67	1
Concrete mixer	4.1	5.5	10.21	0.43	0.26	0.57	0.67	1
Wheel loader	31	42	10.21	0.43	0.26	0.57	0.67	1



	Jumping compactor	Concrete mixer	Wheel loader
CO2	66.365	56.155	428.82
CO	2.795	2.365	18.06
NOX	1.69	1.43	10.92
HC	3.705	3.135	23.94
PM	4.355	3.685	28.14

(a)

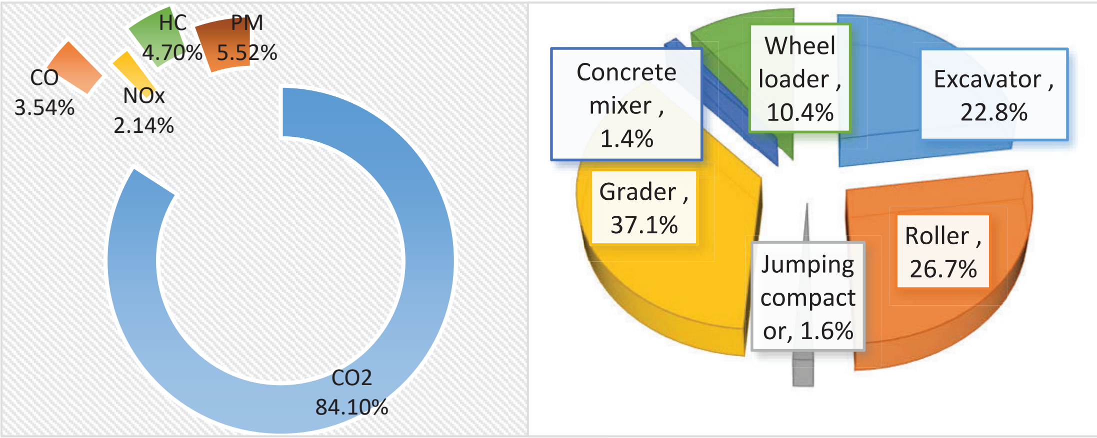


	Excavator	Grader	Roller
CO2	939.32	1531.5	1102.68
CO	39.56	64.5	46.44
NOX	23.92	39	28.08
HC	52.44	85.5	61.56
PM	61.64	100.5	72.36

(b)

Fig. 3: Total emissions per hour for the sampled equipment: (a) and b)

high horsepower as per (Rasdorf *et al*. (2010); Arocho *et al.* (2014); Fan (2017). All the sampled equipment emitted more CO_2 than any other emissions, which accounted for about 84.1% of the total emissions (Fig. 4a). The trend is similar to other studies like Reddy (2017) where CO_2 was 99.6%, Barati and Shen (2016) at 98.8%, Heidari and Marr (2015) at 98%. In this study the air pollutant emissions were lower than what was obtained by Barati and Shen (2016) for all the pollutants in grams per hour, except HC for the excavator and the loader plus the CO for the excavator. The lowest emitted air pollutant from all the sampled equipment was NOx, accounting for 2.1% of the total emissions (Fig. 4a). The concrete mixer contributed the least emissions of NOx at 1.43 g/h. In Barati and Shen (2016), who studied the loader and the excavator, their findings differ also on the lowest emitter which was found to be HC at 0.08 %. The grader was still the overall greatest contributor of the other air pollutants of CO, NO_x, HC, and PM at 37.1%, followed by the roller at 26.7% (Fig. 4b). These very high and very low emissions from the grader



(a) (b)

Fig. 4: Air pollutant emissions; a) percentage contribution of each air pollutant; b) percentage contribution from each sampled equipment to the emissions

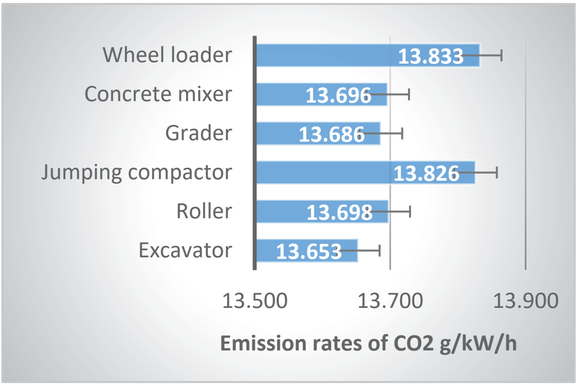
and concrete mixer respectively were attributed to their horsepower values. The emissions were then analyzed based on grams per kilowatt-hour and their respective concentration levels at the source, so as to compare with various permissible limits (Table 2). Among the air pollutant category, NOx emitted in grams per kilowatt-hour satisfied many requirements, for example the ones for European Union and China for heavy duty vehicles of 3.5 g/kW/h. All the sampled equipment did not exceed the emission standard of CO and NOx for non-road diesel engines according to EPA diesel engineNet 2016, acceptable back to the environment. The permissible limit of CO for the construction equipment with less than 130 kW is required to be less than 5.0 g/kW/h for all tiers 1 – 4. For NOx, the limit is supposed to be 9.2 g/kW/h or 0.40 g/kW/h for tier 1-3 and tier 4 respectively (DieselNet, 2016).

All the equipment fell short of the PM limit as per the European Union and China standards of 0.02 – 0.03 g/kW/h (Birol, 2016) and 0. 02 g/kW/h following EPA tier 1 - 4 (DieselNet, 2016). On assessing the concentration limits required for the health of workers, the toxic CO for all the equipment did not meet the OSHA limit of 50 ppm (OSHA, 2019) and 35 ppm as per NAAQs criteria (EPA, 2016) in an hour. The NOx also was above the ceiling value set for all the construction equipment considered hazardous to workers of 5 ppm (OSHA, 2019) as seen in Table 2. The CO_2 did not exceed to permissible levels of concentration in relation to human health of 0.5% (Table 2) as per OSHA. This is because it is considered minimally toxic by inhalation. In all the construction equipment sampled, the GHGs of CO_2 and HC emitted were more than the criteria air pollutants at approximately 88.8 % of the total air pollutants (Fig. 4a). This is in line with other studies were diesel-powered construction equipment has been established as a possible primary source of GHGS during the construction (Heidari and Marr, 2015). Therefore this equipment accounts for a significant portion of GHGs and other air pollutions in urban areas during site preparation, the foundation works, road construction, and maintenance. On the side of criteria air pollutants, PM contributed the highest portion at 5.52% followed by CO at 3.54% (Fig. 4a). This finding confirms why studies made by researchers like Kirenga *et al.* (2018), showed that ambient air pollution exists in Kampala and had led to lower lung function in this urban area.

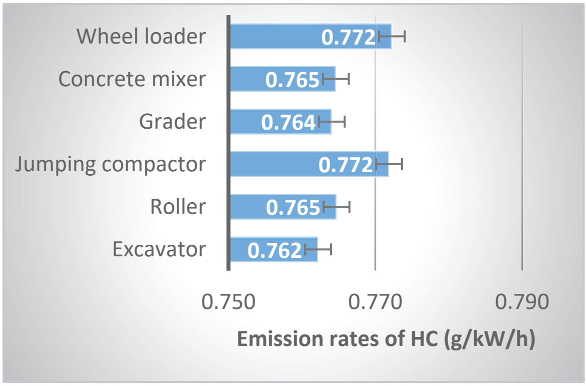
This particle pollution which includes both the PM_{10} and $PM_{2.5,}$ affects different classes of people from those on foot, on bicycles, or cars, to those working or owning shops, and restaurants among others. The businesses end up keeping their doors closed during working hours as observed on the Namirembe road project. On average, for all the 5 air pollutants studied, the grader produced 28% higher air pollution emissions than the roller. The jumping compactor and the wheel loader produced more

Table 2: Estimated modelled emission rates of the sampled construction equipment

Equipment (Make)	Emission rate (g/kW/h)						Concentration		
	Rated power kW	CO_2	CO	NO_x	HC	PM	NOx (ppm)	CO (ppm)	CO_2 (vol %)
Excavator (JCB backhoe site master)	68.8	13.653	0.575	0.348	0.762	0.896	52.392	160.123	0.215
Roller (Dynapac CA 301)	80.5	13.698	0.577	0.349	0.765	0.899	52.565	160.65	0.216
Jumping compactor	4.8	13.826	0.582	0.352	0.772	0.907	53.057	162.153	0.218
Grader (CAT 140G)	111.9	13.686	0.576	0.349	0.764	0.898	52.52	160.514	0.216
Concrete mixer (BC-260-4 Honda GX 160)	4.1	13.696	0.577	0.349	0.765	0.899	52.559	160.632	0.216
Wheel loader (CAT 903D Compact)	31	13.833	0.583	0.352	0.772	0.908	53.083	162.234	0.216



(a)



(b)

Fig. 5: Emissions rates of GHGs for sampled in g/kW/h; a) CO2; b) HC

emissions per kilowatt-hour because of their relative power rating as seen in Fig. 5 for GHGs.

Based on the findings, there is a need to adopt exhaust regulations and also adoption of diesel soot reduction techniques like the use of particle filter systems and selective catalytic reduction. This will greatly improve air quality (Notter and Schmied, 2015).

Sound (noise) pollution levels

The sound levels from the respective equipment used in this research were recorded for 10 working days from Monday to Friday. These were used to compute mean sound levels for all the construction equipment as seen in Table 3. It can be observed that the lowest sound level was 67.08 decibel (dB) for the wheel loader. The highest was recorded for the roller at 90.86 dB, 29.8% higher than the acceptable sound level for the roads and road construction from Monday to Friday (07:00 to 19:00 hours) (NER, 2013). This was followed by the concrete mixer and the jumping compactor at 18.6% and 18.56% higher than the permissible limit of 70 dB respectively. The results compared well with other studies like Roberts (2009), were his excavator was 81 dB, front end wheel loader 78 dB and Caterpillar scrapper at 83 dB. On average the sound mean level produced by all the construction equipment was at 79.06 dB, hence higher than allowable noise levels for the roads and the road construction of 70 dB. The findings indicate

Table 3: The mean sound levels from the construction equipment studied

Equipment	Sound level decibel (dB)										
	March 2019			April 2019							Mean sound level (dB)
	27th	28th	29th	1st	2nd	3rd	4th	5th	8th	9th	
Excavator	69.43	80.07	84.63	68.30	79.63	66.53	83.20	77.73	71.83	80.00	76.14
Roller	84.50	98.40	89.30	75.70	89.03	97.67	96.17	93.03	88.30	96.53	90.86
Jumping compactor	80.67	87.50	85.03	69.47	87.60	87.53	84.57	87.83	80.77	78.90	82.99
Grader	78.43	73.80	67.83	69.10	77.73	68.13	77.90	78.23	77.70	74.90	74.38
Concrete mixer	83.40	86.20	84.07	72.47	85.37	87.30	85.93	85.20	87.33	72.73	83.00
Wheel loader	68.10	69.70	59.23	59.47	68.20	68.13	68.17	69.63	70.33	69.80	67.08

Table 4: Vibration levels of the respective equipment

Equipment	Mean vibration levels	
	Frequency (Hz)	Velocity (mm/S)
Excavator	47	13
Roller	120	20
Jumping compactor	60	16
Grader	48	12
Concrete mixer	52	14
Wheel loader	35	10

that the equipment was also higher than the set hygienic limits of acoustic pressure of 65 dB from 7 am – 9 pm (Kantova, 2017).

This is in line with studies like Lee *et al.* (2017), where it was established that among all equipment studied, the peak sound levels were above 80 dB and the highest was for a vibratory pile at 100.9 dB. Since most of the construction equipment considered in this research were too noisy during operations, it is considered harmful to the human hearing system and the surroundings. The people within the nearby businesses are likely to be more affected than those passing by, because they are more connected to the construction site and constantly exposed to this noise (Andersson and Johansson, 2012). To partly reduce the effects, the regulatory authorities like NEMA need to enforce regulations like the installation of mufflers or silencers of the construction equipment considered to emit noise levels above the acceptable limits (Feng *et al.,* 2020).

Vibration levels

The permissible vibration velocity compared with the one at the closest part of any property to the source of vibration as per NER (2013) for a frequency of less than 10 Hz, 10 – 50 Hz, and 50 – 100 Hz was 8 mm/s, 12.5 mm/s, and 20 mm/s respectively. From Table 4, the study discovered that among the sampled equipment there was none in the category of frequency less than 10 Hz and the roller was above 100 Hz. The wheel loader, excavator, and grader lied in the category of 10 – 50 Hz, and they all satisfied the required permissible vibration velocity limit of 12.5 mm/s except the excavator. Its vibration velocity exceeded the permissible limit by 4%. Therefore, the excavator posed some small risk of building damage to the nearby properties. The concrete mixer and the jumping compactor in the category of 50 – 100 Hz, satisfied the permissible vibration velocity limit of 20 mm/s. The vibration values obtained however, were higher than other established by other studies like Robert (2009) whose impact pile divers, rollers, bulldozers, and loaded trucks were 6.2, 1.3, 0.6, and 0.5 mm/s respectively. This is because in his study, these vibrations were obtained at a distance of 30 m away from the construction equipment yet in this study vibrations were measured at the source. All the construction equipment were being used by workers beyond the allowable daily exposure durations. This was against the recommended practice, for example, NER (2013) provides that maximum exposure of hands to vibration in any direction for peak particle velocity above 12 mm/s should be less than one hour. Employees in this project operated this equipment for the entire day with exposure nearly up to 6 hours.

Therefore, continuous human exposure to these vibrations could also result in whole- body vibration (WBV) and vibration white finger (VWF) (Svinkin, 2004). The vibration annoyance potential to humans of all the construction equipment sampled was considered strongly perceptible, because it ranged between 6.3 mm/s and 22.9 mm/s at the transient source (Robert, 2009). The vibrations of the roller and jumping compactor were considered a threat to the nearby buildings and they are likely to develop cracks Ozcelik (2018).

CONCLUSION

The survey of the construction equipment on a road infrastructure development in typical urban center has presented a novel work, because it analyzed comprehensively the effects of the construction equipment. It has established the likely effects of this construction equipment in terms of air pollutant emissions, noise, and vibrations. This has not been the case for other studies who had focused on only one effect. The study revealed that construction equipment in Kampala city road infrastructure projects emits more GHGs (88.8%) compared to the criteria air pollutants (11.2 %). This is likely to highly contribute to ozone depletion because very high global warming potential of these emissions especially CO_2. The criteria air pollutants of CO and NOx did not exceed the limits of emissions as per the EPA limits of emissions to the environment. However, their concentration levels did not satisfy the permissible limits of OSHA and NAAQs considered healthy to employees operating this construction equipment. The particulate matter was way above the acceptable limit, hence, the findings confirm that the ongoing road infrastructure projects in Kampala and other urban centers, partly contribute to ambient air pollution levels reported in urban centers in Uganda. The noise levels produced by all the equipment was above recommended by the National Environment of 70 dB except the wheel loader. This means the hypothesis was accepted. This implies the ongoing infrastructure projects are likely to cause negative effects to the human hearing system of the site employees and people on the nearby economic activities around these road construction projects. Vibration velocity produced by the construction equipment considered in this study were generally within the acceptable level except for the excavator and the roller. More studies are needed which focus on the global warming potential of these emissions, so as facilitate developing of standards and monitoring by the regulatory bodies. Other studies which employ models that are based on fuel consumption and real-time measurements of these air pollutant emissions need to be conducted. Finally, the general observation made was that workers were not provided with personal protective equipment (PPE) which could limit on the effect of toxic emissions, noise, and vibration effects. This is likely to increase chances of workers health being in danger. Therefore, provision of PPEs should be highly emphasized by regulatory bodies on infrastructure projects using the identified equipment. These may include: recommended N95 masks, ear plugs, anti-vibration gloves, and install vibration damping seats.

AUTHOR CONTRIBUTIONS

N. Robinah performed the literature review, experimental design, analyzed and interpreted the data. A. Safiki prepared the manuscript text, and manuscript edition. T. Okello compiled the data and manuscript preparation. B. Annette performed the literature review and manuscript preparation.

ACKNOWLEDGEMENTS

The authors would love to express their appreciation to the Department of Lands and Architectural Studies Kyambogo University for the support during the entire study.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

ABBREVIATIONS

%	Percentage
am	Before midday
μg/m³	Milligrams per cubic meter
CARB	California Air Resources Board
CAT	Caterpillar Incorporation
CMS	City Mayors Statistics
CO	carbon monoxide
CO_2	Carbon dioxide
dB	Decibel
DEQ	Department of Environmental Quality
E	Easting
JCB	Joseph Cyril Bamford
EPA	Environmental Protection Agency
Eq.	Equation
Fig	Figure
g	Grams
GHGs	Greenhouse gases
GHGs	Limited
HC	hydrocarbons
Hp	Horsepower
Hz	Hertz
h	Hour
Km	Kilometer
kW	kilowatt
Km^2	Square kilometer
LA	A-Weighted, sound level
M/S	Messrs
M^2	Square Meters
N	Northing
NAAQs	National ambient air quality standards
NEMA	National Environment management authority
NER	National Environment Regulations
NO_x	Nitrogen dioxide
OSHA	Occupational Safety and Health Administration
ppm	Parts per million
vol%	Parts volume percent
S	Southing
PM	Particulate matter
PPE	Personal protective equipment
$PM_{2.5}$	Particulate matter 2.5 times
pm	After midday
UBOS	Uganda Bureau of Statistics
US$	United States dollar
USA	United States of America
VWF	Vibration white finger
WBV	whole body vibration
WHO	World health organization

REFERENCES

Ahn, C.; Martinez, J.C.; Rekapalli, P.V.; Peña-Mora, F.A., (2009). Sustainability analysis of earthmoving operations. In Proceedings of the 2009 Winter Simulation Conference. IEEE. 2605-2611 (**7 pages**).

Akan, M.Ö.A.; Dhavale, D.G.; Sarkis, J., (2017). Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. J. Cleaner Prod., 167: 1195-1207 (**13 pages**).

Alzard, M.H.; Maraqa, M.A.; Chowdhury, R.; Khan, Q.; Albuquerque, F.D.; Mauga, T.I.; Aljunadi, K.N., (2019). Estimation of greenhouse gas emissions produced by road projects in Abu Dhabi, United Arab Emirates. Sustainability, 11(8): 2367 (**16 pages**).

Andersson, P.; Johansson, A., (2012). Disturbances of the surroundings in an urban infrastructure project. Master's thesis, Chalmers University of Technology. Sweden (**36 pages**).

Arocho, I.; Rasdorf, W.; Hummer, J., (2014). Methodology to forecast the emissions from construction equipment for a transportation construction project. Const. Res. Cong. 2014: Cons. Global Net., 554-563 (**10 pages**).

Avetisyan, H.G.; Miller-Hooks, E.; Melanta, S., (2011). Decision models to support greenhouse gas emissions reduction from transportation construction projects. J. Constr. Eng. Manage., 138(5): 631-641 (**11 pages**).

Azizi, A.; Malakmohamadi, B.; Jafari, H.R., (2016). Land use and land cover spatiotemporal dynamic pattern and predicting changes using integrated CA-Markov model. Global J. Environ. Sci. Manage., 2(3): 223-234 **(12 pages).**

Balasbaneh, A.T.; Marsono, A.K.B., (2017). Strategies for reducing greenhouse gas emissions from residential sector by proposing new building structures in hot and humid climatic conditions. Build. Environ., 124: 357-368 (**12 pages**).

Barati, K.; Shen, X., (2016). Operational level emissions modelling of on-road construction equipment through field data analysis. Autom. Constr., 72: 338-346 (**9 pages**).

Battaglia, M.; Sampling, N.; Lavrakas, P.J., (2008). Encyclopedia of survey research methods (**11 pages**).

Birol, F., (2016). Energy and air pollution: world energy outlook special report 2016 **(226 pages).**

CARB, (2009). Carl moyer memorial air quality standards attainment program.

CMS, (2018). The world's fastest-growing cities and urban areas from 2006 to 2020. City Mayors Statistics.

DEQ, (2017). Sources of diesel exhaust. Department of environmental quality.

DieselNet, (2012) "What are Diesel Emissions," DieselNet Technology Guide, 2012.

EPA, (2005). User's guide for the final NONROAD2005 model. EPA-420-R-05-013, U.S. Environmental Protection Agency, office of transportation and air quality, Ann Arbor, MI (**42 pages**).

EPA (2016) "NAAQS table," US Environmental Protection Agency.

EPA, (2017). Multi-pollutant Comparison: Air Emissions Inventories. US Environmental Protection Agency.

EPA, (2008). Quantifying greenhouse gas emissions in key industrial sectors. EPA 100-R-08-002, Sector Strategies Division, US EPA, Washington D.C. (**132 pages**).

Fan, H., (2017). A critical review and analysis of construction equipment emission factors. Procedia Eng., 196: 351-358 (**8 pages**).

Feng, C.Y.; Noh, N.I.F.M.; Al Mansob, R., (2020). Study on the factors and effects of noise pollution at construction site in Klang Valley. J. Adv. Res. Appl. Sci. Eng. Tech., 20(1): 18-26 (**9 pages**).

Giunta, M., (2020). Assessment of the environmental impact of road construction: Modelling and prediction of fine particulate matter emissions. Build. Environ., 176: 106865 (**8 pages**).

Giunta, M.; Bosco, L.D.; Leonardi, G.; Scopelliti, F., (2019). Estimation of gas and dust emissions in construction sites of a motorway project. Sustainability, 11(24): 7218 (**14 pages**).

Heidari, B.; Marr, L.C., (2015). Real-time emissions from construction equipment compared with model predictions. J. air. Wast. Manag. Assoc., 65(2), 115-125 (**12 pages**).

Israel, G.D., (1992). Determining sample size (**5 pages**).

Kantová, R., (2017). Construction Machines as a Source of Construction noise. Procedia Eng., 190: 92-99 (**8 pages**).

Lee, H.P.; Wang, Z.; Lim, K.M., (2017). Assessment of noise from equipment and processes at construction sites. Build. Acoust., 24(1), 21-34 (**14 pages**).

Kirenga, B.J.; Nantanda, R.; De Jong, C.; Mugenyi, L.; Meng, Q.; Aniku, G.; Williams, S.; Tukamuhebwa, H.A.; Kamya, M.; Schwander, S.; Molen, T.D.; Mohsenin, V., (2018). Lung function of children at three sites of varying ambient air pollution levels in Uganda: a cross sectional comparative study. Int. J. Environ. Res. Public Health. 15(12): 2653 (**13 pages**).

Kwon, N.; Park, M.; Lee, H.S.; Ahn, J.; Kim, S., (2017). Construction noise prediction model based on case-based reasoning in the preconstruction phase. J. Constr. Eng. Manage., 143(6): 04017008.

Mangalekar, S.B., Jadhav, A.S., & Raut, P.D., (2012). Study of noise pollution in Kolhapur city, Maharashtra, India. Sleep, 35, 16 (**5 pages**).

Marzouk, M.; Abdelkader, E.M.; El-zayat, M.; Aboushady, A., (2017). Assessing environmental impact indicators in road construction projects in developing countries. Sustainability, 9(5): 843 (**21 pages**).

Matagi, S. V., (2002). Some issues of environmental concern in Kampala, the capital city of Uganda. Env. Monit. assess., 77(2): 121-138 (**18 pages**).

Montadka, N.P., (2017). Comprehensive analysis of PM2. 5 pollution from construction activities (**87 pages**).

Moretti, L.; Mandrone, V.A.D.A.; D'Andrea, A.; Caro, S., (2018). Evaluation of the environmental and human health impact of road construction activities. J. Cleaner Prod., 172: 1004-1013 (**20 pages**).

National Environment Regulations (NER) (2013). Noise and vibrations standards and control (**75 pages**).

Notter, B.; Schmied, M., (2015). Non-road energy consumption and pollutant emissions, Study for the period from 1980 to 2050, Feder. Offic. Env., Bern. Env. Stud., (1519): 237 (**239 pages**).

Occupational safety and health administration (OSHA) (2019). Permissible Exposure Limits for Airborne Contaminants: Safety and Health Regulations for Construction.

OSHA, (2017) "Diesel exhaust/diesel particulate matter," Occupational safety and health (**4 pages**).

Ozcelik, M., (2018). Back analysis of ground vibrations which cause cracks in buildings in residential areas Karakuyu (Dinar, Afyonkarahisar, Turkey). Nat. Hazard., 92(1): 497-509 (**13 pages**).

Pilusa, T.J.; Mollagee, M.M.; & Muzenda, E., (2012). Reduction of vehicle exhaust emissions from diesel engines using the whale concept filter. Aer. Air Qua. Res., 12(5), 994-1006 (**13 pages).**

Rasdorf, W.; Frey, C.; Lewis, P.; Kim, K.; Pang, S.H.; Abolhassani, S., (2010). Field procedures for real-world measurements of emissions from diesel construction vehicle. J. Infrastruct. Syst., 16(3): 216-225 (**10 pages**).

Reddy, B.S.A., (2017). Estimating Air pollutant emissions for non-road equipment using EPA moves–case study of a building project (**83 pages**).

Roberts, C., (2009). Construction noise and vibration impact on sensitive premises. Proceed. Acoust. 2009 (**10 pages**).

Schwander, S.; Okello, C.D.; Freers, J.; Chow, J.C.; Watson, J.G.; Corry, M.; Meng, Q., (2014). Ambient particulate matter air pollution in Mpererwe District, Kampala, Uganda: A pilot study. J. Environ. Public Health. Article ID 763934 (**8 pages**).

Schwela, D., (2012). Review of urban air quality in Sub-Saharan Africa region. (**251 pages**).

Svinkin, M.R., (2004). Minimizing construction vibration effects. Pract. Period. Struct. Des. Constr., 9(2): 108-115 (**8 pages**).

UBOS, (2015). 2015 Statistical abstract. Kampala: Uganda bureau

of statistics **(353 pages)**.
WHO, (2018). World Health Organization
WUT, (2014). World urbanization prospects the 2014 revision. World urbanization trends (**517 pages**).
Zhang, G.; Sandanayake, M.; Setunge, S.; Li, C.; Fang, J., (2017). Selection of emission factor standards for estimating emissions from diesel construction equipment in building construction in the Australian context. J. Environ. Manage., 187: 527-536.

AUTHOR (S) BIOSKETCHES

Robinah, N., B.Sc., Department of Lands and Architectural Studies, Faculty of Engineering Kyambogo University, Kyambogo, Uganda.
Email: *rnabatuusa75@gmail.com*
ORCID: 0000-0002-6554-6990

Safiki, A., Ph.D. Candidate, Instructor, [1]Department of Lands and Architectural Studies, Faculty of Engineering Kyambogo University, Kyambogo, Uganda. [2]Department of Construction Economics and Management, School of Built Environment, College of Engineering, Design, Art and Technology, Makerere University, Kampala, Uganda.
Email: *sainomugisha@kyu.ac.ug*
ORCID: 0000-0001-7425-5442

Thomas, O., Ph.D. Candidate, Instructor, Department of Lands and Architectural Studies, Faculty of Engineering Kyambogo University, Kyambogo, Uganda.
Email: *tokello@kyu.ac.ug*
ORCID: 0000-0003-0991-9868

Annette, B., M.Sc., Instructor, Department of Lands and Architectural Studies, Faculty of Engineering Kyambogo University, Kyambogo, Uganda.
Email: *annettebazairwe@gmail.com*
ORCID: 0000-0003-1811-608X

HOW TO CITE THIS ARTICLE

Robinah, N.; Safiki, A.; Thomas, O.; Annette, B., (2022). Impact of road infrastructure equipment on the environment and surroundings. Global J. Environ. Sci. Manage., 8(2): 251-264.

DOI: 10.22034/gjesm.2022.02.08

url: https://www.gjesm.net/article_245962.html

Global J. Environ. Sci. Manage. 8(2): 265-280, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

Dispersion modelling of particulate matter concentrations of sand product plants in a mineral complex

Y. Zehtab Yazdi[1], N. Mansouri[1,*], F. Atabi[1], H. Aghamohammadi[2]

[1] *Department of Environment Engineering, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[2] *Department of Remote Sensing and Geographical Information System, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran*

ARTICLE INFO

Article History:
Received 07 June 2021
Revised 24 September 2021
Accepted 22 October 2021

Keywords:
AERMOD model
Air quality
Emission factor
Particulate matter
Sand and gravel product plant

DOI: 10.22034/gjesm.2022.02.09

ABSTRACT

BACKGROUND AND OBJECTIVES: Sand and gravel product plants are among the significant sources of dust pollutants. This study was conducted to estimate dust concentrations released from these plants in a mineral complex in the southwest of Tehran.

METHODS: Initially, the amount of silt and moisture content of the samples taken from these plants were determined according to the American Society for Testing and Materials C136 and D2216 methods, respectively. Accordingly, the rates of particulate matter emissions from these plants were determined by the AP-42 dust emission estimation methods published by the United States Environmental Protection Agency. Next, a Gaussian model was used to estimate the particulate matter concentrations in the surrounding residential areas. Finally, the simulated concentrations were compared with the United States Environmental Protect Agency and World Health Organization standards.

FINDINGS: Results showed that hauling operations, with producing 70%, 86%, and 90% of total $PM_{2.5}$, PM_{10} and total suspended particulates, respectively, were the major sources of dust emission in the sand and gravel product plants. The lowest dust emission was related to stockpiling handling, producing 0.24%, 0.33%, and 0.16% of the total $PM_{2.5}$, PM_{10} and total suspended particulates. The results of the presented model indicated that 24-hour average concentrations of $PM_{2.5}$, PM_{10}, and total suspended particulates produced by mining activities were about 36, 183, and 690 $\mu g/m^3$ in the working zone and less than 30, 100, and 400 $\mu g/m^3$ beyond the mineral complex boundary, respectively. Thus, annual average dust concentrations were negligible. The concentrations of $PM_{2.5}$ and PM_{10} produced by these plants in the mineral complex ambient air were higher than the standard average values recommended by the United States Environmental Protect Agency and World Health Organization. However, the concentrations of $PM_{2.5}$ and PM_{10} from these plants in the residential areas around the complex, were below the standard limits proposed by the Environmental Protection Agency.

CONCLUSION: Sand and gravel mining activities increased the concentrations of particulate matter in the air of the surrounding areas and, to some extent, farther cities. $PM_{2.5}$ and PM_{10} resulting from the sand and gravel mining activities could damage the workers in the mineral complex. They exceeded the 24-hour average permissible limits proposed by the United States Environmental Protection Agency about 1 and 33 $\mu g/m^3$, respectively. This study showed the necessity of changing the industrial policies adopted to decrease dust emission rates. The results of this study can help the air pollution experts develop proper strategies for improving the air quality in the vicinity of surface mines.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
46	7	6

*Corresponding Author:
Email: *nmansourin@gmail.com*
ORCID: 0000-0002-4228-6444

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

Fugitive dust is the major pollutant produced by the sand and gravel industry (Leili *et al.,* 2008). Particulate matter (PM) that affects the health of miners and people living in the vicinity of these industries is considered a critical pollutant (USEPA, 2020a). PM is classified according to the particle diameter size of the component particles as fine inhalable particles ($PM_{2.5}$) and inhalable particles (PM_{10}). The diameters of $PM_{2.5}$, PM_{10} are less than or equal to 2.5 and 10 microns, respectively (US EPA, 2021a). Particles with an aerodynamic diameter of fewer than 30 microns (PM_{30}) are referred to as total suspended particulate matter (TSP) (Lashgari and Kecojevic, 2016). Acute and chronic diseases are caused by inhaling the particles such as PM_{10} and $PM_{2.5}$ (Ezeh *et al.,* 2012). Dust can cause cardiovascular and cerebrovascular diseases, respiratory stress, oxidative stresses (Anderson *et al.,* 2012), hypertension, prematurity, neonatal weight loss, and infant mortality (Ruckerl *et al.,* 2011). Onabowale and Owoade (2015) showed that indoor air particulate was responsible for 28% of illnesses and deaths in developing countries. According to Heger and Sarraf studies (2018), $PM_{2.5}$ was responsible for 4000 annual premature deaths in Tehran, Iran. Particulates can also be emitted from natural and anthropogenic sources such as pollen and quarrying (Owen Harrop, 2005; Lohe *et al.,* 2015). Particulates may also be classified according to their origin as 1) primary particles which are emitted directly from a process to the atmosphere (traffic, road dust, sea spray and etc.); and 2) secondary particles which are subsequently formed by a chemical reaction (sulphates, nitrates, ammonium, etc.) (Theodore, 2008). The sand and gravel industry is a mineral industry for the processing and storage of granular media. Granular materials obtained from natural deposits in the river bed or sea are transferred by, for example, movable loaders, motor buckets, and safety carriers from where they were removed (Cho, 2006). These industries are often located near residential centers (Van Der Meulen and Salman, 1996). Based on product specifications, crushing, screening, washing, and stockpile handling are considered complementary operations of sand and gravel processes. Main sources of fugitive dust in sand and gravel product plants include crushing, aggregate handling and storage piles, vehicle travelling on paved and unpaved roads, wind erosion of open storage piles and open areas (USEPA, 1995a). Emission rates of pollutants from different operations in mines and their negative effects on the environment have attracted the attention of many researchers during recent years. Sastry *et al.,* (2015) predicted and analyzed the dispersion of particulate matter from drilling operations in opencast coal mines using USEPA models. Lashgari and Kecojevic (2016) estimated the dust emission from digging and loading equipment in a surface coal mine using the AP-42 dust emission estimation methods. Gautam and Patra (2014) investigated the dispersion of particulate matter from a copper open cast mine. Badr and Harion (2007) predicted the concentrations of dust from stockpiles in an open-pit mine. Naveen Saviour (2012) investigated the effects of sand mines on the environment and showed the harmful effects of sand and gravel mining activities on air quality, water quality, land use, soil quality, flora, fauna, etc. Ako *et al.,* (2014) studied the effects of sand and gravel mining on the environment using field observations and analysis of soil samples. They finally showed that the pollutants emitted from these mines negatively affected humans, animals, and plants. Neshuku (2012) believed that it was essential to have a comprehensive approach to understand the air pollution caused by different mining operations. Holmes and Morawska (2006) indicated that several dispersion air quality models, such as Gaussian models, including California Puff Model (CALPUFF), American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee Dispersion Model (AERMOD), and United Kingdom Atmospheric Dispersion Modeling System (UK-ADMS) and SCREEN3); Lagrangian/Eulerian models including Graz Lagrangian Model (GRAL), and The Air Pollution Model (TAPM), box models including Air Quality Modeling in Urban Regions using an Optimal Resolution Approach (AURORA), Canyon Plume Box (CPB) and Photochemical Box Model (PBM); and Computational Fluid Dynamic (CFD) models including Microscale flow and dispersion model (MISKAM), and Microscale California Photochemical Grid Model (MICRO-CALGRID), were used to predict air quality. Neshuku (2012) analyzed PM_{10} emission from a uranium mine using the ADMS model. Trivedi *et al.* (2009) estimated the concentrations of the TSP emitted from a coal mine using a fugitive dust model. CALPUFF and AERMOD have been approved by the

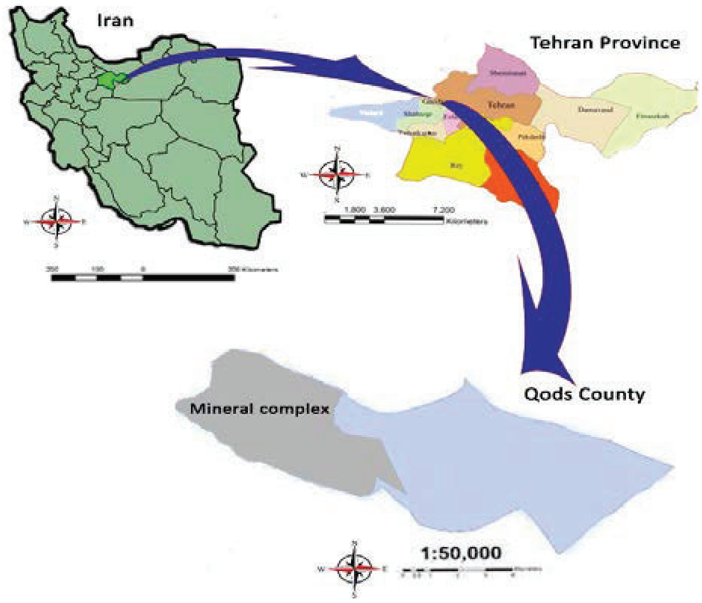


Fig. 1: Geographic location of the study area in Shahre Qods in the southwest of Tehran, Iran

USEPA and can deal with the deposition of pollutants (Cimorelli et al., 2005). Compared to other models, the Gaussian models are easier to use (Asif et al., 2018). Lilic *et al.,* (2012) indicated that the Gaussian AERMOD model could be efficiently used in planning for decreasing the dust impact on air quality around open-pit mines. Sand and gravel product plants, located southwest of Tehran, are one of the major sources of dust in the city. These plants, which emit a large amount of dust to the atmosphere, have been developed in recent years. To the best of the authors' knowledge, no study has been done to investigate the dust emission rate from these plants so far. Therefore, it seems necessary to estimate the dust emission rate from these plants to the atmosphere and dust concentrations reaching the surrounding cities. Such estimation may have an important role in urban planning programs and policies, regional development, land use, health and environment, air quality management, and development of surface mines in the future. The main objective of this study was to analyze the distribution of particulate matters emitted from the sand and gravel product plants in the southwest of Tehran. The hypothesis followed in this study is that the fugitive dust emission from the sand and gravel product plants in the southwest of Tehran significantly increases the airborne levels of particulate matter in nearby areas. This study aims to estimate the particulate matter emission rates using the emission factors suggested by the USEPA, simulate the particulate matter concentrations at a distance of 50 km away from the pollution source using AERMOD model, describe the results of dispersion modelling, and compare the simulated values with the EPA and WHO standard values. This study was performed in Shahre Qods in the southwest of Tehran, Iran, in 2020.

MATERIALS AND METHODS

The study area

This study was performed in a mineral complex in the southwest of Tehran, Iran. The mineral complex has been set up on the alluvium of an old branch of Karaj riverbed. It covers an area of about 2500 ha in Shahre Qods, which is a small part of Shahriar County (Fig. 1). The complex lies between the longitude of 51° 02' and 51° 06' E and latitude of 35° 41' and 35° 45' N and includes 62 sand and gravel product plants covering an area of about 1200 ha. These plants are evenly distributed all over the complex. In addition to sand and gravel product plants, there are other industries such as asphalt factories, moulding factories, and a military barrack. Furthermore, many cities and townships exist in different directions at 1-9 km from the mineral complex.

At the mineral complex, sand and gravel processing operation are performed five days (except

Table 1: Types of vehicles travelling on paved/unpaved roads in the mineral complex

Vehicle	Vehicle class	Average daily traffic [#/day]		Full weight (ton)	Empty weight (ton)
		Paved road	Unpaved road		
Mercedes-Benz 608	Light truck	298	837	7	4
Budsun 6B	Light truck	155	435	7	4
Dong Feng 106C	Light truck	103	289	6	3.330
Isuzu 75 NPR	Light truck	91	256	7.5	3.650
Mercedes-Benz 1921	LK truck 2 Axles-6 Wheels	117	328	20	6.530
Mercedes-Benz 1924	LK truck 2 Axles-6 Wheels	453	1274	20	6.530
Mercedes-Benz 2624	LK truck 3 Axles-10 Wheels	92	259	28	8.930
Mercedes-Benz 2628	LK truck 3 Axles-10 Wheels	39	109	28	8.930
Volvo N10	LK truck 3 Axles-10 Wheels	10	28	28	9.1

on public holidays) a week (Saturday to Wednesday) for eight hours a day (07:00 am-03:00 pm). This operation generally occurs 230 days per year. Aggregate production amounts to approximately 8.5 million tons per year. About 30% and 70% of this production are natural sand and gravel (2.55-million-ton) and broken sand and gravel (2.55-million-ton sand and 3.4-million-tons gravel). The produced gravels are 6-12, 12-19, and 19-25 mm in size, and the produced sand is in the dimension of 0-6 mm. Operations proceed on the same schedule during the year, but the production level is lower in winter (22 September-19 March) than in summer (20 March-21 September). The average number of conveyor transfer points in each plant is 6. The average length of the paved road among the plants for travelling of all vehicles is about 3 km. Also, the average estimated length of unpaved roads in each plant is 1.2 km. The unpaved roads in these plants are watered once or twice a day to prevent the dust emissions caused by vehicular traffic. Usually, nine types of vehicles travel on roads in the mineral complex (Table 1).

Emission factor and estimation of dust emission

The emission factor is a ratio between the emissions generated and the outputs of production. Emission factors are considered as one of the crucial tools for air quality management. These factors facilitate the estimation of emissions from different air pollution sources. Compilation of Air Pollutant Emission Factors (AP-42) published by US EPA. AP-42 suggested a large number of equations to estimate fugitive dust emission factors. The latest version of these equations is available on the EPA website (US EPA, 2020b). In this study, the emission factors suggested by the US EPA were used to estimate the dust emission rates resulting from sand and gravel processing operations. Multiplication of activity rate by emission factors is widely used for determining the air pollutant emission rate from non-stack sources as expressed by Eq. 1 (US EPA, 1995b).

$$E = A \times EF \times (1 - ER/100) \quad (1)$$

Where, E is the emission rate of the pollutant; A is the activity rate; EF is the pollutant's emission factor, and ER is the efficiency reduction percentage (%). The activity rate represents the degree of using the source within the analysis period. The efficiency reduction percentage represents the reduction of emissions before releasing them into the atmosphere, and it can be achieved through some processes or activities that seek to reduce emissions. This study calculated the dust emission rate for each mining activity (crushing, handling of piles, hauling in paved/unpaved roads). In addition, dust emission rate from open area wind erosion in the sand and gravel product plants was also considered. The empirical formulas (Eqs. 2-5) recommended by the US EPA in the fifth edition of AP-42 were used to calculate the emission factor of particulate matter (Table 2).

In Eq. 2, k is particle size multiplier which was 0.053, 0.35, and 0.74 for $PM_{2.5}$, PM_{10}, and TSP, respectively; U is average wind speed (m/s) at the height of 10 m, and M is material moisture content (%). In Eq. 3, k is particle size multiplier which was 0.15, 0.62, and 3.23 for $PM_{2.5}$, PM_{10}, and TSP, respectively; sL is road surface silt loading of the travel surface (g/m^2) (typical

Table 2: Emission Factor equations for sand and gravel mining processes

Activities	Empirical equations	unit	Eq.	Reference
Aggregate handling and storage piles	$EF = k(0.0016)\frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$	kg/ton	(2)	US EPA, 2006a
Paved roads	$EF = k(sL)^{0.91} \times (W)^{1.02}$	g/VKT	(3)	US EPA, 2011
Unpaved roads	$EF = k\left(\frac{S}{12}\right)^{a} \times \left(\frac{W}{3}\right)^{b}$	lb/VMT	(4)	US EPA, 2006b
Wind erosion	$EF = k\sum_{i=1}^{N} P_i$, $P = 58(u* - ut*)2 + 25(u* - ut*)$; $P = 0$ for $u* \leq ut*$	g/m^2	(5)	US EPA, 2006c

the mean silt loading value for paved roads at sand and gravel processing is 70 g/m^2). W is the average of empty and full vehicle weights travelling on paved roads (ton). In Eq. 4, k, a, and b are empirical constants based on the stated aerodynamic particle sizes; k is particle size multiplier which is 1.5, 0.15, and 4.9 for $PM_{2.5}$, PM_{10}, and TSP, respectively; a is 0.9, 0.9 and 0.7 for $PM_{2.5}$, PM_{10}, and TSP, respectively; b is 0.45, 0.45 and 0.45 for $PM_{2.5}$, PM_{10}, and TSP, respectively; S is surface material silt content (%), and W is average of empty and full vehicle weights travelling on unpaved roads (tons). In Eq. 5, N is the number of disturbances per year (365 per year); Pi is erosion potential of a dry surface (g/m^2); k is particle size multiplier which was 0.075, 0.5, and 1.0 for $PM_{2.5}$, PM_{10}, and TSP, respectively; u* is friction velocity (m/s), and u_t* is threshold friction velocity (m/s). Since the emission factor for the dust from the vehicles travelling on unpaved roads is in lb/VMT (Eq. 4), lb/VMT was converted to metric conversion (g/VKT) using Eq. 6.

$$1\left(\frac{lb}{VMT}\right) = 281.9\left(\frac{g}{VKT}\right) \quad (6)$$

Moreover, VKT/VMT was calculated based on Eq. 7.

$$VKT / VMT = ADT \times \text{Length of roads} \times \text{Operating days / year} \quad (7)$$

Fleet average weight for vehicle classes on the segmented road (WFLEET) is necessary for calculations. "WFLEET" is the calculated mean weight multiplied by the percentage of traffic on the road segment. u* in Eq. 5 was calculated based on Eq. 8.

$$U^{*} = 0.053U_{10}^{+} \quad (8)$$

Where, u^{+}_{10} is the average wind speed at the height of 10 m (m/s). u_t* was calculated from the aggregate size distribution mode. This study estimated wind emission based on a continuously exposed open area (12 million m^2). The wind erosion rate was calculated using Eq. 9.

$$E = EF \times S \quad (9)$$

Where, E is wind emission rate (g), and EF is emission factor (g/m^2), S is surface area (m^2).

In this study, the emission factors for handling and storage piles activities were 4.082E-05, 2.693E-04, and 5.695E-04 kilogram of $PM_{2.5}$, PM_{10}, and TSP per ton of the material processed (uncontrolled), respectively. The emission factors for paved roads were 75.339, 311.401, and 1622.301 g of $PM_{2.5}$, PM_{10}, and TSP per vehicle kilometer travelled, respectively. The emission factors for unpaved roads were 0.062, 0.623, and 2.109 kilograms of $PM_{2.5}$, PM_{10}, and TSP

Table 3: Emission factors for crushed stone processing operations (US EPA, 2004)

Crushed stone processing operations	Emission factor (kg/ton material throughput)		
	$PM_{2.5}$	PM_{10}	TSP
Truck unloading-fragmented stone	2.25E-06	8.0E-06	1.5E-5
Aggregate scalping screen	0.0018	0.0043	0.0125
Crushing	0.0012	0.0012	0.0023
Fines crushing	0.0029	0.0075	0.0195
Screening	0.0018	0.0043	0.0125
Fines screening	0.0225	0.036	0.15
Conveyor transfer points	2.25E-04	5.5E-4	0.0015
Truck loading	1.5E-05	5.0E-5	9.8E-5

per vehicle kilometer travelled. According to the aggregate size distribution mode, the threshold friction velocity for the study area was 0.71 m/s. Meteorological data for 2019 were used to calculate the erosion potential (P_i). According to the data, the annual total erosion P_i was 4.26 g/m^2. The emission factors for wind erosion were 0.32, 2.13, and 4.26 g of $PM_{2.5}$, PM_{10}, and TSP per square meter of open area (uncontrolled), respectively. The dust emission factors related to crushing stone processing operations are presented in Table 3.

Sampling and analysis

The guidelines for sampling surface and bulk dust loading (US EPA, 1993a) and laboratory analysis of surface and bulk dust loading samples (US EPA, 1993b) suggested by the USEPA were used to determine the number and volume of the required samples and laboratory analysis methods, respectively. The amount of silt of unpaved roads was determined by measuring the percentage of loose dry particles passing through a number 200 sieve which had a mesh screen with a diameter of 75 µm, according to the ASTM C136 method. Moreover, the moisture content of stockpiles was determined by calculating the percentage of loose dry dust according to the ASTM D2216 method. Finally, the threshold friction velocity for wind erosion was determined using the aggregate size distribution mode. In this study, seven aggregate product plants were randomly selected. From these selected plants, three composite samples weightings of a) 7.2 kg from unpaved roads for estimating silt content, b) 5 kg from stockpiles for estimating moisture content, and c) 5 kg from surface materials for estimating the mode of size distribution to determine the threshold friction velocity were selected. Finally, the composite samples were taken to the laboratory for analysis. The moisture content of the composite sample of stockpiles, the amount of silt of the composite sample of unpaved roads, and the aggregate size distribution mode of the composite sample of open-pit mines were obtained as 4.66%, 10.12%, and 1.3 mm, respectively.

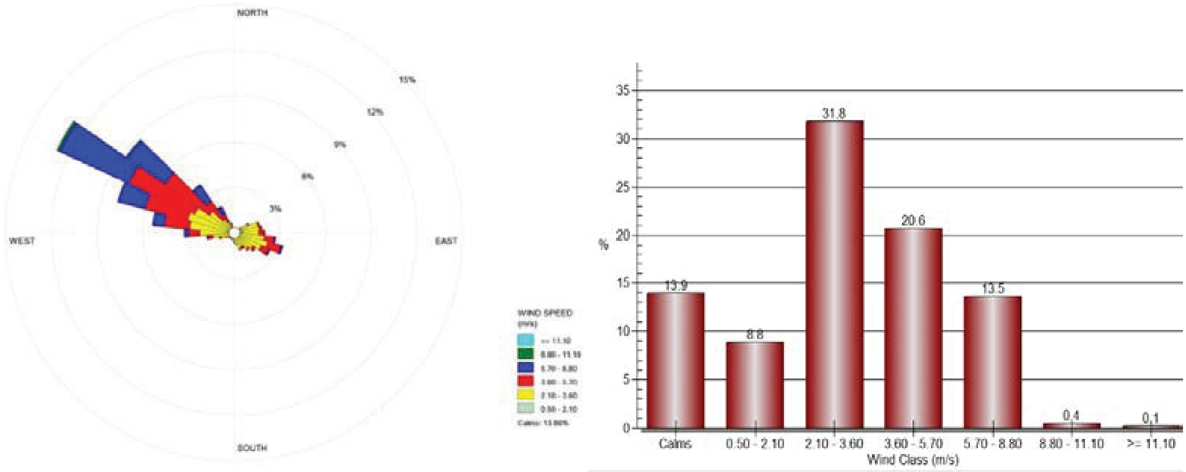
Model description AERMOD

AERMOD, developed by USEPA and AMS, is a steady-state Gaussian plume model for measuring the dispersion of airborne pollutants up to 50 km within the source radius. The Gaussian plume model is used to estimate the dispersion of air pollutants (Cheremisinoff, 2002). The hypothesis of this model is that molecular diffusion causes plum spread and dispersion of pollutants (Thad Godish, 2005). In a coordinate system based on wind orientation, the Gaussian plume model mass balance is expressed using Eq. 10 (Cheremisinoff, 2002).

$$\partial Ci / \partial t + U \partial Ci / \partial x = \partial i / \partial y \left(Ky \partial Ci / \partial y \right) + \partial i / \partial z \left(Kz \partial Ci / \partial z \right) + C1 \quad (10)$$

Where, Ci is the average concentration (g/m^3 or µg/m^3); U is average wind speed (m/s); t is time; x is the x-axis extending horizontally in the direction of the mean wind; y is the y-axis in the horizontal plane perpendicular to the x-axis; z is the z-axis extending vertically; C1 is the rate of loss or gain by chemical reactions, precipitation (washout), or adsorption by suspended particles; Ky is Uσ2y/2x, and Kz is Uσ2z/2x.

AERMOD model is used in rural and urban areas, flat and complex terrain, surfaces and elevated releases, and multiple sources as points, area, and volume sources. The model input consists of



(a) (b)

Fig. 2: (a) Wind rose diagram and (b) wind class frequency distribution of the study area (2015-2019)

meteorological and topographical data of the study area, source types, emission rates, location of sources, and receptors. Wind speed and direction, temperature, pressure, relative humidity, rainfall, and cloud cover are considered as meteorological data. AERMOD model has a main processor, called AERMOD, and two pre-processors called meteorological pre-processor (AERMET) and terrain pre-processor (AERMAP). AERMET pre-processor processes the meteorological data. AERMET incorporates meteorological observations from the surface and upper stations, calculates the boundary-layer meteorological parameters, and prepares these data in the formats readable by AERMOD (Cimorelli et al., 2004). AERMAP analyzes the terrain and generates receptor grids for AERMOD. The main processor of the model integrates the meteorological and topographical data and source PM emissions to predict the downwind concentrations of the source(s). In this study, the AERMOD model (version 8.9) was used to estimate the 24-hour and annual average concentrations of $PM_{2.5}$, $PM_{10,}$ and TSP from sand and gravel processing operations. Lack of upper air meteorological data was the limitation of using the AERMOD model in this study.

Meteorological data

The required meteorological data during five years (2015 to 2019) was extracted from Shahriar synoptic station, the closest station to the mineral complex. It is located at a distance of 3.5 km at the southwest of the mineral complex between a longitude of 51.01 N and a latitude of 35.40 E. The wind rose plotted by WRPLOT software, and the wind frequency classification of the study area are shown in Fig. 2a and b, respectively. Wind frequency classification shows the percentage of wind with a different speed range. It also shows the time in which a calm situation prevailed.

AERMOD model requires hourly meteorological data to simulate the pollutant dispersion. Since the collected meteorological data were based on three-hour periods, they were converted to hourly data by the weighted interpolation of data with the help of Excel formula functions. To perform calculations, AERMET pre-processor needs three surface characteristics: 1) Bowen ratio (surface moisture determination index), 2) Albedo coefficient (fraction of solar radiation that is reflected into space without being absorbed by the surface), and 3) surface roughness coefficient (altitude that is the average horizontal wind speed). The USEPA values suggested for these surface characteristics are presented in Table 4 (US EPA, 2021b).

Terrain elevation data

The mineral complex, marked as dotted lines in Fig. 3, is located at an altitude of 1000 to 1500 m (1200

Table 4: Values for surface roughness length, Albedo, and Bowen ratio

Surface characteristics	Spring	Summer	Autumn	Winter	Land-use
	0.14	0.16	0.18	0.35	Urban
Albedo coefficient	0.14	0.2	0.18	0.6	Cultivated Land
	0.3	0.28	0.28	0.45	Desert Shrubland
	1	2	2	1.5	Urban
Bowen ratio	0.3	0.5	0.7	1.5	Cultivated Land
	3	4	6	6	Desert Shrubland
	1	1	1	1	Urban
Surface roughness	0.03	0.2	0.05	0.01	Cultivated Land
	0.3	0.3	0.3	0.15	Desert Shrubland

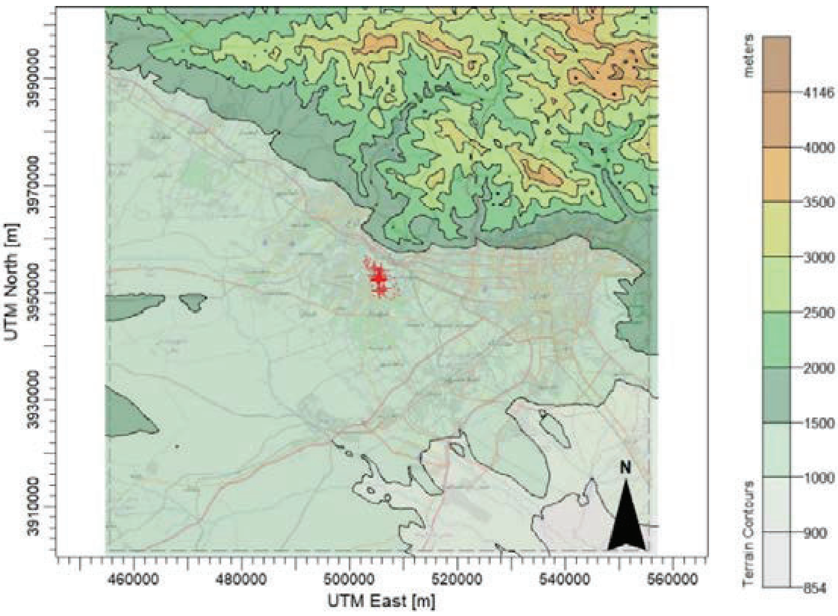


Fig. 3: Map of terrain features of the study area (up to 50 km)

m). There is a relatively complex topography in the northern and northeastern parts of the complex at 3 km. However, in other territories around the mineral complex, the topography is relatively flat. According to the region's topography, a digital elevation model (DEM) with an accuracy of 90 m was used, and the output was fed into the model in XYZ format.

Emission rate

The dust emission rates from different sand and gravel processing operations during the year of operation were calculated based on the experimental equations suggested by USEPA. The required data were gathered from the technical reports of the plants to estimate the rates of dust emission from different mining source activities. 70% control efficiency (C.E.) was assumed for watering at the crushing, screening operation, and conveyors transfer points (USEPA, 1995a) and 55% control efficiency was considered for watering the unpaved roads twice a day (WRAP, 2004). The rates of emission from different sand and gravel mining operations are presented in Table 5.

RESULTS AND DISCUSSION

The rates of particulate matter emission from sand and gravel product plants in a mineral complex were emphasized in this study. The dispersion of these pollutants up to a distance of 50 km was also modelled. The standard values of $PM_{2.5}$ and PM_{10} were compared with the simulated values.

Table 5: Emissions from various pollutant sources in the sand and gravel mining complex

Pollutants	Crushed stone processing operations	Stockpile handling	Unpaved road	Paved road	Open area wind erosion	Total emissions
	ton/y	ton/y	ton/y	ton/y	ton/y	ton/y
$PM_{2.5}$	38.32	0.345	29.377	70.594	3.84	142.476
PM_{10}	71.237	2.289	295.191	291.789	25.56	686.066
TSP	216.54	4.481	999.292	1520.128	51.12	2791.561

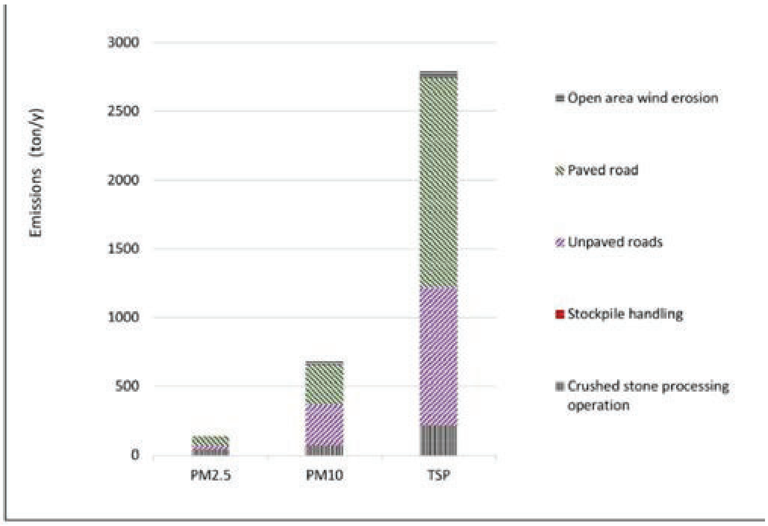


Fig. 4: $PM_{2.5,}$ PM_{10} and TSP emissions from the sand and gravel mining processes

Influential parameters

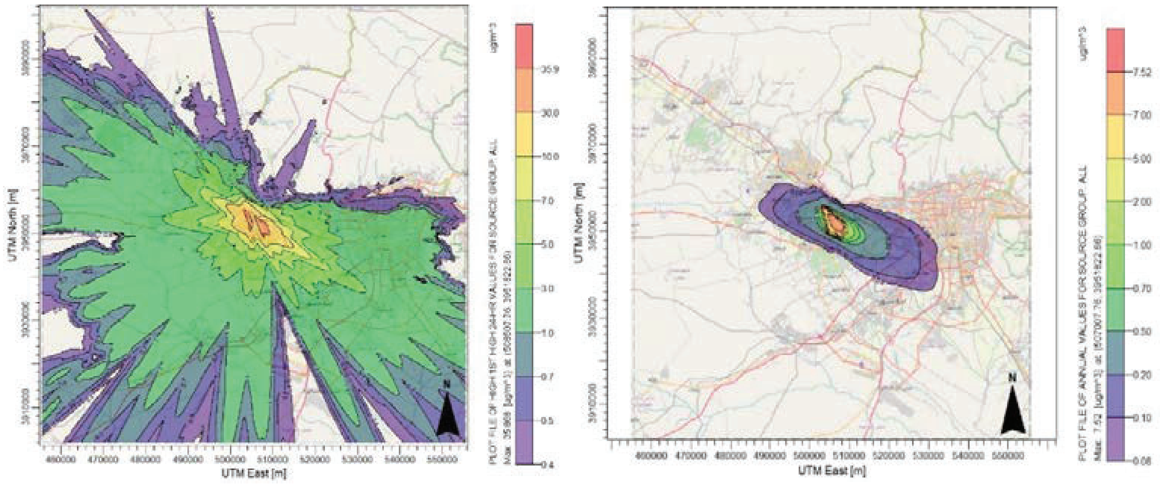
As previously explained by Eqs. 2-5, the wind speed in the area, moisture content of stockpiles, silt content of unpaved roads, silt loading value for paved roads at industrial facilities, and weight of the vehicle travelling on roads were the factors affecting the emission rate of dust from sand and gravel mining operations. The concentration of fugitive dust decreased with a decrease in wind speed, silt content, road surface silt loading, and mean vehicle weight. In contrast, the moisture content is indirectly related to the dust emission from sand and gravel processing operations. Dust emission rate increased with the decrease of moisture content, the weight of particles increased with the increase of moisture content. The moisture made particles heavy and prevented them from dispersing into the atmosphere.

Meteorology

The concentration of pollutants was proportional to the emission rate, wind speed and direction, atmospheric turbulence, and horizontal diffusion direction. In addition to the horizontal flow, the concentration of pollutants was affected by the vertical wind flow. Wind speed changed the concentration of pollutants. Fig. 2 illustrates that the most frequent winds for this period (2015-2019) blew from the northwest direction. The wind speed in the study area varied in the range of 0.5 and 11.10 m/s, and the average wind speed during 2015-2019 was 3.12 m/s. The minimum frequency distribution percentage of the wind speed (0.1%) was related to the speed of over 11.1 m/s, and the maximum frequency distribution percentage of the wind speed (31.8%) was associated with 1.3-2.3 m/s. Calms (wind speed <5 m/s) during the study period occurred 13.9% of the time. The predominant wind direction was towards the southeast direction.

Distribution of particles among aggregate product operations

Fig. 4 shows the total PM2.5, PM10, and TSP emissions from sand and gravel processing operations in the mineral complex. PM2.5, PM10, and TSP



(a) (b)

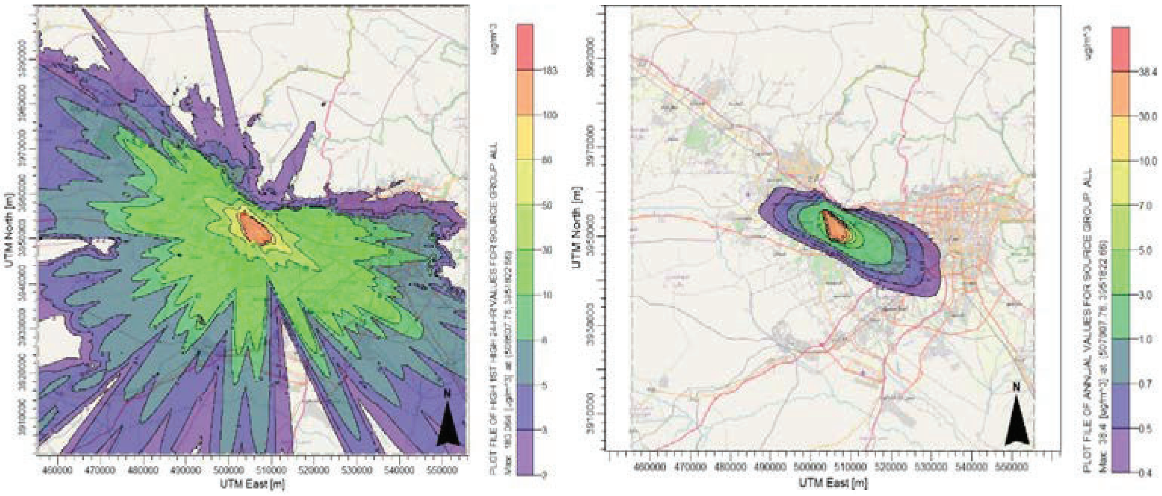
Fig. 5: Dispersion of $PM_{2.5}$ from the sand and gravel product plants: (a) 24-hour average and (b) annual average

emissions were 142.476, 686.066, and 2791.561 tons/y, respectively. Vehicular traffic on paved roads, in the first stand, accounted for 49.55% of the total $PM_{2.5}$ emission, and crushed stone processing operations, which produced 26.90% of the total $PM_{2.5}$ emission, placed the second. Mandal *et al.* (2012) performed a similar study. They found that vehicle travelling on roads was responsible for the highest amount of total dust generation (about 80%) during the operations in opencast mines. In the third stand, Unpaved roads accounted for about 20.62% of the total $PM_{2.5}$ emission, and open area wind erosion contributing to 2.70 % of the total $PM_{2.5}$ emission was in the fourth stand. The highest emission of PM_{10} (43.03%) was related to unpaved roads, followed by paved roads, crushed stone processing operations, and open area wind erosion with 42.53%, 10.38%, 3.73% total PM_{10} emissions, respectively. The highest emission of TSP (54.45%) was related to paved roads, followed by unpaved roads, crushed stone processing operations, and open area wind erosion with 35.80%, 7.76%, and 1.83 % total TSP emissions, respectively. The minimum concentration emitted to the air was due to stockpiles handling with 0.24%, 0.33%, and 0.16% emissions of the total $PM_{2.5}$, PM_{10} and TSP, respectively.

Dispersion of particulate matters

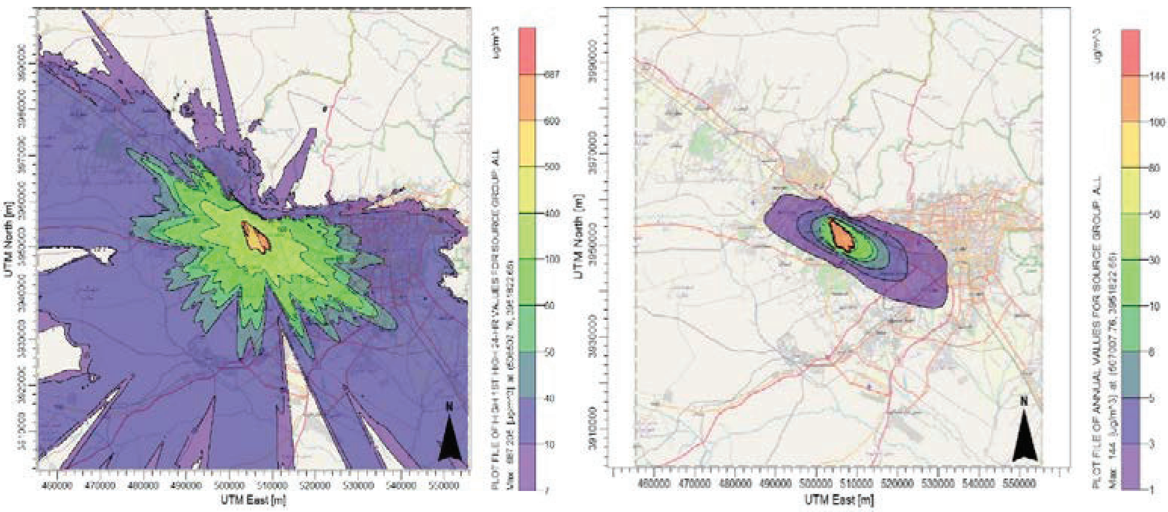
In the Gaussian dispersion model, the concentration of pollutants is directly proportional to the emission rate, wind speed and direction, atmospheric turbulence, horizontal dispersion direction, and vertical wind flow. Vertical and horizontal directions influence concentration. Many factors, such as atmospheric conditions, land use, vegetation cover, and other geographical characteristics, affect atmospheric dust emissions. As shown in Fig. 2, the dominant wind was blowing from northwest to the southeast of the mineral complex, driving the largest particulate matter to residential areas at the southeast of the mineral complex. The dispersion of pollutants concentration in the mineral complex decreased outwards from the source to the point of impact (Fig. 5a-7b) due to wind direction and speed, terrain height, horizontal distance, and other meteorological parameters. Due to the flatness of the study area, particles are uniformly distributed in all areas. Based on the collected data, the sand and gravel product plants in the mineral complex emitted about 36 $\mu g/m^3$ of $PM_{2.5}$ (Fig. 5a), 183 $\mu g/m^3$ of PM_{10} (Fig. 6a), and 687 $\mu g/m^3$ of TSP (Fig. 7a) into the atmosphere in 24-hour average and about eight $\mu g/m^3$ of $PM_{2.5}$ (Fig. 5b), 39 $\mu g/m^3$ of PM_{10} (Fig. 6b), and 144 $\mu g/m^3$ of TSP (Fig. 7b) into the atmosphere in annual average. The maximum 24-hour and annual $PM_{2.5}$, PM_{10}, and TSP concentrations observed in the mineral complex are shown in Table 6.

According to the US EPA reports on ambient air quality, which is valid in Iran as well, the standard values of $PM_{2.5}$ are 35 $\mu g/m^3$ (24-hour average)



(a) (b)

Fig. 6: Dispersion of PM_{10} from the sand and gravel product plants: (a) 24-hour average and (b) annual average



(a) (b)

Fig. 7: Dispersion of TSP from the sand and gravel product plants: (a) 24-hour average and (b) annual average

Table 6: Maximum concentrations of PMs emitted from the sand and gravel product plants

Pollutant	Maximum concentration (µg/m^3)	Average time	Geographical coordinates	
			X	Y
$PM_{2.5}$	35.87	24-hour	508507.76	3951822.66
	7.52	annual	507007.76	3951822.66
PM_{10}	183.06	24- hour	508507.76	3951822.66
	38.39	annual	507007.76	3951822.66
TSP	678.2	24- hour	508507.76	3951822.66
	144.12	annual	507007.76	3951822.66

and 12 µg/m^3 (annual average), the PM_{10} threshold standard value is 150 µg/m^3 (24-hour average), and no standard value is defined for an annual average concentration of PM_{10} (US EPA, 2021c). However, the WHO standard values for $PM_{2.5}$ are 25µg/m^3 (24-hour average) and 10 µg/m^3 (annual average), and for PM_{10} are 50 µg/m^3 (24-hour average) and 20 µg/m^3 (annual average) (WHO, 2006). The USEPA and WHO do not have regulated standard values of TSP.

As previously explained, the most frequent winds in 2015-2019 blew from the northwest direction. Dispersion of particulate matter concentrations indicated the significant impact of dust within the mineral complex. This finding was in agreement with the results reported by Lilic *et al.* (2018), who showed that the distribution of PM_{10} from mining operations had a significant impact on the nearby surface mines. In the present study, the modelling results showed that in a wider area around the mineral complex, the 24-hour average concentrations of $PM_{2.5}$, PM_{10}, and TSP decreased from 30, 80, and 400 µg/m^3 (immediate vicinity of the mineral complex) to 0.50, 3, and 10 µg/m^3 in the Ijdanak and Abyek villages at a distance of about 50 km in the southeast and northwest of the complex, respectively. For example, the 24-hour average concentrations of $PM_{2.5}$, PM_{10}, and TSP, which had reached the areas at distances of 1-9 km from the mineral complex, were approximately in the range of 5-30, 30-80, and 100-400 µg/m^3, respectively. The 24-hour average concentrations of the particulate matters reached the residential areas such as Shahre Qods, Andisheh, Shahriar, Malard, and Mohammadshahr townships were approximately 30, 30, 7, 5, and 5 µg/m^3 for $PM_{2.5}$, 80, 80, 50, 30, and 30 µg/m^3 for PM_{10}, and 400, 400, 400, 100, and 100 µg/m^3 for TSP, respectively. In the mentioned townships, the $PM_{2.5}$ concentrations were 5, 5, 28, 30, and 30 µg/m^3 less than the EPA standard values, and the PM_{10} concentrations were 70, 70, 100, 120, and 120 µg/m^3 less than the EPA standard values, respectively. However, the $PM_{2.5}$ concentrations reached Shahre Qods, and Andisheh townships were 5 and 5 µg/m^3 higher than the WHO standard values, respectively. The $PM_{2.5}$ concentrations reached Shahriar, Mallard and Mohammadshahr townships were 18, 20, and 20 µg/m^3 lower than the WHO standard values, respectively. Moreover, the PM_{10} concentrations that reached Shahre Qods and Andisheh townships were 30 and 30 µg/m^3 higher than the WHO standard values, respectively, and the PM_{10} concentrations in Malard and Mohammadshahr townships were 20 and 20 µg/m^3 less than the WHO standard values, respectively. The PM_{10} concentration in Shahriar was almost equal to the standard value. The 24-hour average concentrations of $PM_{2.5}$, PM_{10}, and TSP in Wardavard zone, located in the western part of Tehran, were approximately 7, 50, and 400 µg/m3, respectively, and the 24-hour average concentrations of $PM_{2.5}$, PM_{10}, and TSP reached the center of Tehran, at a distance of 28 km from the mineral complex, were 3, 10, and 40 µg/m^3, respectively (lower than the standard values). The 24-hour average concentrations of $PM_{2.5}$, PM_{10}, and TSP reached Hakimiyeh district, at the eastern part of Tehran, were 0.5, 3, and 10 µg/m^3, respectively. The 24-hour average concentrations of $PM_{2.5}$ and PM_{10} reached Tehran were below the EPA and WHO standard values. The dispersion of annual average dust concentrations showed a significant decrease. The distributed concentrations of $PM_{2.5}$, PM_{10}, and TSP were 0.1, 0.5, and 3 µg/m^3, respectively, towards the southeast of the study area up to Ahmadabad Mostoufi village at a distance of about 9 km from the mineral complex. The annual average concentrations of particulate matters reached Shahre Qods, Andisheh, Shahriar, Malard, and Mohammadshahr townships were approximately 0.7, 0.5, 0.2, 0, and 0.1 µg/m^3 for $PM_{2.5}$, 5, 3, 0.7, 0 and 0.5 µg/m^3 for PM_{10}, and 30, 10, 3, 0 and 3 µg/m^3 for TSP, respectively (lower than the EPA and WHO standard values). Alkas (2016) monitored the suspended particulate matter and settleable particulate matter parameters in Turkey's sand and gravel industry. He showed that the average values for these parameters in the plant were equal to the standards. Sozaeva and Kagermazov (2020) studied the harmful effects of dust emissions from extraction and sand and gravel processes on air quality. Their findings showed that the dust emissions in the study area exceeded the threshold value and became lower than it was only outside the study area. Although the $PM_{2.5}$ and PM_{10} concentrations reached the residential areas around the mineral complex and Tehran were acceptable, these pollutants, along with the pollutant particles emitted from other emission sources, such as vehicles and other industries, could increase the airborne levels of particulate matters and cause air pollution and threaten the health of the people living in the vicinity of the studied mineral complex. Therefore, reducing dust emissions seemed to be essential for reducing air pollution, and it was suggested to be more careful in locating, constructing and developing sand and gravel product plants. Asphalting the unpaved access roads in sand and product plants, which lead to dust emission due to vehicle travelling, was also suggested. Application of some efficient methods, such as using trucks with higher capacity to carry aggregates, spraying water on paved and unpaved roads, storage piles and crushed stones before loading; choose the best strategy to preserve the moisture content of sand and gravel, reducing the silt content of the unpaved roads, and constructing a green belt around the mineral complex, can be followed to mitigate the dust emission. Moreover, the government and responsible organizations should set up and apply laws, regulations and standards related to the sand and gravel processing operations. They should also monitor the aggregate production plants to ensure that they perform all commitments according to the laws and regulations. The government should improve the urban design to protect public health and move the industries with heavy pollutions into the industrial zones.

CONCLUSION

The demand for sand and gravel for different purposes in industry and construction is growing every day. Sand and gravel mining activities generate particulate matters, including $PM_{2.5}$, PM_{10}, and TSP, which increase airborne dust levels. Stone crushing, stockpile handling, traffic roads, and wind erosion are among the sources of particulate matter emissions. Due to the impossibility of sampling and direct measurement of dust concentrations at any time and place, the application of dispersion models for estimating the pollutants concentrations in the atmosphere has been highlighted. Investigation of large-scale sand and gravel processing operations in the South-West of Tehran revealed that vehicle traffic on roads with the rates of 70.2%, 85.6%, and 90.2% for total $PM_{2.5}$, total PM_{10}, and total TSP, respectively, was responsible for the maximum dust emission. However, stockpile handling and storage piles, with the rates of 0.24%, 0.33%, and 0.16% for total $PM_{2.5}$, total PM_{10}, and total TSP, respectively, had limited potential for dust emission. These plants emitted 36 μg/m^3 of $PM_{2.5}$, and 183 μg/m^3 of PM_{10} in 24-hour average and eight μg/m^3 of $PM_{2.5,}$ and 39 μg/m^3 of PM_{10} in annual average into the atmosphere. The results showed that the particulate matter significantly impacted airborne dust levels within and beyond the studied mineral complex boundaries. The workers/personnel working at these plants were affected by these pollutants. Therefore, the government and the authorities were expected to take immediate actions and adopt proper policies by enacting appropriate laws and regulations. Significant improvements in technology were required to reduce the dust emissions, and windbreaks as product covers and enclosures were necessary to control the pollutant sources. Further study is recommended to estimate the cumulative dispersion of particulate matter produced by all the industries in the study area. It is better to update the emission factors for local use because of the differences in the measuring conditions of these factors, such as vehicle technology, consumption fuel quality, and culture of driving for mobile sources.

AUTHOR CONTRIBUTIONS

Y. Zehtab Yazdi performed the literature review, collected the data, and ran the model. N. Mansouri conceived the original idea, formulated the study goals, analyzed the study data, prepared the manuscript text and performed the manuscript edition. F. Atabi helped in structuring the study and contributed in interpreting the results and editing the manuscript. H. Aghamohammadi elaborated on the maps and figures.

ACKNOWLEDGMENTS

The authors would like to thank the Environmental Department of Shahre Qods and Aggregate Producers Association of Tehran Province for their collaborating. This study has been extracted from the PhD dissertation of Yaser Zehtab Yazdi in environmental engineering at the Science and Research Branch, Islamic Azad University, Tehran, Iran.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the authors have entirely witnessed ethical issues, including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and submission, and redundancy.

PUBLISHER'S NOTE

GJESM Publisher remains neutral concerning jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

%	Percentage
∂	Partial Derivative
ADT	Average Daily Traffic
AERMOD	American Meteorological Society/ Environmental Protection Agency Regulatory Model Improvement Committee Dispersion Model
a.m.	ante meridiem: before noon
AMS	American Meteorological Society
AP-42	Compilation of air emission factor
ASTM	American Society for Testing and Materials
AURORA	Air Quality Modeling in Urban Regions using an Optimal Resolution Approach
°C	Degrees Celsius
CALPUFF	California Puff Model
CE	Control Efficiency
CFD	Computational Fluid Dynamic
CPB	Canyon Plume Box
E	East
EF	Emission Factor
e.g.,	exempli gratia: for example,
EPA	Environmental Protection Agency
etc.	et cetera: and other similar things
Eq.	Equation
et al.	et alia: and others
ER	Efficiency Reduction
FDM	Fugitive Dust Model
Fig	Figure
g	gram
g/m^3	Gram per cubic meters
GRAL	Graz Lagrangian Model
ha	Hectare
ISC-3	Industrial Source Complex 3
Kg	Kilogram
Km	Kilometer
Km^2	Square kilometers
lb	Pound
m^2	Square meters
mm	Millimeter
m/s	Meter per second
$\mu g/m^3$	Microgram per cubic meters
μm	Micrometers
MICRO-CALGRID	Microscale California Photochemical Grid Model
MISKAM	Microscale flow and dispersion model
N	North
OSPM	Operational Street Pollution Model
PBM	Photochemical Box Model
p.m.	post meridiem: Afternoon
PM	Particulate Matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter of less than or equal to 2.5 micrometers
PM_{10}	particulate matter with an aerodynamic diameter of less than or equal to 10 micrometers
TSP	Total suspended particulate

TAPM	The Air Pollution Model
UK-ADMS	UK Atmospheric Dispersion Modeling System
US EPA	United States Environmental Protect Agency
VKT	Vehicle Kilometers Travelled.
VMT	Vehicle Miles Travelled
WHO	World Health Organization
y	Year

REFERENCES

Ako, T.A.; Onoduku, U.S.; Oke, S.A.; Essien, B.I.; Idris, F.N.; Umar, A.N; Ahmed, A.A., (2014). Environmental effects of sand and gravel mining on land and soil in Luku, Minna, Niger State, North Central Nigeria. J. Geosci., 2(2): 42-49 **(8 pages).**

Alkas, D., (2016). A case study for the assessment of settleable and suspended particulate material in sand and gravel industry. J. Pollut. Eff. Cont., 4(3): 1-4 **(4 pages).**

Anderson, J.; Thundiyil, J.; Stolach, A., (2012). Clearing the air: A review of the effects of particulate matter air pollution on human health. J. Med. Toxicol., 8(2): 166-75 **(10 pages).**

Asif, Z; Chen, Z.; Han, Y., (2018). Air quality modelling for effective environmental management in the mining region. J. Air Waste Manage. Assoc., 68(9): 1001-1014 **(14 pages).**

Badr, D.; Harion, J.L., (2007). Effect of aggregate storage piles configuration on dust emissions. J. Atmos. Environ., 41(2): 360-368 **(9 pages).**

Cheremisinoff, N.P., (2002). Handbook of air pollution prevention and control, Elsevier Science (USA).

Cho, D.O., (2006). Challenges to the sustainable development of marine sand in Korea. Ocean Coast. Manage, 49(1-2): 1-21 **(21 pages).**

Cimorelli, A.J.; Perry, S.G.; Venkatram, A.; Weil, J.C.; Paine, R.J.; Wilson, R.B.; Lee, R.F.; Peters, W.D.; Brode, R.W.; Paumier, J.O., (2004). AERMOD: Description of model formulation. U.S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1009OXW.PDF?Dockey=P1009OXW.PDF

Cimorelli, A.J.; Perry, S.G.; Venkatram, A.; Weil, J.C.; Paine, R.J.; Wilson, R.B.; Lee, R.F.; Peters, W.D.; Brode, R.W., (2005). AERMOD: A dispersion model for industrial source applications. Part I: General model formulation and boundary layer characterization. J. Appl. Meteorol., 44(5): 682–693 **(13 pages).**

Ezeh, G.C.; Obioh, I.B.; Asubiojo, O.I.; Abiye, O.E., (2012). PIXE characterization of PM10 and PM2.5 particulates sizes collected in Ikoyi Lagos, Nigeria. Toxicol. Environ. Chem., 94(5): 884-894 **(14 pages).**

Gautam, S.; Patra, A.K., (2015). Dispersion of particulate matter generated at higher depths in opencast mines. Environ. Technol. Innov, 3: 11–27 **(17 pages).**

Heger, M.; Sarraf, M., (2018). Air pollution in Tehran: Health costs, sources, and policies: World Bank Group.

Holmes, N.; Morawska, L., (2006). A review of dispersion modelling and its application to the dispersion of particles: An overview of different dispersion models available. Atmos. Environ., 40(30): 5902-5928 **(27 pages).**

Lashgari, A.; Kecojevic, V., (2016). Comparative analysis of dust emission of digging and loading equipment in surface coal mining. Int. J. Min. Reclam. Environ. 30(3): 181-196 **(16 pages).**

Leili, M.; Naddafi, K.; Nabizadeh, R.; Yunesian, M.; Mesdaghinia, A.; (2008). The study of TSP and PM10 concentration and their heavy metal content in central area of Tehran, Iran. Air Qual. Atmos. Health. 1(3): 159–166 **(7 pages).**

Lilic, N.; Cvjetic, A.; Knezevic, D.; Milisavljevic, V.; Pantelic, U., (2018). Dust and noise environmental impact assessment and control in Serbian Mining Practice. Minerals, 8(2), 34: 1-15 **(15 pages).**

Lilic, N.; Knezevic, D.; Cvjetic, A.; Milisavljevic, V., (2012). Dust dispersion modelling for an opencast coal mining area. Tehnika., 67 (6): 911–918 **(8 pages).**

Lohe, R.N.; Tyagi, B.; Singh, V.; Tyagi, P.; Khanna, D.R.; Bhutiani, R., (2015). A comparative study for air pollution tolerance index of some terrestrial plant species. Global J. Environ. Sci. Manage., 1(4): 315-324 **(10 pages).**

Mandal, K.; Kumar, A.; Tripayhi, N.; Singh, R.S.; Chaulya, S.K.; Mishra, P.K.; Bandyopadhyay, L.K., (2011). Characterization of different road dusts in opencast coal mining areas of India. Environ. Monit. Assess, 184 (6): 3427–3441 **(15 pages).**

Naveen Saviour, M., (2012). Environmental impact of soil and sand mining: a review. Int. J. Sci. Enviro., 1(3): 125-134 **(10 pages).**

Neshuku, M.N.; (2012). Comparison of the performance of two atmospheric dispersion models (AERMOD and ADMS) for open pit mining sources of air pollution. MSc, University of Pretoria.

Onabowale, M.K.; Owoade, O.K., (2015). Assessment residential indoor outdoor airborne particulate matter in Ibadan, Southwestern Nigeria. Donnish J. Physical. Sci., 1(1): 001-007 **(7 pages).**

Owen Harrop, D.; (2005). Air quality assessment and management: A practical guide. Taylor & Francis e-Library.

Ruckerl, R.; Schneider,Chneider, A.; Breitner, S.; Cyrys, J.; Peters, A., (2011). Health effects of particulate air pollution: A review of epidemiological evidence. Inhal. Toxicol., 23(10): 555-92 **(38 pages).**

Sastry, V.R.; Chandar, K.R.; Nagesha, K.V.; Muralidhar, E; Mohiuddin, M.S., (2015). Prediction and analysis of dust dispersion from drilling operation in opencast coal mines. Procedia Earth Planet. Sci., 11: 303-311 **(9 pages).**

Sozaeva, L.; Kagermazov, A., (2020). Environmental impacts of mining and processing of sand-gravel mix. E3S Web Conferences, 157, 02020.

Thad Godish, T., (2005). Air Quality. 4th Edition ed.: Taylor & Francis e-Library.

Theodore, L., (2008). Air pollution control equipment calculations, Hoboken, New Jersey, John Wiley & Sons, Inc.

Trivedi, R.; Chakraborty, M.K.; Tiwary, B.K., (2009). Dust dispersion modelling using fugitive dust model at an opencast coal project of Western Coalfields Limited, India. JSIR, 68(1):71–78 **(8 pages).**

US EPA, (1993a). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: stationary point and area sources Ap-42. Procedures for sampling surface/Bulk dust loading. United States Environmental Protection Agency.

US EPA, (1993b). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: stationary point and area sources Ap-42. Procedures for laboratory analysis of surface/ Bulk dust loading samples. United States Environmental Protection Agency.

US EPA, (1995a). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: stationary point and area sources. Chapter 11: Mineral products industry, 11.19.1 Sand, and gravel processing. United States Environmental Protection Agency.

US EPA, (1995b). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Introduction to AP 42, Volume I. United States Environmental Protection Agency.

US EPA, (2004). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Chapter 11: Mineral products industry, 11.19.2: Crushed stone processing and pulverized mineral processing. United States Environmental Protection Agency.

US EPA, (2006a). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Chapter 13: Miscellaneous sources, 13.2.4: Aggregate handling, and storage pile. United States Environmental Protection Agency.

US EPA, (2006b). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Chapter 13: Miscellaneous sources, 13.2.2: Unpaved Road. United States Environmental Protection Agency.

US EPA, (2006c). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Chapter 13: Miscellaneous sources, 13.2.5: Industrial wind erosion. United States Environmental Protection Agency.

US EPA, (2011). Emissions factors and AP 42, Compilation of air pollutant emission factors. Volume 1: Stationary point and area sources. Chapter 13: Miscellaneous sources, 13.2.1: Paved roads. United States Environmental Protection Agency.

US EPA, (2020a). Criteria air pollutants. United States Environmental Protection Agency.

US EPA, (2020b). Air emissions factors and quantification, AP-42: Compilation of air emissions factors. United States Environmental Protection Agency.

US EPA, (2021a). Particulate matter (PM) basics. United States Environmental Protection Agency.

US EPA, (2021b). User's guide for the AERMOD meteorological pre-processor (AERMET). United States Environmental Protection Agency.

US EPA, (2021c). National ambient air quality standards (NAAQS) for PM. United States Environmental Protection Agency.

Van Der Meulen, F.; Salman, A.H.P.M., (1996). Management of Mediterranean coastal dunes. Ocean Coast Manag, 30(2-3): 177-195 **(19 pages).**

WHO, (2006). WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005: summary of risk assessment. World Health Organization.

WRAP (2004). Fugitive dust control measures applicable for the Western Regional air partnerships. Fugitive dust handbook, Western Governor's Association, Denver, Colorado, USA.

AUTHOR (S) BIOSKETCHES

Zehtab Yazdi, Y., Ph.D. Candidate, Department of Environment Engineering, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran.
Email: *yaser.zehtab.yazdi@gmail.com*
ORCID: 0000-0001-5569-6883

Mansouri, N., Ph.D., Professor, Department of Environment Engineering, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran.
Email: *nmansourin@gmail.com*
ORCID: 0000-0002-4228-6444

Atabi, F., Ph.D., Associate Professor, Department of Environment Engineering, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran.
Email: *far-atabi@jamejam.net*
ORCID: 0000-0001-9206-1967

Aghamohammadi, H., Ph.D., Assistant Professor, Department of Remote Sensing and Geographical Information System, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran.
Email: *hossein.aghamohammadi@gmail.com*
ORCID: 0000-0002-9497-6295

HOW TO CITE THIS ARTICLE

Zehtab Yazdi, Y.; Mansouri, N.; Atabi, F.; Aghamohammadi, H., (2022). Dispersion modelling of particulate matter concentrations of sand product plants in a mineral complex. Global J. Environ. Sci. Manage., 8(2): 265-280.

DOI: 10.22034/gjesm.2022.02.09

url: https://www.gjesm.net/article_246819.html

Global J. Environ. Sci. Manage. 8(2): 281-296, Spring 2022

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

REVIEW ARTICLE

Agricultural waste management generated by agro-based industries using biotechnology tools

D. Sivakumar[1,*], P. Srikanth[1], P.W. Ramteke[2], J. Nouri[3]

[1] *Kalasalingam School of Agriculture and Horticulture, Kalasalingam Academy of Research and Education, Krishankoil, Srivilliputhur, Tamil Nadu, India*

[2] *Faculty of Life Sciences, Mandsaur University, Mandsaur, India*

[3] *Department of Environmental Health Engineering, Tehran University of Medical Sciences, Tehran, Iran*

ARTICLE INFO

Article History:
Received 9 July 2020
Revised 29 September 2020
Accepted 31 October 2020

Keywords:
Agro-Waste;
Bio-enzymes
Bio-lipids
Microorganisms
Oil cakes

ABSTRACT

The amount of agricultural waste generated by agro-based industries such as palm oil, rubber, and wood processing plants have more than tripled. Selangor, Perak, and Johor account for 65.7 percent of the total number of recognised pollution sources in the manufacturing and agro-based sectors. Livestock dung is another major cause of pollution, contributing significantly to increase pollution levels in the environment. Large portion of agro-industrial waste is untreated and unused, it is frequently disposed of by replicating or dumping then again off the cuff landfilling. These untreated wastes wreak havoc on natural change by releasing ozone-depleting chemicals. Aside from that, the usage of fossil fuels is also leading to an increase in ozone-depleting compounds. Agro-waste is a huge environmental hazard in the current epidemic situation. The management of agro-waste and the conversion of agro-waste into a usable product through the application of biotechnological technologies in agriculture are receiving a lot of attention in today's world. Solid state fermentation is the finest approach for converting agro-waste into valuable bio products among biotechnological instruments. Various agro-wastes such as wheat straw, barley straw, cotton stalks, sunflower stacks, and oil cakes from various agriculture goods, as well as major horticulture wastes such as apple, mango, orange peels, and potato peels, were used to create beneficial products in this review. All aspects of the production of industrial products from various agro-waste by using microorganisms such as Amycolatopsis Mediterranean, Xanthomonas campestries, and Aspergillus niger producing biopolymers such as polysaccharides, similar to starch, cellulose, agar, hemi-celluloses, gelatin, alginate, and carrageenan are covered in the current revels. Yeasts and cyanobacteria are commonly employed to make bio-lipids, whereas Bacillus species are utilised to make proteins and bio-enzymes. Cucumber and orange strips, on the other hand, have recently been employed to create proteins and bio-enzymes. As a result, this review covers the many forms of agro-wastes and their by-products as well as biotechnological technologies used to treat them.

DOI: 10.22034/gjesm.2022.02.10

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
89	2	6

*Corresponding Author:
Email: *d.sivakumar@klu.ac.in*
Phone: +91-9790973774
ORCID: 0000-0001-5228-0145

Note: Discussion period for this manuscript open until July 1, 2022 on GJESM website at the "Show Article.

INTRODUCTION

According to Duque-Acevedo *et al.,* 2020, horticulture production has significantly increased to 23.7 million tonnes of food per day during the last 50 years. This current increase has put a lot of pressure on typical assets, which has led to some questions about rural manageability. Some portion of biomass from agriculture products, generate waste, which may not be used as food (Duque-Acevedo *et al.,* 2020). Other major concerns about the manageability of agro-biological systems should be mentioned in this unique situation. Agribusiness consumes a significant amount of soil and water (Aguilera *et al.,* 2020) and it should be recognised that in the next years, there will be an increasing need to improve rural efficiency to care for the growing total population (Sarkar *et al.,* 2020), which has expanded substantially since 1960 and is expected to fill faster in the following many years (Blattner *et al.,* 2020). According to one study, the global population will reach 9.1 billion people by 2050 (Leisner *et al.,* 2020). Natural change is causing a slew of problems. Natural change and subsequent temperature rise documented from 1951 to 2010 are largely due to anthropogenic activities (Dobrynin *et al.,* 2015). On a global basis, temperatures have shown an unmistakable upward trend since 1980. There have been a few gaps, but astonishingly strange warming zeniths have been observed to some extent recently (Hegerl *et al.,* 2019). Transmissions of ozone-depleting substances (methane, nitrous oxide, and carbon dioxide) are thought to be at danger for rising temperatures at globally. The Corban dioxide is released to the atmosphere primarily as a result of the consumption of fuel subordinates (Poore *et al.,* 2018). An increase in global temperature will have a direct impact on the water cycle, fundamentally altering organic structures, with moist areas drying out and dry areas becoming wet (Polson *et al.,* 2013). Among the food domains, it is estimated that soil products account for a significant portion of waste generation about 45 percent of the total production and utilisation chains, resulting in an enormous amount of waste material (Fidelis *et al.,* 2019). According to the advancement of the agro-evolved of life in which they are formed, squanders and side-effects can be divided into four source groups: i) in the fields prior to harvesting, due to irritant invasion and yields impaired by inclement weather; ii) in post-harvest and transportation, when wrecked and injured soil goods are disposed of; iii) in the many assembly phases cycle, like stripping, washing, and cutting; iv) in the retail business sectors, due to waste generation at the end of the time span of usability; (Ravindran and Jaiswal 2016). The cost of recovery and board for these squanders is not insignificant. Irregularity, cross-domain appropriation, and perishability due water and supplements, aswell as the variability of the goods, may address potential problems and challenges for agri-food waste executives (Girotto *et al.,* 2015). Polyphenols found in skins, crush, seeds, or pomace are the most commonly recognised target blends from normal item by item (Kelly *et al.,* 2019), since, at high temperatures, the extraction levels and targeted blends are getting reduced. As a result, top-tier systems should replace old-style strong fluid extraction tactics. In any event, the equipment required and the smoothing out of limits are major challenges for obtaining dynamic combinations from incidental effects in the current situation. Extraction procedures such as squeezing, microwave, and ultrasounds are the most appropriate and frequently utilised for removing polyphenolic components from normal goods outcomes. Extraction procedures usually include certain pre-treatment and post-treatment measures to maximise the yield of bioactive combinations while reducing the proportion of solvents required and energy consumption. Traditionally, pre-treatment techniques are utilized for reducing the cellulose crystallinity, removing lignin and increasing the cell porosity (Kumar *et al.,* 2009). Polyphenols developed non-covalent interactions with polysaccharides, making them polar solvent insoluble. Pre-treatment removes the cross linking of polyphenols and allows for the selection of more important returns (Pérez-Jiménez *et al.,* 2013). As previously stated, the use of modern extraction procedures results in increased yields of various unique mixes (Pereira *et al.,* 2019).

There has been a surge in interest in biotechnological methods for using cutting-edge wastes as components of microorganism growth medium. Such a method enables the complete biodegradation of normal blends as well as the production of something else with added consideration. By using side-effects as medium portions lowers the hard and fast generation costs. The list of by-products extracted from different fruits are presented in Table 1 and various biotechnological products from fruit wastes are shown in Fig. 1. The main contaminants present in the potato wastewater are COD and BOD with the value of 30000 and 22000 mg/L. Its liquid structure and massive totals conveyed pose additional challenges to its use. Potato wastewater was used under regular conditions before the implementation of harsh restrictions for normal protection, by soaking and arable meadows (Muniraj *et al.,* 2015), as a result, the soil nitrogen levels improved and that could be absorbed easily by plants (Singh *et al.,* 2012). Despite the fact that the process allows for total natural disinfection of waste water, it also comes with a slew of major drawbacks. Soil becomes deterred and water vulnerable on a postponed water framework with potato wastewater.

The approach triggers the unfavourable consequence of water eutrophication. Methods involving thermophilic bacteria can be used to lower the quantity of unknown chemicals in potato wastewater. the molasses wrote was prepared from the potato wastewater. The medium with the segment of 77 percent potato wastewater yielded the best return of dry cell material of Saccharomyces cerevisiae (50.1 g/L) after 12 h of retention period. *S. cerevisiae* yeast biomass refinement in the medium was more successful than normal cook's

Table 1: List of by-products extracted from different fruits

Name of the fruit	Fruit by product	Principle	Method of extraction	Reference
Apple	Pomace	Phenolic compounds	Supercritical fluid extraction	Ferrentino *et al.*, 2018
Mango	Peels	Carotenoids, phenolics and flavonoids	Supercritical CO_2 extraction followed by pressurized ethanol from the residue of the stage	Garcia-Mendoza *et al.*, 2015
Orange	Peels	Essential oil, polyphenols and pectin	Ultrasound and microwave extraction	Boukroufa *et al.*, 2015
Orange	Peels	Ferulic acid	Solid liquid extraction by deep eutectic solvents	Ozturk *et al.*, 2018
Grape	Grape marc, skin, pomace, seeds	Polyphenols	Supercritical fluid extraction; ultrasound-assisted extraction; microwave extraction; pulsed electric fields processing; enzyme-aided extraction; high voltage electrical discharges	Kelly *et al.*, 2019

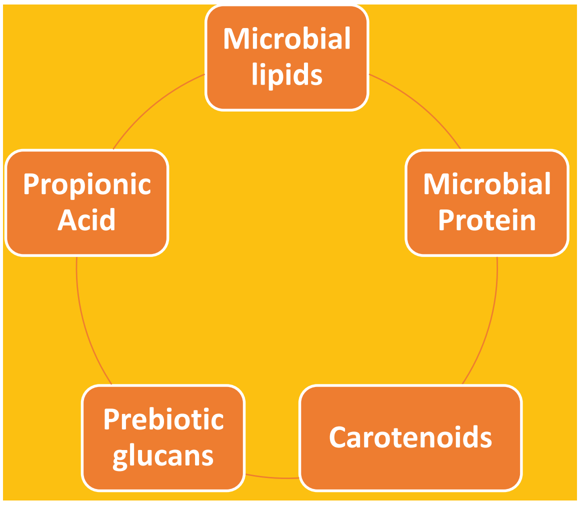


Fig 1: Biotechnological products from fruit wastes

yeast in treating potato effluent; also, it had quality comparable to normal cook's yeast, with better maltose and sucrose maturation activity. Discarded potatoes are among the most abundant starch-rich wastes. In 2019, the whole potato production is expected to exceed 370 million tonnes. Around 30% of the total potato production is thrown and not used for human consumption (Torres *et al.,* 2020), containing a wellspring of frequent tainting since moist potato trash is prone to rapid microbial decay. Potato waste is predicted to be avoided or limited through green for the biodegradable abuse of biomass waste to obtain high-value added items (Jagtap *et al.,* 2019), just as green methods for the environmentally friendly abuse of waste biomass to obtain high-value added items are expected to avoid or limit potato waste creation (Torres *et al.,* 2020). With minor differences in shape, size, and strip damage, discarded potatoes take identical dietary proportions for human consumption. The majority of potato waste is used to generate manure or biogas, resulting in the squandering of nutritious nutrients (Javed *et al.,* 2019). Regardless, the enhancement of abandoned potato that generates various high value products using various biotechnological applications (Ubando *et al.,* 2020). Damaged food supplies, crops left in the field, soil squander products, households, and eateries, and other lost food at any phase in stockpile chains are all examples of food squander. Food waste may not be avoided, but it can be reduced to a possible extent. In recent year, the cost-effective procedure for valorising food waste was established (Ong *et al.,* 2018). Because of its homogeneity, food waste has a lot of promise for making biofuels (Pourkarimi *et al.,* 2021), stage synthetics, and bio-based products using the bio-refinery concept (Matharu *et al.,* 2016). The bioeconomy system of European Unions devised the method for valorisation of food waste (Cristóbal *et al.,* 2018). The bioeconomy is the knowledge-based creation and usage of natural assets to provide things, measures, and benefits in all monetary domains inside the boundary of a reasonable financial framework, according to the bio-economy group. The current review focused on identify the different agro-waste, management of agro-waste by using biotechnological tools and the production of different agro-products from different agro-waste. Previous researchers detailed a few agro-waste management practises, which leads to the conclusion that more research is needed to cover all agro-waste management solutions. By addressing diverse types of agro-waste and transforming them into marketable bioproducts utilising biotechnological approaches, this review paper fills a research vacuum. The main goals of the review are to identify different types of agro-waste and convert them into valuable biotechnological instruments. The review's work is intriguing, and it focuses on detecting different types of agro-waste, managing agro-waste utilising biotechnological tools, and producing various agro-products from various agro-waste. This study has been carried out in Kalasalingam School of Agriculture and Horticulture, Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, India in 2021.

Different types of agro waste

Agricultural residues

Horticulture deposits and contemporary build-ups are two different types of agro-mechanical squanders. Horticulture build-ups can also be divided into two types: field deposits and cycle build-ups. Field build-ups are deposits that form in the field after the yield collection cycle has completed. Leaves, stalks, seed units, and stems make up these field build-ups, while interaction deposits are deposits present even when the crop is prepared as a replacement major asset (Table 2). Bagasse, Molasses, husks, seeds, stems, leaves, straw, tails, shells, mash, stubble, strip, roots, and other materials are found in these deposits and are used for animal feed, soil improvement, manures, and other purposes. A large number of field deposits are produced, the most majority of which are underused. Controlled use of field leftovers can improve the water system's capability and reduce disintegration. Wheat and grain are the most important crops in the Middle East. Other crops such as rice, lentils, maize, chickpeas, natural products, and vegetables are distributed to all locations. Farming deposits are classified based on their accessibility as well as characteristics that distinguish them from other powerful forces such as charcoal, wood, and roast briquettes (Sadh *et al.,* 2018).

Industrial wastes

Every year, food handling activities such as

Table 2: Agriculture industrial waste chemical composition

Industrial waste	Chemical composition % (w/w)					References
	Cellulose	Hemicellulose	Lignin	Ash (%)	Total solids (%)	
Rice straw	39.2	23.5	36.1	12.4	98.62	El-Tayeb *et al.*, 2012
Wheat straw	32.9	24.0	8.9	6.7	95.6	Nigam *et al.*, 2009 and Martin *et al.*, 2012
Barley straw	33.8	21.9	13.8	11	-	Nigam *et al.*, 2009
Corn stalks	61.2	19.3	6.9	10.8	97.78	El-Tayeb *et al.*, 2012
Cotton stalks	58.5	14.4	21.5	9.98	-	Nigam *et al.*, 2009
Sunflower stalks	42.1	29.7	13.4	11.17	-	Motte *et al.*, 2013

Table 3: Fruit industrial waste chemical composition

Fruit Industrial waste	Chemical composition % (w/w)					References
	Cellulose	Hemicellulose	Lignin	Ash (%)	Total solids (%)	
Potato peel waste	2.2%	-	-	7.7%	-	Weshahy and Rao, 2012
Orange peel	9.21%	10.5%	0.84%	3.5%	-	Rivas *et al.*, 2008
Pineapple peel	18.11	-	1.37	-	93.6	Paepatung *et al.*, 2009

Table 4: Oil cake properties

Name of the oil cake	Dry matter	Crude protein	Crude fibre	Ash	Calcium	Phosphorus	References
MOC	89.8	38.5	3.5	9.9	0.05	1.11	Kuo *et al.*, 1967
PKC	90.8	18.6	37	4.5	0.31	0.85	Owusu *et al.*, 1970
GOC	92.6	49.5	5.3	4.5	0.11	0.74	Kuo *et al.*, 1967
OOC	85.2	6.3	40.0	4.2	–	-	Maymone *et al.*, 1961

juice, chips, meat, confectionery, and normal item organisations transport a significant amount of regular stores and related effluents. These standard form-ups can be used with a variety of fuel sources. As the world's population grows, the importance of food and its uses grows as well. As a result, in the vast majority of countries, numerous food and reward firms have expanded spectacularly around them to meet the need for food. Table 3 depicts various mixtures of natural item modern wastes that make up various bits of cellulose, hemicellulose, lignin, clamminess, trash, carbon, nitrogen, and so on. These constituents can interact biochemically to convey important things like biogas, bio-ethanol, and other economically significant models. In view of the fact that India produces a lot of apples, cotton, soy bean, and wheat, about 20% of the development of food types generated from the beginning in India goes to waste every year. As the country's population grew, so did the amount of rubbish that needed to be transported. The waste from food businesses has significant levels of chemical oxygen demand, biochemical oxygen demand and suspended particles. The waste having those parameters may create a negative impact on the environment, human beings and animal prosperity. The waste also contains high value-added natural compounds (Rudra *et al.*, 2015). Particularly in oil explorations, oil cakes are produced from the extraction of seeds. Oil cakes come in a variety of shapes, sizes and properties depending on the substrate (Table 4). The different

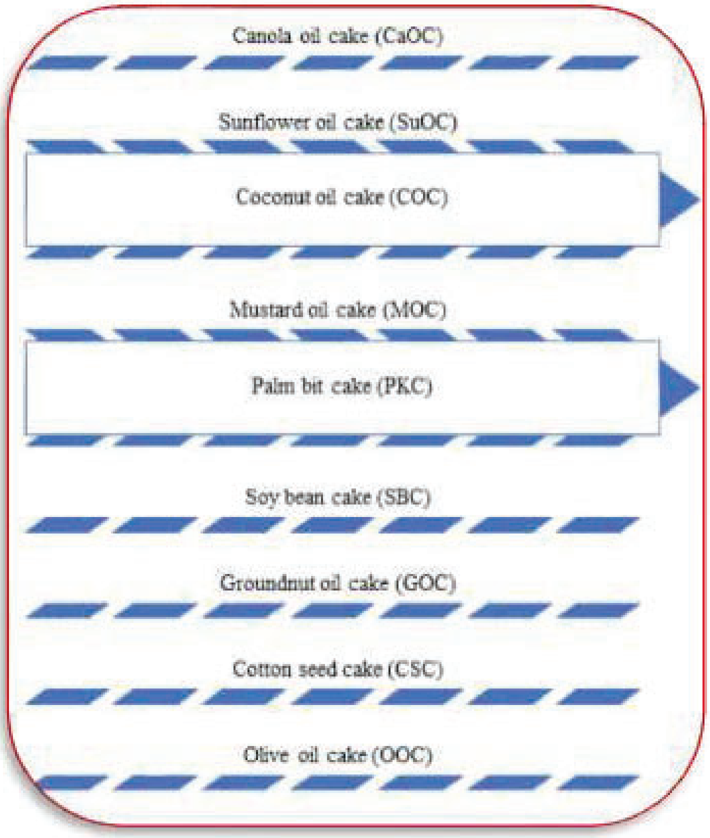


Fig. 2: Different types of oil cakes from the agriculture sectors

types of oil cakes from the agriculture sectors are presented in Fig. 2 (Sadh *et al.,* 2018). The palm oil industry is a major source of pollution and varying degrees of environmental degradation. As a result, environmental problems have multiplied by a factor of ten. Over the previous three decades, immoral behaviours have been substantially to blame for large-scale degradation of the aquatic ecosystem. As a result of environmental degradation, waterborne diseases are on the rise. Palm oil mill effluent (POME) pollutes the environment during palm oil processing, which takes place in mills where oil is recovered from palm tree fruits (Bala *et al.,* 2014).

Biotechnological process of waste

Solid state fermentation (SSF)

In the absence or nearly absence of water, the animal produces the solid substances through solid state fermentation process (Bhargav *et al.,* 2008). All food grains, vegetable seeds, and lignocellulose materials are commonly used substrates in SSF. The polymeric nature of these materials has insoluble, inexpensive and easily accessible for the microbial improvement. Perhaps the most prepared system is food status based on age. A basic examination of the writing reveals that a low proportion of water or a lack of water in SSF has a number of advantages, including easy item recovery, low production measures, less preparation and low energy requirements for mixing and sterilisation (Pandey *et al.,* 2003). Before beginning any development communication, numerous variables such as water, air, temperature, microorganisms, and fermenter should be studied. Single pure social orders, mixed recognised social orders, or a consortium of mixed local microorganisms can all be found in SSF. Some SSF measures, such as tempeh and oncome production, necessitate specified microorganism improvement, such as forms that demand low suddenness levels to conclude development using extracellular impetuses released by developing microorganisms. Table 5 depicts the many microorganisms employed in SSF measurements, such as animals, yeasts, and organisms. Moulds are sometimes utilised in SSF to enlarge the production of large-value-added items since they thrive on fragments of seeds, leaves, stems, woods and roots. The maturation of tiny microorganisms, a higher moisture content is necessary, resulting in a lower yield. SSF involves the following steps: (i) Substrate assurance, (ii) Substrate pre-treatment, which involves improving the binding of polymeric substrates, such as polysaccharides and proteins, either mechanically or biologically to reduce the size of the components, (iii) Hydrolysis of polymeric substrates, such as polysaccharides and proteins, at a very basic level, (iv) The maturation cycle for using hydrolysis products, and (v) Cleaning and measurement of completed results in the downstream process (Sadh *et al.,* 2018).

Bioprocesses with waste for biopolymers synthesis

It is vital to highlight that the synthesis of biopolymers produced from plant waste is dependent on the availability of basic materials. According to the FAO, the crop reserve for 2019 is expected to be 250 million tonnes, resulting in a large amount of waste generation. These wastes contain intriguing molecules (lipids, sugars, and sweet-smelling iotas), which can all be utilised to make polymeric materials. In any case, agro-waste necessitates substance preparation to eradicate and safeguard specific macromolecules. Cellulose, lignin, tannins, and terpenes are particularly appealing because they can be employed to transport bio-plastics. Belgacem and Gandini, 2008 compiled a comprehensive list of the polymers that can be obtained from these sources. This section focused on plant/green development sources (polysaccharides, similar to starch, cellulose, agar, hemi-celluloses, gelatin, alginate, and carrageenan), as well as lignin, lipids, and proteins. The polysaccharides cellulose and starch are important in farming applications. In any case, simple polymers that are comparable to proteins can be used to recognize biodegradable compounds. In a recent movement of works, the value of these various fragments has been adequately appraised, a wonderful framework of the work that standard biopolymers have in the horticulture sector is portrayed. More biodegradable things were produced as a result of this waste, particularly in the farming industry. Mulches, biodegradable seeds, and biopolymer-based dynamic section capsulations are examples of how the speculative round strategy is put to use in the field. In any event, the composition of agricultural waste biopolymers are very limited. The job of traditional biopolymers extracted from growing waste as bio-stimulants and biofertilizers will be examined in the next segment (Chimphango *et al.,* 2020). Using agricultural and industrial wastes as raw materials can reduce manufacturing costs while also reducing pollution levels in the environment. SSF is a result of its relatively simple approach, which uses abundant low-cost biomaterials with little or no pre-treatment for bioconversion, produces less waste water, and can mimic similar micro-environments that are conducive to microbial growth.

Bio-lipids synthesis

The bioprocessing of waste yields both biopolymers and bio-lipids. Since, bio-lipids represent a possible feedstock for biofuels, the commercial and research sectors have been paying increased attention to the manufacture of bio-lipids from waste. The yeasts, cyanobacteria, green development, a few microorganisms, and creatures can accumulate a large proportion of their body weight in lipids (20–80 percent) (Yong *et al.,* 2021). The *Yarrowia lipolytica* MUCL 28849 (oleaginous yeast) used to extract glycerol and microbial lipids as carbon sources from trash. The carbon sources for bio-lipids from waste are low-cost byproducts obtained from *Cryptococcus curvatus* ATCC 20509 yeast cultivation (Gong *et al.,* 2015). *Rhodosporidium toruloides* AS 2.1389 culture was used to produce the bio-lipids of 38.6–48.2 percent through valorised acidic destructive method (Huang *et al.,* 2016) and *Lipomyces starkeyi* DSM 70296 culture was used to produce the bio-lipids of 26.1–26.9 % from sugarcane bagasse hydrolysis method (Xavier *et al.,* 2017). Through the advancement of *Yarrowia lipolytica* W29 (ATCC 20460) with pork fat was used to produce lipase from citrus destructive (Lopes *et al.,* 2018). Pork fat is an animal fat that is only occasionally employed in food preparation due to the risk of vascular and cardiac pollution. As a result,

Table 5: List of microorganisms used in solid fermentation process

Microorganisms	Solid supports	References
	Bacteria	
Pseudomonas spp. BUP6	GOC, COC, SOC, and CSC	Faisal *et al.,* 2014
Amycolatopsis mediterranean MTCC 14	GOC and COC	Vastrad and Neelagund 2011
Xanthomonas campestries MTCC 2286	Potato peel	Vidhyalakshmi *et al.,* 2012
	Fungi	
Aspergillus niger	Wheat bran, rice bran, black gram bran, GOC, and COC	Suganthi *et al.,* 2011
Streptomyces spp	Streptomyces spp	Ezejiofor *et al.,* 2012
Rhizopus arrhizus and *Mucor subtillissimus*	Soybeans, caorncob cassava peel, wheat bran, and citrus pulp	Nascimento *et al.,* 2015
Aspergillus terreus	Palm oil cake	Rahman *et al.,* 2016

it is often regarded as waste. The possibility of using waste from meat handling experiences for microbial oils association was discovered in this study.

Low-value hydrophobic substrates can be converted into microbial oils and other important metabolites by the microbial platform *Yarrowia lipolytica*. This yeast strain was used to manufacture ex novo lipids from animal fat while also synthesizing citric acid and lipase, increasing the utility of the low-cost fatty substrate. The influence of pH, lard content, arabic gum concentration, and oxygen mass transfer rate (OTR) on lipid accumulation in *Y. lipolytica* batch cultures was investigated using a Taguchi experimental design. OTR was by far the most influential parameter in the range from 96 mg/L to 480 mg/L.

Bio proteins and bio enzymes

Microorganisms can grow on a range of substrates and are a typical source of low-cost alternative media for enhancing microorganisms to offer quality results in world. The metabolic products and the actual microbe are the source of countless proteins and impetuses. Single cell proteins can be obtained by holding a social event and drying the microbial biomass (Zepka *et al.,* 2008). It's also known as microbial protein, and it's usually transmitted through slowed development and solid state maturation (Kadim *et al.,* 2015). Yunus *et al.,* 2015 developed *Candida utilis* and *Rhizopus oligosporus* on wheat grain to deliver a single cell protein. At ideal maturing circumstances of 30°C and 48 hours, a protein yield of 41.02 percent was obtained. The metabolic analysis of the microalgae *Aphanothece microscopca nageli* improvement on paddy profluent reveals an abundant level of polyunsaturated unsaturated fat (overwhelmingly gamma linolenic destructive) and an outstanding yield of single cell protein (Zepka *et al.,* 2008). After 96 hours of solid state growth of yam strip by *Saccharomyces cerevisiae* BY4743, protein containing main amino destructive material comparable to threonine, lysine, valine, and leucine was obtained. Single cell protein generates the essential amino acids and has the ability to mass-produce in a short amount of time, allowing it to replace expensive protein sources (Aruna *et al.,* 2017). Fish waste-derived protease and esterase molecules have potential applications in current and clinical research. From the sugar beet incidental impact, an isoelectric-ammonium sulphate precipitation technique yielded 55.15 percent protein yield (Akyüz *et al.,* 2021). *Haloferax lucentensis* GUBF-2 MG076078 was used to produce protease compounds from valorization of shrimp waste at pH 6, 30 % NaCl and 42°C temperature (Mg *et al.,* 2021). The yield of pectinase compound was improved by reducing unsaturated fat biosynthesis and further increased by limiting pyruvate dehydrogenase and unsaturated fat biosynthesis with furfural, to triclosan (Guan *et al.,* 2021). *Bacillus* sp. was used to represent high amylase compound formation (29.23 mg/mL) on mango waste. Microorganisms F-11 (Saleh *et al.,* 2020). Food waste biomass is used to isolate a

Table 6: Bio enzymes from different fruit wastes

S.No.	Substrate	Enzymes	Microorganisms	Reference
1	Groundnut oil cake (GOC)	Lipase	*C. rugosa*	Rekha *et al.,* 2012
2	Coconut oil cake	α-Amylase	*A. oryzae*	Ramachandran *et al.,* 2004
3	Fruits peel waste	Invertase	*A. niger*	Mehta and Duhan 2014
4	Orange peel	α-Amylase	*A. niger*	Sindiri *et al.,* 2013

variety of proteins and combinations. These findings demonstrate the common practise of extracting and removing core mixes and proteins from food waste. For solid state fermentation, this is the substrate. The SSF uses solid waste from a variety of industries, including food, ale and wine, agriculture, paper, materials, cleaning agents, and animal feed. Staying-solid substrates have low clamminess levels, which is ideal for SSF. A previous study used a variety of substrates to study rice (Sadh *et al.,* 2018). Microorganisms thrive in agro-industrial waste because of its diversified composition. Fermentation generates a wide range of enzymes. These wastes are used as a raw material. The use of these substrates accelerated fungus growth, resulting in the conversion of lignocellulosic substrate into less problematic substrates via the activity of many enzymes. Amylase, one of the most important enzymes, was used to break down polysaccharides into sugar components in the starch processing industry (Table 6).

Bio fuel production

Bio-empowers are still important because they are utilised as an alternative to oil subsidiary. Biofuels have been made from favourable agro-modern day agricultural stocks (Duhan *et al.,* 2013; Kumar *et al.,* 2014, 2016). The bioethanol production expanded from one side of the globe to the other, as evidenced by the production of 85 billion litres of bioethanol in 2011 (Avci *et al.,* 2013). It keeps deforestation in check by reducing our reliance on forest area woody biomass with the help of cultivating assemble ups. The field stores have a short harvest season, they are more consistently available for bioethanol production (Limayema and Ricke 2012). Several studies have concluded that ethanol can be produced from lignocellulosic materials (Cadoche and Lopez 1989; Bjerre *et al.,* 1996). Najaf *et al.,* 2009 synthesised the bioethanol from diverse agricultural stores of various agriculture waste. The bioethanol was produced from the lignocellulosic agricultural wastes. The bioethanol is used a biofuel as an alternative substitute to various oil products such as oil and diesel. Because of their discussion and examination of numerous processes for biofuel synthesis, it is obvious that biofuels are not fixed in stone as an environmentally friendly and choice source of energy for the foreseeable future. Crop waste and sugar cane bagasse are used as feedstock in the production of bioethanol. There are 17.86 million tonnes of lost crops with the potential to produce 4.91 million gallons of bioethanol per year. Wheat, rice, barely, and corn are the most suitable bioethanol production sources. Agricultural waste materials can be used to make bioethanol fuel. Bioethanol has the potential to be the most effective gasoline replacement. Paepatung *et al.,* 2009 generated the biogas from several cultivation stocks of two weeds namely *Eichornia crassipes solms* and *Typha angustifolia* L.

Single cell protein production

Mondal *et al.,* 2012 investigated how single-cell protein (SCP) is made from natural item wastes. Cucumber and orange strips were employed as the substrate for the synthesis of SCP employing *S. cerevisiae* and brought down development. When the cucumber strips were arranged differently from the orange strips, they found that the cucumber strips carried a higher proportion of protein. Cucumber strips are larger than orange strips and occupy a huge substate where they are arranged differently than orange strips. As a result, it was suggested that these natural item wastes be converted to SCP employing reasonable microbes. The benefits of bioconversion of agro-industry wastes include a sensible and pleasantly high protein content. The highest biomass production output and protein production in all of the fruit waste substrates were significantly higher on the fourth day. The PAM substrate yielded significantly more dry biomass of 0.429 g (48.32 %) and protein of 0.004 g (2.84 %) than the others, whereas the PGM substrate yielded significantly less biomass and protein.

Production of poly (3-hydroxybutyric acid)

The consumption of citrus fruits from one end of the globe to the other for a variety of mechanical uses such as natural item presses and sticks. The waste from citrus fruits are transported for making various by-products. The polyethylene (3HB) was produced from citrus waste by Sukan *et al.,* 2014. Sukan *et al.,* 2014 discovered polyethylene (3HB) with an extraordinarily straightforward pre-treatment technique employing orange strip as a lone carbon source. The process was first tested on a small scale before being put through its paces in a constantly stirred tank reactor. Orange peel was chosen as the best candidate for P(3HB) manufacture from a variety of agro-industrial waste. AP(3HB) concentration of 1.24 g P(3HB)/L culture broth was obtained with a 41 percent P(3HB)/dcw yield using orange peel as the sole carbon source in an optimised medium with a modified strain of *Bacillus subtilis* (*B. subtilis* OK2).

Biosurfactant production

The bacterial microorganisms found in the oil-tainted objects are more beneficial to humans. One of the bacterial microorganisms *Pseudomonas aeruginosa* PB3A was isolated from an oil-polluted environment (Saravanan and Vijayakumar, 2014). They used agro-squander, such as sunflower oil, castor oil, grain wheat, nut cake, and rice grain, to make biosurfactant with the strain. Using an isolated *P. aeruginosa* strain, they utilised these events as a rich elective carbon focal point for the creation of biosurfactant. The *P. aeruginosa* PB3A strain was isolated from oil-polluted soil and determined to be a promising biosurfactant-generating bacterium based on the following screening methods: hemolytic activity, drop collapse test, emulsification activity, and surface tension measurement. Both the used corn oil and cassava waste flour demonstrated maximum productivity of 0.62 mg/mL and 0.60 mg/mL when grown separately in the MSM medium.

Xanthan production

Because the high cost of generating Xanthan gum from common substrates like glucose and sucrose is a production bottleneck, researchers focused on non-traditional substrates like whey and whey permeate. As a result, low-cost substrates such as whey, milk permeate, and food waste were sought. The preculturing with lactose fermenting organisms such lactic acid bacteria or *Kluveromyces lactis* to change the substrate for xanthan synthesis has been developed to use newer, less expensive substrates like milk or whey permeate. As a food additive, xanthan is utilised. Xanthan production from agricultural wastes is a significant system to consider as a practical matter Vidhyalakshmi *et al.,* 2012. *X. citri*, *X. oryzae*, and *X. musacearum* produced the xanthan with the help of SSF. The xanthan of 2.9, 2.87, 1.5 and 0.5 g was produced from *X. citri, X. campestries, X. oryzae*, and *X. musacearum*.

Heterotrophic food waste
Microalgae cultivation

In a blended bioreactor, heterotrophic microalgae can be grown at high biomass centres. Regardless, high-cost culture medium containing carbon, nitrogen, and phosphorus are necessary (Pleissner *et al.,* 2012). When ordinary wastes are employed as development feedstock, the expenses of upgrades can be reduced (Ryu *et al.,* 2013). Despite the fact that more food waste is produced, some studies revealed that food waste was used as a supplement source in microalgae development. A significant biomass yield (6.69 g/dL) was produced using only wasted yeast as the growing substrate and simple stirring as the pre-treatment. The biomass output was improved to 31.8 g/L by using sequential cultivation to maximise nutrient utilisation. When the C/N ratio was 20:1 (w/w), DHA productivity was at its peak. DHA made up 38.2 percent of the total fatty acids (w/w). As a result, wasted yeast proved to be an ideal growing medium for the production of DHA.

Microalgal biomass and food waste as feedstocks

The green algae *Chlorella pyrenoidosa* is used to produce xanthophylls that are used in the food industry. In consistent social ordering of *C. pyrenoidosa*, 302 g/L of biomass and 0.65 g/L of flat out xanthophylls concentration were achieved. In nitrogen-sufficient and limited social groupings, around 50 g/L of biomass and 0.2 g/L of lutein were transferred from *Chlorella prototheorids* (Prasanna *et al.,* 2007). Regardless of how heterotrophic green development opens the to distinct shadings, the previously mentioned cycles required a lot of glucose. *Galdieria sulphuraria* utilised 260 g/L glucose to produce phycocyanin, while *Chlorella pyrenoidosa* used 520 g/L glucose to produce xanthophylls. As on there was no investigation onto the improvement of *G. sulphuraria* on food waste hydrolysate has been conducted. As a result, it remains hypothetical whether this could be a viable substitute to glucose. Notwithstanding, *C. pyrenoidosa* produces xanthophyll from food waste, and the creation of xanthophylls results in the generation of glucose. (Pleissner *et al.,* 2013).

Contributions of Food wastes for bioeconomy

Depending on whether offal is deemed trash, the overall rate of producing polyhydroxyalkanoate from butchering wastes, which ranged between EUR 1.41 and 1.64 per kg. 437.5 mg of lycopene and 36.5 mg of Carotene was yielded from the supercritical CO_2 extraction of tomato waste (Kehili *et al.,* 2016). Cristóbal *et al.,* 2018 studied the cost analysis and informed that the cost of production of lycopene and carotene as EUR 40,000 and 4,000 per kg. Regardless, in this investigation, the compensation length of time should be carefully considered (the reward time period for other biorefineries actually execution ran some place in the scope of 3 and 15 years). Biddy *et al.,* 2017 demonstrated the ability of four-cross-over set apart down the expense to expand succinct destructive creation. Only 5–10 biorefineries could meet the premium for some speciality designed materials, and only a few biorefineries could meet the requirements of the extremely valuable medicine markets. It is critical to expand the market by exploring subordinate engineered materials (Yang *et al.,* 2020).

CONCLUSION

Ago-waste such as bagasse, molasses, husks, seeds, stems, leaves, straw, tails, shells, mash, stubble, strip, roots, and other materials are found in these deposits and are used for animal feed, soil improvement, manures, and other purposes. A large number of field deposits are produced, the most majority of which are underused. As the world's population grows, the importance of food and its uses grows as well. As a result, in the vast majority of countries, numerous food and reward firms have expanded spectacularly around them to meet the need for food. Microorganisms are the important source of biodegradation of agro-waste in the environment. The strains of *Pseudomonas* spp., *Aspergillus niger* and *Streptomyces* spp. strain's are degrading agro-waste effectively. The yeasts, cyanobacteria, green development, a few microorganisms, and creatures can accumulate a large proportion of their body weight in lipids (20–80 percent). The metabolic products and the actual microbe are the source of countless proteins and impetuses. Single cell proteins can be obtained by holding a social event and drying the microbial biomass. Bio-empowers are still important because they are utilised as an alternative to oil subsidiary. Biofuels have been made from favourable agro-modern day agricultural stocks. Supplement association and bioactive blends are abundant in agro-modern wastes or build-ups. As a result, such wastes should be considered "rough material" rather than "wastes" for other current cycles, as they recall variance for association like sugars, minerals, and proteins. The occurrence of such improvements in these stores provides ideal conditions for microbes to thrive. Different types of agro-waste have been converted by using of different micrograms through solid state fermentation have been explained. In the present review the important aspects of agro-waste management and industrial products are concluded from different micrograms have concluded such as among all microbial Bio-lipids synthesis *Rhodosporidium toruloides* AS 2.1389 culture was produced more bio-lipids of 38.6–48.2 percent through valorised acidic destructive method. The *Bacillus* sp. was to produce high amylase compound formation (29.23 mg/mL) on mango waste. Bioethanol has the potential to be the finest gasoline substitute among bio-diesel products. The PAM substrate produced much more dry biomass and protein in all substrates. Maize oil (0.62 mg/mL) produced more biosurfactant than cassava waste flour (0.60 mg/mL). The highest xanthan production 2.9 g was produced from *X. citri*. The *Chlorella pyrenoidosa* produced the highest biomass 520 g/L glucose to produce xanthophylls among all other microalgae species.

AUTHOR CONTRIBUTIONS

P. Srikanth has performed the writing and preparing the manuscript. D. Sivakumar has done some part of writing, editing and supervision of writing review. P.W. Ramteke has done some part of the writing work. J. Nouri is the advisor in writing review article and gave some important intellectual inputs.

ACKNOWLEDGMENTS

This review work was done in Kalasalingam School of Agriculture and Horticulture, Kalasalingam Academy of Research and Education, Krishnankoil 626126, Srivilliputhur, Tamil Nadu, India.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. The ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

ABBREVIATIONS

%	Percent
BOD	Biological oxygen demand
CaOC	Canola oil cake
C/N	Carbon to nitrogen ratio
COC	Coconut oil cake
COD	Chemical oxygen demand
CO_2	Cobrand di oxide
CSC	Cotton seed cake
DHA	Docosahexaenoic acid
et al.,	And others
FAO	Food and agriculture organization
Fig	Figure
g	Gram
g/dL	Gram per decilitre
g/L	Gram per litre
GOC	Ground nut oil cake
h	Hour
Kg	Kilogram
mg/mL	Milligram per millilitres
mg/L	Milligram per litre
MSM	Minerals slats medium
MT	Metric ton
MOC	Mustard oil cake
OOC	Olive oil cake
OTR	Oxygen mass transfer rate
PGM	Phosphodiesterase mutase
pH	Potential of hydrogen
PKC	Palm bit cake
SBC	Soy bean cake
SCP	Single cell protein
SSF	Soil state fermentation
SuOC	Sunflower oil cake
w/w	Weight concentration

REFERENCES

Aguilera, E.; Díaz-Gaona, C.; García-Laureano, R.; Reyes-Palomo, C.; Guzmán, G.I.; Ortolani, L.; Sánchez-Rodríguez, M.; Rodríguez-Estévez, V., (2020). Agroecology for adaptation to climate change and resource depletion in the Mediterranean Region. A Review. Agric. Syst., 181: 102809 **(21 Pages).**

Akyüz, A.; Ersus, S., (2021). Optimization of enzyme assisted extraction of protein from the sugar beet (*Beta vulgaris* L.) leaves for alternative plant protein concentrate production. Food Chem., 335: 127673 **(31 Pages).**

Aruna, T.E.; Aworh, O.C.; Raji, A.O.; Olagunju, A.I., (2017). Protein enrichment of yam peels by fermentation with *Saccharomyces cerevisiae* (BY4743). Ann. Agric. Sci., 62: 33-37 **(5 Pages).**

Avci, A., Saha, B.C.; Dien, B.S.; Kennedy, G.J.; Cotta, M.A., (2013). Response surface optimization of corn stover pretreatment using dilute phosphoric acid for enzymatic hydrolysis and ethanol production. Biores. Technol., 130: 603-612 **(10 Pages).**

Bala, J.D.; Lalung, J.; Ismail, N., (2014). Palm oil mill effluent (POME) treatment ''microbial communities in an anaerobic digester'': A Review. Int. J. Sci. Res. Publ., 4(6): 1-24 **(24 Pages).**

Belgacem, M.N.; Gandini, A., (2008). Chapter 1: The state of the art, Editor(s): Mohamed Naceur Belgacem, Alessandro Gandini, Monomers, polymers and composites from renewable resources. Elsevier, 1-16 **(16 Pages).**

Bhargav, S.; Panda, B.P.; Ali, M.; Javed, S., (2008). Solid-state fermentation: an overview. Chem. Biochem. Eng., 22(1): 49-57 **(9 Pages).**

Biddy, M.J.; Davis, R.; Humbird, D.; Tao, L.; Dowe, N.; Guarnieri, M.T.; Linger, J.G.; Karp, E.M.; Salvachúa, D.; Vardon, D.R.; Beckham, G.T., (2016). The techno-economic basis for coproduct manufacturing to enable hydrocarbon fuel production from lignocellulosic biomass. ACS Sustain. Chem. Eng., 4: 3196-3211 **(21 Pages).**

Bjerre, A.B.; Olesen, A.B.; Fernqvist, T., (1996). Pretreatment of wheat straw using combined wet oxidation and alkaline hydrolysis resulting in convertible cellulose and hemicellulose. Biotechnol. Bioeng., 49: 568-577 **(10 Pages).**

Blattner, C.E., (2020). Just transition for agriculture? A critical step in tackling climate change. J. Agric. Food Syst. Commun. Dev., 9(3): 53-58 (**6 Pages**).

Boukroufa, M.; Boutekedjiret, C.; Petigny, L.; Rakotomanomana, N.; Chemat, F., (2015). Bio-refinery of orange peels waste: a new concept based on integrated green and solvent free extraction processes using ultrasound and microwave techniques to obtain essential oil, polyphenols and pectin. Ultrason. Sonochem., 24: 72-79 **(8 Pages).**

Cadoche, L.; Lopez, G.D., (1989). Assessment of size reduction as a preliminary step in the production of ethanol from lignocellulosic wastes. Biol. Waste, 30: 153-157 **(5 Pages).**

Chimphango, A.F.A.; Mugwagwa, L.R.; Swart, M., (2020). Extraction of multiple value-added compounds from agricultural biomass waste: A review. In: Daramola M., Ayeni A. (eds) Valorization of biomass to value-added commodities. Green Energy Technol., Springer, Cham., 163-192 **(30 Pages).**

Cristóbal, J.; Caldeira, C.; Corrado, S.; Sala, S., (2018). Techno-economic and profitability analysis of food waste biorefineries at European level. Bioresour. Technol., 259: 244-252 **(9 Pages).**

Dobrynin, M.; Murawski, J.; Baehr, J.; Ilyina, T., (2015). Detection and attribution of climate change signal in ocean wind waves. J. Clim., 28: 1578-1591 **(14 Pages).**

Duhan, J.S.; Kumar, A.; Tanwar, S.K., (2013). Bioethanol production from starchy part of tuberous plant (potato) using *Saccharomyces cerevisiae* MTCC-170. Afr. J. Microbiol. Res., 7: 5253-5260 **(8 Pages).**

Duque-Acevedo, M.; Belmonte-Ureña, L.J.; Cortés-García, F.J.; Camacho-Ferre, F., (2020). Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses. Global. Ecol. Conserv., 22: 1-23 **(23 Pages).**

El-Tayeb, T.S.; Abdelhafez, A.A.; Ali, S.H.; Ramadan, E.M., (2012). Effect of acid hydrolysis and fungal biotreatment on agro-industrial wastes for obtainment of free sugars for bioethanol production. Braz. J. Microbiol., 43(4): 1523-1535 **(13 Pages).**

Ezejiofor, T.I.N.; Duru, C.I.; Asagbra, A.E.; Ezejiofor, A.N.; Orisakwe, O.E.; Afonne, J.O.; Obi, E., (2012). Waste to wealth: production of oxytetracycline using *streptomyces* species from household kitchen wastes of agricultural produce. Afr. J. Biotechnol., 11(43): 10115-10124 **(10 Pages).**

Faisal, l.P.A.; Hareesh, E.S.; Priji, P.; Unni, K.N.; Sajith, S.; Sreedevi, S.; Josh, M.S.; Benjamin, S., (2014). Optimization of parameters for the production of lipase from *Pseudomonas* sp. BUP6 by solid state fermentation. Adv. Enzyme Res., 2: 125-133 **(9 Pages).**

Ferrentino, G.; Morozova, K.; Mosibo, O.K.; Ramezani, M.; Scampicchio, M., (2018). Biorecovery of antioxidants from apple pomace by supercritical fluid extraction. J. Clean. Prod., 186: 253-261 **(9 Pages).**

Fidelis, M.; Moura, D.C.; Junior, K.T.; Pap, N.; Mattila, P.; Mäkinen, S.; Putnik, P.; Kovaˇcevi´c, B.D.; Tian, Y.; Yang, B.; Granato, D., (2019). Fruit seeds as sources of bioactive compounds: Sustainable production of high value-added ingredients from by-products within circular economy. Molecules, 24(21): 3854-3907 **(54 Pages).**

Garcia-Mendoza, M.P.; Paula, J.T.; Paviani, L.C.; Cabral, F.A.; Martinez Correa, H.A., (2015). Extracts from mango peel by-product obtained by supercritical CO_2 and pressurized solvent processes. LWT - Food Sci. Technol., 62(1): 131-137 **(7 Pages).**

Girotto, F.; Alibardi, L.; Cossu, R., (2015). Food waste generation and industrial uses: A review. Waste Manage., 45: 32-41 **(10 Pages).**

Gong, Z.; Shen, H.; Zhou, W.; Wang, Y.; Yang, X.; Zhao, Z.K., (2015). Efficient conversion of acetate into lipids by the oleaginous yeast *Cryptococcus curvatus*. Biotechnol. Biofuels., 8(1): 189-197 **(9 Pages).**

Guan, Y.; Wang, Q.; Lv, C.; Wang, D.; Ye, X., (2021). Fermentation time-dependent pectinase activity is associated with metabolomics variation in *Bacillus licheniformis* DY2. Process Biochem., 101: 147-155 **(9 Pages).**

Hegerl, G.C.; Brönnimann, S.; Cowan, T.; Friedman, A.R.; Hawkins, E.; Iles, C.; Müller, W.; Schurer, A.; Undorf, S., (2019). Causes of climate change over the historical record. Environ. Res. Lett., 14: 123006 **(25 Pages).**

Huang, X.F.; Liu, J.N.; Lu, L.J.; Peng, K.M.; Yang, G.X.; Liu, J., (2016). Culture strate- gies for lipid production using acetic acid as sole carbon source by *Rhodosporidium toruloides*. Bioresour. Technol., 206: 141-149 (**9 Pages**).

Jagtap, S.; Bhatt, C.; Thik, J.; Rahimifard, S., (2019). Monitoring potato waste in food manufacturing using image processing and internet of things approach. Sustainability, 11(11): 3173-3184 **(12 Pages).**

Javed, A.; Ahmad, A.; Tahir, A.; Shabbir, U.; Nouman, M.; Hameed, A., (2019). Potato peel waste-its nutraceutical, industrial and biotechnological applications. AIMS Agric. Food, 4: 807-823 **(17 Pages).**

Kadim, I.T.; Mahgoub, O.; Baqir, S.; Faye, B.; Purchas, R., (2015). Cultured meat from muscle stem cells: A review of challenges and prospects. J. Integr. Agric., 14: 222-233 **(12 Pages).**

Kehili, M.; Schmidt, L.M.; Reynolds, W.; Zammel, A.; Zetzl, C.; Smirnova, I.; Allouche, N.; Sayadi, S., (2016). Biorefinery cascade processing for creating added value on tomato industrial by-products from Tunisia. Biotechnol. Biofuels, 9: 261-272 **(12 Pages).**

Kelly, N.P.; Kelly, A.L.; Mahony, J.A., (2019). Strategies for enrichment and purification of polyphenols from fruit-based materials. Trends Food Sci. Technol., 83: 248-258 **(11 Pages).**

Kumar, P.; Barrett, D.M.; Delwiche, M.J.; Stroeve, P., (2009). Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. Ind. Eng. Chem. Res., 48(8): 3713-3729 **(17 Pages).**

Kumar, A.; Duhan, J.S.; Gahlawat, S.K.; Surekha., (2014). Production of ethanol from tuberous plant (sweet potato) using *Saccharomyces cerevisiae* MTCC170. Afr. J. Biotechnol., 13(28): 2874-2883 **(10 Pages).**

Kumar, A.; Sadh, P.K.; Surekha.; Duhan, J.S., (2016). Bio-ethanol production from sweet potato using co-culture of saccharolytic molds (*Aspergillus* spp.) and *Saccharomyces cerevisiae* MTCC170. J. Adv. Biotechnol., 6(1): 822-827 **(6 Pages).**

Kuo, L.H., (1967). Animal feeding stuffs. Part 3. Compositional data of feeds and concentrates. Malaysia Agric. J., 46(1): 63-79 **(17 Pages).**

Leisner, C.P., (2020). Review: Climate change impacts on food security- focus on perennial cropping systems and nutritional value. Plant. Sci., 293: 110412-110418 **(7 Pages).**

Limayema, A.; Ricke, S.C., (2012). Lignocellulosic biomass for bioethanol production: current perspectives, potential issues and future prospects. Prog. Energy Combust. Sci., 38(4): 449-467 **(19 Pages).**

Lopes, M.; Gomes, A.S.; Silva, C.M.; Belo, I., (2018). Microbial lipids and added value metabolites production by *Yarrowia lipolytica* from pork lard. J. Biotech., 265: 76-85 **(10 Pages).**

Martin, J.G.P.; Porto, E.; Correa, C.B.; Alencar, S.M.; Gloria, E.M.; Cabral, I.S.R; Aquino, L.M., (2012). Antimicrobial potential and chemical composition of agro industrial wastes. J. Nat. Prod., 5: 27-36 **(10 Pages).**

Matharu, A.S.; De Melo, E.M.; Houghton, J.A., (2016). Opportunity for high value-added chemicals from food supply chain wastes. Bioresour. Technol., 215: 123-130 **(8 Pages).**

Mehta, K.; Duhan, J.S., (2014). Production of invertase from *Aspergillus niger* using fruit peel waste as a substrate. Intern. J. Pharm. Biol. Sci., 5(2): 353-360 **(8 Pages).**

Maymone, B.; Battaglini, A.; Tiberio, M., (1961). Feeding value of oil cake. Ann. Ist. sper. zootec. Roma., 8: 257-296 **(40 Pages).**

Mg, G.; Gaonkar, S.K.; Furtado, I.J., (2021). Valorization of low-cost agro-wastes residues for the maximum production of protease and lipase haloextremozymes by *Haloferax lucentensis*. Process Biochem., 101: 72-88 **(17 Pages).**

Mondal, A.K.; Sengupta, S.; Bhowal, J.; Bhattacharya, D.K., (2012). Utilization of fruit wastes in producing single cell protein. Intern. J. Sci. Environ. Technol., 1(5): 430-438 **(9 Pages).**

Motte, J.C.; Trably, E.; Escudié, R.; Hamelin, J.; Steyer, J.P.; Bernet, N.; Delgenes, J.P.; Dumas, C., (2013). Total solids content: a key parameter of metabolic pathways in dry anaerobic digestion. Biotechnol. Biofuels, 6: 1-9 **(9 Pages).**

Muniraj, I.K.; Xiao, L.; Liu, H.; Zhan, X., (2015). Utilisation of potato processing wastewater for microbial lipids and γ-linolenic acid production by *oleaginous* fungi. J. Sci. Food Agric., 95(15): 3084-3090 **(7 Pages).**

Najaf, G.; Ghobadian, B.; Tavakoli, T.; Yusaf, T., (2009). Potential of bioethanol production from agricultural wastes in Iran. Renew. Sustain. Energy Rev., 13(6-7): 1418-1427 **(10 Pages).**

Nascimento, T.P.; Sales, A.E.; Camila, C.S.; Romero, R.M.P.; Takaki, G.M.C.; Teixeira, J.A.C.; Porto, T.S.; Porto, A.L.F., (2015). Production and characterization of new fibrinolytic protease from *mucor subtillissimus* UCP 1262 in solid-state fermentation. Adv. Enzyme Res., 3(3): 81-91 **(11 Pages).**

Nigam, P.S.; Gupta, N.; Anthwal, A., (2009). Pre-treatment of agro-industrial residues. In: Nigam PS, Pandey A (eds) Biotechnology for agro-industrial residues utilization. Springer, Heidelberg, 13-33 **(21 Pages).**

Ong, K.L.; Kaur, G.; Pensupa, N.; Uisan, K., Lin, C.S.K., (2018). Trends in food waste valorization for the production of chemicals, materials and fuels: Case study south and southeast Asia. Bioresour. Technol., 248: 100-112 **(13 Pages).**

Owusu, K.; Christensen, D.A.; Owen, B.D., (1970). Nutritive value of some Ghanian feedstuffs. Can. J. Anim. Sci., 50(1): 1-14 **(14 Pages).**

Ozturk, B.; Parkinson, C.; Gonzales-Miquel, M., (2018). Extraction of polyphenolic antioxidants from orange peel waste using deep eutectic solvents. Sep. Purif. Technol., 206: 1-13 **(13 Pages).**

Paepatung, N.; Nopharatana, A.; Songkasiri, W., (2009). Bio-methane potential of biological solid materials and agricultural wastes. Asian J. Energy Env., 10(01): 19-27 **(9 Pages).**

Pandey, A., (2003). Solid state fermentation. Biochem. Eng. J., 13: 81-84 **(4 Pages).**

Pereira, G.V.M.; Neto, C.D. P.; Ju´nior, A. I. M.; Va´squez, Z. S.; Medeiros, A. B. P.; Vandenberghe, L. P. S., (2019). Exploring the impacts of postharvest processing on the aroma formation of coffee beans-A review. Food Chem., 272: 441-452 **(12 Pages).**

Pérez-Jiménez, J.; Díaz-Rubio, M.E.; Saura-Calixto, F., (2013). Non-extractable polyphenols, a major dietary antioxidant: occurrence, metabolic fate and health effects. Nutr. Res. Re., 26(2): 118-129 **(12 Pages).**

Pleissner, D.; Eriksen, N.T., (2012). Effects of phosphorous, nitrogen, and carbon limitation on biomass composition in batch and continuous flow cultures of the heterotrophic dinoflagellate *Crypthecodinium cohnii*. Biotechnol. Bioeng., 109(8): 1-12 **(12 Pages).**

Pleissner, D.; Lam, W.C.; Sun, Z.; Lin, C.S.K., (2013). Food waste as nutrient source in heterotrophic microalgae cultivation. Biores. Technol., 137: 139-146 **(8 Pages).**

Polson, D.; Hegerl, G.; Zhang, X.; Osborn, T., (2013). Causes of robust seasonal land precipitation changes. J. Clim., 26(17): 6679-6697 **(19 Pages).**

Poore, J.; Nemecek, T., (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392): 987-992 **(6 Pages).**

Pourkarimi, S.; Hallajisani, A.; Alizadehdakhel, A.; Nouralishahi, A., (2021). Bio-oil production by pyrolysis of *Azolla filiculoides* and *Ulva fasciata* macroalgae. Global J. Environ. Sci. Manage., 7(3): 331-346 **(16 Pages).**

Prasanna, R.; Sood, A.; Suresh, A.; Nayak, S.; Kaushik, B., (2007). Potentials and applications of algal pigments in biology and industry. Acta Bot. Hung., 49(1-2): 131-156 **(26 Pages).**

Rahman, K.H.A.; Yusof, S.J.H.M.; Zakaria, Z., (2016). Bioproteins production from palm oil agro-industrial wastes by *Aspergillus terreus* UniMAP AA-1. Pertanika J. Trop. Agric. Sci., 39(1): 29-39 **(11 Pages).**

Ramachandran.; Patel, A.K.; Nampoothiri, K.M.; Francis, F.; Nagy, V.; Szakacs, G.; Pandey, A., (2004). Coconut oil cake—A potential raw material for the production of a-amylase. Bioresour. Technol., 93(2): 169-174 **(6 Pages).**

Ravindran, R.; Jaiswal, A.K., (2016). Exploitation of food industry waste for high-value products. Trends Biotechnol., 34(1): 58-69 **(12 Pages).**

Rekha, K.S.S.; Lakshmi, C.; Devi, S.V.; Kumar, M.S., (2012). Production and optimization of lipase from *Candida rugosa* using groundnut oilcake under solid state fermentation. Intern. J. Res. Eng. Technol., 1: -577 **(7 Pages).**

Rivas, B.; Torrado, A.; Torre, P.; Converti, A.; Domínguez, J.M., (2008). Submerged citric acid fermentation on orange peel autohydrolysate. J. Agric. Food Chem., 56(7): 2380-2387 **(8 Pages).**

Rudra, S.G.; Nishad, J.; Jakhar, N.; Kaur, C., (2015). Food industry waste: mine of nutraceuticals. Intern. J. Sci. Environ. Technol., 4(1): 205-229 **(25 Pages).**

Ryu, B.G.; Kim, K.; Kim, J.; Han, J.I.; Yang, J.W., (2013). Use of organic waste from the brewery industry for high-density cultivation of the docosahexaenoic acid-rich microalga, *Aurantiochytrium sp.* KRS101. Biores. Technol., 129: 351-359 **(9 Pages).**

Sadh, P.K., Duhan, S. and Duhan, J.S. (2018). Agro-industrial wastes and their utilization using solid state fermentation: a review. Bioresour. Bioprocess, 5(1): 1-15 **(15 Pages).**

Saleh, F.; Hussain, A.; Younis, T.; Ali, S.; Rashid, M.; Ali, A.; Mustafa, G.; Jabeen, F.; Al-surhanee, A.A.; Alnoman, M.M.; Qamer, S., (2020). Comparative growth potential of thermophilic amylolytic *Bacillus sp.* on unconventional media food wastes and its industrial application. Saudi J. Biol. Sci., 27(12): 3499-3504 **(6 Pages).**

Sarkar, D.; Kar, S.K.; Chattopadhyay, A.; Shikha.; Rakshit, A.; Tripathi, V.K.; Dubey, P.K.; Abhilash, P.C., (2020). Low input sustainable agriculture: A viable climate-smart option for boosting food production in a warming world. Ecol. Indic., 115: 106412-106425 **(13 Pages).**

Saravanan, V.; Vijayakumar, S., (2014). Production of biosurfactant by *Pseudomonas aeruginosa* PB3A using agro-industrial wastes as a carbon source. Malaysia J. Microbiol., 10(1): 57-62 **(6 Pages).**

Sindiri, M.K.; Machavarapu, M.; Vangalapati, M., (2013). Alfa-amylase production and purifcation using fermented orange peel in solid state fermentation *by Aspergillus niger*. Ind. J. Appl. Res., 3(8): 49-51 **(3 Pages).**

Singh, P.K.; Deshbhratar, P.B.; Ramteke, D.S., (2012). Effects of sewage wastewater irrigation on soil properties, crop yield and environment. Agric. Water Manage., 103: 100-104 **(5 Pages).**

Suganthi, R.; Benazir, J.F.; Santhi, R.; Kumar, R.V.; Hari, A.; Meenakshi, N.; Nidhiya, K.A.; Kavitha, G.; Lakshmi, R., (2011). Amylase production by *Aspergillus niger* under solid state fermentation using agro-industrial wastes. Intern. J. Eng. Sci. Technol., 3(2): 1756-1763 **(8 Pages).**

Sukan, A.; Roy, I.; Keshavarz, T., (2014). Agro-industrial waste materials as substrates for the production of poly (3-hydroxybutyric acid). J. Biomater. Nanobio. Technol., 5: 229-240 **(12 Pages).**

Torres, M.D.; Fradinho, P.; Rodrı´guez, P.; Falque, E.; Santos, V.; Domı´nguez, H., (2020). Biorefinery concept for discarded potatoes: Recovery of starch and bioactive compounds. J. Food Eng., 275: 109886-109895 **(10 Pages).**

Ubando, A.T.; Felix, C.B.; Chen, W.H., (2020). Biorefineries in circular bioeconomy: A comprehensive review. Bioresour. Technol., 299: 122585 **(52 Pages).**

Vastrad, B.M.; Neelagund, S.E., (2011). Optimization and production of neomycin from different agro industrial wastes in solid state fermentation. Intern. J. Pharma. Sci. Drug Res., 3(2): 104-111 **(8 Pages).**

Vidhyalakshmi, R.; Vallinachiyar, C.; Radhika, R., (2012). Production of xanthan from agro-industrial waste. J. Adv. Sci. Res., 3: 56-59 **(4 Pages).**

Weshahy, A.A.; Rao, V.A., (2012). Potato peel as a source of important phytochemical antioxidant nutraceuticals and their role in human health—a review. Phytochemicals as nutraceuticals—Global approaches to their role in nutrition and health, 207-224 **(18 Pages).**

Xavier, M.C.A.; Coradini, A.L.V.; Deckmann, A.C.; Franco, T.T., (2017). Lipid production from hemicellulose hydrolysate and acetic acid by *Lipomyces starkeyi* and the ability of yeast to metabolize inhibitors. Biochem. Eng. J., 118: 11-19 **(9 Pages).**

Yang, M.; Baral, N.R.; Simmons, B.A.; Mortimer, J.C.; Shih, P.M.; Scown, C.D., (2020). Accumulation of high-value bioproducts in planta can improve the economics of advanced biofuels. Proc. Natl. Acad. Sci., 117(15): 8639-8648 **(10 Pages).**

Yong, J.J.J.Y.; Chew, K.W.; Khoo, K.S.; Show, P.L.; Chang, J.S., (2021). Prospects and development of algal-bacterial biotechnology in environmental management and protection. Biotechnol. Adv., 47: 107684-107700 **(17 Pages).**

Yunus, F.U.N.; Nadeem, M.; Rashid, F., (2015). Single-cell protein production through microbial conversion of lignocellulosic residue (wheat bran) for animal feed. J. Inst. Brew., 121: 553-557 **(5 Pages).**

Zepka, L.Q.; Jacob-Lopes, E.; Goldbeck, R.; Queiroz, M.I., (2008). Production and biochemical profile of the microalgae *Aphanothece microscopica Nägeli* submitted to different drying conditions. Chem. Eng. Process. Process Intensif., 47(8): 1305-1310 **(6 Pages).**

AUTHOR (S) BIOSKETCHES

Sivakumar, D., Ph.D., Professor, Kalasalingam School of Agriculture and Horticulture, Kalasalingam Academy of Research and Education, Krishankoil, Srivilliputhur, Tamil Nadu, India.
Email: *d.sivakumar@klu.ac.in*
ORCID: 0000-0001-5228-0145

Srikanth, P.; Ph.D., Assistant Professor, Kalasalingam School of Agriculture and Horticulture, Kalasalingam Academy of Research and Education, Krishankoil, Srivilliputhur, Tamil Nadu, India.
Email: *p.srikanth@klu.ac.in*
ORCID: 0000-0001-5681-7413

Ramteke, P.W., Ph.D., Professor, Faculty of Life Sciences, Mandsaur University, Mandsaur, India.
Email: *pwramteke@gmail.com*
ORCID: 0000-0002-6593-7895

Nouri, J., Ph.D., Professor, Department of Environmental Health Engineering, Tehran University of Medical Sciences, Tehran, Iran
Email: *nourijafar@gmail.com*
ORCID: 0000-0002-9982-3546

HOW TO CITE THIS ARTICLE

Sivakumar, D.; Srikanth, P.; Ramteke, P.W.; Nouri, J., (2022). Agricultural waste management generated by agro-based industries using biotechnology tools. Global J. Environ. Sci. Manage., 8(2): 281-296.

DOI: 10.22034/gjesm.2022.02.10

url: https://www.gjesm.net/article_246977.html

PUBLICATION ETHICS

The ethical policy of GJESM is based on the Committee on Publication Ethics (COPE) guidelines and complies with International Committee of GJESM Editorial Board codes of conduct. Readers, authors, reviewers and editors should follow these ethical policies once working with GJESM. The ethical policy of GJESM is liable to determine which of the typical research papers or articles submitted to the journal should be published in the concerned issue. For information on this matter in publishing and ethical guidelines please visit http://publicationethics.org

Duties and Responsibilities of Publishers

1. GJESM is committing to ensure that editorial decisions on manuscript submissions are the final.
2. GJESM is promising to ensure that the decision on manuscript submissions is only made based on professional judgment and will not be affected by any commercial interests.
3. GJESM is committing to maintain the integrity of academic and research records.
4. GJESM is monitoring the ethics by Editor-in-Chief, Associate Editors, Editorial Board Members, Reviewers, Authors, and Readers.
5. GJESM is always checking the plagiarism and fraudulent data issues involving in the submitted manuscript.
6. GJESM is always willing to publish corrections, clarifications and retractions involving its publications as and when needed.

Duties and Responsibilities of Editors

1. The Editors of the journal should have the full authority to reject/accept a manuscript.
2. The Editors of the journal should maintain the confidentiality of submitted manuscripts under review or until they are published.
3. The Editor-in-Chief should take a decision on submitted manuscripts, whether to be published or not with other editors and reviewers
4. The Editors of the journal should preserve the anonymity of reviewers.
5. The Editors of the journal should disclose and try to avoid any conflict of interest.
6. The Editors of the journal should maintain academic integrity and strive to meet the needs of readers and authors.
7. The Editors of the journal should be willing to investigate plagiarism and fraudulent data issues and willing to publish corrections, clarifications, retractions, and apologies when needed.
8. The Editors of the journal should have the limit themselves only to the intellectual content.
9. The Editors of the journal must not disclose any information about submitted manuscripts to anyone other than the corresponding author, reviewers, potential reviewers, other editorial advisers, and the publisher, as appropriate.
10. Unpublished materials disclosed in a submitted paper will not be used by the editor or the members of the editorial board for their own research purposes without the author's explicit written consent.

Duties and Responsibilities of Reviewers

1. The Reviewers of the journal should assist the Editors in taking the decision for publishing the submitted manuscripts.
2. The Reviewers should maintain the confidentiality of manuscripts, which they are invited to review.
3. The Reviewers should provide comments in time that will help editors to make decision on the submitted manuscript to be published or not.
4. The Reviewers are bound to treat the manuscript received for peer reviewing as confidential, and must not use the information obtained through peer review for personal advantage.
5. The Reviewers comments against each invited manuscript should be technical, professional and objective.
6. The Reviewers should not review the manuscripts in which they have found conflicts of interest with any of the authors, companies, or institutions.
7. The Reviewers should disclose and try to avoid any conflict of interest.

Duties and Responsibilities of Authors

1. Manuscripts must be submitted only in English and should be written according to sound grammar and proper terminology.
2. Manuscripts must be submitted with the understanding that they have not been published elsewhere (except in the form of an abstract or as part of a published lecture, review, or thesis) and are not currently under consideration by another journal published by or any other publisher.
3. The submitting (corresponding) author is responsible for ensuring that the manuscript article's publication has been approved by all the other coauthors.
4. In order to sustain the peer review system, authors have an obligation to participate in peer review process to evaluate manuscripts from others.
5. It is also the authors' responsibility to ensure that the manuscripts emanating from a particular institution are submitted with the approval of the necessary institution.
6. It is a condition for submission of a manuscript that the authors permit editing of the paper for readability.
7. Authors are requested to clearly identify who provided financial support for the conduct of research and/or preparation of the manuscript and briefly describe the role of the funder/sponsor in any part of the work.
8. A copy right release and conflict of interest disclosure form must be signed by the corresponding author in case of multiple authorships, prior to the acceptation of the

manuscript, by all authors, for publication to be legally responsible towards the Journal ethics and privacy policy.

9. Under open access license, authors retain ownership of the copyright for their content, but allow anyone to download, reuse, reprint, modify, distribute, and/ or copy the content as long as the original authors and source are cited properly.
10. All authors have agreed to allow the corresponding author to serve as the primary correspondent with the editorial office, to review the edited manuscript and proof.
11. When author(s) discovers a significant error or inaccuracy in his/her own published work, it is the author's obligation to promptly notify the journal editor or publisher to retract or correct the manuscript.
12. All authors must know that that the submitted manuscripts under review or published with GJESM are subject to screening using Plagiarism Prevention Software. Plagiarism is a serious violation of publication ethics.

Violation of Publication Ethics

1. **Plagiarism:** Plagiarism is intentionally using someone else's ideas or other original material as if they are one's own. Copying even one sentence from someone else's manuscript, or even one of your own that has previously been published, without proper citation is considered by GJESM Journals as plagiarism. All manuscripts under review or published with GJESM are subject to screening using plagiarism prevention software. Thus, plagiarism is a serious violation of publication ethics. The development of CrossCheck is a service that helps editors to verify the originality of papers. CrossCheck is powered by the Ithenticate software from iParadigms, known in the academic community as providers of Turnitin. For a searchable list of all journals in the CrossCheck database, please visit: www.ithenticate.com/search
2. **Data Fabrication and Falsification:** Data fabrication and falsification means the researcher did not really carry out the study, but made up data or results and had recorded or reported the fabricated information. Data falsification means the researcher did the experiment, but manipulated, changed, or omitted data or results from the research findings.
3. **Simultaneous Submission:** Simultaneous submission occurs when a manuscript (or substantial sections from a manuscript) is submitted to a journal when it is already under consideration by another journal.
4. **Duplicate Publication:** Duplicate publication occurs when two or more papers, without full cross referencing, share essentially the same hypotheses, data, discussion points, and conclusions.
5. **Redundant Publications:** Redundant publications involve the inappropriate division of study outcomes into several articles, most often consequent to the desire to plump academic vitae.
6. **Improper Author Contribution or Attribution:** All listed authors must have made a significant scientific contribution to the research in the manuscript and approved all its claims. Don't forget to list everyone who made a significant scientific contribution, including students and laboratory technicians.
7. **Citation Manipulation:** Citation Manipulation is including excessive citations, in the submitted manuscript, that do not contribute to the scholarly content of the article and have been included solely for the purpose of increasing citations to a given author's work, or to articles published in a particular journal. This leads to misrepresenting the importance of the specific work and journal in which it appears and is thus a form of scientific misconduct.

Handling Cases of Misconduct

Once GJESM confirms a violation against GJESM's publication ethics, GJESM addresses ethical concerns diligently following an issue-specific standard practice as summarized below.

1. The first action of the journal Editor is to inform the Editorial Office of GJESM by supplying copies of the relevant material and a draft letter to the corresponding author asking for an explanation in a nonjudgmental manner.
2. If the author's explanation is unacceptable and it seems that serious unethical conduct has taken place, the matter is referred to the Publication Committee via Editorial Office. After deliberation, the Committee will decide whether the case is sufficiently serious to warrant a ban on future submissions.
3. If the infraction is less severe, the Editor, upon the advice of the Publication Committee, sends the author a letter of reprimand and reminds the author of GJESM publication policies; if the manuscript has been published, the Editor may request the author to publish an apology in the journal to correct the record.
4. Notification will be sent to corresponding author and any work by the author responsible for the violation or any work these persons coauthored that is under review by GJESM journal will be rejected immediately.
5. The authors are prohibited from serving on GJESM editorial board and serving as a reviewer for GJESM Journal. GJESM reserves the right to take more actions.
6. In extreme cases, notifications will be sent to the affiliations of the authors and the authors are prohibited from submitting their work to GJESM for 5 years.
7. In serious cases of fraud that result in retraction of the article, a retraction notice will be published in the journal and will be linked to the article in the online version. The online version will also be marked "retracted" with the retraction date.

GUIDE FOR AUTHORS

"Global Journal of Environmental Science and Management" (GJESM) is a double blind peer reviewed electronic and print quarterly publication concerned with all aspects of environmental science and management. GJESM publishes original research papers, review papers, case reports and short communications, letters to editor and authors' response about letters to editor across the broad field of environment. These include but are not limited to environmental science, environmental management, environmental engineering, environmental planning and design, urban and regional landscape design and industrial ecology. Environmentalist disciplines are invited to contribute their knowledge and experience. The publication appears at regular intervals time quarterly. The Journal database is fully open access and full text of published articles are available for everyone who can get access to the Journal website free of cost. The authors never pay any charges for submission, article processing and publication.

Guide for Authors: More details on guide for authors refer: http://gjesm.net/journal/authors.note

GENERAL

1. Authors should submit their contributions electronically through the GJESM website submission system to the Editorial Office.

2. Manuscripts must be submitted only in English and should be written according to sound grammar and proper terminology. Manuscripts should be typed in Times New Roman of 11 pt. font and in MS-Word format in one column with 2.5 cm margin at each side. Manuscript submission must be applied once in order to obtain only one submission ID number. More than one submission for a single manuscript can lose the chance of the manuscript consideration. Manuscript must be accompanied by a covering letter including title and author(s) name.

3. There are no strict formatting requirements but all manuscripts must contain the essential elements needed to convey your manuscript, for example Abstract, Keywords, Introduction, Materials and Methods, Results, Conclusions, Artwork and Tables with Captions. Please ensure the figures and the tables included in the single file are placed next to the relevant text in the manuscript, rather than at the bottom or the top of the file. There are no strict requirements on reference formatting at submission. References can be in any style or format as long as the style is consistent.

BEFORE YOU BEGIN

1. Peer-Review Process: In order to sustain the peer review system, authors have an obligation to participate in peer review process to evaluate manuscripts from others. When appropriate, authors are obliged to provide retractions and/or corrections of errors to the editors and the Publisher. All papers submitted to GJESM journal will be peer reviewed for at least one round. GJESM journal adopts a double-blinded review policy: authors are blind to reviewers, but reviewers are not blind to authors. After receiving reviewers' comments, the editorial team member makes a decision. Because reviewers sometimes do not agree with each other, the final decision sent to the author may not exactly reflect recommendations by any of the reviewers. The decision after each round of peer review may include (a) Accept without any further changes, (b) Accept with minor revision, (c) Major changes are necessary for resubmission and (d) Decline without encouraging resubmission.

2. Post-Publication Evaluation: In addition to rapid Peer Review Process, the GJESM Journal has Post-Publication Evaluation by the scientific community. Post-Publication Evaluation is concentrated to ensure that the quality of published research, review and case report meets certain standards and the conclusions that are presented are justified. The post-publication evaluation includes online comments and citations on published papers. Authors may respond to the comments of the scientific community and may revise their manuscript. The Post-Publication Evaluation is described in such a way; it is allowing authors to publish quickly about Environmental science, management, engineering and technology concepts.

3. Publication Ethics: The ethical policy of GJESM is based on the Committee on Publication Ethics (COPE) guidelines and complies with International Committee of GJESM Editorial Board codes of conduct. Readers, authors, reviewers and editors should follow these ethical policies once working with GJESM. The ethical policy of GJESM is liable to determine which of the typical research papers or articles submitted to the journal should be published in the concerned issue. The ethical policy insisted the Editor-in-Chief, may confer with other editors or reviewers in making the decision. Visit at: http://publicationethics.org

4. Conflict of Interest: Authors are requested to evident whether impending conflicts do or do not exist. A copyright transfer agreement is signed by the corresponding author, upon the acceptance of the manuscript, on behalf of all authors, for publication to be legally responsible towards the journal ethics and privacy policy. Authors will be notified as soon as possible of decisions concerning the suitability of their manuscripts for publication in the journal. The submitted materials may be considered for inclusion but cannot be returned and Editors of the journal reserve the right to accept or reject any article in any stage, if necessary. Conflict of Interest Disclosure form can be found at: www.gjesm.org/conflict_of_interest_discloure_form.docx

5. Submission Declaration and Verification: While submitting a manuscript to GJESM, all contributing author(s) must verify that the manuscript represents authentic and valid work and that neither this manuscript nor one with significantly similar content under their authorship has been published or is being considered for publication elsewhere including electronically in the same form, in English or in other language, without the written consent the copy right holder.

6. Authorship: All contributing authors should qualify for authorship and corresponding author should sign the authorship form while submitting the manuscript. It can be found at: (http://www.gjesm.net/data/gjesm/news/authorship_form.docx).

7. Changes to Authorship: After the manuscript is submitted or accepted for publication, the corresponding author is required to send a request to add or remove an author or to rearrange the author names of the submitted/accepted manuscript by sending the change of authorship form to editorial office. No authorship change is allowed after publication of manuscript. More details may be found at: (http://www.gjesm.net/data/gjesm/news/change_of_authorship_form.docx)

8. Retained Author Rights: As an author, author or authors' employer or institution retains certain rights. For more information on author rights, found at: www.gjesm.org/retained_authors_right.docx.

9. Copy Right: Journals should make clear the type of copyright under which authors' work will be published. For open access articles the publisher uses an exclusive licensing agreement in which authors retain copyright in their manuscript. More details may be found at: (www.gjesm.org/copyright_form.docx)

10. User license Agreement: GJESM provides access to archived material through GJESM archives. Manuscripts are the parts of an open archive are made freely available from GJESM website after certain period, which begins from the final publication date of the manuscript. All articles published open access will be immediately and permanently free for everyone to read and download. Permitted reuse is defined by Creative Commons user license called ***Creative Commons Attribution***. Visit at: **(**Creative Commons Attribution 4.0 International (CC BY 4.0)**)**

11. Plagiarism Prevention and Violation of Publication Ethics: All manuscripts under review or published with GJESM are subject to screening using Plagiarism Prevention Software. Plagiarism is a serious violation of publication ethics. Other violations include duplicate publication, data fabrication and falsification, and improper credit of author contribution. Thus, the Plagiarism or Fraudulent or knowingly inaccurate statements constitute unethical behavior are unacceptable and submitting the same manuscript to more than one journal concurrently constitutes unethical publishing behavior and is unacceptable. The development of CrossCheck is a service that helps editors to verify the originality of papers. CrossCheck is powered by the Ithenticate software from iParadigms, known in the academic community as providers of Turnitin. For more details visit at: www.ithenticate.com/search

12. Handling Cases of Misconduct: Once GJESM confirms a violation against GJESM's publication ethics, the following actions will be taken.

a. The work is rejected / retracted immediately. Notification will be sent to corresponding authors. In extreme cases, notifications will be sent to the affiliations of the authors.
b. The authors are prohibited from submitting their work to GJESM for 5 years.
c. Any work by the authors responsible for the violation or any work these persons coauthored that is under review by any GJESM journal will be rejected immediately.
d. The authors are prohibited from serving on GJESM editorial board. GJESM reserves the right to take more actions.

MANUSCRIPT PREPARATION

1. Title Page: The title page should include: the name(s) of the author(s), a concise and informative title, the affiliation(s) and address (es) of the author(s), and e-mail address, telephone and fax numbers of the corresponding author.

2. Manuscript Title: Title of up to 17 words should not contain the name of locations, countries or cities of the research as well as abbreviations. The title should be oriented to Environmental issues while not being obscure or meaningless.

3. Abstract: An abstract of 150 to 250 words that sketches the purpose of the study; basic procedures; main findings its novelty; discussions and the principal conclusions, should not contain any undefined abbreviations or references.

4. Keywords: Provide 5 to 7 keywords which can be used for indexing purposes. Keywords should not repeat the words of the manuscript title or contain abbreviations and shall be written in alphabetical order as separated by semicolon.

5. Introduction: The Introduction should state the purpose of the investigation and identify clearly the gap of knowledge that will be filled in the Literature review study. Date and location of the research carried out throughout the study must be mentioned at the end of this section.

6. Materials and methods: The Materials and Methods section should provide enough information to permit repetition of the experimental work. It should include clear descriptions and explanations of sampling procedures, experimental design, and essential sample characteristics and descriptive statistics, hypothesis tested, exact references to literature describing the tests used in the manuscript, number of data involved in statistical tests, etc.

7. Results and Discussion: The Results section should describe the outcome of the study. Data should be presented as concisely as possible - if appropriate in the form of tables or figures, although very large tables should be avoided. The Discussion should be an interpretation of the results and their significance with reference to work by other authors. Please note that the policy of the Journal with respect to units and symbols is that of SI symbols.

8. Tables: Do not submit tables and graphs as photograph. Place explanatory matters in footnotes, not in the heading. Do not use internal horizontal and vertical rules. Tables should be called out in the text and should have a clear and rational structure and consecutive numerical order. All tables should be numbered 1, 2, 3, etc. Give enough information in subtitles so that each table is understandable without reference to the text. Footnotes to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data) and included beneath the table body.

9. Figures: Figures/ illustrations should be in high quality art work, within 200-300 dpi and separately provided in Excel format. Ensure that figures are clear, labeled, and of a size that can be reproduced legibly in the journal. Each figure should have a concise caption describing accurately what the figure depicts. Figure captions begin with the term Fig. Figures should be with the captions placed below in limited numbers. No punctuation is to be placed at the end of the caption.

10. Conclusion: This section should highlight the major, firm discoveries, and state what the added value of the main finding is, without literature references.

11. Acknowledgements: Acknowledgments of people, grants, funds, etc. should be placed in a separate section before the reference list. The names of funding organizations should be written in full. Financial support affiliation of the study, if exists, must be mentioned in this section. Thereby, the Grant number of financial support must be included.

12. References: All the references should be cited throughout the manuscript text as well as in the Reference section organized in accordance with Harvard system. Groups of references should be listed first alphabetically, then chronologically. The number of references extracted from each journal should not exceed 3 to 5 citations, which is the average acceptable amount. The number of references should not be less than 30 for original paper, less than 100 for review paper. It is substantially recommended to the authors to refer to more recent references rather than old and out of date ones. Volume, issue and pages of the whole references must be specified according to the GJESM format.

Citing and listing of Web references: As a minimum, the full URL should be given. Any further information, if known (Author names, dates, reference to a source publication, etc.), should also be given.

Text: All citations in the text should refer to: 1. Single author: the author's name (without initials, unless there is ambiguity) and the year of publication; 2. Two authors: both authors' names and the year of publication; and 3. Three or more authors: first author's name followed by "et al." and the year of publication. Citations may be made directly (or parenthetically). Groups of references should be listed first alphabetically, then chronologically. Examples: "as demonstrated (Allan, 1996a, 1996b, 1999; Allan and Jones, 1995). Kramer *et al.,* (2000) have recently shown …".

List: References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same Author(s) in the same year must be identified by the letters "a", "b", "c", etc., placed after the year of publication.

Journal article: Nouri J.; Lorestani B.; Yousefi N.; Khorasani N.; Hassani A. H.; Seif, F.; Cheraghi M., (2011). Phytoremediation potential of native plants grown in the vicinity of Ahangaran lead-zinc mine. Environ. Earth Sci., 62(3): 639-644.

Book: Davis, M. L., (2005). Introduction to Environmental Engineering, 3rd. Ed. McGraw Hill Inc.

Book chapter: Mettam, G. R.; Adams, L. B., (1999). How to prepare an electronic version of your article, in: Jones, B. S., Smith, R. Z. (Eds.), Introduction to the electronic age. E-Publishing Inc., New York.

Conference paper: Brown, J., (2005). Evaluating surveys of transparent governance. In UNDESA, 6th. Global forum on reinventing government: towards participatory and transparent governance. Seoul, Republic of Korea 24-27 May. United Nations: New York.

Dissertation: Trent, J. W., (1975). Experimental acute renal failure. Ph.D. Dissertation, University of California. USA.

Online document: Cartwright, J., (2007). Big stars have weather too. IOP Publishing Physics Web. http://physicsworld.com/cws/article/news/2007/jun/26/big-stars-have-weather-too

AFTER ACCEPTANCE

1. Online Proof Correction: Corresponding authors will receive an e-mail with a link to our online proofing system, allowing annotation and correction of proofs online. Use this proof only for checking the typesetting, editing, completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with permission from the Editor-in-Chief. It is important to ensure that all corrections are sent back to us in one communication. Please check carefully before replying, as inclusion of any subsequent corrections cannot be guaranteed. Proofreading is solely the corresponding author responsibility.

2. Offprints: The offprints can be downloading from the GJESM website once the final corrected manuscripts are disseminated.

AUTHORS INQUIRIES

Authors can track their submitted article through GJESM website on author's login section at: http://gjesm.net/contacts?_action=login

Global Journal of Environmental Science and Management (GJESM)

Copyright Transfer Agreement

1. Parties of the agreement

Author (s):

Manuscript Title:

Manuscript ID:

(Herewith referred to as the "materials"),

Journal Title: Global Journal of Environmental Science and Management (GJESM)

2. Subject of the agreement

A) Copyright

1- The Author and each co-authors shall transfer and sell to the Publisher for the length of the copyright starting from the moment the present agreement comes into force the exclusive rights to the materials, including the rights to translate, reproduce, transfer, distribute or otherwise use the materials or parts (fragments) contained therein, for publication in scientific, academic, technical or professional journals or other periodicals and in derivative works thereof, worldwide, in English, in print or in electronic editions of such journals, periodicals and derivative works in all media or formats now existing or that may exist in future, as well as the right to license (or give permission to) third parties to use the materials for publication in such journals, periodicals and derivative works worldwide. The transfer under this agreement includes the right to adapt the presentation of the materials for use in conjunction with computer systems and programs, reproduction or publication in machine-readable format and incorporation into retrieval systems.

2- Reproduction, placement, transfer or any other distribution or use of the materials, or any parts of the materials contained therein, in any way permitted under this Agreement, shall be accompanied by reference to the Journal and mentioning of the Publisher, namely: the title of the article, the name of the Author (Co-authors), the name of the Journal, volume/number, copyright of the publisher.

B) Reserved Rights

The Author (Co-authors) or the employer of the Author (Co-authors) of the materials shall retain all proprietary rights (with the exception of the rights transferred to the Publisher under the present Agreement).

C) Author Guarantee

The Author (Co-authors) guarantees that the materials are an original work, submitted only to GJESM, and have not been published previously.
In case the materials were written jointly with co-authors, the Author guarantees that he/she has informed them of the terms of this Agreement and obtained their signatures or written permission to singe on their behalf.
The Author guarantees as well that:
The materials do not contain libelous statements.
The materials do not infringe on other persons' rights (including without limitation copyrights, patent rights and the trademark right).
The materials do not contain facts or instructions that can cause damage or injury to third parties and their publication does not cause the disclosure of any secret or confidential information

---

Author (Corresponding Author):

Correspondence Address:

Phone:

Fax:

Email:

Corresponding Author Name: Signature Date

On Behalf of the Publisher:

Iran Solid Waste Association,
Faculty of Environment, University of Tehran,
Postal Code: 1417854511, Tehran,
Iran

Telefax: (+9821) 2610 5110

Email: *editor@gjesm.net*

Gjesm.publication@gmail.com

Website: www.gjesm.net

Accepted for publication ☑ Signature Date

PLEASE NOTE: The accepted manuscript cannot be processed for publication until the publisher has received this signed form. The form MUST be signed by the Corresponding Author and then scanned and sent through the system or email. If the manuscript is not published in the Journal, this release will not take effect.

The sole responsibility for the whole content (s) of the article remains only with the corresponding author. However, Editor would reserve the right to adjust the style to certain standards of uniformity before publication.

CONFLICT OF INTEREST DISCLOSURE FORM

Conflict of Interest is defined as a set of conditions in which professional judgment concerning a primary interest, such as the validity of research, may be influenced by a secondary interest, such as financial gain. A Conflict of Interest Disclosure is an agreement or notification from the authors that they have not been paid for the work, or if they have, stating the source of their payment. The purpose of Conflict of Interest Disclosure form is to provide readers of authors' manuscript with information about authors' interests that could influence how the authors receive the work. The corresponding author (on behalf of all co-authors) should submit a conflict of interest disclosure form and is responsible for the accuracy and completeness of the submitted manuscript. Conflict of Interest Disclosure form can be signed by the corresponding author on behalf of all co-authors and stating that the submitted manuscript is the authors' original work, has not received prior publication and is not under consideration for publication elsewhere, permission has been received to use any material in the manuscript much as tables, figures etc. or no permissions have necessary to publish the authors' work.

1. Name of the corresponding author

2. Affiliation including e-mail and phone number

3. Manuscript Title

4. Do the authors or authors' institution at any time receive payment or services from a third party (government, commercial, private foundation, etc.) for any aspect of the submitted manuscript (including but not limited to grants, data monitoring board, study design, manuscript preparation, statistical analysis, etc.)?

   Are there any relevant conflicts of interest? Yes / No

5. Do the authors have any patents, whether planned, pending or issued, broadly relevant to the work?

   Are there any relevant conflicts of interest? Yes / No

6. Are there other relationships or activities that readers could perceive to have influenced, or that give the appearance of potentially influencing, what the authors' information in the submitted manuscript?

   Are there any relevant conflicts of interest? Yes / No

7. Are there any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies or not.

   Are there any relevant conflicts of interest? Yes / No

Corresponding Author Signature	Print Name	Date

AUTHORSHIP FORM

By completing and signing the following statements, the corresponding author acknowledges and accepts the responsibility on behalf of all contributing authors, if any, concerning Authorship Responsibility.

Manuscript title:

Corresponding author:

Affiliation:

Email:

Phone No:

By signing and filling this form, the corresponding author certifies that each author has met all criteria below (A, B, C, and D) and indicates each author general and specific contributions by listing his or her name next to the relevant section.

A. I certify that

- The manuscript is authentic and valid and that neither this manuscript nor one with considerably similar content under my authorship has been published or is being considered for publication elsewhere, except as described in an attachment, nor copies of closely related manuscripts are provided.
- I will provide the data or will contribute fully in providing and obtaining the data on which the manuscript is based for examination by the editors or their assignees, if requested.
- Every author has agreed to allow the corresponding author to serve as the primary correspondent with the editorial office, to review the edited manuscript and proof.

B. Each author has given final approval of the submitted manuscript.

C. Each author has participated sufficiently in the work to take public responsibility for the whole content.

D. Each author qualifies for authorship by listing his or her name on the appropriate line of the categories of contributions listed below. List appropriate author next to each section – each author must be listed in at least 1 field. More than 1 author can be listed in each field.

- conception and design
- acquisition of data
- analysis and interpretation of data
- drafting of the manuscript
- critical revision of the manuscript for important intellectual content
- statistical analysis
- obtaining funding
- administrative, technical, or material support
- supervision
- no additional contributions
- other (specify)

Corresponding Author Signature **Print Name** **Date**

CHANGE OF AUTHORSHIP FORM

Manuscript Title:

Corresponding Author:

Please check all that apply.

☐ New author(s) have been added.

☐ There is a change in the order of authorship.

☐ An author wishes to remove his/her name. An author's name may only be removed at his/her own request in writing.

ORIGINAL AUTHORSHIP

List ALL AUTHORS in the same order as the original (first) submission.

Print Name	Print Name
Name (1)	Name (6)
Name (2)	Name (7)
Name (3)	Name (8)
Name (4)	Name (9)
Name (5)	Name (10)

NEW AUTHORSHIP

List the ALL AUTHORS in same order as the new version.

Print Name	Print Name
Name (1)	Name (6)
Name (2)	Name (7)
Name (3)	Name (8)
Name (4)	Name (9)
Name (5)	Name (10)

I attest that:

1. The manuscript is not currently under consideration, in press, or published elsewhere, and the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by the journal (posting of submitted material on a web site may be considered prior publication-note this in your cover letter).
2. The manuscript is truthfully original work without fabrication, fraud, or plagiarism.
3. I have made an important scientific contribution to the study and am thoroughly familiar with the primary data.
4. I have read the complete manuscript and take responsibility for the content and completeness of the manuscript and understand that I share responsibility if the paper, or part of the paper, is found to be faulty or fraudulent.

Corresponding Author Signature Name Date

SUBSCRIPTION FORM

Subscription form

Global Journal of Environmental Science and Management

Please enter my annual subscription to the Global Journal of Environmental Science and Management (GJESM), including 4 quarterly issues for the Year .... Vol. .... Nos.........

	Domestic (Rials)	International (USD)
▪ Institutional	3,000,000	150
▪ Individual	2,000,000	100
▪ Student	1,000,000	80
▪ Single Copy	500,000	50

Name: **Tel.:** **Email:**

Mailing Address:

Payment method: Check or money order must be made in order of:
Account #. 0101834143005, Account name: J. Nouri
Bank Melli Iran, IAU Branch, Code 1017, Tehran, Iran

□ Bank receipt enclosed

** Please allow 3 to 5 weeks for delivery*

Please send this filled in order form along with the Bank receipt payment to:

Global Journal of Environmental Science
and Management
No. 2, Kouhestan Deadend, Janpour Street,
Darabad, Tehran 1956934461 Iran

Global

Journal of Environmental Science and Management

CONTENTS

Volume 8, Number 2, Spring 2022

(Serial # 30)