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1. Editorial

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ORIGINAL REEARCH PAPER

Economic policy of Eastern European countries in the field of energy in the context of global challenges

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ABSTRACT

BACKGROUND AND OBJECTIVES: The crisis in the energy sector of Eastern European countries determines the search for alternative ways to solve the above problem, one of which is the development of economic policy in the field of energy in the context of European integration. The purpose of the article is to develop conceptual, theoretical-methodological and methodical-practical foundations of economic policy in the field of energy.
METHODS: The methodological basis of the paper is a set of techniques, principles, general theoretical, special, interdisciplinary methods of scientific study. The method of metric ranking is used in assessing the levels of energy security in countries with high energy use. Based on the method of system equations, a functional system of critical infrastructure of the country is built.
FINDINGS: A model of compatibility of energy infrastructure with other components of critical infrastructure (institutional and technological) was developed in order to ensure uninterrupted interaction between all key elements of critical infrastructure of the country and increase the level of energy, economic and national security of the country. Based on the content analysis of the legislation of the countries, it has been proven that in the system of critical infrastructure the energy sector is a key factor of national security. The calculated indicators of the level of energy efficiency of the energy system of Ukraine until 2035 based on the use of blockchain technology proved that the level of energy intensity of Gross domestic product should be reduced by more than half (53.57 %).
CONCLUSION: As a conclusion, the developed model of the system of management of distribution of energy resources in the country using blockchain technology will contribute to decentralization of energy transactions, generation and supply of energy based on renewable and traditional sources, will allow to solve the problem of significant distance between renewable energy sources and industrial centers (its main consumers).

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INTRODUCTION

The problem of rational use of energy resources, increasing the level of energy efficiency and energy security is a necessary condition for the harmonious economic and social development of each country. Providing all sectors of the economy of a country with various types of energy and fuel is one of the most important tasks of the management system, the economic policy of a country, a necessary condition for its successful and harmonious development. The formation and implementation of the energy policy of a country is a very important component of the economic policy as a whole. Only successful mutual complementation (complementarity) of economic and energy policies will allow achieving the harmonious development of the country in the context of global challenges. Given the limited energy resources, there is an acute problem of their efficient use, geographical and other types of diversification of energy products by a country. Improving energy supply will help to create conditions for the harmonious development of the economy of a country, will ensure increased levels of energy efficiency, and a high level of economic and national security. A significant number of scientific studies have been devoted to the problems of energy management, in particular, the formation of energy policy. Bauer *et al*., (2017) describe the experience of developing energy strategies in world countries with the purpose of increasing their energy security. Pollit (2017) studies the problems, prospects of stimulating investment attraction in the energy sector of a country. A study of the energy management processes of individual regions is covered in the papers of Jafarigol *et al.,* (2016); Sadeghi-Pouya *et al.,* (2017); Kemp and Never (2017); Obama, B. (2017). The strategies of regional energy development were analyzed by Nakano *et al.*, (2017); Rogge *et al*., (2017); Kooij *et al*., (2018). An analysis of economic approaches to the use of energy resources is given in the papers of Garrett-Peltier (2017); van Veelen (2017); Lyytimäki (2018); Gielen *et al*., (2019). The motivational function in the energy sector was studied by Keeley and Ikeda (2017); Khan and Singh (2017); Aized *et al*., (2018); Oh *et al*., (2018). The problems of forming strategies at energy enterprises are the subject of studies of such scientists as Skiba *et al.,* (2017); Adams *et al*., (2018). Curran and Spigarelli (2017); Moreau and Vuille (2018) analyzed the implementation of the energy strategy of a specific country. Zandi *et al*., (2017) reviewed energy security management processes. Shahbaz *et al*., (2017) examined the problems of increasing the level of energy efficiency of a national economy, etc. A great contribution to the formation of the methodological foundations of the analysis of the energy market of a country was made by economists, namely: Koçak and Şarkgüneşi (2017). The problems of development of global energy, the use of alternative sources in this area, were analyzed by scientists, among which the papers of Jiang *et al*., (2017), Papageorgiou *et al*., (2017) Pollitt (2017) and others can be emphasized. However, the conceptual, theoretical-methodological, and methodical foundations of forming a complementary economic and energy policy of the country based on harmonious development remain insufficiently substantiated and formed. The development of a system of compatibility of energy infrastructure with elements of critical infrastructure is required. There is a need to develop a method of cost estimation of the level of the economic effect of the implementation of energy-saving measures within the framework of introduction of renewable energy sources. There is a need to improve energy supply through integrating it with the European Union system by bringing it in line with European regulations. Given the limited energy resources, the reduction of the availability of traditional energy resources in nature, the growing need for diversifying energy resources, increasing the level of energy security, solving the above problems should be carried out on the basis of scientific substantiation and with the help of the most relevant measures. The problems of critical infrastructure protection are related with the rapid development of new approaches to national security in developed countries, which is due to the rapid changes taking place in the security environment in the global, regional and national dimensions. The energy sector is part of the critical infrastructure of the Eastern Europe countries. When studying theoretical-practical principles, the above problems still remain at the level of insufficient substantiation, and the corresponding conceptual, methodological, methodical-practical principles are insufficiently formed, which determines the level of importance of studies in the field of energy. Unpredictable changes in price levels for various types of energy resources, a high level of energy import dependence of the economy of a country cause an increase in the level of uncertainty in the energy sector of a country and risk level, which leads to a decrease in the level of energy and, accordingly, economic and national security. All of the above determined the selection of the subject of the paper, its purposes and its objectives. The purpose of the paper is to develop conceptual, theoretical-methodological and methodical-practical foundations of the formation of economic policies in the energy sector. Achieving the set goal conditioned the solution of such problems: to develop a model of compatibility (coherence) of energy infrastructure with other components of critical infrastructure in Eastern Europe (institutional and technological ones); to develop a method of intellectualization of energy systems of the countries in the conditions of European integration; to substantiate the system of management of distribution of energy resources in Ukraine based on blockchain technology. This study was conducted in the Eastern European countries (Bulgaria, Poland, Ukraine, Slovakia, Russia) during 2015–2020.

MATERIALS AND METHODS

The methodological basis of the paper is a combination of techniques, principles, general theoretical, special, and interdisciplinary methods of scientific study. To achieve the set purpose and solve determined objectives, the following methods were used: method of theoretical generalization for the formation of own approach to understanding the key concepts in the area of economic policy in the energy sector; statistical and comparative analysis for study of the state of the energy sector and identification of trends in the energy sector, setting priorities for the energy sector; method of synthesis when forming individual elements of the structure of an integrated economic policy in the energy sector. As already mentioned, the energy sector is a key sector of critical infrastructure in many countries, including the Eastern Europe countries. Functionally, the system of critical infrastructure can be defined by this system using Eq. 1.

$$\begin{cases} I_k = S^1_{I_k} \cup S^2_{I_k} \cup \ldots \cup S^n_{I_k} \\ S^n_{I_k} = \sum_{l=1}^{p} F_l \end{cases} \quad (1)$$

Where, I_k — critical infrastructure of a country; $S^1_{I_k}, S^2_{I_k}, S^n_{I_k}$ — critical infrastructure sectors of a country; F_l — factors influencing the relevant sector of the critical infrastructure of a country; n — number of critical infrastructure sectors of a country; l — the number of factors influencing the critical infrastructure sectors of a country. It should be noted that each country has an appropriate system of critical infrastructure (Table 1).

The countries listed in Table 1 were selected in accordance with the following requirements: the US legislation for the first time identified the subjects and objects of the critical infrastructure of a country, China as the fastest growing country, Great Britain as a country that left the EU, Poland and Bulgaria as Eastern European countries that are members of the EU. It can be concluded that the energy sector is a mandatory element of the critical infrastructure of the analyzed countries. Of course, the security of the energy sector is influenced by both global (world scale) and local (for the national level) factors. The importance of protection of the energy infrastructure of a country has grown significantly. This infrastructure is significantly influenced by the following factors (which also apply to the global energy sector as a whole): the need to ensure a high degree of reliability of the public energy supply system; growth in global energy trade; expansion of energy infrastructure, in particular, cross-border grids; the use, by some countries, of energy resources, energy infrastructure for conducting a geopolitical struggle; intensification of the activities of terrorist groups that purposefully destroy the energy infrastructure; growing requirements for the level of protection of the environment and human beings from the results of the activity of the energy sector of the economy. Functionally, the influence of key factors on the energy sector of the critical infrastructure can be determined using Eq. 2.

$$S^E_{I_k} = \sum_{l=1}^{6} F_l = F_1 + F_2 - F_3 + F_4 - F_5 + F_6 \quad (2)$$

Where, $S^E_{I_k}$ — energy sector of the critical infrastructure of a country; $F_1, F_2, F_3, F_4, F_5, F_6$ — factors influencing the energy sector of the critical infrastructure of a country.

Thus, according to the author's study, based on the content analysis of the legislation of Eastern Europe, the functional impact of the factors on the level of protection of energy infrastructure of the main factors in the energy sector of critical infrastructure can be determined by the following elements: F_1 – The need to ensure the sustainability of the energy system; F_2 – Increase in the volume of world trade in energy; F_3 – Use by countries of energy resources and energy infrastructure as tools for geopolitical struggle; F_4 – Expansion of energy infrastructure, including cross-border networks; F_5 – Intensifying the activities of terrorist groups that steadily destroy the energy infrastructure; F_6 – Strengthening the environmental and human protection requirements of the energy sector.

RESULTS AND DISCUSSION

The issue of energy security is becoming increasingly acute in the world since it is both an integral component of national security and a determining condition for the formation of the economic and political independence of each country. There is a high level of energy hazards in the world economy. Dynamic and substantive approaches are fully tied to a single project and do not allow for comprehensive and holistic energy security management. Energy security management based on a functional approach is built on the implementation of basic management functions. An approach that identifies 5 key management functions is effective: planning, organization, motivation, control, and regulation. Based on literature review, an energy security management for an enterprise, region, country, which is based on the principles of a functional approach, was developed (Fig. 1).

Energy security management using a functional approach is carried out by planning (development, making investment plans, forecasting, etc),

Table 1: Critical infrastructure sectors of some countries

Item No.	Sector	Country: USA	China	Great Britain	Poland	Bulgaria
1.	Information and communication	+	+	+	+	+
2.	Emergency services	+	-	+	-	-
3.	Energy	+	+	+	+	+
4.	Financial and banking	+	+	+	+	+
5.	Food (and agriculture)	+ (+)	+	+	-	+
6.	State administration	+	+	+	+	+
7.	Health care	+	+	+	+	+
8.	Transport	+	+	+	-	+
9.	Water supply (and treatment)	+ (+)	+	+	+	+
10.	Defense	+	-	+	-	-
11.	Nuclear	+	-	+	-	-
12.	Space	-	-	+	-	-
13.	Chemical	+	-	+	-	-
14.	Security	-	+	-	-	+
15.	Industrial	+	-	-	-	+
16.	Air	-	-	-	+	-
17.	Railway	-	-	-	+	-
18.	Electricity	-	-	-	+	-
19.	Fuel	-	-	-	+	-
20.	Logistics	-	-	-	+	-
21.	Waste disposal and water treatment	-	+	-	-	-
22.	Commercial	+	-	-	-	-
23.	Communications	+	-	-	-	-
24.	Hydrotechnical	+	-	-	-	-

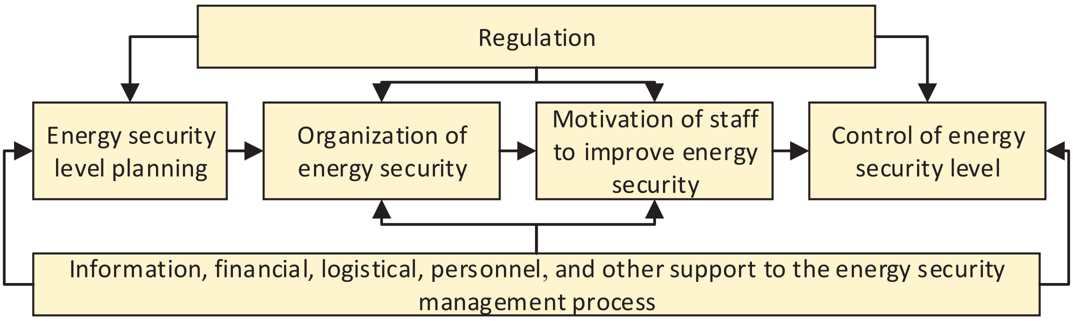

Fig. 1: Energy security management based on a functional approach

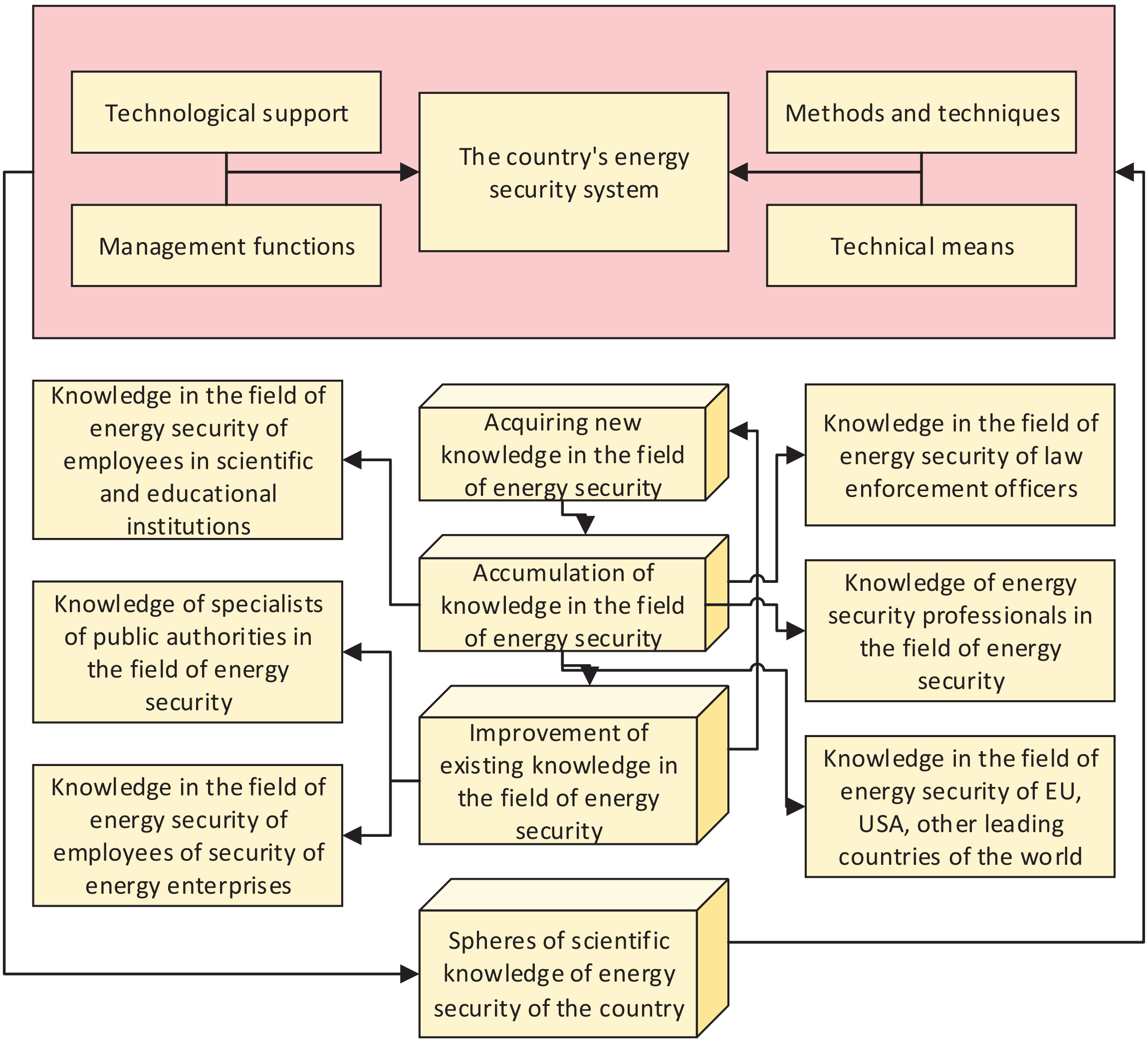

Fig. 2: System of knowledge management in the field of energy security of the country

organization (creating the necessary units for the implementation of investment activity), motivation (stimulating the increase of the level of the investment component of economic security), control (ensuring verification of the obtained results of the investment activity with the planned ones, evaluation of the effectiveness of the investment activity, achievement of the goals), regulation (elimination of deviations and deficiencies found in the process of controlling investment activity, implementation of corrective actions). It should be noted that energy security and its investment component (since capital investments are required to increase energy security, which are quite large in volume) must be ensured not only by economic methods (without denying their priority) but also by other methods (non-economic): political, military, information, etc. These resources can be used for approximately another 100 years for energy use. That is why the development of alternative (renewable) energy is a relevant (although not profitable in the first stages) timely direction for the development of the world energy sector, and, in particular, of each country, as it will help reduce the consumption of fossil fuels. In Fig. 2, the suggested system of knowledge management in the field of energy security of the country is considered.

The suggested model for the formation of knowledge in the area of energy security will enable the entities of the energy security system of a country to accumulate developments when performing their functions, as well as international (including European) experience, which will allow obtaining new knowledge in the area of the energy security of a country, improving existing one, effectively using it in the activities of energy security systems of business entities, government agencies and other

Table 2: Ranking of energy security levels in the world countries with high energy use (IIESR, 2018)

Countries	Risk level of energy security of the country	Ranks of the countries, which are the largest energy consumers
Norway	774	1
Mexico	802	2
Denmark	819	3
New Zealand	866	4
Great Britain	885	5
USA	893	6
Canada	912	7
France	942	8
Germany	944	9
Australia	962	10
Poland	987	11
Spain	1037	12
Italy	1043	13
Turkey	1087	14
Japan	1088	15
Netherlands	1106	16
Russia	1115	17
India	1164	18
Indonesia	1164	18
China	1172	20
South Africa	1175	21
South Korea	1306	22
Brazil	1307	23
Thailand	1616	24
Ukraine	2009	25

participants of energy markets. The knowledge in the area of energy security is formed in various scientific fields, it is somewhat disparate by nature and doesn't allow to effectively implement comprehensive ensuring energy security. It is necessary to develop theoretical-methodological tools for energy security management, as well as to form a scientific school. Not only energy but also economic and national security will largely depend on it. The suggested model of knowledge management in the area of energy security of a country will contribute to the acquisition of new knowledge in the area of energy security, which will become the basis for the formation of innovative energy security systems of a country, which are capable of responding adequately, timely and highly effectively to all dangers/threats to the activity of economic entities and the country as a whole. The above circumstances require a substantial revision of the economic policy of a country in the energy sector regarding increasing the level of protection of important energy facilities (that is, critical energy infrastructure) and reflection of corresponding priorities in the national legislation. So, when creating a clear system for protecting the critical energy infrastructure of the country it is necessary at the legislative level to determine the functions and objectives of state authorities, energy economic entities of various forms of ownership. The establishment of joint responsibility for ensuring the necessary level of protection of the critical

Table 3: Metric ranking of energy security levels in countries with high energy use (IIESR, 2018)

Market and price indicators				Energy consumption intensity levels			
No	Level of energy expenditures from the country's budget	No	GNP per capita	No	Energy consumption per capita	No	Energy consumption intensity level
1.	Norway	1.	Norway	1.	India	1.	India
2.	Germany	2.	Denmark	2.	Indonesia	2.	Indonesia
3.	Great Britain	3.	USA	3.	Brazil	3.	Brazil
4.	Mexico	4.	Netherlands	4.	Mexico	4.	Mexico
5.	USA	5.	Germany	5.	Turkey	5.	Turkey
6.	Denmark	6.	Great Britain	6.	Thailand	6.	Thailand
7.	New Zealand	7.	Canada	7.	China	7.	China
8.	France	8.	Australia	8.	Poland	8.	Poland
9.	Netherlands	9.	Japan	9.	South Africa	9.	South Africa
10.	Turkey	10.	France	10.	Ukraine	10.	Ukraine
11.	Italy	11.	New Zealand	11.	Italy	11.	Italy
12.	South Korea	12.	Italy	12.	Spain	12.	Spain
13.	Spain	13.	Spain	13.	Great Britain	13.	Great Britain
14.	Canada	14.	South Korea	14.	Denmark	14.	Denmark
15.	Australia	15.	Poland	15.	Japan	15.	Japan
16.	Japan	16.	Turkey	16.	France	16.	France
17.	Poland	17.	Mexico	17.	Germany	17.	Germany
18.	India	18.	Russia	18.	New Zealand	18.	New Zealand
19.	Russia	19.	South Africa	19.	Russia	19.	Russia
20.	China	20.	Brazil	20.	South Korea	20.	South Korea
21.	South Africa	21.	China	21.	Netherlands	21.	Netherlands
22.	Indonesia	22.	Thailand	22.	Australia	22.	Australia
23.	Thailand	23.	Ukraine	23.	USA	23.	USA
24.	Brazil	24.	Indonesia	24.	Canada	24.	Canada
25.	Ukraine	25.	India	25.	Norway	25.	Norway

infrastructure of a private sector of the country at the level of corresponding state authorities should be an important element. Table 2 shows the ranking of energy security levels in countries with high energy use.

In the energy sector, the EU is strict with regulation of safety standards. Member countries must adhere to the "Emergency Preparedness and Response Plan", i.e., the plan of preparation, actions in emergency situations (Eurostat, 2018). The energy component of critical infrastructure is faced with certain risks. In particular, when transporting energy, lightning problems are most likely to occur, followed by fires/other natural disasters, equipment problems, or human error, followed by problems caused by strong wind. Table 3 shows the metric ranking of energy security levels in countries with high energy use. In terms of intensity of use, developing countries such as India, Indonesia, China, Brazil and others are ahead of us.

A high level of implementation of the latest technologies is a sign of the level of development of the country and a determining factor of its competitiveness (a necessary condition for achieving the goals of national interests). However, with innovative advantages, technological progress also leads to a high level of dependence of a person and society on systems (systems providing energy, communication, information, transportation, financial, and other types of services). Given the impossibility of simultaneously protecting all of these infrastructure systems (primarily due to limited resource potential), the concept of "critical infrastructure" is being implemented in developed countries. At the same time, the results of such studies make it possible to more efficiently distribute the resources allocated to ensure the stable operation of critical infrastructures. The analysis allows

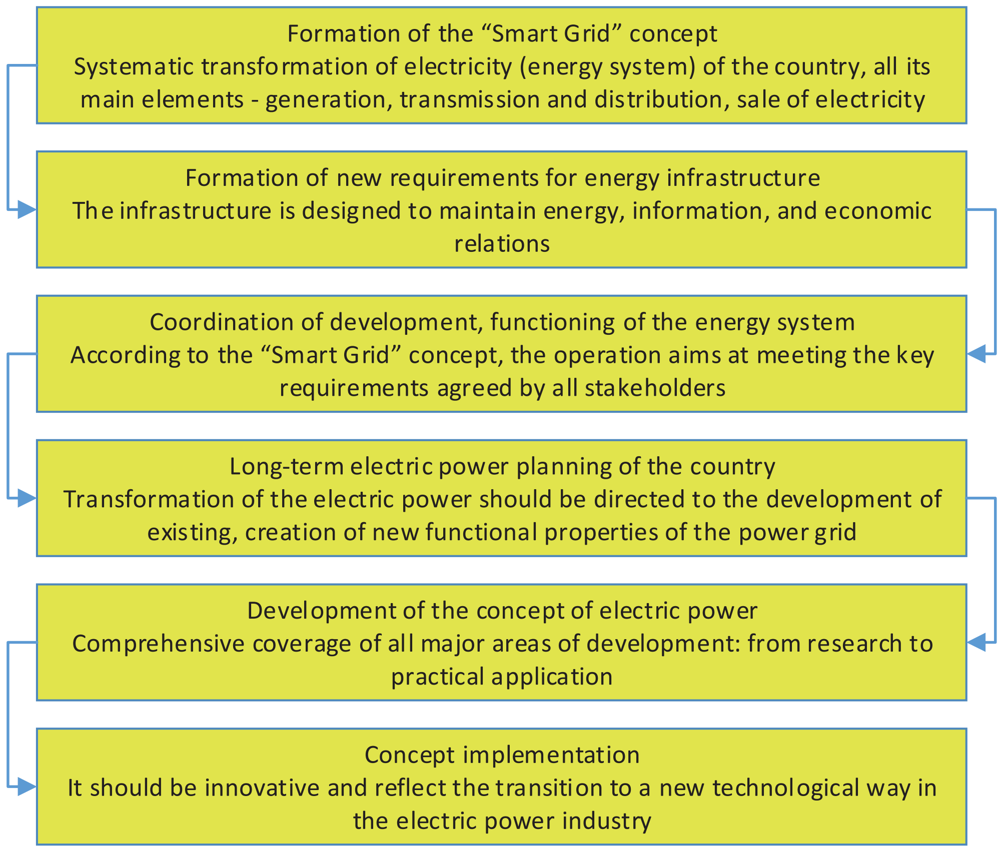

Fig. 3: Stages of "Smart Grid" implementation in the electric system of a country

forming a sequence of basic postulates, blockchain, development stages, and development of the "Smart Grid" concept in the country (Fig. 3).

In developed countries, to solve new problems, considerable attention is paid to the problems of introducing "smart" technologies, such as "Smart Grid", "Smart Metering" in the energy industry, in particular in the electrical energy industry. Globally, obsolete metering devices are being replaced by the "smart" energy metering system "Smart Metering", which is able to provide at a qualitatively new level of reliability: measurement of energy resources; management and control of their supply, transportation and consumption; automated transmission, processing and provision of information on resource consumption; creation of situational databases on energy consumption with elements of information support of tasks of management of consumption of energy resources and a number of other tasks. Smart Metering technologies allow to evaluate the efficiency of energy saving technologies, make transparent payments for used energy resources, promptly receive data on current electricity consumption and its modes, to monitor the state of meters, to draw the balance for groups of meters (which helps to identify unaccounted consumption and the facts of action on meters). The introduction of smart metering technology is a key element in the creation of intelligent energy systems with an active-adaptive grid ("Smart Grid"), thanks to which the reliability and efficiency of energy supply is taken to a new level. Table 4 gives a comparative description of the functional characteristics of the current (existing) energy system in the country and the energy system created on the basis of the implementation of the "Smart Grid" concept.

That is, an innovative energy system, which is based on the "Smart Grid" concept has significant advantages over the current one. The main advantage is the cost-effectiveness, efficiency, and operational controllability (adjustability) of the system. The development and implementation of functional capabilities (Table 4) will significantly increase the level of efficiency of the electrical energy industry and provide the expected benefits for all interested parties. It should be noted that for each individual stakeholder implementation of the concept of "Smart Grid" in the energy sector will have different economic effects. This method is based on a comparison of the efficiency of the existing energy systems of Eastern Europe countries (without elements of "Smart Grid") and the suggested one (with elements of "Smart Grid"). For example, for consumers this will be provision of minimum operating costs provided that sufficiently comfortable conditions are created. For their own needs, consumers of electricity will

Table 4: Comparative characteristics of the functional characteristics of the current energy system and the energy system based on the concept of "Smart Grid"

Current energy system	Energy system based on the concept "Smart Grid"
One-way communication between elements or its complete absense	Two-way communication
Centralized generation - distributed generation with a complex integration process	Distributed generation
Radial topology prevails	Grid topology prevails
Responding to the consequences of an accident	Responding to predicting and preventing (avoidance) an accident
Operation of the equipment until complete failure (breakdown)	Continuous monitoring, self-diagnosis, which help to extend the life of the equipment
Manual recovery in the case of errors, crashes, etc.	Automatic grid recovery ("self-healing grids")
High level of system crashes	Forecasting of the development of system crashes, predicting their occurrence
Manual, fixed grid allocation	Adaptive grid allocation
Checking the equipment on site	Remote monitoring of equipment
Limited power flow control	General power flow control
End-user price level information is not available or too late	End-user price level is displayed in real time

be able to convert it into other types of energy (for example, thermal, mechanical, etc.). When a consumer receives different types of energy, energy redistribution will be carried out, which will increase the volume of electricity consumption. It is advisable to present the total volumes of electricity (W) received by a consumer in a simplified form using the mathematical Eq. 3.

$$W = \begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix} = \sum_{1}^{3} A_i \qquad (3)$$

Where, A_1, A_2, A_3 — volumes of electric, thermal energy, thermal energy of hot water supply, respectively.

The volumes of energy will depend on the corresponding parameters, which are the arguments for the function A_i. The values A_1, A_2, A_3 in the energy supply of consumers of the combined energy supply system are presented in the form of the function $A_i = f(A_1, A_2, A_3, ..., A_r)$ from the variable parameters A_i as: Electrical energy using Eq. 4.

$$A_1 = f(c_1, U, I, k, t_1) \qquad (4)$$

Thermal energy using Eq. 5.

$$A_2 = f(c_2, m, g, \Delta Q, t_2) \qquad (5)$$

Thermal energy of hot water supply using Eq. 6.

$$A_3 = f(c_3, m, g, \Delta Q, t_3) \qquad (6)$$

Moreover, if there are other types of energy (A_r), one can also introduce them into the suggested model. The designations of the constituent elements in the dependences (4–6) mean the following: U - voltage (phase or line) in the power supply system; I - load current; k - load factor, which characterizes the ratio of active energy to total energy; m - heating mass; g - specific heat capacity; ΔQ - difference between the final (maximum permissible) and initial temperature of the substance; c_1, c_2, c_3 - coefficients that include constants characteristic of the corresponding type of energy; t_1, t_2, t_3 - time of production, use of the corresponding type of energy. These functional dependencies (4–6) allow to proceed to the implementation of the stage of making sound management decisions on the design of components for automatic control devices, their interactions and/or selection (modernization, improvement of its technical and economic parameters) of existing power plants, devices, etc. of the local energy supply system using renewable energy sources. It is expedient to put substantiation of functional dependence of the sizes of consumption of types of energy as a basis at designing of components of the device of automatic control of a smart electrical grid. The beginning for the development of the "Smart Grid" concept in industrialized countries was the formation of a clear strategic vision of the goals and objectives of the development of the electrical energy industry, which would meet the constantly growing requirements of society, stakeholders, namely: the state, science, manufacturers, economy, business, consumers, and so on (Table 5).

Thus, the structure of smart electrical grids is promising (Fig. 4) since to connect renewable energy sources to the electrical grid of a country in the context of the development of the electricity market, it is necessary to use the appropriate "Smart Grid" systems for the purpose of automated control of energy flows, timely performance regulation of power flows, consumption of electricity by the system maneuvering capacities, and the like. It is also associated with the level of development of electric transport in the country.

Since 2010, the process of activating the introduction of systems based on Smart Grid technology has been started. The first step in this direction is the integration of the smart measuring equipment such as "Smart Meters". In accordance with it, "Smart Grid" acts as a concept of a fully integrated, self-regulating, self-sufficient, self-healing electrical energy system, which has a grid topology, including all generation sources, bulk and distribution grids, all varieties of electricity consumers, which are controlled by a unified network of information and control devices, real-time systems. The low speed of information exchange hindered the achievement of the goals of harmonious development (converting the global energy system to the green one, combining the interests of all participants in energy market relations). It is the blockchain system that can solve this problem. The blockchain system in the energy sector will also help to create the conditions for the accumulation,

Table 5: Requirements of stakeholders for implementing the "Smart Grid" concept in the energy industry (systematized by the author)

Groups of stakeholders	Stakeholders	Requirements/expected effects
Energy companies	Wholesale sellers of electrical energy Retail sellers of energy services Electricity transmission companies Distribution grid companies	Operational improvements. Transparent metering and billing system. Outage management in real time. Improving energy management processes. Decrease in the level of electricity losses. Optimization of asset management. System planning. Maintenance, real-time monitoring.
Regulatory authorities	State regulation bodies of the country Wholesale electricity market operator Reliability regulators	Improvement of the reliability of electrical supply Transparent system of supply and metering of electric energy. Improvement of the energy management processes. Decrease in the level of electricity losses. Lower electricity tariffs.
End users	Industrial Commercial	Improvement of the reliability of electrical supply; increase in the overall level of service. Access to real-time electrical supply information. Ability to control power consumption levels. The opportunity to participate in the demand management process.
	Population	Optimized distributed generation relationship. The possibility of selling electricity to the market. The potential for a significant reduction in the cost of electrical supply.
	State and society as a whole	Reducing the level of electricity prices due to increased levels of operating, market efficiency, attracting new consumers. Reducing the level of consumer costs by increasing the level of reliability. Improving the grid security level by increasing its level of stability. Reducing emissions through the integration of renewable energy sources, reducing costs. New jobs and GDP growth. The possibility of innovative development of the transmission and distribution of electrical energy.

processing, and analysis of huge arrays of non-financial information. This information is contained in the agreements and is unified, which makes it important for both participants in energy markets and representatives of the financial sector of the economy. This applies to the physical characteristics of energy resources: fuel, electricity, etc. The model of a system for managing the distribution of energy resources using blockchain technology is suggested. Its use will contribute to the decentralization of energy transactions, generation and supply of energy based on renewable and traditional sources (Fig. 5).

The system is based on the characteristics of the product - electricity (the production and consumption processes do not coincide in time (it is impossible to determine in advance the volumes of its consumption and generation with a high degree of probability (accuracy)); the inability to accumulate electricity in the required volume and place; it is impossible to connect a specific producer and electricity consumer; and it takes into account the possibilities of technological development of the electrical energy industry (decentralized production (generation) of electricity on the basis of renewable/traditional sources; accumulation of produced (generated) electricity where it is necessary to align load schedules and improve the quality of electricity; supply of excess capacity to the grid for other consumers while controlling the grid operating conditions, monitoring it, etc). Distributed registry or blockchain technology is a data structure distributed between all network nodes in the form of

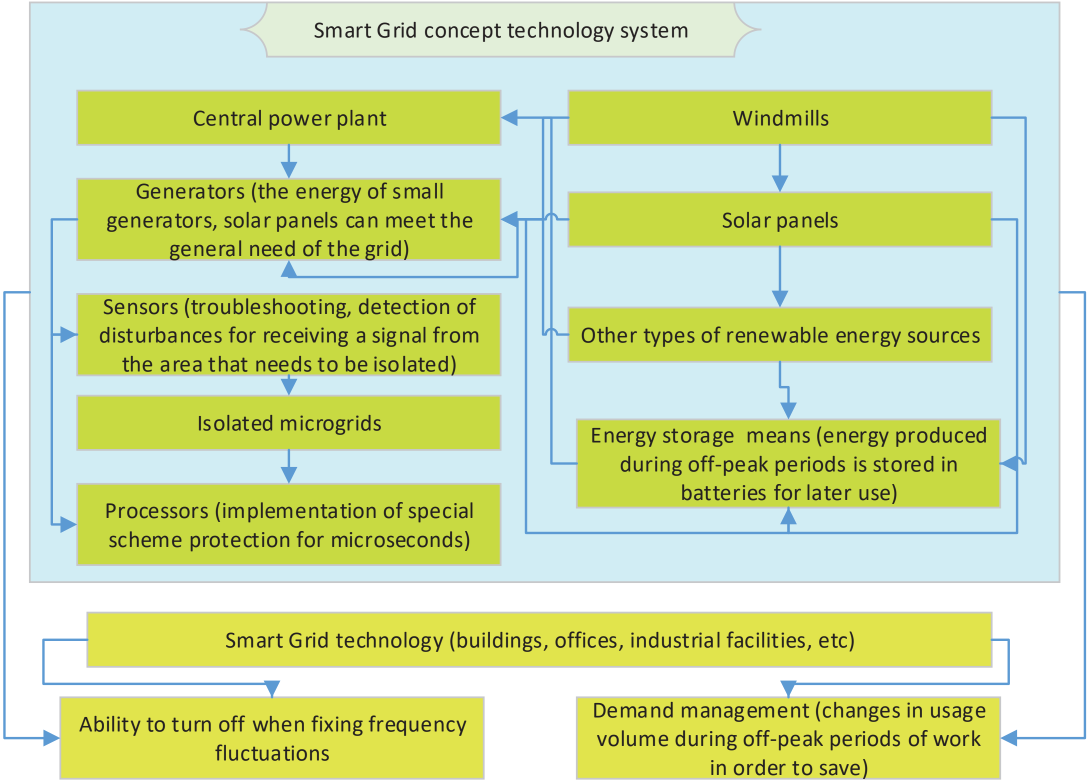

Fig. 4: “Smart electrical grid” structure

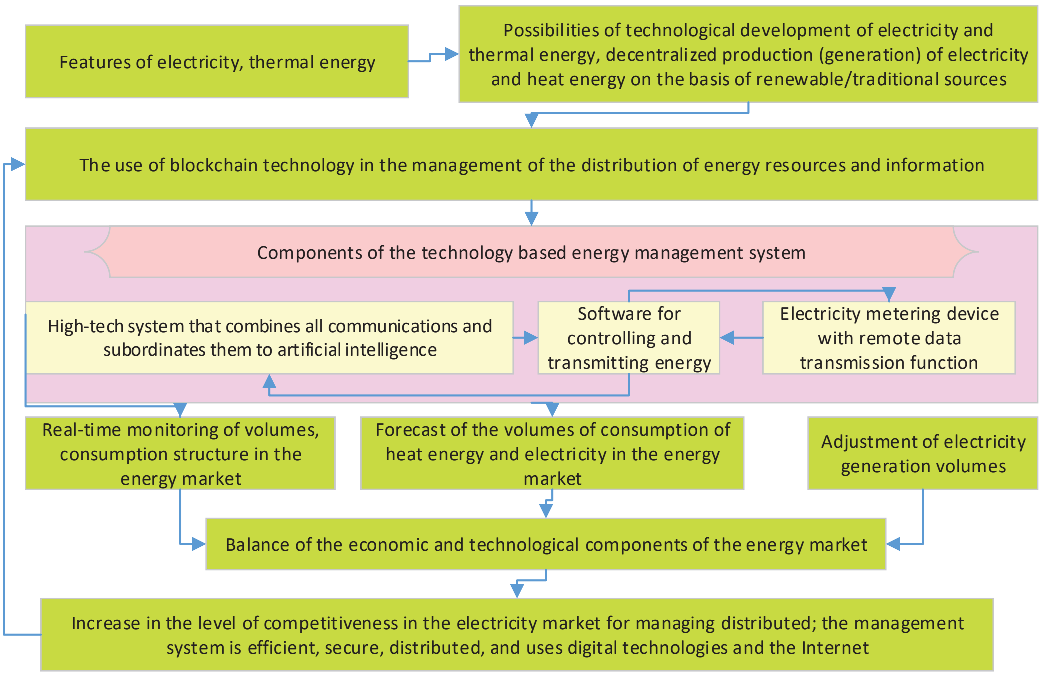

Fig. 5: Blockchain technology management system

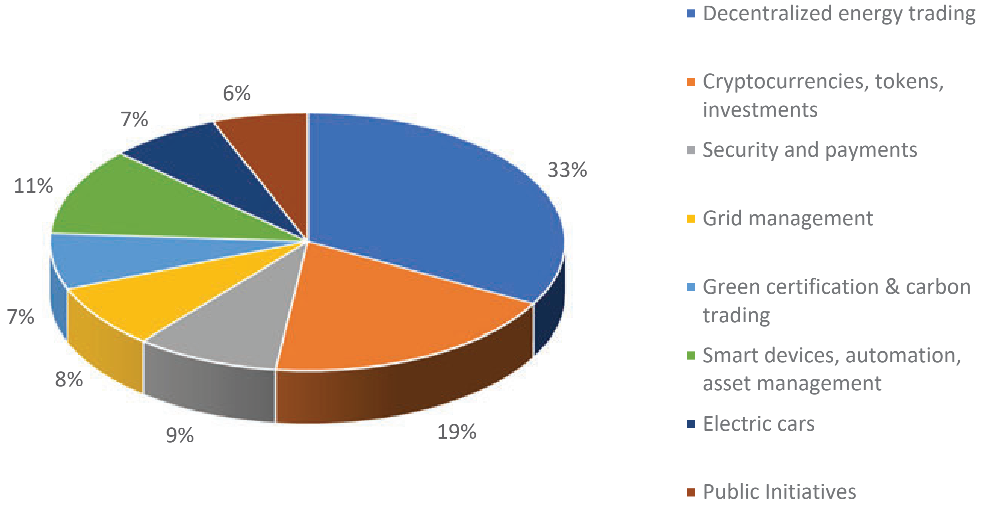

Fig. 6: Scenarios of blockchain use in energy sector projects

Table 6: Indicators of the level of energy efficiency of the energy system of Ukraine until 2035 based on the use of blockchain technology

Indicators	Values of indicators by years					Deviation of 2035 until 2015	
	2015	2020	2025	2030	2035	Absolute	Relative
Energy intensity of GDP, total primary energy supply calculated as the sum of production (extraction), import, export, international bunkering of vessels and changes in energy reserves of the country, toe/thousand dollars GDP	0.28	0.20	0.18	0.15	0.13	– 0.15	–53.57
Fuel costs for the amount of electricity sent to the energy market, generated at TPS, kg oe/kWh	396	384	367	353	334	–62	–15.66
Specific costs in the production of heat by boiler stations, kg oe/Gcal	165	160	155	150	145	–20	–12.12
Share of losses in electrical grids, %	> 12	10	9	8	< 7.5	-	-
Share of losses in heat networks, %	> 20	< 17	< 13	< 11	< 10	-	-

a digital replica of all information recorded within the framework of accessing it. Storage of all transactions taking into account their chronological order is a distinctive feature of this structure. Figure 6 shows the ratio of different uses of blockchain in the energy sector (Fig. 6).

The grid will be able to monitor its condition on-line (collect, process information regarding both the production process and electricity consumption). This will facilitate the transition from the use of traditional sources to generate electricity to renewable (non-traditional) ones, that is, take into account the differences that exist in the process of generating electricity from renewable sources, provide on-line monitoring of volumes, the structure of consumption in the market. The system will automate the processes of production/consumption, purchase/sale of generated energy. Also, the introduction of blockchain technology in the energy sector will solve the problem of a significant distance between places of energy generation from renewable sources and industrial centers. Moreover, the use of blockchain technology is not limited only to the energy and financial sectors of the economy but is gradually expanding due to related industries. Here is an example of possible use of blockchain technology in the energy system of one of the countries of Eastern Europe (Ukraine) and possible increase in the efficiency of the energy sector (Table 6).

In the crisis conditions that the economy of Ukraine is characteristic of, the problems of accounting for energy costs, energy saving are relevant. The economy of Ukraine is one of the most energy-intensive in Europe and in the world as a whole. The long period of inactivity in finding ways to save energy resources is one of the main reasons for this situation. According to the energy strategy of Ukraine for the period up to 2035, the level of energy intensity of GDP of Ukraine (Table 6) should be decreased by more than half (53.57 %), and other energy efficiency indicators are also projected to be decreased.

CONCLUSION

Today, the concept of critical infrastructure protection is implemented both in European legislation and in the national legislation of EU member states (pan-European critical infrastructure is considered to be of cross-border (within the EU) significance. Only two sectors (energy, transport) are identified as priorities at the European level. The model of energy management system of Eastern Europe countries based on blockchain technology was developed, which will contribute to the decentralization of energy transactions, generation and supply of energy based on renewable and traditional sources, will solve the problem of significant distance between renewable energy sources and industrial centers (their main consumers). The suggested model will facilitate the adoption of balanced, innovation decisions by civil servants of national executive bodies on the harmonious development and decentralization of the energy sector of the economy. The method of intellectualization of energy systems was further developed, which is based on the distribution of networks, departure from intermediaries and the transition to direct interaction with counterparties, processing, analysis of the array of non-financial information contained in agreements, has a unified form required for energy market participants, representatives of the financial sector, and application of "Smart Grid" (electrical grid including operational, energy saving measures, renewable energy sources, energy efficiency resources, etc.).

The introduction of electronic management of electricity parameters, production/distribution will contribute to reforming and further harmonious development of the energy sector of the economy, in accordance with European regulations and requirements.

AUTHOR CONTRIBUTIONS

S. Bogachov performed an experimental design and analyzed the data. A. Kirizleyeva defined the concept and methodology of the research. O. Mandroshchenko ranked the data into tables and figures. S. Shahoian performed the literature survey. Y. Vlasenko customized the manuscript to meet the requirements of the GJESM Journal.

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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

A_1, A_2, A_3	Volumes of electric, thermal energy, thermal energy of hot water supply, respectively
A_r	Other types of energy
c_1, c_2, c_3	Coefficients that include constants characteristic of the corresponding type of energy
et al.	Others
etc	And so on
EU	European Union
Fig.	Figure
$F_1, F_2, F_3, F_4, F_5, F_6$	Factors influencing the energy sector of the critical infrastructure of the country
F_l	Factors influencing the corresponding sector of the critical infrastructure of the country
g	Specific heat capacity
Gcal	gigacalories
GDP	Gross domestic product
GNP	Gross natinal product
HPS	Hydroelectric power station
I	Load current
I_k	Critical infrastructure of the country
k	Load factor, which characterizes the ratio of active energy to total energy
kg	Kilograms
l	Number of factors influencing the critical infrastructure sectors of the country
m	Heating mass
№	Sequence number
n	Number of critical infrastructure sectors of the country
NPS	Nuclear power station
oe	Oil equivalent
P2P	Peer-to-peer
$S_{I_k}^E$	Energy sector of the critical infrastructure of the country
t_1, t_2, t_3	Time of production, use of the corresponding type of energy
toe	Tonne of oil equivalent
TPS	Thermal power station
U	Voltage (phase or line) in the power supply system
USA	United States of America
W	Total volumes of electricity
ΔQ	Difference between the final (maximum permissible) and initial temperature of the substance

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ORIGINAL RESEARCH PAPER

Distribution of energy in propagation for ocean extreme wave generation in hydrodynamics laboratory

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ABSTRACT

BACKGROUND AND OBJECTIVES: The hydrodynamic uncertainty of the ocean is the reason for testing marine structures as an initial consideration. This uncertainty has an impact on the natural structure of the topography as well as marine habitats. In the hydrodynamics laboratory, ships and offshore structures are tested using mathematical models as input to the wave marker. For large wavenumbers, Benjamin Bona Mahony's equation has a stable direction and position in the wave tank. During their propagation, the generated waves exhibit modulation instability and phase singularity phenomena. These two factors refer to Benjamin Bona Mahony as a promising candidate for generating extreme waves in the laboratory. The aim of this research is to investigate the distribution of energy in each modulation frequency change. The Hamiltonian formula that describes the phenomenon of phase singularity is used to observe energy. This data is critical in determining the parameters used to generate extreme waves.

METHODS: The envelope of the Benjamin Bona Mahony wave group can be used to study the Benjamin Bona Mahony wave. The Benjamin Bona Mahony wave group is known to evolve according to the Nonlinear Schrodinger equation. The Hamiltonian governs the dynamics of the phase amplitude and proves the Nonlinear Schrodinger equation's singularity for finite time. The Hamiltonian is derived from the appropriate Lagrangian for Nonlinear Schrodinger and then transformed into the Hamiltonian $H(G,\phi)$ with the displaced phase-amplitude variable.

FINDINGS: Potential energy is related to wave amplitude and kinetic energy is related to wave steepness in the study of surface water waves. When $\tilde{\nu}=0.5$, the maximum wave amplitude and steepness are obtained. When $\tilde{\nu}>0.5$, extreme waves cannot be formed due to steepness. This is due to the possibility of breaking waves into smaller waves on the shore. In terms of position, the energy curve is symmetrical.

CONCLUSION: According to Hamiltonian's description of the energy distribution, the smaller the modulation frequency, the greater the potential and kinetic energy involved in wave propagation, and vice versa. While the wave's amplitude and steepness will be greatest for a low modulation frequency, and vice versa. The modulation frequency considered as an extreme wave generator is $\tilde{\nu}=0.5$, because the resulting amplitude is quite high and the energy in the envelope is also quite large.

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INTRODUCTION

Mathematical equations have been used to investigate marine structure tests (Samaras and Karambas, 2021; Ikhwan *et al.*, 2021). This test ensures that the building will not be damaged by high-energy waves and currents. High-energy waves have an impact on the natural structure of the topography as well as marine habitats. Extreme waves are based on events that have occurred and are scientifically recorded tests (Didenkulova, 2020). Activities in the hydrodynamics laboratory necessitate the use of mathematical models for water surface waves. The water waves created in this laboratory are used to assess the durability of ship and offshore structure models. There are several mathematical models that have been used including Korteweg de Vries (KdV) (Horn *et al*., 1999; Karjanto *et al*., 2010) and Benjamin Bona Mahony (BBM) (Shiralashetti and Hanaji, 2021). However, the wave that will be generated has high characteristics and will not break, which is known as an extreme wave (Waseda *et al*., 2012; Zhao *et al*., 2010). Given the limitations of the laboratory's current testing pool, this characteristic is required. When the height of a wave exceeds 2.2 times that of the average wave, it is considered extreme (Dean, 1990). Following the simplification of the Boussines Equation, KdV and BBM, have only one direction of propagation. Korteweg de Vries was the first to propose the KdV equation (Korteweg *et al*., 1895). A study of KdV revealed that the resulting waveform was unstable for large *k* wavenumbers (Myint-U *et al*., 2007, Wang *et al.,* 2018). The characteristics of the waves generated in the hydrodynamic laboratory pond, on the other hand, must have a short wavelength or a large wave number. These flaws appear to be overcome by the BBM equation (Benjamin *et al*., 1972). BBM wave is useful as initial wave because it does not propagate in short waves with large wavenumbers (Debnath, 2012; Ren *et al*., 2021). Furthermore, it is known that the BBM wave exhibits modulation instability during propagation (Halfiani *et al*., 2018, Zakharov, 2006). This modulation instability is one of the drivers of the emergence of extreme waves. As a result, BBM waves are both intriguing and promising in terms of generating extreme waves in the laboratory. The modulation frequency which is at modulation instability ($0<\tilde{\nu}<\sqrt{2}$) and phase singularity interval ($0<\tilde{\nu}<\sqrt{3/2}$) is an important input and it is necessary to find its value to avoid trial and error when testing on the wave tank (Fadhiliani *et al*., 2020). The BBM wave can be studied using either the BBM equation (Qausar *et al*., 2019) or the envelope of the BBM wave group. The BBM wave group is known to evolve according to the Nonlinear Schrodinger equation (NLS) (Hu *et al*., 2015), and a phase singular phenomenon appears when the real value of the amplitude $|A_{SFB}|$ disappears (Conforti *et al*., 2020; Wang and Wei, 2020). The presence of wave dislocation, as indicated by the merging or splitting of two waves, characterizes phase singularity. The amplitude of the wave changes significantly as a result of this phenomenon (Andonowati *et al*., 2007). The investigation of wave dynamics using the BBM group envelope, which is interpreted in the form of an Argand diagram, reveals the same thing: phase singularity appears in wave propagation (Fadhiliani *et al*., 2020). The Hamiltonian can also be used to explain this phase singularity. Hamiltonian can also explain the distribution of wave energy during its propagation because it contains potential energy (Sulem and Sulem, 1999). The wave group envelope equation, namely NLS, is used to derive this Hamiltonian formula. The aim of this research is to investigate the distribution of energy in each modulation frequency change. The modulation frequency is changed based on the value of the modulation instability interval, ie $0<\tilde{\nu}<\sqrt{2}$. In this range there is also a phase singularity interval, ie $0<\tilde{\nu}<\sqrt{3/2}$. It is done to improve knowledge of the energy characteristics of waves during their propagation and to determine the appropriate parameters for generating extreme waves in the laboratory. This study has been carried out in the Modeling and Simulation Laboratory, Department of Mathematics, Universitas Syiah Kuala, Indonesia in 2021.

MATERIALS AND METHODS

BBM Equation and wave group envelope

The Benjamin Bona Mahony (BBM) equation simulates one-way wave propagation with high wave numbers and low amplitudes. The energy formula takes using Eq. 1 (Benjamin *et al*., 1972).

$$\eta_t + \eta_x + \eta\eta_x - \eta_{xxt} = 0. \qquad (1)$$

It is assumed that ansatz is periodic, $\eta(x,t) = a(x,t)e^{i\theta} + c.c,$ as a solution to the Eq. 1, where $\theta = (kx - \omega t)$, $a(x,t)$ express the amplitude of the wave, *k* is the wavenumber, ω is the frequency of the wave, and c.c. declares complex comrade.

The envelope or curve of the energy wave amplitude evolves according to the NLS equation, allowing these equations to be used to analyze the propagation of the energy wave envelope. Spatial NLS equations can be used as a mathematical model to predict the evolution of the envelope in space. The reduction in the BBM equation's spatial NLS equation is expressed using Eq. 2 (Slunyaev *et al.*, 2015).

$$A_{\xi} + i\hat{\beta}A_{\tau\tau} + \hat{\gamma}|A|^2 A = 0, \tag{2}$$

where, A express the envelope amplitude, dispersive coefficient $\hat{\beta} = -\left(2\omega p + \frac{\grave{u}^2}{k}\right)/p^3$, nonlinear coefficient $\hat{\gamma} = \omega\left(\frac{2}{p-1} - \frac{k}{8k^2\omega + 2\omega - 2k}\right)/p$ with $p = (1+2k\omega)/(1+k^2)$ through the multiple scale method (Halfiani *et al.*, 2017). Eq. (2) is obtained by applying the fast to slow variable transformation, where $\theta = (kx - \omega t)$ as fast variable and slow variable; $\xi = \varepsilon^2 x$, $\tau = \varepsilon(t - x/p)$, $a(x,t) = \varepsilon A(\xi,\tau)$. Independent variables ξ and τ express different meanings for different problems. In the case of dispersive waves, ξ describes spatial variables (space) and τ represents the time variable.

Spatial NLS is appropriate for problems involving wave signals as the initial signal on the wave marker to describe space propagation. The NLS equation has numerous solutions that describe various phenomena. Soliton on Finite Background (SFB) is one of many NLS exact solutions that can describe extreme wave events in a hydrodynamics laboratory (Karjanto *et al.*, 2007).

SFB with displaced variables

The SFB solution is a non-linear interaction of an amplitude monochromatic signal r_0, i.e. $r_0 e^{-i\gamma r_0^2 \tau}$, which is disturbed by a modulating wave with a small κ wavenumber interval and results in an instability that increases exponentially with the rate $\sigma(\kappa) = \kappa\sqrt{2r_0^2\beta\gamma - \beta^2\kappa^2}$. A signal of this type is known as a Benjamin Feir (BF) signal (Benjamin and Feir, 1967; Karjanto *et al.*, 2011). The SFB wave signal was chosen because it can be generated with moderate amplitude on the wavemaker. While the other solutions, Ma breather soliton (Mahato *et al*, 2021), Akhmediev breather soliton (González-Gaxiola and Biswas, 2018) and the rational solution, all solutions describe the finite background wave type, they are not suitable as wavemaker inputs in practice. The Ma soliton wave signal cannot be used because it requires a maximum amplitude as input to the wavemaker, and the rational solution is difficult to use because the rational wave signal has an infinite modulation period, or it is not periodic with respect to space or time (Karjanto, 2006). The SFB solution to the spatial NLS, using Eq. 3.

$$A(\xi,\tau) = A_{SFB}(\xi,\tau)\, r_0 e^{-i\gamma r_0^2 \xi}, \tag{3}$$

Where,

$$A_{SFB}(\xi,\tau) = \frac{(\hat{v}^2 - 1)\cosh(\sigma(v)\xi) + \sqrt{1 - \frac{\hat{v}^2}{2}}\cos(v\tau) - i\hat{v}\sqrt{2 - \hat{v}^2}\sinh(\sigma(v)\xi)}{\cosh(\sigma(v)\xi) - \sqrt{1 - \frac{\hat{v}^2}{2}}\cos(v\tau)}$$

and v states the modulation frequency, $\sigma(v) = v\sqrt{2r_0^2\hat{\beta}\hat{\gamma} - \hat{\beta}^2 v^2}$ and $\hat{v} = v/\left(r_0\sqrt{\hat{\gamma}/\hat{\beta}}\right)$.

Displaced phase-amplitude variables are the results of the transformation of SFB variables that were originally in real form into complex forms (van Groesen *et al.*, 2006). Its purpose is to investigate changes in amplitude in complex planes with phase that is solely dependent on position. This NLS solution is derived based on variational formula depends on phase ϕ. With (ξ,τ) = (0,0) as the maximum position and time (Fig. 1).

As a result of the change in phase with respect to position, the wavelength of the carrier waves from the wave group changes, and this becomes a driving force towards extreme waves. SFB form with displaced phase-amplitude variables is given using Eq. 4.

$$A(\xi,\tau) = A_0(\xi)F(\xi,\tau), \tag{4}$$

where, $F(\xi,\tau) = G(\xi,\tau)e^{i\phi(\xi,\tau)} - 1$, $\phi(\xi,\tau)$ as a

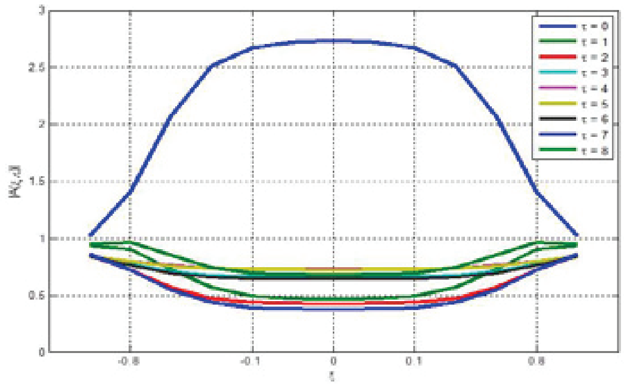
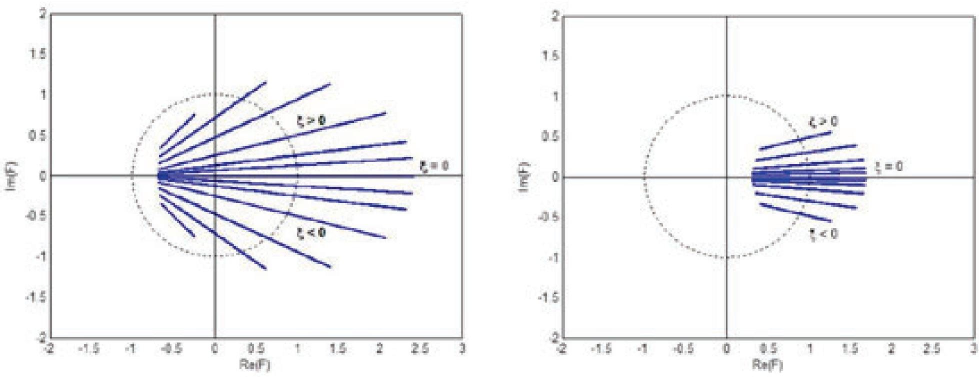


Fig. 1: Graph of envelope $|A_{SFB}|$ for $(\tilde{r}_0, \beta, \gamma, \tilde{\nu}) = (1,1,1, \sqrt{1/2})$ (Fadhiliani *et al.*, 2019)



(a) (b)

Fig. 2: Argand diagram SFB for $(\tilde{r}_0; \tilde{k}) = (0.2; 0.9186)$; (a) $\tilde{\nu} = 1$ and (b) $\tilde{\nu} = 1.3$ (Fadhiliani *et al.*, 2020)

replacement phase, and $G(\xi,\tau)$ as a replacement amplitude.

The phase singularity phenomenon can be proven by transforming the SFB variable into a complex form and presenting the results in an Argand diagram. When the modulation frequency is in the interval $\left[0, \sqrt{3/2}\right]$, the phenomenon of phase singularity occurs. This interval is represented by a straight line that passes through the origin twice (Fig. 2a). Meanwhile, for waves with modulation frequencies in the modulation instability $\left(0, \sqrt{2}\right)$ interval but not in the phase singularity interval, the straight line on the Argand diagram passes through the origin only once (Fig. 2b). A significant increase in amplitude is caused by modulation instability, which is a mechanism for extreme wave and phase singularity phenomena.

Hamiltonian formula

In Lagrangian form, the NLS equation is a dynamic system. The integral of the equation contains a large number of quantities. One of the quantities in question is Hamiltonian, but there is also wave energy, mass, or wave power in optics, as well as a conserved quantity known as momentum (linear). The equations for wave-ship interactions are based on the Lagrangian variational principle, which results in the combined system being formulated as a Hamiltonian system (van Groesen *et al.*, 2017). Because it contains potential energy and proves singularity for finite time in the NLS equation, the Hamiltonian plays a role in regulating phase amplitude dynamics.

The Hamiltonian is derived from the Lagragian according to the NLS equation which satisfies the evolution of the BBM wave envelope. The exact solution from NLS was chosen, namely SFB because it is able to explain the dynamics of wave propagation that have modulation instability and is suitable for input signals to wavemakers in the laboratory. The SFB transformation uses displaced variables so that they can be interpreted geometrically, and these variables are also used in Hamiltonian. The Hamiltonian for NLS, using Eq. 5.

$$H(A)=\int_{-\infty}^{\infty}\left(-\frac{1}{2}\beta|\partial_\tau A|^2+\frac{1}{4}\gamma|A|^4\right)d\tau, \qquad (5)$$

so that the Hamiltonian transformation $H(G,\phi)$ is obtained which contains the displaced phase-amplitude variable using Eq. 6.

$$H(G,\phi)=\int_{-T/2}^{T/2} \left(\begin{array}{l}-\frac{1}{2}\beta r_0^2\left[(\partial_\tau G)^2+G^2(\partial_\tau\phi)^2\right]\\ +\frac{1}{4}\gamma r_0^4\left(G(G-2\cos\phi)+1\right)^2\end{array}\right)d\tau. \qquad (6)$$

The Hamiltonian equation $H(G,\phi)$ containing the displaced phase-amplitude variable begins with the spatial NLS equation and is not time dependent. Because the Hamiltonian for this system is not time dependent, Hamiltonian represents total energy as the sum of kinetic and potential energies and that it is independent of time (Akhmediev *et al*., 1997; Eisberg and Resnick, 1985). The total energy is conserved and is the sum of the kinetic and potential energies. Hamiltonian provides a phase-space integrated solution that is good for equations of motion and can also be interpreted geometrically (Karjanto, 2006).

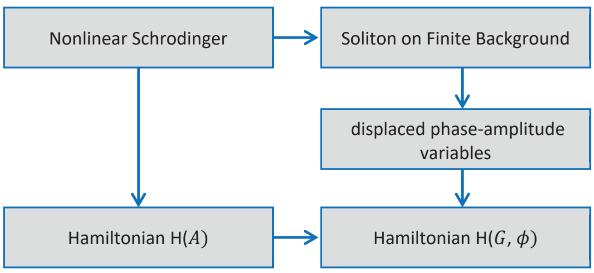
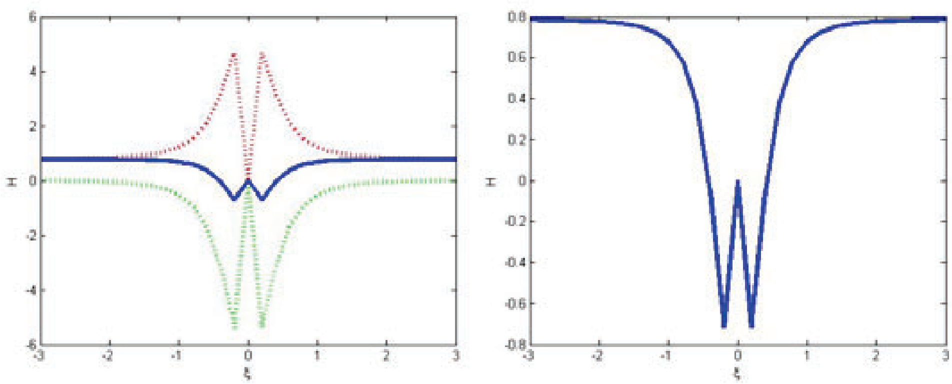


Fig. 3. Schematic diagram of methods

RESULTS AND DISCUSSION

The Hamiltonian function is used to investigate the distribution of BBM wave energy during its propagation. Because it contains potential energy, the Hamiltonian plays a role in regulating phase amplitude dynamics and also in proving singularity at finite time in the NLS-BBM equation. Previously, the Hamiltonian form $H(G,\phi)$ containing displaced phase-amplitude variables was obtained. Because the Hamiltonian for this system does not depend on time, it will be equal to the mechanical energy or total energy, which is the sum of the kinetic and potential energies. The variables and parameters considered are non-dimensional, so the presentation of figures does not use units.

The results for normalized conditions are presented visually in Fig. 4. The modulation frequency is $\tilde{\nu}=\sqrt{½}$ in the interval of modulation instability, and other parameters are 1. The red curve in Fig. 4 represents potential energy, the green curve represents kinetic energy, and the blue curve represents the Hamiltonian. It was found that the curve has symmetry with respect to position as shown



(a) (b)

Fig. 4: (a) Energy distribution and (b) Hamiltonian's curve for normalized $(\tilde{r}_0,\beta,\gamma,\tilde{\nu})=(1,1,1,\sqrt{½})$

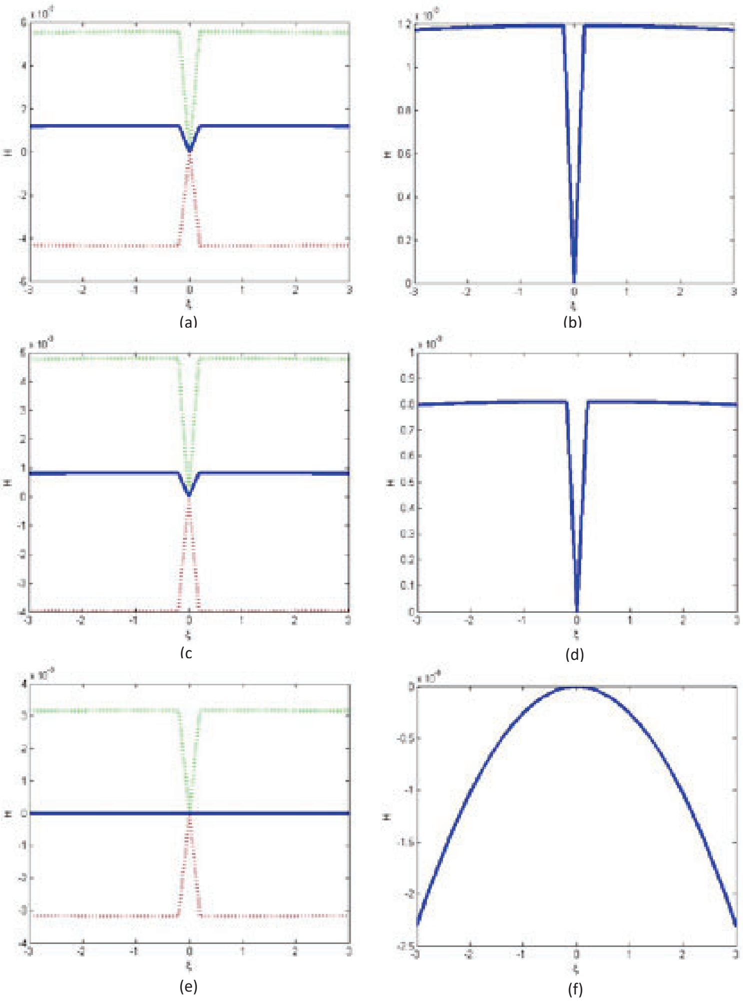


Fig. 5 : Energy distribution (left column) and Hamiltonian's curve (right column) for $(\tilde{r}_0;\tilde{k}) = (0.2;0.9186)$; (a) - (b) $\tilde{\nu}$ = 0.5, (c) – (d) $\tilde{\nu}$ = 0.7, and (e) – (f) $\tilde{\nu}$ = 1

in the graph of the envelope (Fig. 1). The resulting energy *H* has the same value on the negative and positive sides of the variable of position in space ξ. The shape of the symmetry is due to the symmetry envelope generated by the normalized frequency. This is an early sign that the distribution of wave energy in its propagation affects the amplitude and phase angle of the wave.

Fig. 5 contains the energy distribution and Hamiltonian curve for the modulating frequency at interval of the phase singularity phenomenon, it is $0 < \tilde{\nu} < \sqrt{3/2}$. In this frequency group, the curve also has a symmetrical shape with respect to position and has an optimum value when ξ = 0 according to the initial assumption. For modulation frequency $\tilde{\nu} = 0.5$ and $\tilde{\nu} = 0.7$, kinetic energy has a larger portion than potential energy, both are almost the same when the modulation frequency $\tilde{\nu} = 1$.

The energy distribution and Hamiltonian curves presented in Fig. 6 for the modulation frequency are outside the phase singularity interval but in the modulation instability interval, ie $0 < \tilde{\nu} < \sqrt{2}$. The curve has a symmetrical shape with respect to position and peak occurs when v. Potential energy has a larger portion than kinetic energy when the modulation frequency $\tilde{\nu} = 1.3$ and $\tilde{\nu} = 1.4$, but is not greater than the potential energy in the wave with less frequency.

Potential energy is energy related to position due to the influence of gravity. When viewed physically in the study of surface water waves, potential energy is

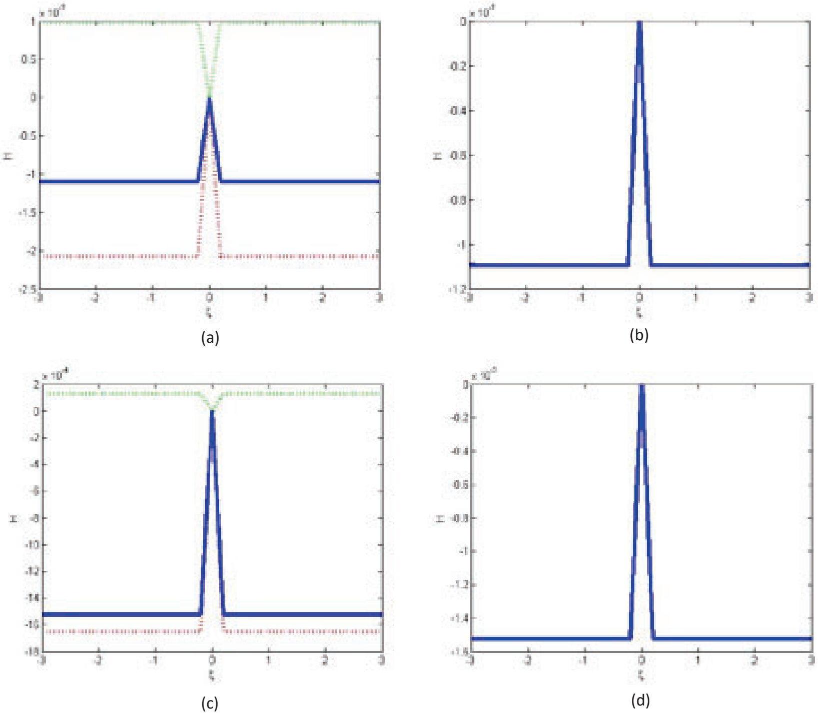


Fig. 6 : Energy distribution (left column) and Hamiltonian's curve (right column) for $(\tilde{r}_0;\tilde{k})=(0.2;0.9186)$; (a) - (b) $\tilde{\nu}$ = 1.3 and (c) – (d) 1.4

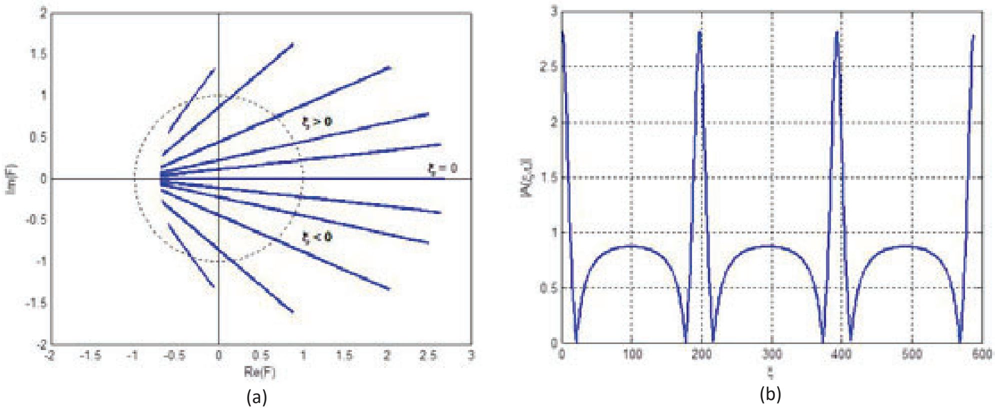


Fig. 7 : (a) Argand diagram and (b) envelope, for $(\tilde{r}_0;\tilde{k};\tilde{\nu})=(0.2;0.9186;0.5)$

related to the wave amplitude. On the other hand, there is kinetic energy related to the wave motion to reach a certain speed and physically related to the steepness of the wave. Based on Figs. 5 and 6, the largest potential energy and kinetic energy are in the wave with the modulation frequency $\tilde{\nu}=0.5$ which is the smallest modulation frequency in this study.

The wave amplitude for the modulating frequency $\tilde{\nu}=0.5$ is shown by the envelope curve (Fig. 7). The amplitude for that frequency has a greater value than the wave amplitude at other modulating frequencies. Meanwhile, the phase angle with the same modulation frequency is shown through the Argand diagram (Fig. 7a) and is found to have a greater value than the phase angle at other modulating frequencies (the envelope curve and Argand diagrams for other frequencies can be seen in Figs. 1 and 2). Thus, it is obtained that the amplitude will be smaller for the greater the modulation frequency. Similarly, the phase angle will be smaller for the greater the modulation frequency and the greater the phase angle, the steeper the wave will be. The generated wave (extreme) is a high wave and not broken. The use of a smaller modulation frequency seems to have to be decided with great consideration. High waves are needed to test the durability of the model ship in the test pool, but breaking waves should be avoided because they can damage laboratory facilities. More detailed observations are needed to see how the energy distribution relates to other parameters. They are wave number and initial amplitude in order to determine the combination of parameters to be used in order to obtain a wave with a maximum height and can maintain its shape.

CONCLUSION

The distribution of energy in wave propagation is studied to complete information about the wave characteristics that will be used as the initial signal input to the wavemaker. The characteristics of the waves that have been obtained are used to decide whether certain mathematical models in this case BBM are suitable to be applied in the hydrodynamics laboratory in order to obtain extreme waves or at least approach them with all their limitations. This study simply computes some signal input modulation frequency in wave generation. This is for efficient use of the laboratory, avoiding the practice of trial and error. Based on the information that has been obtained previously, that the BBM wave experiences modulation instability for the modulation frequency at intervals of $0<\tilde{\nu}<\sqrt{2}$ which causes amplitude amplification. Then the phase singularity phenomenon also appears in wave propagation which gives a significant increase in amplitude for the modulation frequency interval $0<\tilde{\nu}<\sqrt{3/2}$). It is interesting to see the energy distribution of the BBM wave in the modulation frequency interval. Singularities and energy distributions can be described by the Hamiltonian. The Hamiltonian used contains displaced-phase amplitude in a complex plane with a phase that only depends on position, so that the Hamiltonian will be equal to the total energy which is the sum of the potential energy and kinetic energy. The modulation frequency considered as an extreme wave generator is $\tilde{\nu}=0.5$, because the resulting amplitude is quite high and the energy in the envelope is also quite large. Hamiltonian curve is symmetrical with respect to position. The modulation frequency affects the amount of energy that participates in wave propagation. The smaller the modulation frequency, the greater the potential energy and kinetic energy. Potential energy is related to the amplitude and kinetic energy is related to the steepness of the wave so that the amplitude and steepness of the wave will be maximum for small modulating frequencies. In practice, even if a wave with a maximum amplitude is desired, the selection of a smaller modulation frequency must be considered because it will have an impact on the steepness of the resulting wave. Other parameters, namely wave number and initial amplitude, are limitations in this paper, so it can be a concern to get closer to the goal of extreme waves in the laboratory.

AUTHOR CONTRIBUTIONS

D. Fadhiliani 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 the manuscript text, and manuscript edition. M. Ramli performed the literature review, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. S. Rizal performed the literature review, prepared the manuscript text, and manuscript edition. M. Shafwan performed the literature review, prepared the manuscript text, and manuscript edition.

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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.

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ABBREVIATIONS

A	Equation of envelope amplitude
$\|A\|$	Modulus of complex number A
A_0	Plane wave solution of the NLS equation
a	Equation of amplitude
BBM	Benjamin Bona Mahony
BF	Benjamin Feir
β	Dispersion coefficient of the NLS equation
$\hat{\beta}$	Dispersion coefficient of the NLS Spatial equation
$c.c.$	Conjugate complex
Eq.	Equation
e	Euler's Number, $e = 2,71828\ldots$
ε	Small positive real number parameter
η	Wave elevation
F	Complex amplitude of waves on finite background
Fig.	Figure
G	Real-valued displaced amplitude
γ	Nonlinear coefficient of the NLS equation
$\hat{\gamma}$	Nonlinear coefficient of the NLS spatial equation
H	Hamiltonian
i	Imaginary number, $i = \sqrt{-1}$
KdV	Koerteweg de Vries
κ	Modulation wavenumber
k	Dimensionless wave number
$\tilde{k}$	Dimensional wavenumber
NLS	Nonlinear Schrödinger
ν	Modulation frequency
$\hat{\nu}$	Normalized ν
$\tilde{\nu}$	Dimensional modulation frequency
ω	Dimensionless wave frequency;
$\tilde{\omega}$	Dimensional wave frequency
p	Phase of carrier wave
ϕ	Displaced phase
r_0	The initial amplitude of the dimensionless wave
$\tilde{r}_0$	The initial amplitude of the dimension wave
σ	Instability level
SFB	Soliton on Finite Background
T	Period
t	Time variable
τ	Time slow variable
θ	Phase of monochromatic wave
x	Spatial variables
ξ	Spatial slow variable

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ORIGINAL RESEARCH PAPER

Forecasting particulate matter concentration using nonlinear autoregression with exogenous input model

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ABSTRACT

BACKGROUND AND OBJECTIVES: Air quality in some developing countries is dominated by particulate matter, especially those with size 10 micrometers and smaller or PM_{10}. They can be inhaled and sometimes can get deep into lungs; some may even get into bloodstream and cause serious health problems. Therefore, future PM_{10} concentration forecasting is important for early prevention and in urban development planning, which is crucial for developing cities. This paper presents the development of PM_{10} forecasting model using nonlinear autoregressive with exogenous input model.
METHODS: To improve performance of nonlinear autoregressive with exogenous input model, principal component analysis is used prior to the model for variable selection. The first stage of principal component analysis involves Scree plot, which determines the number of principal components based on explained variance. This is then followed by selecting variables using a rotated component matrix, based on their strength of contribution towards variation of PM_{10} concentration. To test the model, PM_{10} data in Kota Kinabalu from 2003 – 2010 was used. Neural network models are developed using this data by varying number of input variables with the inclusion of temporal variables. The developed forecasting models are evaluated using data PM_{10} in the city from 2011 to 2012. Four performance indicators, namely root mean square error, mean absolute error, index of agreement and fractional bias are reported.
FINDINGS: Results from principal component analysis show that five variables including wind direction index, relative humidity, ambient temperature, concentration of nitrogen dioxide and concentration of ozone strongly contribute to the variation of PM_{10} concentration. By using these variables together with temporal variables as input in the nonlinear autoregressive with exogenous input models, the resultant model shows good forecasting performance, with root mean square error of 7.086±0.873 μg/m^3. The selection of significant variables helps in reducing input variables inside the forecast model without degrading its forecast performance.
CONCLUSION: This model shows very promising performance in forecasting PM_{10} concentration in Kota Kinabalu as it requires fewer input variables and does not require variable transformation.

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INTRODUCTION

Particulate matter (PM) is one of the components that causes air pollution, along with other gaseous pollutants. In urban areas, substances such as metals, elemental carbon and organic matters make up PM, which can enter human respiratory system and causes various health problems depending on its size and composition (Kim *et al.*, 2015; Ul-Saufie *et al.*, 2013). The health effect is more apparent on children and infants compared to other age groups (Karri *et al.*, 2018). Due to negative health effects of PM_{10}, it has received much attention from scientific community in recent years. PM_{10} is constantly monitored around the world. In Malaysia, more than 50 air quality monitoring stations across the country collect and store hourly meteorological and air pollutant data, including PM_{10} under Continuous Air Quality Monitoring (CAQM) network (Dominick *et al.*, 2012). These stations are operated by Alam Sekitar Sdn. Bhd., under administration of Department of Environment (DOE). While Kota Kinabalu is continuously developing, public transportation is still poor in terms of efficiency, reliability, safety and availability (Besar *et al.*, 2020). Many commuters prefer private vehicles rather than public transportation, which consequently causes traffic congestion, especially during peak hours. High traffic density, especially in commercial areas, lead to high emission of air pollutant, mainly PM_{10} (Ul-Saufie *et al.*, 2013). Local authorities are required to manage public transportation and infrastructure in Kota Kinabalu. Furthermore, Kota Kinabalu is a developing city as certain roads and housing areas are currently under development in most areas. Therefore, it is essential to study the long-term forecast model. The forecasting and prediction model is developed as early preventive measures to curb negative impacts of PM_{10} on health, environment, and economy. Many statistical approaches have been employed in developing PM_{10} forecasting and prediction model. The most widely used method in model development is regression analysis, particularly the multiple linear regression (MLR) (Abdullah *et al.*, 2016; Özbay *et al.*, 2011; Ul-Saufie *et al.*, 2013). MLR is relatively simple and does not require data from past research (Shahraiyni and Sodoudi, 2016). Despite the popularity, MLR suffers high multicollinearity in which the predictor variables are highly correlated towards each other (Abdul Wahab *et al.*, 2005). Principal component regression (PCR) solves the problem by applying principal component analysis (PCA) before MLR (Gvozdić *et al.*, 2011). This is because PCA converts original predictor variables into principal components (PCs), reducing dimensionality in the process (Polat and Gunay, 2015). PCR is best suited for linear systems (Shahraiyni and Sodoudi, 2016). This does not consider non-linear relationship such as the behaviour of PM_{10} at different humidity levels (Lou *et al.*, 2017). To consider non-linear relationship involving PM_{10} concentration, artificial neural network (ANN) is applied in developing PM_{10} concentration forecast model. ANN is a machine learning technique for model development inspired by biological neural network (Franceschi *et al.*, 2018). Just like the human brain, ANN obtains relationship between input and output variables based on available data (Arhami *et al.*, 2013). Artificial neurons in ANN are connected by synaptic weights. Data propagates through neurons by passing through summation of input-weight product and activation function (Elangasinghe *et al.*, 2014), as shown in Fig. 1.

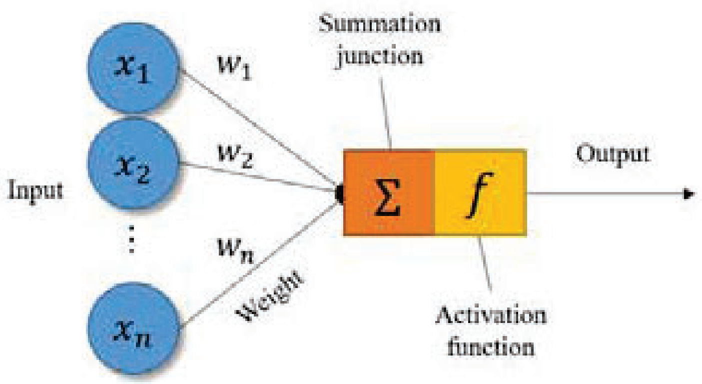


Fig 1: Basic parts of artificial neuron
(Ul-Saufie *et al.*, 2013)

Table 1: Several PM_{10} concentration prediction research using ANN model in Malaysia from 2011

Author (Year)	Study area	Best development method	RMSE (µg/m³)
Ul Saufie *et al.* (2011)	Seberang Perai, Pulau Pinang	FFBP	8.369
Ul-Saufie *et al.* (2013)	Nilai, Negeri Sembilan	PCA-ANN and PCA-MLR	18.269
Ul-Saufie *et al.* (2015)	Seberang Perai, Pulau Pinang	FFBP	18.823
Abdullah *et al.* (2018)	Pasir Gudang, Johor	RBF with spread number of 0.3 and 12 hidden neurons	41.067
Abdullah *et al.* (2019)	Kuantan, Pahang	MLP	5.580

Several studies had focused on building and evaluating models to predict PM_{10} concentration in Malaysia, especifically in Peninsular Malaysia. Some of the predictions include long-term and short-term forecasting. Usage of ANN in these studies is more embraced in PM_{10} concentration forecast studies. Ul-Saufie *et al.,* (2011) studied on developing a prediction model of PM_{10} concentration in Seberang Perai, Pulau Pinang using MLR and feedforward backpropagation (FFBP) neural network. The prediction result showed that the FFBP neural network outperforms MLR due to lower RMSE of the FFBP neural network (8.369 µg/m3) compared to the MLR model (9.938 µg/m³). Ul-Saufie *et al.,* (2013) then conducted another study on developing daily PM_{10} concentration prediction for Nilai, Negeri Sembilan. Prediction models are developed using MLR and ANN, as well as incorporating both methods with PCA. The result showed that models that incorporate PCA have the best prediction performance, with PCA-ANN having the lowest RMSE for next day prediction (11.1071 µg/m³) and PCA-MLR having the lowest RMSE for the next two-day (RMSE = 14.4758 µg/m³) and three-day prediction (RMSE = 18.2686 µg/m³). Then, another study conducted by Ul-Saufie *et al.,* (2015) compared the performance of FFBP neural network and general regression neural network (GRNN) in predicting hourly PM_{10} concentration for the next three days in Seberang Jaya, a suburban located in Pulau Pinang. It is proven that FFBP generally performed better than GRNN in predicting the next three days of PM_{10} concentration. Abdullah *et al.,* (2018) developed a daily PM_{10} concentration forecast model for monitoring stations in Pasir Gudang, Johor using the radial basis function (RBF) model. While RBF model shows good performance during training, its performance significantly plummets during testing. In the following year, Abdullah *et al.* (2019) conducted another study developing a PM10 concentration forecast model in Kuantan, Pahang using the multilayer perceptron (MLP) model, with varying numbers of neurons in the hidden layer and activation function. Although studies on predicting future PM_{10} concentration in Malaysia was conducted extensively in the past years, the development and evaluation of models have not been conducted in Sabah yet. Table 1 presents several PM_{10} concentration prediction research using ANN model in Malaysia up to 2011.

This study aims to present performance evaluation results for forecast model of PM_{10} concentration in Kota Kinabalu, Sabah in Malaysia. $PM_{2.5}$ is not focused in this study as monitoring stations across Malaysia do not measure $PM_{2.5}$ concentration as of the year 2012. Nonlinear autoregressive with exogenous input (NARX) network was used in several studies in forecasting future PM_{10} concentration data with various sets of inputs (Abdulkadir and Yong, 2014; Saxena and Mathur, 2017; Vijayaraghavan and Mohan, 2016). Due to its performance, NARX network was used in this study. Models were tested for forecasting performance with different sets of input variables along with principal component analysis (PCA) as the accompanying method. This study was carried out in monitoring station in Kota Kinabalu of Malaysia in 2020.

MATERIALS AND METHODS

Study area and location

Kota Kinabalu (5.98°N, 116.07°E) is the capital city of Sabah, located at west coast of North Borneo at an altitude of 13 m above sea level, as shown in its map location in Fig. 2. Based on Köppen climate classification, Kota Kinabalu is categorized under tropical rainforest climate (Chang *et al.*, 2018). Kota Kinabalu experiences a hot and humid climate and seasonal circulation of monsoons (Djamila *et al.*, 2011). It is the busiest cities in Sabah as activities such as industry, trading and tourism are concentrated

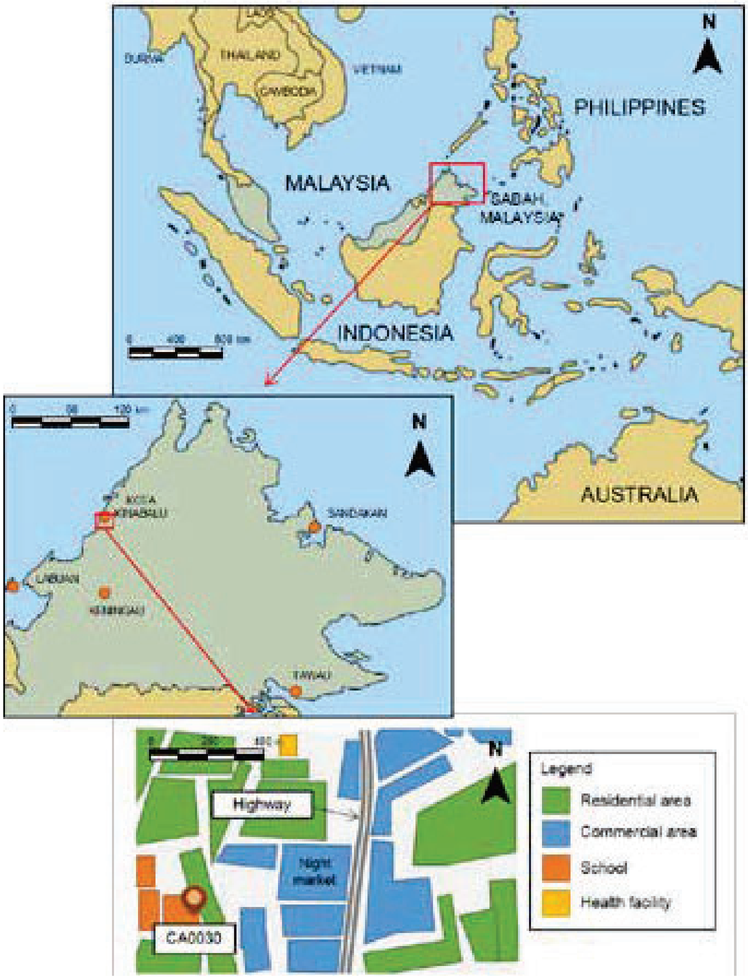


Fig. 2: Geographic location of the study area in Kota Kinabalu, Malaysia

here (Noor *et al.*, 2014). CA0030 is located in Putatan district, 10 km away from Kota Kinabalu city. Several buildings and infrastructure such as night markets and highway are the possible sources of PM_{10} measured by CA0030.

One of the monitoring stations in CAQM network, namely CA0030, collects meteorological and air pollutant data in Kota Kinabalu. CA0030 is located in the vicinity of SMK Putatan, approximately 10 km from Kota Kinabalu. This monitoring station collects four meteorological parameters namely wind speed (WS), wind direction (WD), relative humidity (RH) and ambient temperature (Temp). It also collects five concentrations of air pollutants which are carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and PM_{10}. These data are collected at 1-hour interval. 10-year data ranging from 2003 to 2012 were used in this study. Table 2 highlights the descriptive statistics of the PM_{10} data used.

Table 2: Descriptive statistics of PM_{10} concentration in Kota Kinabalu from 2003 to 2012

Descriptive statistics	Values
Mean (μg/m^3)	35.90
Standard Deviation (μg/m^3)	19.10
Skewness	2.32
Kurtosis	16.59
Minimum (μg/m^3)	5
Maximum (μg/m^3)	495
1st Quartile (μg/m^3)	24
Median (μg/m^3)	33
3rd Quartile (μg/m^3)	42

Data preparation

Pre-processing of data is required before it is applied for any calculation or forecast modelling. The pre-processing work includes converting WD to wind direction index (WDI), converting hourly data to daily data, adding day of year (DOY) and month of year (MOY), and removing missing data. Raw data includes WD has discontinuity at 360°. The magnitude of wind direction does not reflect strength of wind itself. To remove discontinuity at 360°, WD was converted into a new variable namely WDI. WD was converted using Eqs. 1 and 2 (Vlachogianni *et al.*, 2011):

$$WDI = 1 + \sin\left(WD - \varphi\right) \quad (1)$$

$$\varphi = WD_{max} - 90° \quad (2)$$

WD_{max} in Eq. 2 represents wind direction at maximum PM_{10} concentration, while ö in Eq. 1 is the angle shift caused by WD_{max}. Both values can be obtained from polar plot of PM_{10} concentration against wind direction. Average values of PM_{10} concentration for every direction of 16 wind compass points are used for polar plots. Long-term forecasting model is defined as a model that uses dataset with temporal resolution of at least one day (Shahraiyni and Sodoudi, 2016). To develop the model for PM_{10} concentration, dataset obtained from the monitoring station was converted from hourly to daily temporal resolution. Arithmetic mean was used as 24-hour average value for all variables. As for WD, the average value was calculated using circular mean, which can be calculated using Eq. 3. “atan2” is a MATLAB function that returns the value ranging from 0° to 360°. This function is different from inverse tangent which only returns values in quadrant I (angles below 90°) and IV (angles above 270°). To preserve variation of WDI dataset, Eq. 3 was applied before WD is converted into WDI. 24 h dataset that consists of only missingness (CAL or N/A) is denoted as missing daily data.

$$WD_{daily} = \text{atan2}\left(\frac{1}{n}\sum\nolimits_{i=1}^{n} \sin WD_i, \frac{1}{n}\sum\nolimits_{i=1}^{n} \cos WD_i\right) \quad (3)$$

PM_{10} concentration in Kota Kinabalu exhibits daily and yearly variations (Muhammad Izzuddin *et al.*, 2019). In order to take temporal variations into account, temporal variables such as day of year (DOY) and month of year (MOY) are introduced. Temporal variables are calculated using Eqs. 4 and 5, where d_{th} represents integer day in a year, T represents number of days in a year, and m_{th} represents integer month in a year. For example, 1^{st} February is represented by d_{th} = 32 and m_{th} = 2. Study by Arhami *et al.* (2013) claimed that the consideration of temporal variables improves forecast performance of model.

$$DOY = \cos\left(\frac{2\pi d_{th}}{T}\right) \quad (4)$$

$$MOY = \cos\left(\frac{2\pi m_{th}}{12}\right) \quad (5)$$

Missing data leads to error in estimation during forecasting PM_{10} concentration (Cabaneros *et al.*, 2017). Previous studies showed that nearest neighbour method (NNM) imputes data with better performance compared to expectation-maximization (EM) algorithm (Muhammad Izzuddin *et al.*, 2020). This method applies for Fourier analysis which requires continuous stream of dataset. In this study, missingness is removed instead in forecast model development as data imputation may distort variation and correlation when used incorrectly (Graham, 2009). Exclusion of missingness is appropriate as only 6% of data are missing.

Principal component analysis (PCA)

Principal component analysis (PCA) is an assisting method in time series forecasting that transforms input variables X into a new set of variables known as principal components (PCs) (Gvozdić *et al.*, 2011). PCA accompanies ANN by reducing the complexity of the neural network model by determining relevant inputs in forecasting future PM_{10} concentration (Ul-Saufie *et al.*, 2013). Several studies show that PCA improves forecasting performance of ANN model (Azid *et al.*, 2014; Cabaneros *et al.*, 2017; Ul-Saufie *et al.*, 2013; Voukantsis *et al.*, 2011). PCA converts input variables into PCs by evaluating loading factor l in a way that every PCs are orthogonal to each other (Ul-Saufie *et al.*, 2013). The relationship between X, l and PC is given in Eq. 6 (Dominick *et al.*, 2012).

$$PC_i = \sum_{j=1}^{n} l_{ji} X_i \quad (6)$$

In this paper, PCA was executed using SPSS software version 25.0. Dataset consisting of meteorological variables (WS, WDI, RH, Temp) and air pollutant variables (CO, NO, O_3, SO_2) are fed into PCA. PM_{10} is not included in PCA as only input variables are considered in the selection of variables (Gvozdić *et al.*, 2011). Apart from loading factor 1 in the form of component matrix, PCA produces eigenvalue that describes the significance of each of the PCs towards PM_{10} concentration. Eigenvalue is plotted against respective PCs in Scree plot along with Kaiser criterion which states that only eigenvalue above 1 is selected (Azid *et al.*, 2014). Kaiser criterion implies that the variation of such PCs is considered to be significant (Franceschi *et al.*, 2018). The component matrix contains factor loadings describes the strength of variables in contribution towards variation of certain PCs (Dominick *et al.*, 2012). To better interpret factor loadings in this component matrix, Varimax rotation is applied to convert the loading factor to Varimax factors (VF) by raising the value of more significant loadings and lowering the value of smaller loadings (Azid *et al.*, 2014). The VFs reflect the strength of the contribution of a variable towards particular PCs and similarity of one variable towards the other (Voukantsis *et al.*, 2011). A variable has strong contribution when its VF has value larger than 0.75, moderate for 0.50 – 0.75, and weak for 0.30 – 0.49 (Dominick *et al.*, 2012).

Development of ANN model

Nonlinear autoregression with exogenous input (NARX) is a type of neural network model that falls under recurrent neural network (RC-NN), whose signal is processed via feedforward and is back-propagated into input level (Biancofiore *et al.*, 2017). NARX is used in air quality forecast research by using observed values from the past to predict PM_{10} concentration data in several time steps ahead (Vijayaraghavan and Mohan, 2016). Exogenous input in NARX model is fed with observed values of meteorological and air pollutant data. Previous research study has shown that NARX model has better forecasting performance of PM_{10} concentration compared to other models such as feed-forward (FF) neural network. NARX model is employed in developing forecast model in this research and its topology is illustrated in Fig. 3, where X represents exogenous input and Y represents PM_{10} concentration data. NARX has a feedback loop which sends output data back to input level. A variation of NARX model is known as nonlinear autoregression (NAR), in which the forecasting of PM_{10} concentration data depends only on past values of itself (Potdar and Pardawala, 2017).

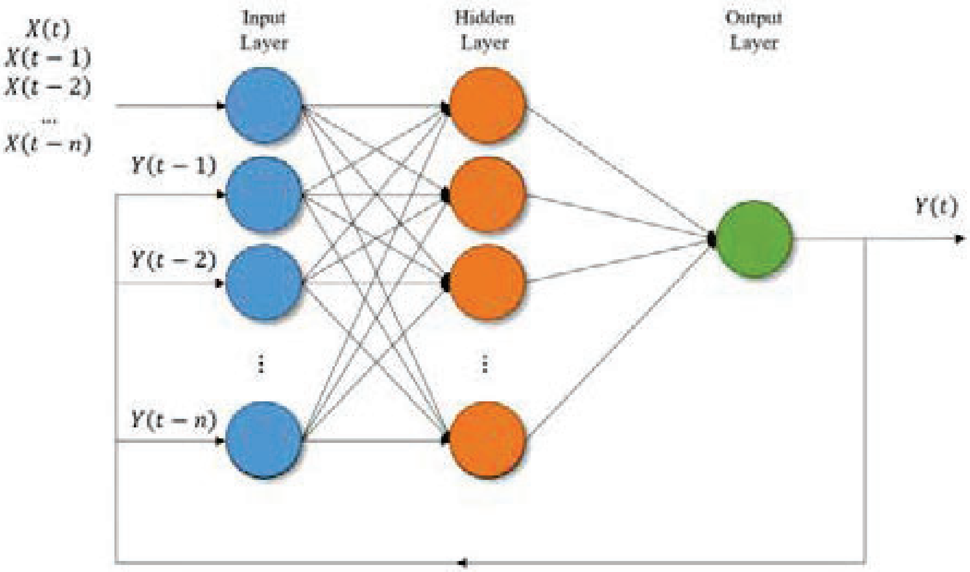


Fig. 3: NARX neural network architecture
(Abdulkadir and Yong, 2014)

Dataset from 2003 to 2010 (8-year data) are used to develop open-loop NAR and NARX models using MATLAB version 2018b. The 8-year data is further divided into 3 smaller sets which are training set (70% of 8-year dataset), validation set (15%) and testing set (15%). The proportion is MATLAB default setting and has been used in several previous studies (Cabaneros *et al.*, 2017; Ceylan and Bulkan, 2018; Feng *et al.*, 2015; Shekarrizfard *et al.*, 2012). Neurons at hidden and output layers have their activation function set as tansig (hyperbolic tangent) and purelin (identity linear), respectively. Hidden layer uses tansig as activation function because it can produce normalized values at both positive and negative ranges (Ul-Saufie *et al.*, 2013). As for the output layer, purelin activation function is used to optimize model performance (Wu *et al.*, 2019). NAR and NARX models are trained using Levenberg-Marquardt (LM) algorithm because it trains model at relatively short amount of time and guarantees convergence (Yu and Wilamowski, 2016). A total of 10 forecast models are developed to forecast PM_{10} concentration data from 2011 to 2012 (2 years of data), by varying inputs (U, M, G, P and S) in 5 ways and include or exclude temporal variables (MOY and DOY) for each way. U (univariate) model uses only PM_{10} concentration as inputs. M (meteorological) model includes four meteorological variables (WS, WD, RH, Temp) along with PM_{10} concentration data. G (gaseous) model further adds four air pollutant concentration variables (CO, NO_2, O_3, SO_2) along with meteorological variables and PM_{10} concentration. P (principal component) model uses PC scores obtained from PCA as inputs instead of original variables. Finally, S (selection) model uses only certain original variables selected by Scree plot and rotated component matrix. These models are labelled by two characters, in which the first character denotes variables used as neural network model inputs (U, M, G, P and S) and second character denotes inclusion of temporal variables as inputs (0: exclude temporal variables, 1: include temporal variables). 10 replicates shown in Table 3 together with their properties were developed for each model to verify their stability. N_s (number of selected variables) is used in Table 3 because it depends on result from rotated component matrix. The number

Table 3: List of developed forecast models

Model	Number of external inputs	Inclusion of temporal variables	Network type	Number of hidden neurons
U0	0	No	NAR	1
U1	2	Yes	NARX	5
M0	4	No	NARX	9
M1	6	Yes	NARX	13
G0	8	No	NARX	17
G1	10	Yes	NARX	21
P0	8	No	NARX	17
P1	10	Yes	NARX	21
S0	N_s	No	NARX	$2N_s + 1$
S1	$N_s + 2$	Yes	NARX	$2N_s + 5$

Table 4: Input variables for development of forecast models

Model	Input variables
U0	PM_{10}
U1	PM_{10}, MOY, DOY
M0	PM_{10}, WS, WDI, RH, Temp
M1	PM_{10}, WS, WDI, RH, Temp, MOY, DOY
G0	PM_{10}, WS, WDI, RH, Temp, CO, NO_2, O_3, SO_2
G1	PM_{10}, WS, WDI, RH, Temp, CO, NO_2, O_3, SO_2, MOY, DOY
P0	PM_{10}, PC_1, PC_2, PC_3, PC_4, …, PC_8
P1	PM_{10}, PC_1, PC_2, PC_3, PC_4, …, PC_8, MOY, DOY
S0	Significant variables from PCA
S1	Significant variables from PCA, MOY, DOY

of hidden neurons is set as 2N + 1 (N represents number of external inputs) following the study by Cabaneros *et al.* (2017) because it does not require determination of number of hidden neurons. The input variables for each model are listed in Table 4.

Evaluation of NAR and NARX models

To assess the forecast performance of NAR and NARX models, a set of performance indicators are used, namely root mean square error (RMSE), mean absolute error (MAE), index of agreement (IA) and fractional bias (FB). RMSE and MAE indicates accuracy of forecast model and are frequently used in many studies (Antanasijević *et al.*, 2013; Díaz-Robles *et al.*, 2008; Feng *et al.*, 2015; Grivas and Chaloulakou, 2006; Paschalidou *et al.*, 2011; Wu *et al.*, 2019). Both RMSE and MAE show better accuracy as their values approach zero. While RMSE tends to change with frequency distribution of error, MAE only depends on average magnitude of error (Willmott and Matsuura, 2005). IA expresses the difference between predicted and observed values, indicating the agreement of both datasets as the name suggests (Fan *et al.*, 2013). IA ranges from 0 to 1 with better agreement indicated by higher performance. FB indicates underestimation and overestimation of forecast model (Biancofiore *et al.*, 2017). FB ranges between -2 to 2 where the boundary levels indicate extreme underestimation and overestimation respectively. These four performance indicators are evaluated using Eqs. 7 to 10, where P denotes forecasted value and O indicates observed value. Both $\bar{P}$ and $\bar{O}$ are mean values of forecasted and observed values, respectively.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O_i - P_i\right)^2} \quad (7)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|O_i - P_i\right| \quad (8)$$

$$IA = 1 - \frac{\sum_{i=1}^{n}\left(O_i - P_i\right)^2}{\sum_{i=1}^{n}\left(\left|O_i - \bar{O}\right| + \left|P_i - \bar{O}\right|\right)^2} \quad (9)$$

$$FB = \frac{2\left(\bar{P} - \bar{O}\right)}{\bar{P} + \bar{O}} \quad (10)$$

RESULTS AND DISCUSSION

Principal component analysis (PCA)

Eigenvalue is plotted as a function of PC in Scree plot as shown in Fig. 4. Red dashed line represents Kaiser's criterion, implying that only PCs with eigenvalues above this line are selected. Based on Fig. 4, the first three PCs were selected as their eigenvalues are above 1. Other principal components are neglected because of their eigenvalues below 1, implying redundancy with less important factors (Azid *et al.*, 2014).

Selected PCs then undergo Varimax rotation, in which factor loadings are converted into VF (Table 5). VFs with magnitude exceeding 0.75 and corresponding variables are highlighted in bold. The variables that

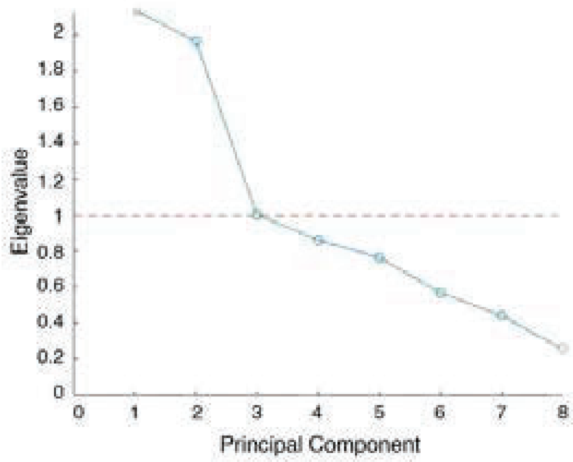


Fig. 4: Scree plot for PCA in CA0030

have VF above 0.75 in one of the PCs are WDI, RH, Temp, NO_2 and O_3, which becomes inputs for S models in neural network model. VFs with higher value imply that these variables have strong contribution towards variability of PM_{10} concentration for CA0030.

The first PC (PC_1) account for 26.70% of the total variation of PM_{10} concentration. It can be seen from Table 5 that O_3 concentration and ambient temperature (Temp in Table 5) shows strong positive contribution while relative humidity shows strong negative contribution towards PM_{10} concentration. This is closely correlated with meteorological condition in Kota Kinabalu. PM_{10} absorbs water vapour and becomes too heavy to stay suspended at high humidity level (Munir *et al*., 2017), which is a normal condition at Kota Kinabalu. PM_{10} gains kinetic energy from heat to stay airborne, which explains the strong positive contribution in ambient temperature (Temp). Furthermore, abundance in solar radiation is received by Kota Kinabalu, ranging between 278.52 W/m^2 and 407.89 W/m^2 (Teong *et al*., 2017). This induces generation of ground level O_3 (Xie *et al*., 2015). High concentration of both O_3 and PM_{10} occur simultaneously during hot climate, which leads to strong positive contribution in O_3 concentration. PC_2 is related to motor vehicle emission and account for 24.57% of the total variation for PM_{10} concentration. In this PC_2, NO_2 concentration shows strong positive contribution while CO concentration shows moderate positive contribution, with VF of 0.648. This is because PM_{10} often accompanies NO_2 and CO as by-product of incomplete combustion by motor vehicles (Xie *et al*.,

Table 5: Rotated component matrix in CA0030

Variables	PC_1	PC_2	PC_3
WS	0.281	-0.695	-0.006
WDI	-0.014	-0.023	**0.987**
RH	**-0.870**	0.040	0.011
Temp	**0.830**	0.190	-0.038
CO	0.143	0.648	0.083
NO_2	0.040	**0.832**	0.022
O_3	**0.767**	-0.103	0.026
SO_2	0.025	0.566	-0.143
Variance explained (%)	26.70	24.57	12.52

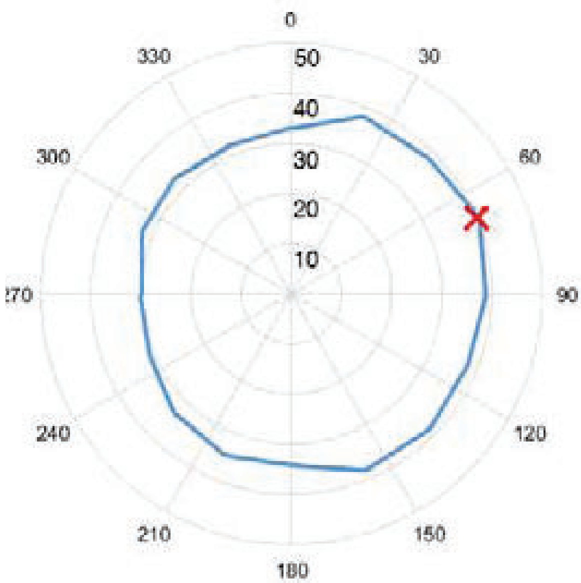
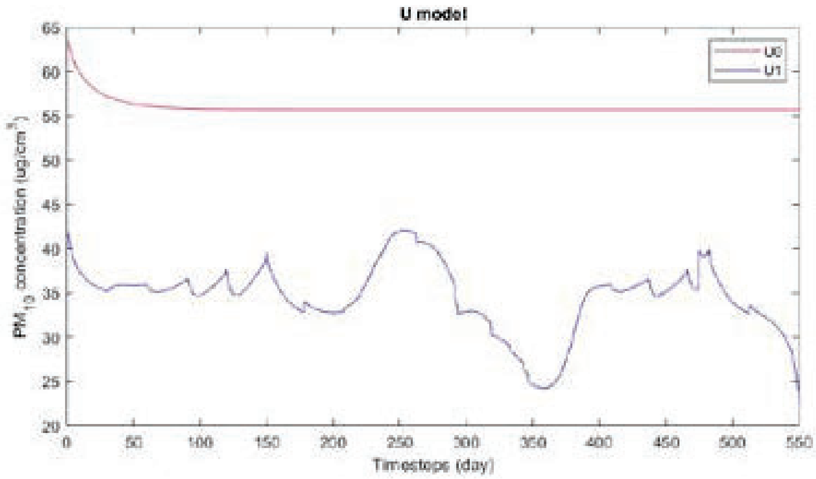


Fig. 5: Polar plot of PM_{10} concentration (radial axis) against WD (angular axis) for CA0030



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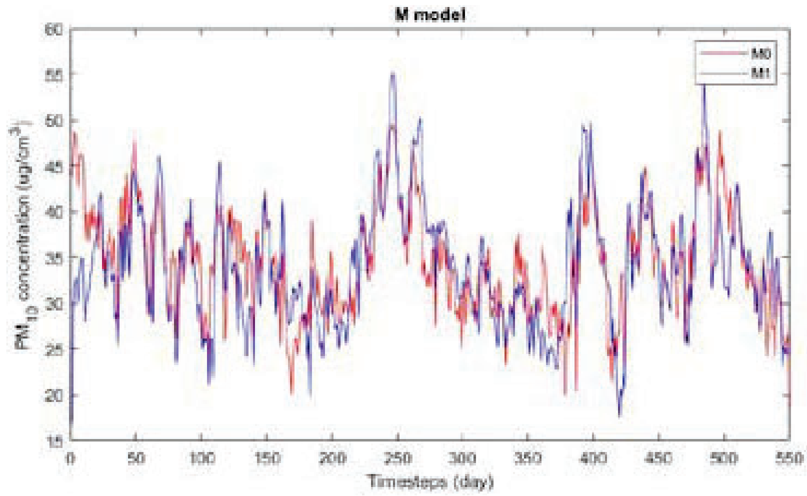

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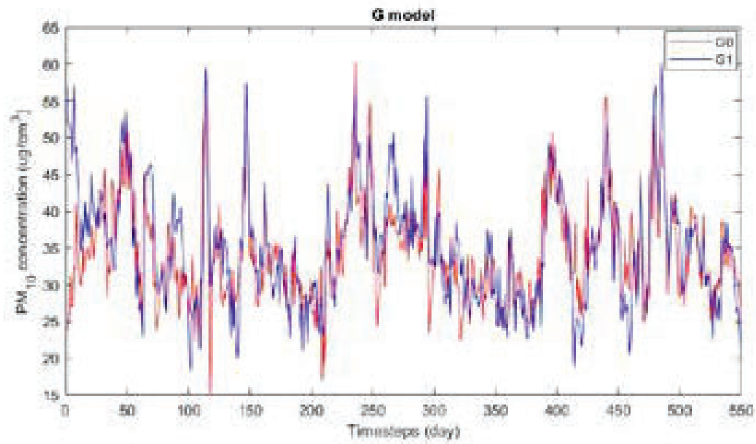
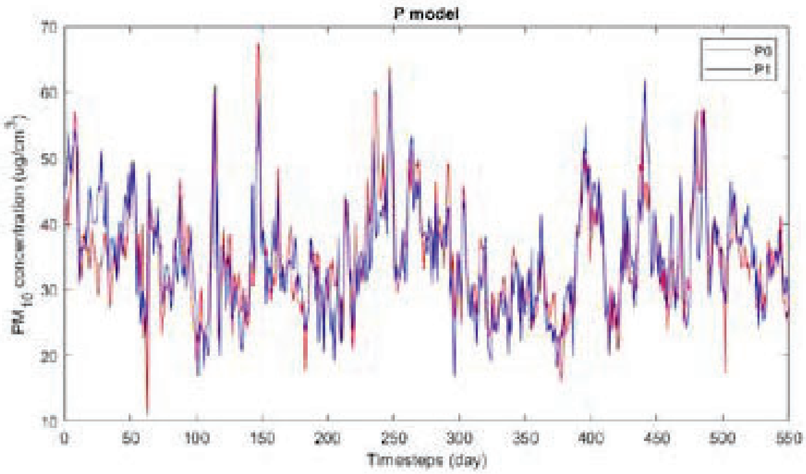


(c)

Fig. 6: Time series plot of forecasted data calculated using (a) U models, (b) M models, (c) G models, (d) P models, and (c) S models



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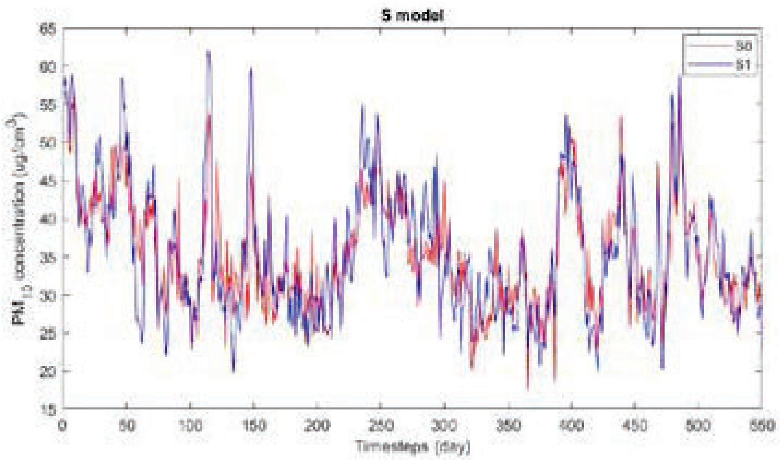


(c)

Fig. 6: Time series plot of forecasted data calculated using (a) U models, (b) M models, (c) G models, (d) P models, and (c) S models

2015). VF for NO_2 concentration is higher compared to CO, suggesting that oxygen gas react with ambient nitrogen gas. As for PC_3, it accounts for 12.52% of the total variation. It can be seen from Table 5 that WDI shows strong positive contribution in this PC. This suggests that PM_{10} concentration is highest when wind is blown from direction of WD_{max}, which is determined to be 67.5° based on red cross mark in polar plot as shown in Fig. 5. Examining the location of the monitoring station CA0030 and its vicinity shown in the map in Fig. 2, the direction of WD_{max} is indicated by the area in blue with 22.5° wide. It can be observed that night markets and highway are located inside the area. Wind direction blowing from these buildings and infrastructures may also contribute to higher PM_{10} concentration.

Artificial neural network (ANN)

Ten neural network models were developed to forecast PM_{10} concentration in Kota Kinabalu from 2011 to 2012. The result for each forecasting model is plotted in time series graph as shown in Fig. 6. It can be seen that the U model clearly does not forecast the future trends of PM_{10} concentration in contrast to other models. U0 model for example shows a future trend of PM_{10} concentration with the value settles down to a certain constant value over time, which does not represent the actual trend of

Table 6: Number of days exceeding allowable PM_{10} concentrations as forecasted by NAR and NARX models

Model	Number of days exceeding allowable PM_{10} concentration
U0	550
U1	0
M0	0
M1	8
G0	19
G1	22
P0	26
P1	31
S0	22
S1	28
Actual	36

Table 7: Performance indicators (in terms of mean ± standard deviation) of neural network models for PM_{10} concentration in Kota Kinabalu

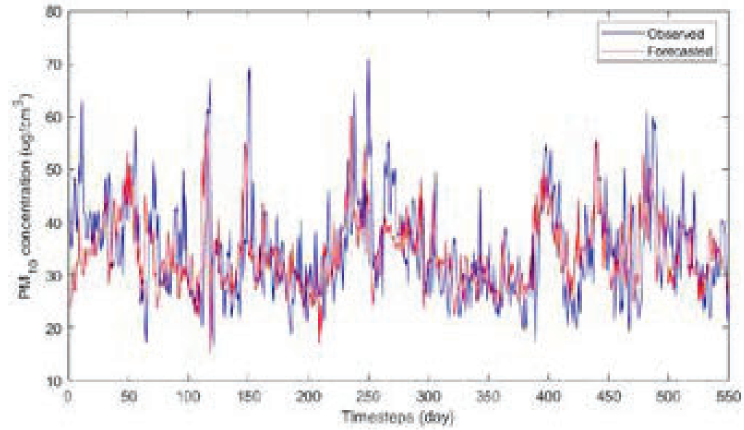
Model	RMSE (μg/m^3)	MAE (μg/m^3)	IA	FB
U0	9.292±0.072	7.343±0.113	0.145±0.046	-0.00002
U1	8.740±0.295	6.876±0.268	0.458±0.092	-0.0071
M0	7.596±0.741	5.833±0.590	0.701±0.130	0.0084
M1	7.062±0.668	5.445±0.507	0.772±0.068	-0.0015
G0	6.264±0.552	4.822±0.454	0.846±0.034	0.0056
G1	6.567±0.392	5.116±0.319	0.830±0.031	-0.0059
P0	6.236±0.526	4.850±0.421	0.844±0.034	-0.0039
P1	5.964±0.648	4.630±0.540	0.860±0.048	-0.0054
S0	7.109±0.450	5.500±0.365	0.779±0.041	0.0017
S1	7.086±0.873	5.350±0.523	0.812±0.034	-0.0156

PM_{10} concentration at all. Meanwhile, U1 model only forecasts rough trends of PM_{10} concentration. All other models including M, G, P and S show almost similar periodic pattern of PM_{10} concentration, in which the minima and maxima of PM_{10} concentration in dataset can be identified.

According to the Malaysian Ambient Air Quality Guidelines (MAAQG), the allowable 24-hour average PM_{10} concentration was set as 50 μg/m^3 before the year 2015. Based on Fig. 6(b) to (c), daily average PM_{10} concentration at certain timesteps exceeded the allowable limit as set in MAAQG. This is mainly due to unusually higher traffic density, more active night markets and also influence from wind direction. The trend of PM_{10} concentration events is not observed in Fig. 6(a) due to severe underfitting of U models as a result of limited number of neurons in hidden layer (Ceylan and Bulkan, 2018). Table 6 shows the number of days exceeding allowable PM_{10} concentration as forecasted by these models. Models P and S tend to forecast the number of days closer to the actual data. This shows that models P and S are able to forecast days exceeding allowable PM_{10} concentration with good accuracy.

The forecast performance (in terms of mean ± standard deviation) of all ten neural network models is tabulated in Table 7. None of the models show significant underestimation or overestimation as indicated by FB centred close to zero. U0 model shows severe underfitting, indicated by relatively low IA and constant trend over time as observed in Fig. 6. This is because U0 model only uses past values of PM_{10} concentration, which is too few variables used for forecasting, leading to failure in capturing the variability of time series dataset (Dotse *et al.*, 2018). This is also true for U1 which uses temporal variables in addition to past values of PM_{10} concentration.

Inclusion of meteorological and gaseous variables as in M and G models significantly improves the performance of forecasting PM_{10} concentration as measured by CA0030. Neglecting FB (as no severe underestimation and overestimation occurs), G0 shows better forecasting performance (RMSE = 6.264±0.552 μg/cm^3, MAE = 4.822±0.454 μg/cm^3, IA = 0.846±0.034) compared to M models and U models. This can be seen in the verification shown in Fig. 7 that G0 model can forecast 2-year of PM10 concentration data more accurately. Slight performance degradation



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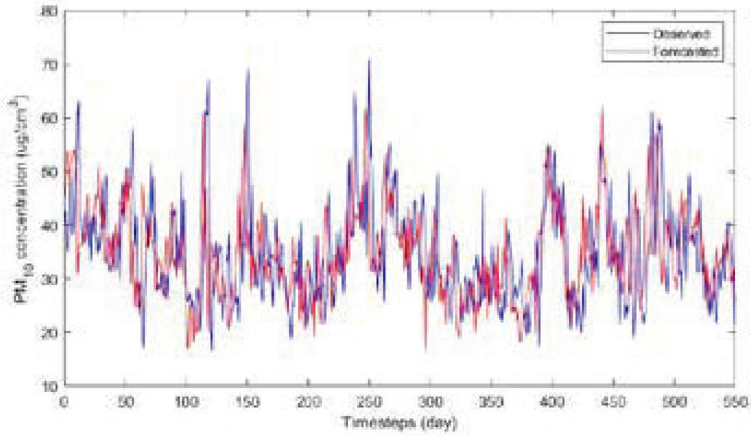

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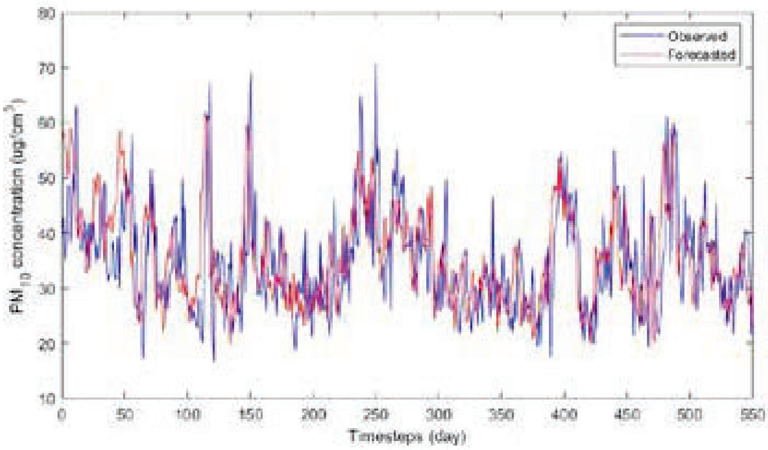

(c)

Fig. 7: Time series plot of observed (blue) and forecasted (red) data by (a) G0 model, (b) P1 model, and (c) S1 model, for PM_{10} concentration in CA0030

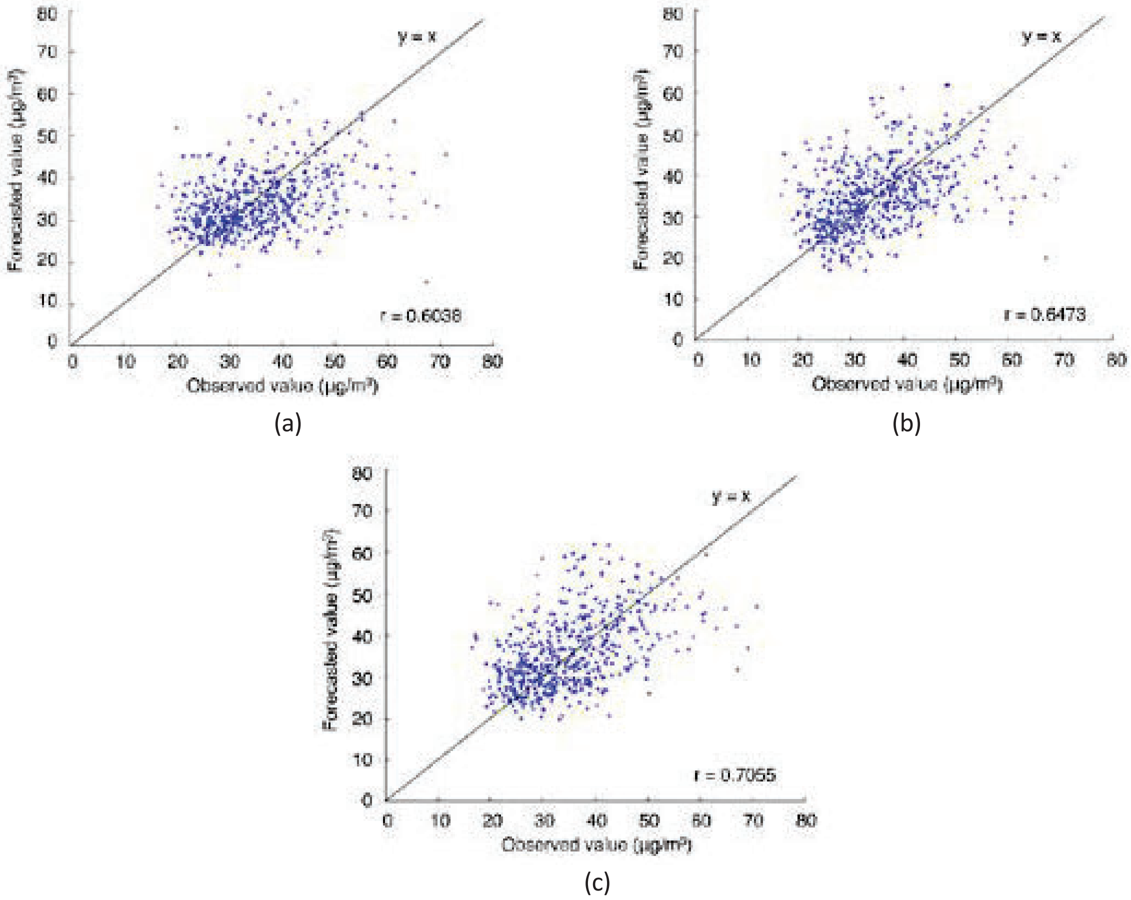

Fig. 8: Plot of forecasted value against observed value for (a) G0 model, (b) P1 model, and (c) S1 model

occurs for G1 model as indicated by higher RMSE and MAE, as well as low IA. This is attributed to overfitting of forecast model which occurs when too many input variables are used (Ceylan and Bulkan, 2018). Using PCs as input variables instead of original variables (as in P models) also improves performance of forecasting model (RMSE = 5.964±0.648 μg/m^3, MAE = 4.630±0.540 μg/m^3, IA = 0.860±0.048). It can be seen that unlike G models, inclusion of temporal variables (as in P1 model) does not cause overfitting because PCs are orthogonal and uncorrelated to each other (Ul-Saufie *et al.*, 2013). Higher standard deviation in the performance indicators for P1 model suggests that the performance of forecast model is less consistent with every forecast attempt. As for S models, the forecasting performance is not the best as compared to other models, which may be due to a smaller number of input variables used in forecasting. However, S1 model is capable of forecasting PM_{10} concentration with good performance (RMSE = 7.086±0.873 μg/m^3, MAE = 5.350±0.523 μg/m^3, IA = 0.812±0.034), as reflected by time series plot in Fig. 7(b) with relatively high IA as shown in Table 7. Fig. 8 reveals that there is moderately strong correlation between forecasted value from the three models (G0, P1 and S1) and observed value. Although the coefficient of correlation for the three models does not show strong correlation, the three models can still capture future trend of PM_{10} concentration as revealed by high IA values and time series plots in Fig. 7.

P1 model forecasts PM_{10} concentration in Kota Kinabalu with the best performance as shown in Table 7. This is reflected by its highest IA value while having the lowest RMSE and MAE compared to other models. This is possible because P1 model uses principal components converted from all variables together with principal components. The performance indicators in RMSE and MAE and show that P1 has a relatively high standard deviation, suggesting that slight overfitting occasionally occurs during development. Overall, S1 model forecasts PM_{10} concentration with good performance as illustrated by time series plot in Fig. 7(b). Unlike G and P models, S1 does not require all input variables and PCA transformation to achieve good forecasting performance.

CONCLUSION

Based on PCA conducted in this research, rotated component matrix shows that WDI, RH, Temp, NO_2 and O_3 (from the first three PCs) strongly contributes to variation of PM10 concentration in 10 years (from 2003 to 2012). PC_1 suggests that meteorological condition and ground ozone generation strongly contributes to PM_{10} concentration variation. PC_2 concerns with motor vehicle emission, mainly reaction of oxygen gas and ambient nitrogen gas in engines. PC_3 is related to PM_{10} emission sourced from buildings and infrastructures, mainly night markets and highway located close to CA0030 monitoring station. As for forecast model developed using NAR and NARX, U models show severe underfitting, reflected by failure in forecasting PM_{10} concentration data accurately and is confirmed by low values of IA. Addition of more input variables in NARX model led to better forecasting performance, as indicated by M and G models. Among U, M and G models, the performance peaks at G0 model (RMSE = 6.264±0.552 $\mu g/cm^3$, MAE = 4.822±0.454 $\mu g/cm^3$, IA = 0.846±0.034), and overfitting occurs at G1 model as slightly too many input variables were used. Using principal components as inputs instead of original variables also show good performance as reflected by P models. Addition of temporal variables further improves the performance of forecast model, as in P1 (RMSE = 5.964±0.648 $\mu g/m^3$, MAE = 4.630±0.540 $\mu g/m^3$, IA = 0.860±0.048). While P1 model in overall shows the best forecast performance, it is not the most ideal model when used in real time application. Not only that it requires all variables in addition with variable transformation, but the standard deviation of performance indicators also indicate that the development of P1 model is not the most stable. S1 model is selected because it can forecast PM_{10} concentration with good performance (RMSE = 7.086±0.873 $\mu g/m^3$, MAE = 5.350±0.523 $\mu g/m^3$, IA = 0.812±0.034) without requiring all input variables and variable transformation. In real-time application, S1 model is preferred in forecasting PM_{10} concentration data for Kota Kinabalu as it requires fewer input variables to achieve accurate result. The method of model development is yet to be studied for other monitoring stations in Sabah. Furthermore, models with fewer input variables especially univariate (U0) models should be studied in order to achieve good forecasting results without requiring many input variables.

AUTHOR CONTRIBUTIONS

R. Muhammad Izzuddin is the main contributor to this paper. He carried out the data analysis and modelling; and drafted the manuscript. F.P. Chee participated in the design of this study and led this project. R. Muhammad Izzuddin, F.P. Chee and H.W.J. Chang conceived the original idea with many helpful suggestions from Sentian, J. Dayou and C.M. Payus participated in the study coordination and helped to review the manuscript. S.S.K. Kong assisted in the data collection from the Department of Environment.

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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.

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ABBREVIATIONS

0	without temporal variables (U, M, G, P and S models)
1	with temporal variables (U, M, G, P and S models)
ANN	Artificial neural network
CAQM	Continuous air quality monitoring
CO	Carbon monoxide
d_{th}	Integer day in a year
DOE	Department of Environment
EM	Expectation maximization
FB	Fractional bias
FF	Feedforward
FFBP	Feedforward backpropagation
G	Gaseous (ANN model with meteorological and gaseous input variables)
GRNN	General regression neural network
IA	Index of agreement
l	Factor loading
km	kilometre
LM	Levenberg-Marquardt
m	Metre
m^2	Metre Square
m_{th}	Integer month in a year
M	Meteorological (ANN model with meteorological input variables only)
MAAQG	Malaysian Ambient Air Quality Guidelines
MAE	Mean absolute error
MATLAB	Matrix laboratory
max	maximum value
MLP	Multilayer perceptron
MLR	Multiple linear regression
N	Number of input variables
NAR	Nonlinear autoregressive
NARX	Nonlinear autoregressive with exogenous input
NNM	Nearest neighbour method
NO_2	Nitrogen dioxide
O	Observed value
$\bar{O}$	Average observed value
O_3	Ozone
P	Predicted value
P	Principal (ANN model with PC as input variables)
$\bar{P}$	Average predicted value
PC	Principal component
PCA	Principal component analysis
PCR	Principal component regression
PM	Particulate matter
PM_{10}	Particulate matter with aerodynamic diameter below 10 microns
RBF	Radial basis function
RC-NN	Recurrent neural network
RH	Relative humidity
RMSE	Root mean square error
S	Selected (ANN model with selected variables based on rotated component matrix)
SO_2	Sulphur dioxide
T	Number of days in a year
Temp	Ambient temperature
U	Univariate (ANN model without meteorological or air quality input variables)
VF	Varimax factor
w	Synaptic weight
WD	Wind direction
WD_{max}	Wind direction at maximum PM_{10} concentration
WDI	Wind direction index
WS	Wind speed
W/m^2	Watt per squared metre
X	Input variable
$\mu g/m^3$	Microgram per cubic metre
φ	Shift in sine function

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CASE STUDY

Energy-innovation knowledge common connection point management in preventing outbreak of the Covid-19 pandemicin a University

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ABSTRACT

BACKGROUND AND OBJECTIVES: The new wave of the Covid-19 pandemic has complicated the working conditions of higher education institutions in Ukraine. In this regard, saving energy resources of the university offers an opportunity to get out of the crisis. The purpose of the study is to develop a management system for energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of Covid-19 pandemic.

METHODS: The method of Deutsche Gesellschaft für Nachhaltiges Bauen was used to conduct energy audits, construct energy profiles of university offices. The cluster analysis was used to perform energy certification of university offices according to the indicators of integral energy efficiency potential and the level of annual specific energy consumption. Fuzzy methods made it possible to classify all the buildings into 3 categories (A, B, C) to prioritize their use in the light of Covid-19 pandemic. The system for monitoring the attained level of energy efficiency is based on the use of discriminant analysis.

FINDINGS: Implementation of the weighted strategy has proved that the classes will be given online, 23% of all offices. Category A (administrative, technical, service buildings; laboratories with unique equipment with 24-hour service) will be used in a pessimistic scenario (continuation of Covid-19 pandemic). In the optimistic scenario (end of Covid-19 pandemic), by means of the suggested energy efficiency monitoring system, the probability of using category A officesmakes100%, B offices- 50% and C offices- 13%.

CONCLUSION: Implementation of the developed energy efficiency action plan will offer the opportunity for the University to use reasonably the common connection point of knowledge management of energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of the Covid-19 pandemic. The profitability of implementing a weighted energy efficiency strategy is 15%, with a payback period of 6.7 years for the purchase and installation of non-conventional renewable energy equipment. In the future, it would be advisable to convert gradually all of the remaining 14 university buildings to the autonomous use of non-conventional renewable energy sources, using a common connection point for the knowledge management of the energy complexes.

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INTRODUCTION

There is a strong potential for energy saving in Ukrainian higher education institutions: the effect of reducing energy costs provides the universities with an opportunity to reduce their dependence on the external funding and increases the autonomy of public institutions. But, in most cases, Ukrainian university buildings are energy inefficient and outdated (Gryshchenko *et al*., 2017). The COVID-19 pandemic has put new demands on the economical use of resources, including energy (Abu-Rayash *et al*., 2020; Wang *et al*., 2021). Universities were forced to reduce all costs, including wages (teachers wages were paid on an hourly basis, administrative and support staff were given unpaid holidays), utility costs, including energy, were reduced by complete disconnection of resources, etc. Furthermore, the Covid-19 pandemic resulted in a significant reduction in funding for budget institutions, particularly those in the social sphere – in the spring of 2020, the Ukrainian government transferred UAH 5 billion from the education sector to the Covid-19 Response Fund. The Covid-19 pandemic has thus become not only an opportunity for Ukrainian universities to save energy, but also a major challenge to optimize internal and external resources. According to studies by (García *et al*., 2020; Nayak *et al*., 2021; Nicola *et al.*, 2020; Werth *et al.*, 2021) the use of energy saving methods, technologies and materials under the pandemic conditions can be considered as one of the priority areas of university energy efficiency. The results of university energy efficiency research in the COVID-19 pandemic can be conditionally divided into 3 groups. The first group of study Di Stefano, (2000) is devoted to the specific features of energy consumption and the search for methods to improve the energy efficiency of university buildings in the COVID-19 pandemic. For example, Xing *et al.* (2019) presented a multi-criteria optimization model for distributed energy systems under COVID-19 pandemic conditions, involving methods to reduce heat losses in buildings through the development and use of energy-efficient space planning and construction solutions based on the use of energy-efficient equipment and non-conventional energy supply systems. The second group of study Hansen *et al.* (2019) is devoted to searching for the methods to optimize energy consumption in the COVID-19 pandemic related to the need for heating and warm air recovery in university buildings. Fan *et al.* (2020) suggest that energy-efficient technologies and materials that improve the energy efficiency of buildings in the light of the COVID-19 pandemic are one of the priorities for modern global economic development. Amirreza *et al.* (2021) find that the likelihood of possible energy resources in the light ofCOVID-19 pandemic leads to a significant increase in their cost at the existing volumes and rates of consumption growth, taking into account the limited availability of existing and poor progress of alternative energy sources. Most authors (Liu *et al*., 2019; Zhong *et al*., 2020) agree that methods to reduce heat loss in the context of COVID-19 pandemic can be divided into active and passive. According to Chen *et al.* (2020) the use of active heat control methods (manual and automatic) and the installation of heat meters are particularly relevant under the pandemic conditions. However, in the course of the pandemic, the use of passive methods, according to Sovacool *et al.* (2020), improves the thermal insulation of the envelope buildings and the heat distribution network as well as the increase of the heat emission of the radiators and other heat exchangers. However, only the complex of all methods and obligatory individual economic responsibility of the consumer in the light ofCOVID-19 pandemic can result in significant energy saving (Navon *et al.,* 2021). The third group can include scientific developments during the COVID-19 pandemicthat make it possible to consider the problems of energy efficiency management of universities in an integrated manner: introduction of thermo-modernization projects of existing buildings (Soava *et al*., 2021), construction of passive buildings (Shcherbak *et al*., 2019). During development of energy saving measures, it is very important to evaluate the energy saving potential of a building (Balode *et al*., 2021). Many scientists have studied the issue of assessing energy saving potential and efficiency improvement of energy consumption in the course of COVID-19 pandemic. As a rule, the reserves on saving of fuel and energy resources are determined in the course of energy audit (Abu-Rayash *et al*., 2020; Kaplun *et al*., 2016). Some researchers (Edomah *et al.,* 2020; Khan *et al.,* 2021) consider thermal imaging as one of the most advanced energy auditing methods during the present pandemic. This method is used, first of all, in those cases when it is necessary to localize the areas of advantageous heating and ventilation heat losses which are often caused either by design errors, or defects arising at the stages of construction and operation (Jiang *et al*., 2021). At the same timein the course ofCOVID-19 pandemic, the problem of quantitative interpretation of the survey results, which should provide the adoption of justified decisions on strengthening the thermal protection of the inspected buildings, is not completely solved in the building thermal diagnostics. The use of thermal imaging to determine the thermal transmission resistance of the building envelope can determine up to 15% of the transmission heat loss during the heating period. On a practical level, during pandemic constraints it is difficult to account for the thermal inertia and the thermal dynamics of the external and internal environment when a number of thermal imaging survey rules are followed (Zhang *et al*., 2020; Steffen *et al*., 2020).Most university buildings in Ukraine have a strong energy saving potential, when taking into consideration generally the levels of insulation of building structures, the practical absence of process controls (heating, lighting and others) in the buildings. In the course of COVID-19 pandemic, there was an increase in the cost of energy and the energy intensity of basic equipment (Mastropietro *et al*., 2020). Improving the efficiency of energy consumption is therefore a priority for the university (Papageorgiou *et al*., 2017). The following challenges arise when developing implementation plans to improve energy efficiency during the present pandemic: limited financial assets for their implementation (Krarti *et al*., 2021); a large number of measures and available alternative measures that cannot be implemented simultaneously for technical reasons (Jiang *et al*., 2021). Under these conditions improving the energy efficiency of reconstructed residential buildings based on the integrated use of energy saving technologies and renewable energy sources will make it possible to cover the deficit of heat energy for heating, which inevitably arises as a result of infill construction (Huang *et al*., 2021). The need for significant energy efficiency improvements in an economic sense can result in a large-scale reconstruction of outdated buildings. The economic efficiency of this approach involves individual changes: replacement of windows, renovation of facades, roofing, which will result in the improved energy efficiency. On the other hand, it will reduce the use of natural resources at the operational stage of the buildings and reduce the adverse impact on the environment. Analysis of methods to improve energy efficiency in the course of COVID-19 pandemic shows that it is necessary to use a set of both active and passive methods in order to improve the thermal insulation properties of buildings and to create comfortable conditions in the offices. By using active methods, it is possible to save a significant part of the heating costs (10-15%). Passive methods will result in greater savings (30%). Consequently, the combination of these methods will save almost 50% of the costs (Kanda *et al*., 2020; Kuzemko *et al*., 2020). The creation of an energy management service and energy supply system on the basis of the virtual solar plant at Kiev National University of Technology and Design has approved that the integrated energy management system should be based on the international energy efficiency standards: ISO 50004:2014 Energy management systems - Guidance for the implementation, maintenance and improvement of an energy management system; ISO 50006:2014 Energy management systems - Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) - General principles and guidance; ISO 50002:2014 Energy audits - Requirements with guidance for use (Shaposhnikova *et al*., 2016; Vieira *et al*., 2020). At the same time, the implementation of an effective energy management system in the course of the COVID-19 pandemic should be based on energy monitoring, energy audits and energy certification of university buildings (Halbrügge *et al*., 2021). Thus, there is a lack of consistency between the existing both theoretical and practical approaches in determining the most appropriate energy management systems, ranking the factors that have the greatest impact on the level of energy efficiency of universities in the context of the COVID-19 pandemic (Edomah *et al*., 2020; Klemeš *et al*., 2020; Ruan *et al*., 2021). In other words, many problems remain unresolved, controversial and require further study. The problem that this project aims to solve is the necessity to develop an integrative approach to energy conservation and energy efficiency management at the university in the context of preventing a new outbreak of the Covid-19 pandemic. The aim of the study is to develop a management system for energy complexes with non-conventional renewable energy sources based on the Common connection point (CCP) in the context of preventing a new outbreak of the Covid-19 pandemic. The objectives of the study are; 1) to conduct energy audit, energy certification of university building offices, 2) to construct energy profiles of university building offices, 3) to develop an energy management plan to increase university energy efficiency, 4) to offer a system to monitor the achieved level of energy efficiency. This study has been carried out at Kyiv National University of Technology and Design (KNUTD) as the case study in 2020.

MATERIAL AND METHODS

The hypothesis of the study is that applying an integrative approach to university energy efficiency management in the context of preventing a new outbreak of the Covid-19 pandemic will increase the university's energy savings and its level of energy autonomy from budgetary funding. The algorithm of the study procedure is as follows: 1 stage –to conduct an energy audit of university buildings (offices) to construct an energy profile; 2 stage –to implement energy certification to classify university buildings by energy consumption and energy losses; 3 stage –to develop an energy management action plan to optimize energy saving in higher education institutions in order to prevent a new Covid-19 pandemic outbreak; 4 stage –to monitor the achieved level of energy efficiency. At the first stage, an energy audit was conducted. The energy audit has resulted in the construction of an energy profile according to the critical criteria. The energy profile tool is the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) method. According to (Shcherbak *et al.*, 2019) the advantage of this method is the easy information collection and processing regarding the technical condition, planning and socio-economic aspects of the operation of university buildings in terms of energy efficiency, and the reliability of the results obtained. The second stage involves energy certification of university buildings. From the point of view of (Kaplun *et al.*, 2016) it is more reasonable to carry out energy certification of university building offices on the basis of the results of energy audit by means of a cluster analysis method. The cluster analysis method in this study is used to rate university buildings according to the level of energy consumption, energy losses, and the possibility to use alternative energy sources. At this stage the energy efficiency potentials of university buildings are calculated according to the key energy saving areas. The thermal energy saving potential for the heating period is calculated using Eq.1.

$$P_{heat} = (P_{cal} - P_{act}) \times \beta_h, \quad (1)$$

Where, P_{cal} is the actual heat consumption for heating the building during the heating period, *J*; P_{act} is the heat input during the heating period, *J*; β_h is the coefficient taking into account extra heat consumption of the heating system related to the heat flow discreteness of the range of heating appliances, *J*.

The heat gain potential during the heating period is calculated using Eq. 2.

$$P_{act} = (P_{\text{int}} + P_s) \times \gamma \times \phi \quad (2)$$

Where, P_{int} is the potential for domestic heat gain during the heating period, *J*; P_s is the potential for heat gain through windows from solar radiation during the heating period, *J*; γ is the reduction factor for heat gain due to thermal inertia of the envelope building; φ is the efficiency factor for auto regulation of the heating system, *J*.

The heat saving potential due to the envelope building improvement (increasing the thermal resistance of exterior walls, windows, doors, attic floors and floors) is calculated using Eq. 3.

$$P_{build/env} = 0,0864 \times D_d (K_{t1} A_{e1} - K_{t2} A_{e2}) \times \phi, \quad (3)$$

Where, D_d - degree-days of the heating period, *°C-day/year.*; $K_{t1,}$ K_{t2} - heat transfer coefficients of the building before and after improvement of the building envelope, *W/(m²-°C)*; $A_{e1,}$ A_{e2} – surface areas of external envelope structures, including the upper floor (slab) and floor slab of the lower heated room, before and after improvement of the building envelope, *m²*.

The heat gain decrease potential due to the thermal inertia of the internal building envelope (screens behind radiators) is calculated using Eq. 4.

$$P_{\text{int}/env} = \tau \times F \times (K_1 - K_2) \times (t_{rad} - t_{outs})[(t_{ind} - t_{outs})/(t_{\max} - t_{ind})] \quad (4)$$

Where, τ - duration of the heating period; *F* - surface area of heating devices from the side of the building envelope, m^2; t_{rad} - average air temperature between the wall and the heating device, ^0C; t_{outs} - average outdoor air temperature during the heating period, ^0C; t_{ind} - indoor reference temperature, ^0C; t_{max} - standard outdoor air temperature of the coldest five-day heating period, ^0C; *K1, K2* - heat transfer coefficients through the building envelopes before and after improvement of internal building envelopes, *W/(m²-°C)*.

The savings potential of the building heating system due to the use of autoregulation (introduction of individual heating substations, thermostats) is calculated using Eq. 5.

$$P_{autoreg} = (P_{\text{int}} + P_s) \times \gamma \times \beta_h (\phi_2 - \phi_1), \quad (5)$$

Where, φ_1, φ_2 are the efficiency coefficients of auto regulation of heat supply before and after the implementation of the individual heating substation, thermostats in the building heating system.

The potential for energy savings due the use of non-conventional renewable energy sources (installing a solar panel on the building roof of the university) is calculated using Eq. 6.

$$P_{solar} = \frac{30W}{W_m} P_m, \quad (6)$$

Where, *W* is the average daily electricity consumption of all university buildings, *kWh*; P_m is the capacity of the solar power plant module, *J*; W_m is the amount of energy generated by the solar power plant module using Eq. 7.

$$W_m = \frac{kP_m E}{1000}, \quad (7)$$

Where, *E* is the insolation value for the heating period, *kWh/m²*; *k* is a factor taking into account the correction for the power loss of the solar cells when they heat up in the sun, as well as the oblique incidence of the rays on the surface of the modules during the day.

The integral potential of energy efficiency is calculated using Eq. 8.

$$P_{\text{int}} = \sqrt[6]{P_{heat} \times P_{act} \times P_{build/env} \times P_{\text{int}/envt} \times P_{autoreg} \times P_{solar}}, \quad (8)$$

The third stage includes the development of energy management action plan using the fuzzy method (Skiba *et al*., 2017). This method makes it possible to classify all the offices of the university buildings using ABC analysis. ABC analysis is based on the well-known Pareto principle, which states that 20% of effort yields 80% of the result. The principle of using ABC analysis is as follows. Group “A” includes the offices that give 80% of energy efficiency potential implementation; group “B” offices - 15%; group “C” offices - 5%.A single indicator, the integral energy efficiency potential (Equation 8), was used to apply the ABC analysis. This indicator includes a comprehensive characteristic of the energy efficiency of all offices (buildings) and makes it possible to classify all the offices according to the achieved level of energy efficiency. Energy efficiency improvement plan of university offices is drawn up as follows. There is some set of system object categories (university offices) $C= \{C_A, C_B, C_C\}$. Each category of offices C_i is characterized by a set of attributes (energy efficiency potentials), it corresponds to a subset of objects having the listed attributes - $O_i = \{o_1^i, o_2^i, ...o_N^i\}$, where *N* is the number of university offices. The state of an object is characterized by a set of values of its attributes (energy efficiency potentials) related to a particular object (room): $P(o_j^i) = \{p_1^i, p_2^i, ...p_N^i\}$. The state of the university’s managed energy efficiency system is characterized by a set of attribute values (energy efficiency potentials) of all its objects (offices), using Eq. 9.

$$\bar{U} = \bigcup_{o_j^i \in 0} P(o_j^i) \quad (9)$$

Probable outcomes for each of the offices include its classification to one of the groups according to the value of the integral energy efficiency potential: A, B, C. For each combination of actions, the probable outcomes of all actions are combined into generating options - lists of outcomes, where each object corresponds to one implementation of an action, using Eq.10.

$$Vres(\bar{U}) = (o_j^i, p_j^i) \quad (10)$$

It is followed by a combination of general list actions into private ones that describe the aggregate managing decisions to classify the offices into one of the three C_j categories, using Eq.11.

$$Ags(\bar{U}) = Ag(c_j, o_j^i) \quad (11)$$

The university offices are classified into 3 categories (A, B, C) due to the fact that in case of remote university activity in the context of the Covid-19 pandemic, only category A offices will be used. During the heating season, Category C offices will not be used regardless of the University's activity schedule. Category B offices will be used upon return to normal working conditions. This is shown graphically in Fig. 1.

The implementation of energy management measures makes it possible to optimize energy conservation in higher education institutions in the context of preventing a new outbreak of the Covid-19 pandemic (Gryshchenko *et al*., 2017). In the fourth stage, the suggested system for monitoring the achieved level of energy efficiency is based on the method of discriminant analysis. The essence of its use is that the strategy of using a certain room is determined by the maximum value of the discriminant function $f_{i/j}$, where *I* is the strategy of using this room determined in the third stage, *j* is the category of energy certification of this room determined in the second stage.

The performance of the suggested energy efficiency measures (Ganushchak-Efimenko *et al*., 2018) is determined by the Eq. 12.

$$K_{eff} = \frac{\mathrm{Cos}\,t_1 - \mathrm{Cos}\,t_2}{\mathrm{Cos}\,t_{equip}}, \quad (12)$$

Where, $Cost_1, Cost_2$ - costs of electricity and heating before and after the implementation of energy efficiency measures, *UAH*; $Cost_{equip}$ - cost of complete solar power plant equipment, heating unit, thermostats, design and installation works, *UAH*.

The payback period of the project is determined using Eq. 13.

$$ROI = \frac{\mathrm{Cos}\,t_{equip}}{\mathrm{Cos}\,t_1 - \mathrm{Cos}\,t_2}, \quad (13)$$

Data description

Data collected according to the methodology of the DGNB were used in order to conduct energy audit and construct an energy profile. The empirical data to conduct energy audit and construct an energy profile are presented in Table 1.

The data in Table 1 were collected by the employees of Center for Energy Efficiency of Kyiv National University of Technology and Design (KNUTD) for all university offices (Table 2).

All the coefficients resulted fromEqs.1 to 11 are reference values. All other components of Eq. 1 - 11 are estimated values derived from the data on actual consumption of heat, electricity, the condition of external and internal coverings of the buildings. Data for calculation of Eqs.12 - 13 have been obtained from the financial statements of the university.

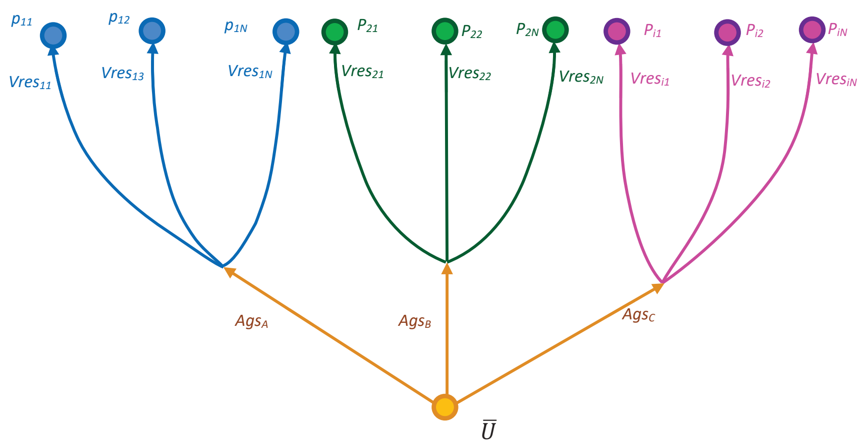

Fig. 1: Converted fragment of a fuzzy hierarchical situation-evidence-based university offices classification network based on the ABC-principle

RESULTS AND DISCUSSION

The first stage involved energy audit of 15 KNUTD buildings (Table 2) was conducted according to 14 key energy efficiency indicators. The list of indicators was selected according to the methodology of DGNB and is shown in Table 1. As a result of this energy audit an energy profile was constructed in Fig. 2.

Fig. 2 shows the practical use of the application package, the "Cluster Method - K-means clustering" tab. Using this method, 15 buildings can be classified into separate energy efficiency groups based on 14 indicators.

The second stage included energy certification of offices based on the calculation of integral energy efficiency potentials for all 880 offices in 15 university buildings. The energy certification of university buildings was carried out on the basis of energy efficiency rating of the offices (Fig. 3).

The results of the energy efficiency potential calculations and their classification are shown on the example of 113 offices of KNUTD Academic Building B4 (Fig. 4).

Fig. 4 shows the practical use of the application package STATISTICA 10, tab "Cluster method - K-means clustering". In this case, this method was used to classify 113 offices of KNUTD academic building B4 into 3 groups A, B, C according to 6 energy efficiency potentials.

The structure of the category A offices group of KNUTD academic building B4 is shown in Table 3.

Table 3 shows that 26 from among 113 offices of KNUTD Building B4 (23%) fell within Category A.

The structure of category B offices group of KNUTD academic building B4 is shown in Table 4.

Table 1: System of indicators for conducting energy audits and constructing an energy profile

Indicators	Identification
costs for the entire life history of the building	x_1
use of renewable energy sources for heat and electricity	x_2
indoor climate	x_3
use of environmentally friendly materials	x_4
use of heat energy	x_5
building design principles relating to energy efficiency	x_6
quality control of energy use	x_7
roof insulation	x_8
wall insulation	x_9
floor insulation	x_{10}
heat transfer coefficient of windows	x_{11}
air permeability of the building	x_{12}
ventilation	x_{13}
heating and cooling	x_{14}

Table 2: The main buildings of the KNUTD and their technical specifications

Designation	Building name	Area	Building volume	Year built	Rated energy consumption	Specific energy consumption	Average workload (%)
B1	Academic Building No. 1	32066,8	132132,3	1970	0,025	228,7	28,13
B2	Academic Building No. 2	5366,9	20570,7	1965	0,023	242,7	38,88
B3	Academic Building No.3	5239,9	17815,3	1968	0,029	238,9	29,99
B4	Academic Building No.4	18029,1	78311,8	1976	0,025	213,7	31,78
B5	Academic Building No.5	1785,1	6243,7	1966	0,034	247,5	56,05
B6	Academic Building No. 8	878,5	2749,6	1914	0,039	263,8	21,78
B7	Build. No.6	745,3	3320,5	1976	0,039	233,1	32,44
B8	Build. No.7	559,2	3010,2	1960	0,039	267,8	41,17
B9	Dormitory No. 2	4981,14	14098,1	1970	0,032	245,3	68,6
B10	Dormitory No. 3	4884,6	13879,8	1962	0,032	231,9	44,8
B11	Dormitory No. 4	6225,4	20763,4	1996	0,024	153,5	87,0
B12	Dormitory No. 5	4920,2	13926,5	1975	0,032	200,1	67,3
B13	Dormitory No. 6	4862,1	14325,7	1977	0,032	197,8	55,8
B14	Dormitory No. 7	10514,1	44286,9	1984	0,026	178,3	59,7
B15	Dormitory No. 8	5524,3	15873,8	1996	0,030	219,8	41,9

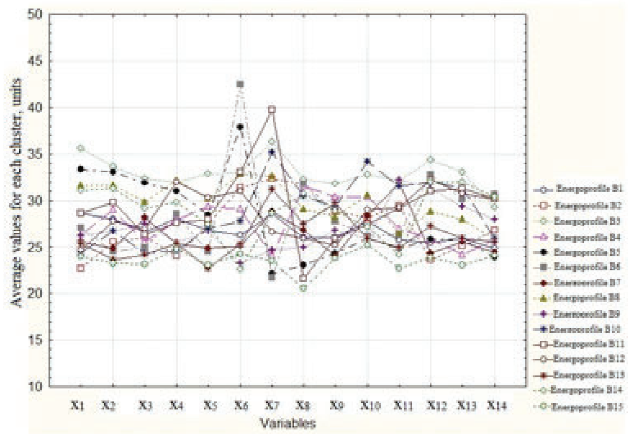

Fig. 2: Energy profiles of 15 KNUTD buildings; graph of average values for 14 indicators (STATISTICA 10 listing)

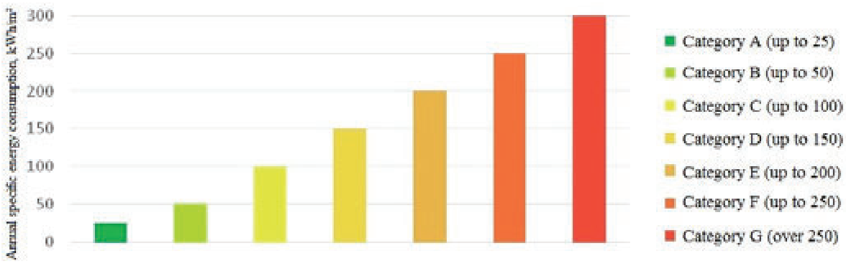

Fig. 3: Energy efficiency levels of buildings according tothe estimated annual specific energy consumption

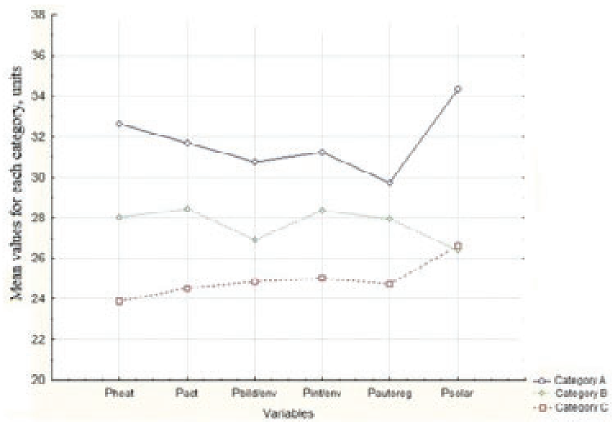

Fig. 4: Energy Efficiency Potential Rating of 113 offices of KNUTD Academic Building B4 (STATISTICA 10 listing)

Table 4 shows that 40 from among 113officesof KNUTD academic building B4 (35%) fell within category B. The structure of category C offices group of KNUTD academic building B4 is shown in Table 5.

Table 5 shows that 47 from among 113 offices of KNUTD academic building B4 (42%) fell within category C. The results of energy certification of 113 offices of KNUTD building B4 according to categories A, B, C are shown in Table 6.

The third stage involved the development of energy management action plan using the fuzzy sets method. The nodes in the upper layer of the network are evaluated (Fig. 1) by means of an evaluation model of the managed system state. Managing decisions are evaluated through the evaluations of the nodes to which they lead, convolved according to the chosen decision evaluation strategy. The possible strategies are as follows. Pessimistic strategy: the decision is evaluated by the worst-case estimate of the nodes to which it leads. Optimistic strategy: the decision is evaluated by the best estimate of the nodes to which it leads. Risk reduction strategy: the decision is evaluated by the sum of the fuzzy transition probabilities of the resulting nodes with an estimate below the threshold. Strategy to increase the winning probability: the decision is evaluated by the sum of the fuzzy transition probabilities to the resulting nodes with an estimate above the threshold. A weighted strategy that averages the outcome estimates according to their probabilities (analogous to the mathematical expectation). The maximum estimates of the managing decisions coming from every node are arguments for estimating the lower level transitions. Once the estimates of the transitions originating from the root node have been determined, an inference sub-tree is constructed, where the group transition with the maximum estimate is selected for every node. The arbitrary output sub-graph is evaluated by the deviation of the estimates of the selected transitions from the maximum estimates (Fig. 5).

The energy management plan to improve the energy efficiency of the university is presented in Table 7.

According to the weighted strategy, outcome estimates have been averaged based on the probability of their occurrence. It means that in a

Table 3: The structure of Category A offices group B4 of the KNUTD academic building (STATISTICA 10 listing)

Members of cluster number 1 (Data_ABC) and distances from respective cluster center. Cluster contains 26 cases													
Case No.	C_1	C_4	C_8	C_13	C_15	C_17	C_21	C_22	C_23	C_27	C_36	C_38	C_40
Distance	2,62	3,51	3,82	2,30	1,54	5,79	3,15	3,54	1,83	2,54	1,60	2,12	5,35
Case No.	C_45	C_47	C_49	C_51	C_53	C_55	C_57	C_58	C_59	C_74	C_95	C_99	C_103
Distance	1,91	2,217	3,536	3,047	2,404	3,763	3,303	3,130	5,461	3,313	3,682	9,445	5,307

Table 4: The structure of category B group offices of KNUTD academic building B4 (STATISTICA 10 listing)

Members of cluster number 2 (Data_ABC) and distances from respective cluster center. Cluster contains 40 cases										
Case No.	C_5	C_6	C_7	C_9	C_11	C_12	C_20	C_28	C_29	C_30
Distance	2,187	2,3160	2,5555	2,3113	2,0193	3,0281	3,5198	1,5902	1,6714	2,3149
Case No.	C_32	C_34	C_35	C_37	C_43	C_44	C_46	C_48	C_50	C_52
Distance	1,520	1,9872	2,8181	2,3457	4,1016	5,1931	4,5922	2,7539	1,2416	4,0800
Case No.	C_54	C_56	C_61	C_65	C_66	C_67	C_79	C_81	C_82	C_84
Distance	2,893	3,4271	4,5223	2,7658	2,0742	6,5260	1,4172	3,4108	3,1505	3,3346
Case No.	C_92	C_96	C_101	C_102	C_104	C_105	C_107	C_111	C_112	C_113
Distance	3,245	1,2659	3,6594	3,1049	2,7800	2,7238	3,4511	1,9286	2,0129	3,0617

Table 5: The structure of Category C offices group B4 of the KNUTD academic building (STATISTICA 10 listing)

Members of cluster number 3 (Data_ABC) and distances from respective cluster center. Cluster contains 47 cases										
Case No.	C_2	C_3	C_10	C_14	C_16	C_18	C_19	C_24	C_25	C_26
Distance	1,9616	1,6096	1,5591	2,40379	1,47362	2,2345	2,7229	2,8112	1,6891	2,4268
Case No.	C_31	C_33	C_39	C_41	C_42	C_60	C_62	C_63	C_64	C_68
Distance	1,3078	2,5628	1,1275	1,13783	2,08440	1,7166	3,4863	6,5185	3,6726	3,7203
Case No.	C_69	C_70	C_71	C_72	C_73	C_75	C_76	C_77	C_78	C_80
Distance	3,6603	1,5009	3,6647	3,74253	3,52055	3,7136	3,2354	3,3711	1,8664	5,0750
Case No.	C_83	C_85	C_86	C_87	C_88	C_89	C_90	C_91	C_93	C_94
Distance	2,8804	0,7783	3,0476	3,17184	3,30961	3,5671	2,9974	3,3115	3,5823	2,9531
Case No.	C_97	C_98	C_100	C_106	C_108	C_109	C_110			
Distance	1,7752	3,0426	2,4980	2,305041	3,251413	3,2113	2,4021			

Table 6: Energy certification of 113 offices of KNUTD building B4 according to categories A, B, C (STATISTICA 10 listing)

B4 KNUTD offices codes	Category / number of offices	Integral energy efficiency potential value / Annual specific energy consumption level
C_1; C_4; C_8;C_13;C_15;C_17;C_21;C_22;C_23;C_27;C_36;C_38;C_40; C_45; C_47; C_49; C_51; C_53; C_55; C_57; C_58; C_59; C_74; C_95; C_99; C_103	A /26	High level of integral energy efficiency potential / Low level of annual specific energy consumption
C_5; C_6; C_7; C_9; C_11; C_12; C_20; C_28; C_29; C_30; C_32; C_34; C_35; C_37; C_43; C_44; C_46; C_48; C_50; C_52; C_54; C_56; C_61; C_65; C_66; C_67; C_79; C_81; C_82; C_84; C_92; C_96; C_101; C_102; C_104; C_105; C_107; C_111; C_112; C_113	B /40	Average level of integral energy efficiency potential / Average level of annual specific energy consumption
C_2; C_3; C_10; C_14; C_16; C_18; C_19; C_24; C_25; C_26; C_31; C_33; C_39; C_41; C_42; C_60; C_62; C_63; C_64; C_68; C_69; C_70; C_71; C_72; C_73; C_75; C_76; C_77; C_78; C_80; C_83; C_85; C_86; C_87; C_88; C_89; C_90; C_91; C_93; C_94; C_97; C_98; C_100; C_106; C_108; C_109; C_110	C/47	Low level of integral energy efficiency potential / High level of annual specific energy consumption

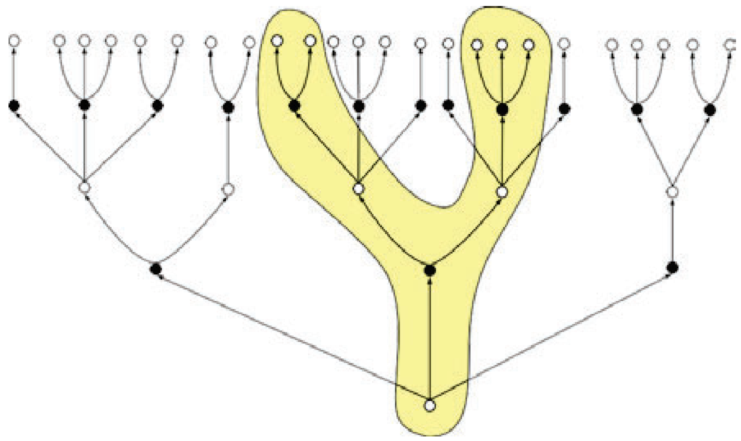

Fig. 5: Fuzzy hierarchical situation-evidence network and the ABC-principle output sub-graph of university offices classification

pessimistic scenario (continuation of the Covid-19 pandemic) classes will be given online. In this case only the Category A offices will be used: administrative, technical, service offices; laboratories with unique equipment with 24-hour service. In an optimistic scenario (completion of Covid-19 pandemic) category A and B offices will be used under the conditions of returning to normal working conditions. Category C offices with low integral energy efficiency potential will not be used during the heating season. The system for monitoring the achieved level of energy efficiency was presented in the fourth stage (Table 8) and the impact of the suggested energy efficiency measures was assessed.

The use of the suggested energy efficiency monitoring system has shown that the probability of using the optimistic strategy for Category A offices makes 100%, for B offices- 50% and for C offices- 13%.

The cost-effectiveness of the measures (installation of solar plant equipment, heating substation, thermostats, floor insulation) will be K_{eff}= (3317257 – 2030212)/ 8580300 = 0,15, where 3317257 UAH - costs of electricity and heating before implementation of energy-efficiency measures; 2030212 UAH - cost of electricity and heating after implementation of energy-efficiency measures; 8580300 UAH - cost of complete solar plant equipment, heating substation, thermostats, design and installation works. Payback period of the project is as follows: ROI = 8580300 / (3317257 - 2030212) = 6.67 years. Calculations showed that the cost-effectiveness of the measures (installation of solar plant equipment, heating substation, thermostats, insulation of floors) will be 15%. The payback period for the purchase and installation of non-conventional renewable energy equipment will make 6 years and 8 months. As a discussion, it should be noted that as opposed to (Xing *et al.,* 2019), who suggested using a multi-criteria optimization model for distributed energy systems in the context ofCOVID-19 pandemic, our study suggests using anCCP. The use of CCPin university energy management makes it possible to conduct the interactive monitoring of the energy efficiency of individual room groups (A, B, C) and adopt timely decisions on their utilization strategy. The authors (Zhonget *al.*, 2020; Chen *et al.*, 2020; Sovacoolet *al.*, 2020; Navonet *al.*, 2021; Soavaet *al.,* 2021; Kanda *et al.,* 2020; Kuzemko *et al.,* 2021; Kanda *et al.*, 2020; Khan *et al.,* 2021; Edomah *et al.,* 2020; Zhang *et al,* 2020) believe that either active or passive management techniques should be used to reduce heat loss and energy savings under COVID-19 pandemic conditions. In contrast to these authors' views, we have suggested a synergistic sequential integration of energy audits, energy certification, energy management and monitoring of achieved energy efficiency under theCOVID-19 pandemic. Moreover, according to (Huang *et al.,* 2021) energy-saving technologies and renewable energy sources, including solar panels, should be used either during construction or in the course of building renovation. Our approach of using non-conventional renewable energy sources in the context of preventing a new outbreak of the Covid-19 pandemic would significantly improve the energy efficiency of the university.

Table 7: Energy management action plan to improve the energy efficiency of the university

Category of KNUTD offices	Integral energy efficiency potential value / Annual specific energy consumption level	Energy management strategy		
		Pessimistic	Optimistic	Weighted (probabilistic)
A	High level of integral energy efficiency potential / Low level of annual specific energy consumption	100% use of administrative, technical, office space; laboratories with unique 24-hour service equipment		
B	Average level of integral energy efficiency potential / Average level of annual specific energy consumption	It is possible to use category B offices under the condition that:$P_{solar} \geq P_{autoreg}$	100% utilization of category B offices	It is possible to use category B offices under the condition that: $P_{solar} = P_{act}$
C	Low level of integral energy efficiency potential / High level of annual specific energy consumption	Category C offices will not be used	Category C offices can be used provided that: $P_{solar} \geq P_{autoreg}$	Category C offices can be used provided that: $P_{solar} = P_{act}$

Table 8: A system for monitoring the level of energy efficiency achieved

Strategy	Category of KNUTD offices		
	A	B	C
Pessimistic	$f_{P/A}$= -32,7+ 0,11x_1 + 0,43x_2 + 2,63 x_3 – 59,54x_4– 3,17x_5+ x_6 +0,03x_7 +0,02x_8 + 0,15x_9-0,13x_{10} -0,03x_{11} +0,52x_{12} + 0,13x_{13} + 0,04x_{14}	$f_{p/B}$ = -17,6+ 0,03x_1+x_2+0,96x_3-0,3x_4+0,29x_5+ 0,03x_6 +x_7+0,96x_8-0,3x_9+0,29x_{10}-0,09x_{11} - 0,09x_{12} +0,13x_{13} -0,18x_{14}	$f_{p/C}$ = -12,8+ 0,02x_1+0,06x_2+0,7x_3-0,03x_4+0,03x_5+0,02x_6 +0,06x_7 +0,7x_8 - 0,03x_9+0,03x_{10}-0,19x_{11} ++ 0,53x_{12} - 0,17x_{13} -0,1x_{14}
Optimistic	$f_{O/A}$ = -19,1+ 0,8x_1+0,32x_2-0,28x_3-0,18x_4+0,13x_5+0,8x_6+0,32x_7 -0,28x_8-0,18x_9+0,13x_{10}+ 0,01x_{11} - 0,44x_{12} + 0,72x_{13}-0,01x_{14}	$f_{O/B}$ = 37,1-0,28x_1+0,29x_2+x_3+ 0,04x_4-0,01x_5- 0,28x_6+0,29x_7+x_8+ 0,04x_9 - 0,01x_{10}-0,05x_{11} +0,4x_{12} + 0,05x_{13} + x_{14}	$f_{O/C}$ = -21,2+ -0,28x_1+0,29x_2+x_3+ 0,04x_4-0,01x_5+0,22x_6 + 0,96x_7 +0,33x_8 - 0,33x_9 +0,33x_{10} -0,1x_{11} ++ 0,19x_{12} - 0,5x_{13} +0,13x_{14}
Weighted (probabilistic)	$f_{W/A}$ = -17,5+ 0,32x_1+0,3x_2+0,4x_3-0,53x_4+0,43x_5- 0,28x_6 + 0,29x_7 + x_8 + 0,04x_9 -0,01x_{10} - 0,05x_{11} +0,22x_{12}+ x_{13} +0,4x_{14}	$f_{W/B}$ = -16,5+ 0,22x_1 + 0,33x_2 + 2,63x_3 – 59,54x_4– 3,17x_5+0,3x_6 + 0,29x_7 + x_8 + 0,04x_9 +0,24x_{10} - 0,29x_{11} - 0,23x_{12} + 0,23x_{13} - 0,11x_{14}	$f_{W/C}$ = -32,7+ 0,11x_1 + 0,43x_2 + 2,63x_3 – 59,54x_4– 3,17x_5+0,32x_6 + 0,3x_7 + 0,4x_8 - 0,53x_9 + 0,43x_{10} - 0,17x_{11} + 0,15x_{12}-0,03x_{13} -0,1x_{14}

CONCLUSION

The article suggests a new scientific and practical integrative approach to create university energy-innovative CCP of knowledge management of energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of Covid-19 pandemic on the example of KNUTD. The novelty of the developed scientific and practical integrative approach consists in synergetic sequential integration of energy audit, energy certification, energy management, monitoring of the achieved level of energy efficiency. The proposed approach will address the university's energy conservation and efficiency in the context of preventing a new outbreak of the Covad-19 pandemic. Energy audit performance on critical DGNB indicators made it possible to construct energy profiles of 15 university buildings. The energy certification of 880 university offices was conducted by cluster analysis on 6 energy efficiency potentials: potential of heat energy saving during the heating period, potential of heat gain during the heating period, potential of heat energy saving due to improvement of building envelope, potential of heat gain reduction due to the thermal inertia of internal building envelope, potential of heating system saving due to use of automatic control of building's heating system, potential for saving electricity through the use of non-conventional renewable energy sources. The energy management action plan, using the fuzzy sets method, was based on the rating of university buildings using ABC analysis. For this purpose, group "A" offices were classified as those that give 80% of the implementation of the integral energy efficiency potential; group "B" offices - 15%; group "C" offices - 5%. The results of the weighted strategy shows that in a pessimistic scenario (continuation of the Covid-19 pandemic), classes will be given online, only offices of category A (administrative, technical, service offices; laboratories with unique equipment with 24-hour maintenance) will be used - 23% of the total offices. In case of an optimistic scenario (end of the Covid-19 pandemic), under the condition of returning to a normal work rhythm, 58% of offices with category A and B will be used. Monitoring of the weighted energy efficiency strategy performance has shown that the cost-effectiveness of the measures (installation of solar plant equipment, heating substation, thermostats, floor insulation) will make 15%. The payback period for the purchase and installation of non-conventional renewable energy equipment will make 6.7 years. Thus, the implementation of the suggested plan of measures for energy saving and energy efficiency will make it possible for the university to use reasonably the CCP of knowledge management of energy complexes with non-conventional renewable energy sources in the context of preventing a new outbreak of pandemic Covid-19. The prospect of further research is the economic and technical feasibility to implement the plan regarding gradual conversion of all university buildings to autonomous use of non-conventional renewable energy sources using CCP.

AUTHOR CONTRIBUTIONS

V. Shcherbak substantiated the research methodology, validation, conceptualization, I. Gryshchenko supervised the project administration, L. Ganushchak-Yefimenko collected and analyzed literature, wrote the initial draft; O. Nifatova did the research, observation, visualisation; V. Bobrovnik did the reviewing and editing; M. Verhun did the software, the validation, the formal analysis.

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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.

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ABBREVIATIONS

%	Percentage
°C-day/year	Degree-days of the heating period
^0C	Degrees Celsius
CCP	Common connection point
COVID-19	Coronavirus Disease 2019
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
EnB	Measuring energy performance using energy baselines
EnPI	Energy performance indicators
Eq.	Formula of calculation
Expl.Var	Explanatory Variable
Fig.	Figure
ISO	International Organization for Standardization
J	Joule, the unit of measure of work, energy and quantity of heat in the International System of Units
KNUTD	Kyiv National University of Technology and Design
kWh	Kilowatt-hour
kWh/m^2	Kilowatt-hour per square meter
m^2	Square meter
Prp.Totl	Percentage of the total variance explained
STATSTICA	Statistical analysis software package
UAH	Hryvnia
Var	Variable
$W/(m^2$-°C)	Watt per square meter Celsius

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ORIGINAL RESEARCH PAPER

Dissolved organic matter and its correlation with phytoplankton abundance for monitoring surface water quality

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ABSTRACT

BACKGROUND AND OBJECTIVES: Dissolved organic matter has a fundamental role in supporting phytoplankton abundance and growth in aquatic environments. However, these organisms produce dissolved organic matter with varied quantities or characteristics depending on the nutrient availability and the species composition. Therefore, this study aims to assess the characteristic of dissolved organic matter on surface water and its correlation with phytoplankton abundance for monitoring water quality.
METHODS: The sample was obtained at four Kali Surabaya river stations for further dissolved organic matter analysis and phytoplankton species analysis. The analysis was presented through bulk parameters of total organic, ultraviolet at 254 nm wavelength, specific ultraviolet absorbance value, and fluorescence spectroscopy using excitation-emission matrices with fluorescence regional integration analysis.
FINDINGS: The results showed the bulk parameters of dissolved organic matter at all stations were significantly different, as Station 1 and 2 were higher, while 3 and 4 had a lower concentration. Furthermore, the fluorescence spectroscopy identified four components of dissolved organic matter at all stations, namely aromatic proteins-like, humic acid-like, soluble microbial by-products-like, and fulvic acid-like, which is the unit of fluorescence spectra in arbitrary unit. Also, stations 1 and 2 were grouped in the high percentage fluorescence regional integration of humic substance (fulvic acid-like and humic acid-like), while 3 and 4 were classified in the high percentage fluorescence regional integration of non-humic substances (aromatic proteins-like and soluble microbial by-products-like).
CONCLUSION: The main phytoplankton species, namely Plectonema sp., Pinularia sp., Nitzchia sp., Navicula sp., had the highest abundance at Stations 1, 3, and 4, respectively. A strong correlation between dissolved organic matter analysis and phytoplankton abundance led to the usage of these methods for monitoring surface water quality.

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INTRODUCTION

Human, industrial and agricultural activities have significantly changed aquatic ecosystems due to high organic and inorganic wastewater discharge. This runoff has appeared in the eutrophication of rivers and tributary (Conley *et al*., 2009; Bhattacharya and Osburn, 2017) causing blooming phytoplankton and consequently, and the environmental issues (Paerl *et al*., 2008; Heisler *et al*., 2008; Biggs, 2000). It is eminent that phytoplankton community dynamics (i.e., taxonomic composition, abundance, and biomass) regard the quantity of inorganic phosphorus and nitrogen in the aquatic surrounding (Cao *et al*., 2016; Cuvin-Aralar *et al*., 2004). Furthermore, the impact of the organic pollutants contributes to the quantity or quality of dissolved organic matter in surface water. Allochthonous and autochthonous with effluent organic matter are the source of dissolved organic matter (DOM) in the surface water, since allochthonous could be generated from the upstream, midstream and the downstream. The upstream was found to be covered with perennial vegetation; the midstream is used for agriculture and covered with least forest; the downstream was mainly used for residential and utilized for different forms of agriculture (Dumago *et al*., 2018). In addition, biogeochemical cycles will affect the quality and quantity of DOM from the surrounding environment. Also, DOM has an essential role in supporting phytoplankton abundance and growth in aquatic surroundings (Kissman *et al*., 2017; Burpee *et al*., 2016) due to its usage as an organic nutrient source. It can be used by these micro-organisms as a source of nitrogen, phosphorus, and carbon when inorganic phosphorus and nitrogen are unavailable (Burpee *et al*., 2016). The primary producers were proposed as an important source that influences its composition in surface water (Biddanda and Benner, 1997). Conversely, DOM can be produced by phytoplankton (Thornton, 2014), with varied characteristics and quantity which are mostly dependent on nutrient availability (Myklestad, 1995), composition of phytoplankton type (Biddanda and Benner, 1997), and bacterial interaction (Ramanan *et al*., 2016). According to previous studies, various types of DOM have been found and released by different taxonomic groups of phytoplankton (Fukuzaki *et al*., 2014; Romera-Castillo *et al*., 2010). Phytoplankton production, microbial metabolism, residue from microbial degradation after their death and other processes, release protein-like materials as one of DOM components (Liu *et al*., 2019; Mangal *et al*., 2016). The fluorescence spectroscopy fingerprints, identified the signals of protein-like and humic-like materials released from extracellular Microcystis aeruginosa (Ziegmann *et al*., 2010). In addition, the DOM which is closely related to the phytoplankton community dynamics, mainly consist of humic-like and protein-like materials (Suksomjit *et al*., 2009; Zhang *et al*., 2014) and exhibits their blooming (Altman and Paerl, 2012; Hounshell *et al*., 2017). The qualitative and quantitative methods for characterizing organic matter analysis have been implemented to clarify the types of DOM transformation through the treatment process or in source water and their following removal. For example, using the bulk parameters of dissolved organic carbon (DOC) concentration, UV/vis at 254 nm wavelength to measure the aromaticity degree of organic matter and specific ultraviolet absorbance (SUVA) (Edzwald *et al*., 1985; Lai *et al*., 2015; Hidayah *et al*., 2017), high-performance size exclusion chromatography (HPSEC) with ultraviolet detector (UVD) or an on-line organic carbon detector (OCD) (Jiao *et al*., 2014; Lai *et al*., 2015), fluorescence spectroscopy as well as fluorescence excitation-emission matrices (FEEM) (Hidayah *et al*., 2017; Ho *et al*., 2019). These procedures have been previously applied in observing the contribution of phytoplankton degradation to DOM as chromophoric by using fluorescent spectroscopy (Zhang *et al*., 2009), to characterize DOM excreted by phytoplankton (Chari *et al*., 2013), and to reveal its relationship with the community (Liu *et al*., 2021). The use of bulk parameters and fluorescent spectroscopy methods, simultaneously for characterizing organic matter considering the phytoplankton abundance, have been rarely observed. Therefore, resulting in poor implementation of optimal water quality control measures. Furthermore, using these techniques to characterize organic matter and its correlation with phytoplankton abundance for monitoring surface water quality seems to urgently need implementation. Hence, this study aims to assess the characteristic of dissolved organic matter on surface water, as well as its correlation with phytoplankton abundance using the bulk parameters and fluorescence spectroscopy to monitor surface water quality. This study was conducted in the Kali Surabaya River, Surabaya, Indonesia, in 2021.

MATERIALS AND METHODS

Data collection

This study used water from the Kali Surabaya River in Surabaya city, a surface water source for public supply. The position of station 1 to station 4 is as shown in Table 1 and Fig. 1. The sample was collected twice per week from January to March 2021, and the DOM analysis, as well as phytoplankton abundance was measured through the bulk parameters and fluorescence spectroscopy. The parameters include TOC, UV_{254}, SUVA value, while fluorescence spectroscopy identified aromatic proteins-like (AP-like), humic acid-like (HA-like), soluble microbial products-like (SMPs-like), and fulvic acid-like (FA-like).

Table 1: The study sampling location characteristics

No.	Sampling station	Coordinate	Climate	Environmental condition
1	Rolag Telu dam	7°26’40” S 112°27’25” E	- Tropical - Sunny weather - Temperature 29^{O}C	- Downstream of the Brantas river - Stagnant water - No residential
2	Wringin Anom district	7°24’21” S 112°30’27” E	- Tropical - Sunny weather - Temperature 29^{O}C	- Agricultural land - There are residential - There are domestic activities (bathing, washing, latrine)
3	Cangkir district	7°22’04” S 112°37’47” E	- Tropical - Sunny weather - Temperature 29^{O}C	- Industrial area - Densely populated - Temporary dump site
4	Karang Pilang drinking water company inlet	7°20’54” S 112°40’51” E	- Tropical - Sunny weather - Temperature 29^{O}C	- Industrial area - There are residential - There are domestic activities (bathing, washing, latrine)

Fig. 1: Geographic location of the study area in the Kali Surabaya River, Indonesia

As this study targeted on dissolved organic matter in source water, 0.45 m filter paper was used to filter the collected source water (Millipore Corporation, USA) to eliminate suspended particles before analysis the parameters. Furthermore, the ultraviolet absorbance at 254 nm (UV_{254}) and total organic carbon (TOC) concentration of the water was measured for common physicochemical characteristics based on Standard Methods procedures (APHA *et al*., 2012).

TOC was quantified using TOC-500 Model (Shimadzu, Japan), while UV_{254} was detected by UV/vis spectrophotometer Model U-2001 (Hitachi, Japan). The SUVA value showed the dissolved organics were contained in hydrophilic fraction as calculated from measurements of UV_{254} and DOC samples. Perkin Elmer LS-55 spectrometer with excitation-emission wavelength pair was used to measure the fluorescence in the source water. Moreover, the excitation-emission matrix (EEM) were resulted for each sample by skimming overexcitation (Ex) wavelengths between 230 and 400 nm at an interval of 10 nm with emission (Em) wavelengths between 300 and 547.5 nm at 0.5 nm interval (Murphy *et al*., 2013; Hidayah *et al*., 2017). Counting of fluorescence regional integration (FRI) analysis was used to provide the cumulative fluorescence reaction of organic matter with identical characteristic in selected regions by integration beneath EEMs (Chen *et al*., 2003). The phytoplankton sampling was conducted using a plankton net mesh size 60 mm as much as 100 liters. Meanwhile, its identification was carried out in the laboratory using a binocular microscope with 10 x 10 magnification (AmScope B100B-MS). Also, the abundance was calculated using Sedgewick-Rafter Counting Chamber for three replications (Marienfeld GmbH).

Analytical framework

The Kolmogorov-Smirnov, one-way Analysis of Variance (ANOVA), and Pearson correlations were applied utilizing SPSS Statistics 17.0 software (IBM, Armonk, NY, USA). The Kolmogorov-Smirnov test opposed the empirical cumulative distribution function of bulk parameters data and the results of FRI analysis with the distribution expected when the data were standard. When the observed difference is adequately significant, the test will reject the hypothesis of bulk parameters data, the results of FRI analysis data, and phytoplankton abundance normality. However, when the p-value of this test is less than 5%, it can be concluded that the bulk parameters data, the results of FRI analysis data, and phytoplankton abundance are non-normal. The one-way ANOVA was applied to determine whether any statistically significant differences between the means of bulk parameters and the results of FRI data. It was also used to determine at least two groups of the parameters data as the results of FRI analysis were different. In addition, The Pearson correlation coefficients measured the strength of the linear relationship variables among TOC, UV_{254}, SUVA value, AP-like, FA-like, SMPs-like, HA-like, and phytoplankton abundance.

RESULTS AND DISCUSSION

The bulk parameters of dissolved organic matter in the river segment.

The distribution data for the bulk parameters of dissolved organic matter in the river segment as tested by Kolmogorov–Smirnov showed the TOC concentration ($P > 0.15$), UV_{254} concentration ($P > 0.15$), and SUVA value ($P > 0.15$) was normal. Furthermore, the normal distribution data was performed using ANOVA testing to know the differences in mean concentrations of TOC and $UV_{254,}$ as well as SUVA value. ANOVA with the Tukey 95% confidence interval also determined whether there were statistically significant or non-significance differences. The results indicated statistically significant differences in the mean concentration of the bulk parameters among the river segment with a p-value of 0.011, 0.001, and 0.004 in TOC, UV_{254}, and SUVA values, respectively. Moreover, enough evidence was provided, which concluded that the average of the bulk organic matter parameters at all stations was significantly different. The Tukey analysis classified the bulk parameters concentration at each station into two main groups. Station 1 and 2 were grouped in the high concentration, while 3 and 4 were classified in the bulk parameters' low concentration, which means the former had averages significantly different from the latter. The average TOC concentration for stations 1 and 2 was about a value 10.1-11.7 mg/L, while 3 and 4 were between 9.8-10.9 mg/L. The average UV_{254} concentration for stations 1 and 2 was in the range of 10.1-11.7 mg/L, while 3 and 4 were in between 9.8-10.9 mg/L. The average UV_{254} concentration for stations 1 and 2 was in the range of

0.65-0.8/cm, while 3 and 4 were 0.39-0.65/cm. The average SUVA concentration of stations 1 and 2 was 5.3-6.4 L/mg/m, while 3 and 4 were 4.0-5.3 L/mg/m. Furthermore, statistical box plot analysis presented the pattern for the bulk parameters of dissolved organic matter in the surface water. Figs. 2, 3, and 4 show a box plot of the average concentration of TOC, UV_{254}, and average SUVA value respectively. Fig. 2 shows that the highest average TOC concentration occurred at Station 2 with a varying range. In comparison, the lowest average TOC concentration with a low range occurred at station 4. In addition, the results showed the average concentration from the highest to the lowest was found at stations 2, 1, 3, and 4. The surface water used in this study contained 7.36 – 15.50 mg/L TOC concentration, which was typically associated with the DOC range. River water has a typical concentration about 2 to 10 mg/L of dissolved organic carbon, which was much higher than groundwater and seawater. Variation in average concentrations of TOC indicated various physical or ecological drivers, chemical processes, spatial changes, which can significantly affect on organic matters dynamics (Maie et al., 2006). The organic matter compositional changes could be induced by biophysical controls, such as changes in composition, which likely result in bioavailability, photoreactivity, nutrient cycling, or chelating capacity and can affect carbon fluxes consequentially ecological drivers not accounted for (Jaffe, 2008). In addition, the hydrology dynamics of surface runoff contributed to the surface water stream (Hood et al., 2006).

Fig. 3 describes the concentration of UV_{254}, which corresponded to the organic compounds with an aromatic structure, double bonds of C=C (Matilainen *et al*., 2011). In this study, the concentration of UV_{254} for surface water was 0.148 – 1.524/cm, which was within the typical range of river (0.085 – 0.4/cm) (Edzwald *et al*., 1985). The results showed that the average highest aromatic compound was detected at Station 1, while Station 4 had the average lowest concentration. Therefore, Station 1 contained higher humic matter with conjugated C=C double structural bonds than the others. Meanwhile, Station 4 contained lower humic matter than the others. As well known, organic compounds of humic matter contain unsaturated carbon bonds (double or triple) or aromatic rings in their molecular structure. Hence, it absorbs an amount of UV light through the water sample (Her *et al*., 2002).

Fig. 4. Shows the hydrophobicity of organic matter characteristic or specific UV-absorbance (SUVA) value. The results revealed a value between 1.45 – 9.36 L/mg/m. However, it was mostly higher

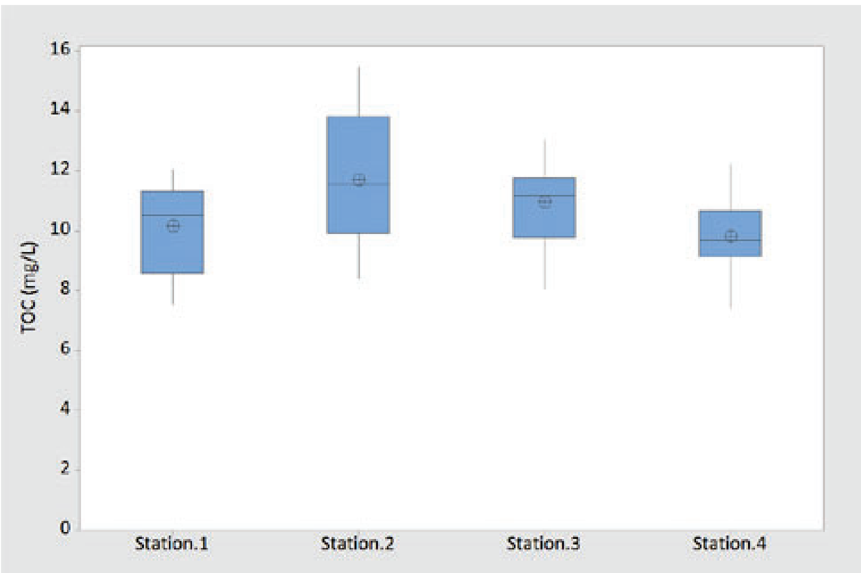


Fig. 2: The average TOC concentration in the river segment at various stations.

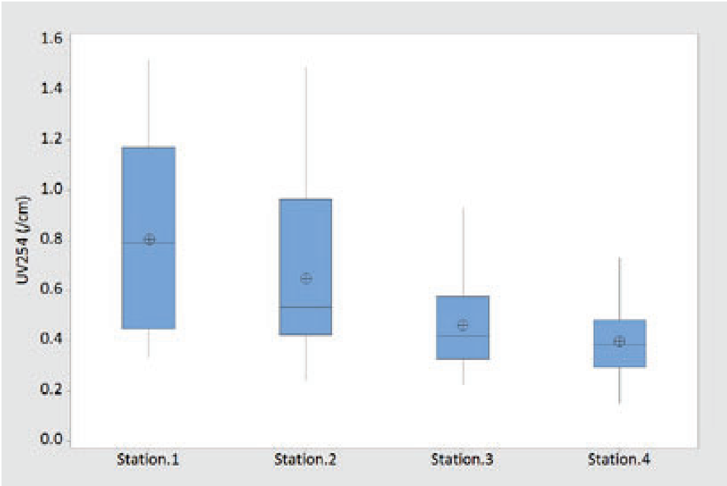


Fig. 3: The average UV_{254} concentration in the river segment at various station

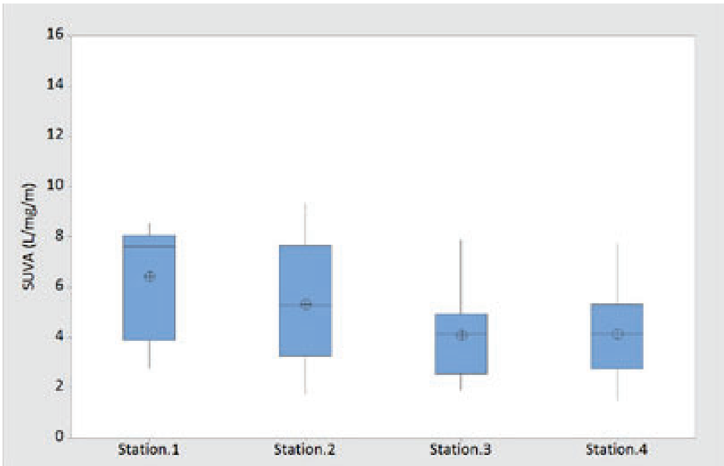


Fig. 4: The average SUVA value in the river segment at various station4

than 4 along the river segment, which means that the organic matter is mainly consists of humic, hydrophobic, and high molar mass organic material. According to Edzwald and Tobiason (2011), SUVA is a parameter of the organic matter composition in water. Source water with SUVA values ≥ 4 indicated that natural organic matter composed mainly of humic or hydrophobic matter, while those < 2 contained mainly non-humic or hydrophilic natural organic matter. The results were consistent with the high concentration of UV_{254} (0.148 – 1.524/cm). The values typically ranged from 1.0 to 6.0 L/mg/m for surface water. However, values greater than 6.0 were revealed for interstitial waters dominated by a solid terrestrial signature (Jaffe *et al.*, 2008). According to previous studies, these higher values can be as a result of the absorption at 254 nm from colloids, iron, or other components in the sample (Weishaar *et al.*, 2003; Hudson *et al.*, 2007). Combining the bulk parameters of TOC, $UV_{254,}$ and SUVA value led to characterize the organic matter in the river. Station 2 was mainly composed of the highest TOC with lower aromatic and hydrophobic than 1, and vice versa. Also, station 4 was mainly composed of lower bulk parameters than 3. Therefore, 2 contained more aliphatic organic matter that does not absorb at 254 nm than the others. The lower SUVA value among all stations indicated the mixtures of aquatic humics, hydrophobic and hydrophilic, and molecular weights of organic matter.

Characteristic of fluorescence dissolved organic matter in the river segment through volumetric fluorescence distribution.

Fig. 5. Illustrates the fluorescence excitation-emission matrices (FEEMs) for dissolved organic matter in the river segment at a different station, taken on the first week sampling time. Dissolved organic carbon was classified into four regions based on its excitation/emission wavelengths (Ex/Em), namely Region 1 indicated the aromatic proteins-like (AP-like), such as tyrosine and tryptophan, at Ex/Em <250 nm/<350 nm. Region 2 identified the fulvic acid-like (FA-like) substances at Ex/Em <250 nm/>380 nm, Region 3 was corresponded to the soluble microbial by products-like (SMPs-like) substances at Ex/Em 250-280 nm /<380 nm, while Region 4 was identified as the humic acid-like (HA-like) substances with Ex/Em >280 nm/>380 nm (Chen *et al*., 2003).

This study shows that the fluorescence component from FEEM analysis has consistent results with previous studies (Her *et al*., 2003; Yao *et al*., 2016; Moradi *et al*., 2018; Hidayah *et al*., 2020). Generally, HA-like and FA-like correlated with aromatic compounds. They mainly exist as carboxylic and phenolic functional groups in natural dissolved organic matter. These fluorescence structures are mostly present as a significant percentage of humic substances, which typically represent over 50% of natural organic matter (Shon *et al*., 2012). In addition, source water may contain protein-like materials which microbial activities can generate. The amount, characteristics, and properties of dissolved organic matter in the aquatic system depend on their origin and environmental biochemical cycles. Sources of organic matter are classified as allochthonous (generated from a terrestrial watershed) and autochthonous (produced by organism activities,

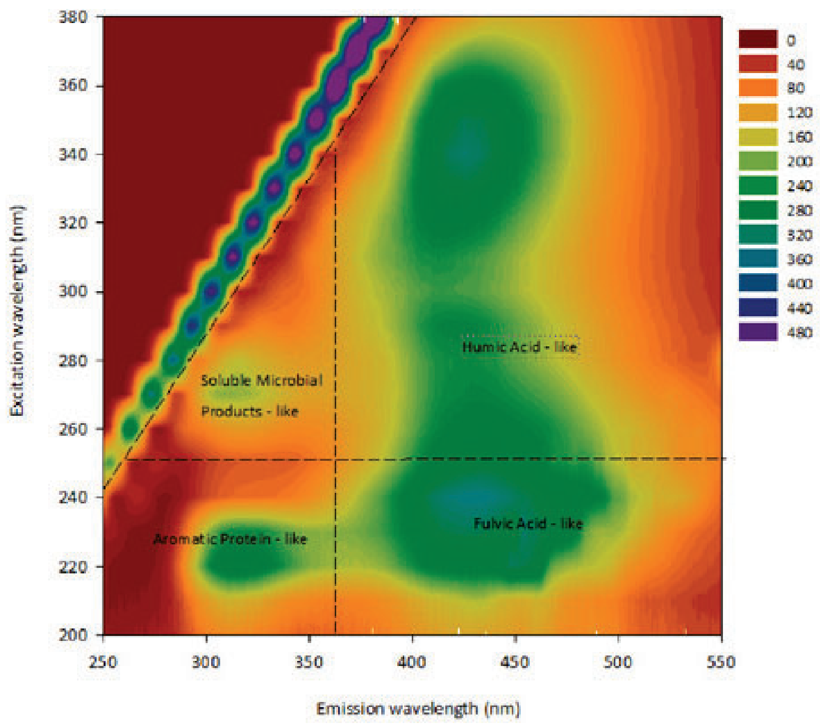


Fig. 5: Spectrum of fluorescence spectrometer analysis in the river segment

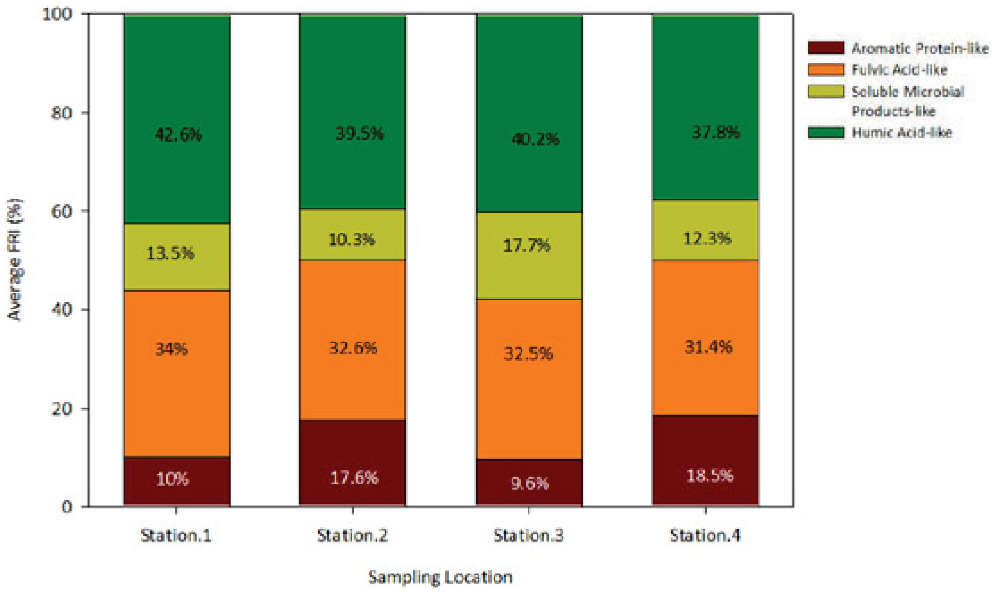
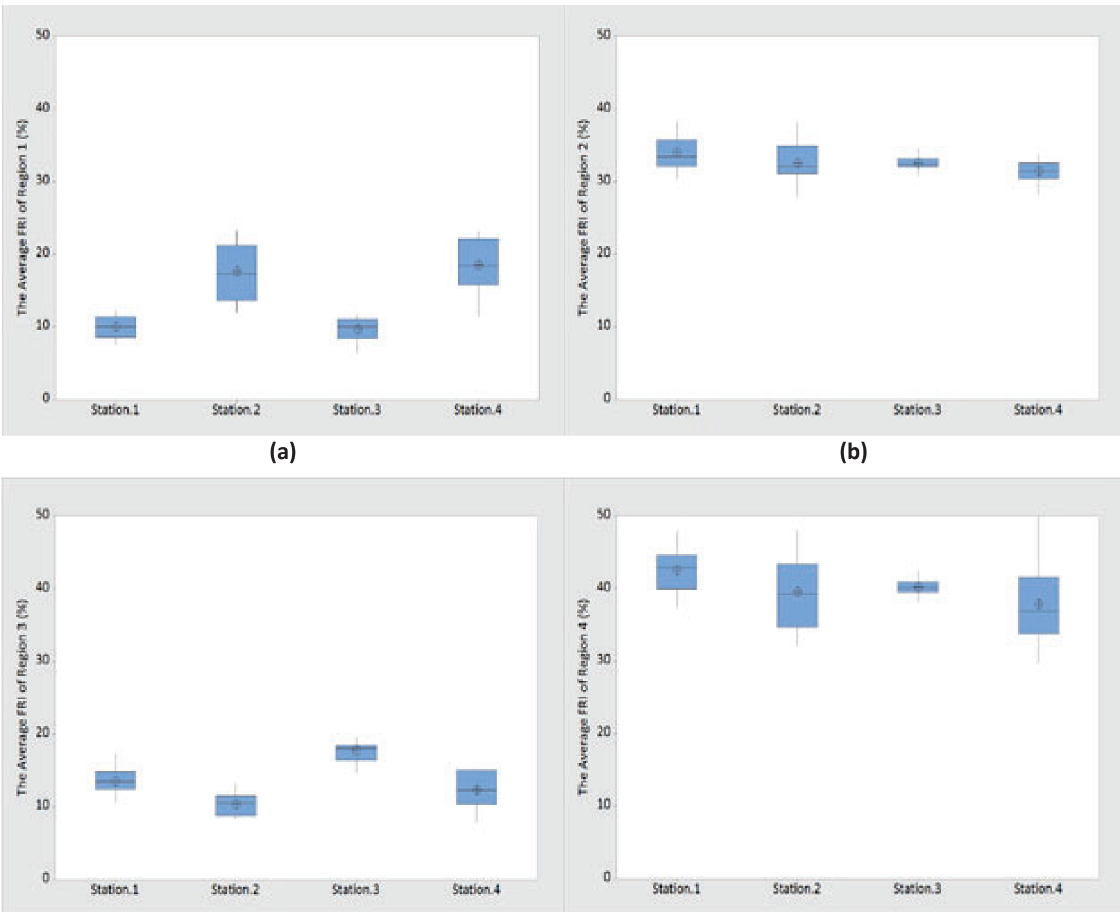


Fig. 6: FRI distribution of fractionated organic matter from the various river segment

such as phytoplankton activities) (Chari *et al*., 2013; Zhang *et al*., 2009; Haraguchi *et al*., 2019). Terrestrial watershed is mainly composed of humic substances such as fulvic and humic acids as well as humin, which are primarily hydrophobic and rich in aromatic carbon. The autochthonous source material is microbially derived organic, such as algal-derived and effluent organic matter (Kelso and Baker, 2020). Fig. 6 showed the percentage fluorescence response, which was calculated by Fluorescence Regional Integration (FRI) method. The percentage of fluorescence distribution indicated the four fractions quantity of fluorescence organic matter. This study classified the fraction into humic and non-humic substances-like. The first was represented by Region 2 (FA-like) and 4 (HA-like), while the second one by Region 1 (AP-like) and 3 (SMPs-like). Firstly, the results showed the highest total percentage of FRI in Region 2 and 4 was at Station 1 (76.6%), and the lowest total percentage for humic substances-like was at Station 4 (69.2%). Both components are classified as humic substances and are mainly composed of aromatic compounds with high to medium molecular weight (Watson *et al*., 2018; Hua *et al*., 2020). Their total percentage FRI showed a consistent UV_{254} concentration and SUVA value. Furthermore, Station 1 had the highest bulk parameters, while 4 had the lowest. Secondly, the highest total percentage FRI of Region 1 and 3 (30.8%) was identified at Station 4, with the lowest at 1 (23.4%). This indicated that Station 4 contained abundant proteins substances and microbial-like fluorescence than the others and followed the lowest SUVA value of Station 4 with the highest for Station 1. Region 1 and 3 correlated with high molecular weight protein-like, which had chemical properties related to aromatic amino acids, tryptophan or tyrosine-like (Yamashita *et al*., 2008; Hua *et al*., 2020) and low molecular weight microbial humic-like as well as less conjugated double bond organic matter (Nguyen *et al*., 2013; Hua *et al*., 2020).

The distribution data for the fluorescence of dissolved organic matter in the river segment was tested by Kolmogorov–Smirnov and the bulk parameters. The results showed distribution data for percentage FRI of Region 1 (AP-like), 2 (FA-like), 3 (SMPs-like), and Region 4 (HA-like) with $P > 0.000$, 0.007, 0.000 and 0.013 respectively were normal. Furthermore, Analysis of Variance (ANOVA) testing was carried out to determine the differences in mean percentage FRI for each region. The statistical analysis ANOVA One-Way with the Tukey 95% confidence interval also determined whether statistically significant or non-significance differences in percentage FRI of AP-like, FA-like, SMPs-like, and HA-like among all stations. The results showed statistically significant differences in the mean percentage FRI of all fluorescence organic fractions at all stations with p = 0.000, 0.007, 0.000, and 0.013 in AP-like, FA-like, SMPs-like, HA-like, respectively. The results provided enough evidence to conclude that the mean percentage FRI of all fluorescence organic fractions at all stations was significantly different. Moreover, the Tukey analysis classified their percentage FRI at each station into two main groups. Station 1 and 2 were grouped in the high percentage FRI of humic substance-like (FA-like and HA-like), while 3 and 4 were classified in the low percentage. This means the former had an average percentage FRI of FA-like and HA-like, which were significantly different from the latter. In addition, stations 3 and 4 were grouped in the high percentage FRI of non-humic substance-like (AP-like and SMPs-like), while stations 3 and 4 were grouped in the low percentage. This showed both had average percentage FRI of AP-like and SMPs-like, which were significantly different from stations 1 and 2. Moreover, statistical box plot analysis presented the pattern of the fluorescence organic matter in the river segments. Fig. 7a to 7d presented box plot with average percentage FRI of the organic matter. Firstly, a comparison among all fluoresces organic compounds showed the average FRI of HA-like was much higher and much lower for SMPs-like than the others. However, HA-like, located at Region 4 of the fluorescence spectra, had the most extensive range of excitation and emission wavelengths. Therefore, the humic acid substances-like region had the most extensive volume distribution of FRI when compared to others (Chen *et al*., 2003). Meanwhile, SMPs-



(a) (b)

(c) (d)

Fig. 7: The average percentage FRI of fluorescence organic matter in the river segment at various stations

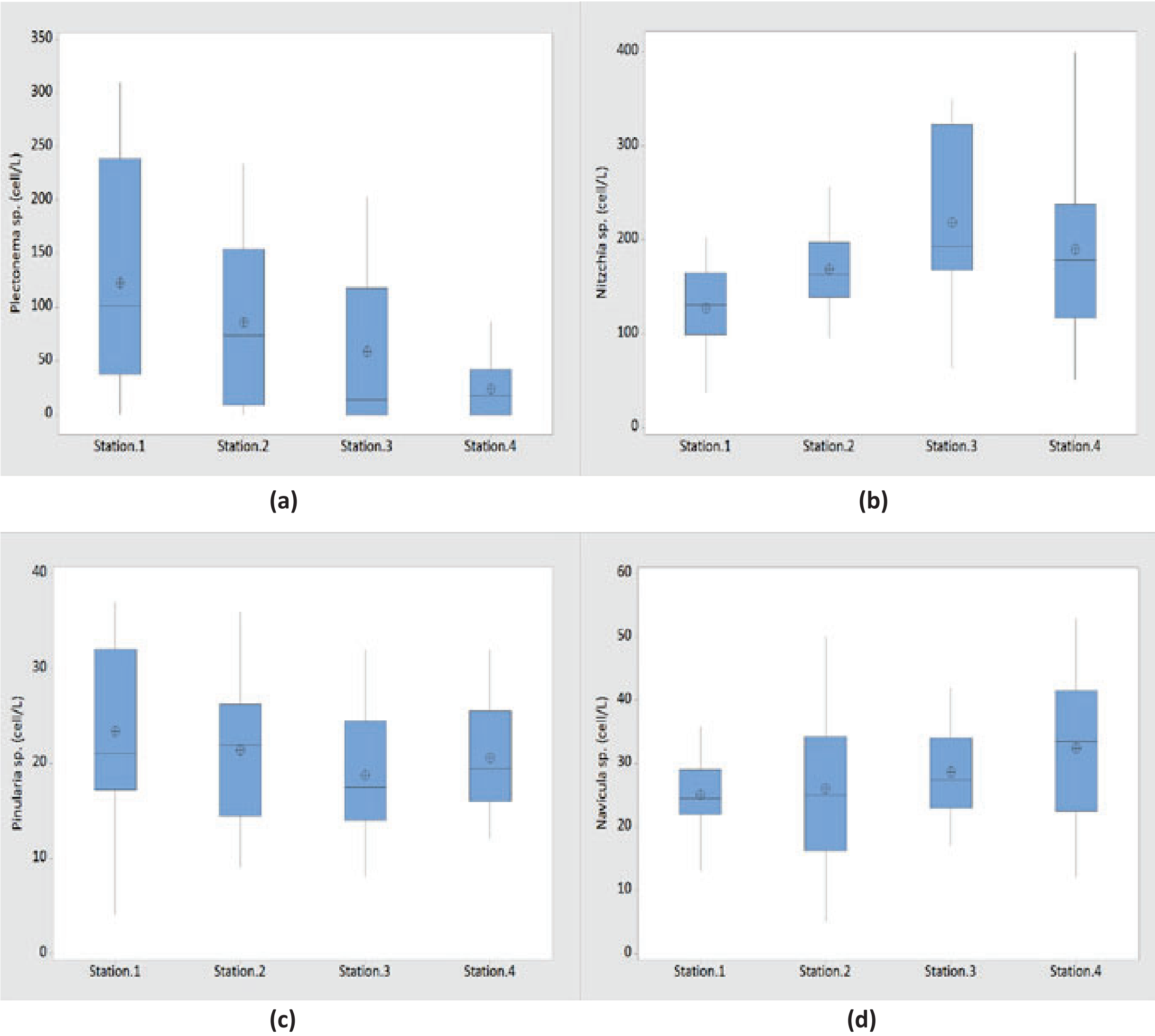


Fig. 8: The average of phytoplankton abundance in the river segment at various station

like or Region 3 comprised a dominant percentage of the fluorescence in wastewater treatment plant effluent (Chen *et al.*, 2003) and was closely related to the phytoplankton activities (Liu *et al.*, 2021; Hua *et al.*, 2020). Second, the average percentage FRI of the organic matter indicated different quantities and quality at each station. The non-humic substances-like fluorescence as presented by AP-like, SMPs-like, with statistical analysis, had a higher percentage FRI at stations 3 and 4 than the others. It was likely that Station 3 and 4 had a higher percentage of extracellular biological organic matter fraction than the other river segments. The fraction was supposed to contain soluble microbial products of amino acids and carbohydrates. Tryptophan and tyrosine which are aromatic amino acids, were confirmed as biological activity products in natural systems and exhibited a distribution of fluorescence response similar to AP-like and SMPs-like of this study (Coble 2007; Determann *et al.*, 1998). The humic substances-like fluorescence as presented by FA-like and HA-like had a higher percentage FRI at stations 1 and 2 than others and were tested by ANOVA One-Way. Combining the bulk parameters of TOC, UV_{254}, SUVA value, and fluorescence spectroscopy convinced the characteristic of organic matter in the river. Station 1 and 2 had high UV_{254} concentration, SUVA value, high percentage FRI of FA-like and HA-like substances. It was conjectured that stations 1 and 2 were mainly composed of aromatic, hydrophobic, humic substances organic matter, which may be generated from terrestrial systems.

Station 3 and 4 had lower UV concentration and SUVA values, with a high percentage FRI of AP-like and SMPs-like than the others. There was a lower SUVA value among all stations indicates in the mixtures of aquatic humics, hydrophobic and hydrophilic, as well as molecular weights of organic matter. This showed that Station 3 and 4 comprised more autochthonous and sources of organic matter from anthropogenic activities. The river ecosystem, which source is terrestrial, autochthonous, and anthropogenic, provided hotspots for storing, transporting, and transforming organic matter. The sources proportions were primarily and terrestrially derived with increased autochthonous inputs from macrophytes. In addition, the sources of dissolved organic matter are a mixture of terrestrial, autochthonous, or primarily from wastewater effluent (Kelso and Baker, 2020).

Contribution of phytoplankton abundance to fluorescence dissolved organic matter in the river segment.

This study discovered four main phytoplankton species with various abundance in the river segments, namely Plectonema sp., Nitzchia sp., Navicula sp., and Pinularia sp. The distribution data of the phytoplankton abundance in this segment was tested by Kolmogorov–Smirnov. The results showed a usual distribution data for Plectonema sp., Nitzchia sp., Navicular sp., and Pinularia sp. as abundance $P > 0.000$, 0.007, 0.000, and 0.013, respectively. Furthermore, ANOVA testing was carried out to determine the differences in the mean phytoplankton abundance of the river segments. The statistical analysis ANOVA One-Way with the Tukey 95% confidence interval determined whether there were statistically significant or non-significance differences in the abundance of the species among all stations. According to the results, there were statistically significant differences in the mean abundance of phytoplankton at all stations with p-value = 0.006 and 0.01 in Plectonema sp. and Nitzchia sp. abundance, respectively. Meanwhile, the analysis generated p-value = 0.156 and 0.412 for Navicula sp. and Pinularia sp. abundance, respectively, therefore, classified as only one group of phytoplankton abundance. This showed that there were non-significantly differences in both species abundance among all stations. The Tukey analysis classified Plectonema sp. and Nitzchia sp. abundance at each station into two main groups. Station 1 and 2 were grouped in the high Plectonema sp. and low Nitzchia sp. abundance, while Station 3 and 4 were classified in the low Plectonema sp. and high Nitzchia sp. abundance. Furthermore, the statistical box plot analysis presented the pattern of the phytoplankton abundance in the river segments.

Fig. 8a to 8d present box plots of their average abundance. Firstly, a comparison among the species at all stations conjectured that Nitzchia sp. had a higher abundance, and Pinularia sp. was lower than the others. Meanwhile, Plectonema sp. had the highest at Station 1 and the lowest at 4. Nitzchia sp. had a higher abundance at Station 3 and lower at 1. Moreover, Navicula sp. had the highest abundance at Station 4 and the lowest at Station 1. Pinnularia sp. gave the highest at Station 1, with the lowest at Station 3. This phytoplankton abundance was strongly influenced by migration, which can occur due to population density and physical environmental conditions, such as changes in temperature and currents (Basu and Mackey, 2018). Secondly, Station 1 was likely to contain a similar abundance in Plectonema sp. and Nitzchia sp., and the same for Navicula sp. and Pinularia sp. Stations 2 and 3 showed that the abundance of Nitzchia sp. was primarily dominant than others. However, Navicular sp. was similar to Pinularia sp. Station 4 identified a similar abundance of Plectonema sp., Navicular sp., and Pinularia sp. There is competition in several phytoplankton species that use the same resource lacking in availability, or even regardless of sufficient availability, and competition still occurs when they take advantage of the resource, with one attacking the other or vice versa (Burson *et al*., 2018).

The relationship among the bulk parameters, organic fluorescence parameters, and phytoplankton abundance

The degree correlation between the bulk parameters, fluorescence organic matter, and

Table 2: The degree correlation among the bulk parameters, fluorescence organic matter, and phytoplankton abundance*

Parameters	TOC	UV_{254}	SUVA	AP-like	FA-like	SMPs-like	HA-like	Navicula sp.	Plectonema sp.	Pinnularia sp.
UV_{254}	0.085 0.502									
SUVA	-0.044 0.729	0.887 0.000								
AP-like	-0.287 0.022	-0.440 0.000	-0.373 0.002							
FA-like	0.254 0.042	0.105 0.411	0.047 0.710	-0.249 0.048						
SMPs-like	-0.038 0.764	-0.198 0.116	-0.228 0.070	0.638 0.000	-0.085 0.505					
HA-like	-0.035 0.786	0.344 0.005	0.344 0.005	-0.674 0.000	-0.022 0.862	-0.348 0.005				
Navicula sp.	-0.109 0.392	-0.331 0.007	-0.289 0.021	0.193 0.126	-0.102 0.422	0.090 0.480	-0.082 0.521			
Plectonema sp.	0.271 0.030	0.137 0.281	0.131 0.303	-0.346 0.005	0.293 0.019	-0.057 0.652	0.110 0.386	0.166 0.189		
Pinnularia sp.	-0.097 0.448	-0.239 0.058	-0.292 0.470	-0.245 0.051	0.142 0.263	-0.268 0.032	0.220 0.080	0.137 0.279	0.320 0.010	
Nitzchia sp.	-0.243 0.053	-0.283 0.023	-0.203 0.108	0.160 0.205	-0.203 0.107	0.176 0.164	0.070 0.585	0.168 0.184	0.035 0.785	0.174 0.170

*Cell Contents description; Pearson correlation (the first row of the number of correlation between parameters); P-value (the second row of the number of correlation between parameters)

phytoplankton abundance was examined, as shown in Table 2. Correlation analysis was carried out using TOC and UV_{254} concentrations, SUVA value with percentage FRI of AP-like, FA-like, SMPs-like, or HA-like, as well as the abundance of Plectonema sp., Nitzchia sp., Navicula sp., and Pinularia sp. Firstly, based on the correlations of the bulk parameters, TOC concentration was positively higher with Region 1 (AP-like) and Region 2 (FA-like). In addition, UV_{254} concentration and SUVA value were significantly correlated with Region 1(AP-like) and Region 4 (HA-like). The results showed fluorescence spectroscopy, which fractionated AP-like, FA-like, SMPs-like, and HA-like could be used to identify the quantity and quality of organic matter in the source water.

This result was expected since TOC measured all organic carbon, including humic and non-humic substances, as presented by AP-like and FA-like. Secondly, a strong positive correlation between UV_{254} concentration and SUVA value indicated that higher aromatic conjugated double bond corresponded to higher molecular weight organic, more hydrophobic, and content of humic substances. These results are consistent with the Pearson correlation between bulk parameters of UV_{254} correlation, SUVA, and fluorescence organic matters of AP-like and HA-like. Furthermore, it was conjectured that fluorescence spectroscopy could be used to assess the properties of organic matter existing in the source water. Thirdly, the results showed that TOC had a stronger correlation with AP-like than HA-like. This was probably because the humic structure may incorporate protein-like-fluorophores due to weak interactions based on x-x or van der Waals forces between the dissolved organic matter components. Previous studies indicated that proteins and humic supramolecules containing specific structures attained from phenol or aniline might contribute to the fluorescence. Fourth, this study discovered a strong correlation between DOM and phytoplankton abundance. Plectonema sp. correlated with TOC, AP-like, and FA-like, while Navicula sp. and Nitzchia sp. correlated with UV_{254}, and Pinularia sp. with SMPs-like. The existence of phytoplankton was likely to enhance the quantity and characteristics of DOM in the aquatic environment. The production of marine-like fluorophores accompanied phytoplankton degradation as a significant source of autochthonous DOM (Wada *et al*., 2007). In addition, higher molecular weight compounds such as protein (tryptophan)-like fluorescence were presented in exudates when phytoplankton grows (Chari *et al.*, 2013). The combination of the bulk parameters (TOC, UV_{254}, and SUVA value), fluorescence spectroscopy, and phytoplankton abundance convinced the quality of organic matter in the surface water. However, it could be eventually used to monitor the water's quality.

CONCLUSION

This study showed that the quality and quantity of DOM at all stations were significantly different, as classified into two groups with higher bulk parameters at stations 1 and 2 and a lower concentration at 3 and 4. The average TOC concentration for stations 1 and 2 was about a value 10.1-11.7 mg/L, while 3 and 4 were in between 9.8-10.9 mg/L. The average UV_{254} concentration for stations 1 and 2 was in the range of 10.1-11.7 mg/L, while 3 and 4 were between 9.8-10.9 mg/L. The average UV_{254} concentration for stations 1 and 2 was 0.65-0.8/cm, while 3 and 4 were 0.39-0.65/cm. The average SUVA concentration of stations 1 and 2 was in the range 5.3-6.4 L/mg/m, while 3 and 4 were 4.0-5.3 L/mg/m. In addition, fluorescence spectroscopy with FRI analysis showed stations 1 and 2 were grouped in the high percentage FRI of humic substance-like (FA-like and HA-like) about 74.35%. It was conjectured that stations 1 and 2 were mainly composed of aromatic, hydrophobic, humic substances organic matter, which may be generated from terrestrial systems, while stations 3 and 4 were classified in high percentages non-humic substances-like (AP-like and SMPs-like) about 29.05%. This showed that Station 3 and 4 comprised more autochthonous and sources of organic matter from anthropogenic activities. According to phytoplankton abundance, Station 1 had a high abundance of Plectonema sp. (238.5 cell/L) and Pinularia sp. (32 cell/L), while stations 2 and 3 mainly consisted of Nitzchia sp. (197.5 cell/L and 322.75 cell/L), and Navicula sp. (41.5 cell/L) was dominant at Station 4. The Pearson correlation showed a strong relationship between DOM and phytoplankton abundance. Therefore, Plectonema sp. was in correlation with TOC (0.271), AP-like (-0.346), and FA-like (0.293), while Navicula sp. and Nitzchia sp. correlated with UV_{254} (-0.331 and -0.283), and Pinularia sp. correlated with SMPs-like (-0.268). This study conjectured that the bulk parameters of DOM, fluorescence spectroscopy, and phytoplankton abundance could be used to assess the characteristic of DOM, while the combination of these methods could be used to monitor the surface water quality. Future work should be conducted on the laboratory scale for phytoplankton observation in order to identify the characteristic of organic matter that a kind of phytoplankton species has released. Therefore, it could be used to predict the amount of DOM derived by phytoplankton, DOM derived in the aquatic, and DOM from the terrestrial watershed.

AUTHOR CONTRIBUTIONS

O.H. Cahyonugroho performed the experimental design, analyzed the data, and prepared the manuscript text as well as the literature review. S. Hariyanto and G. Supriyanto interpreted the data and helped in manuscript preparation.

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CONFLICT OF INTEREST

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

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ABBREVIATIONS

%	Percent
/cm	Per centimeter
ANOVA	Analysis of variance
AP-like	Aromatic proteins-like
C=C	Carbon chain double bonds
cell/L	The number of phytoplankton cell per liter
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
Em	Emission wavelength
Ex	Excitation wavelength
FA-like	Fulvic acid-like
FEEM	Fluorescence spectroscopy using excitation-emission matrices
FRI	Fluorescence regional integration
HA-like	Humic acid-like
L/mg/m	Liter per miligrams per meter
mg/L	Miligrams per liter
mm	Milimeter
µm	Micrometer
Navicula sp.	Navicula species
Nitzchia sp.	Nitzchia species
NOM	Natural organic matter
nm	Nanometer
OCD	Organic carbon detector
P >	Probability value more than
P =	Probability value equal
Pinnularia sp.	Pinnularia species
Plectonema sp.	Plectonema species
P-value	Probability value
SMPs-like	Soluble microbial by products-like
SUVA	Specific ultraviolet absorbance
TOC	Total organic carbon
UV_{254}	Ultraviolet at 254 nm wavelength
UVD	Ultraviolet detector
UV/vis	Ultraviolet visible

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CASE STUDY

Implications of irrigation water quality in tropical farms

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ABSTRACT

BACKGROUND AND OBJECTIVES: Irrigation system water quality is a complex issue that involves the combined effects of various surface water management parameters. Monitoring of irrigation water quality is essential for the sustainability of crop production and productivity. The department of Sucre, in northern Colombia, is predominantly a ranching and agricultural region where agriculture is the main source for livelihoods. The purpose of this study was to assess the physicochemical quality of surface water in irrigation systems at 141 farms.
METHODS: To this end, 141 water samples were taken to determine 22 physicochemical parameters. All in-situ measurements and laboratory analysis were performed using standard methods. The results obtained were compared with the international standards proposed by the United Nations' Food and Agriculture Organization and the World Health Organization. Salinity and sodicity were measured using the irrigation water classification diagram, and the level of correlation between the 22 variables was assessed by means of correlation analysis.
FINDINGS: The results obtained indicate that based on the measured parameters, the water is classified as appropriate for use in irrigation systems. The maximum and minimum pH values were 9.32 and 4.40, respectively; the maximum and minimum values of electrical conductivity were 669 and 19.80 µS/cm respectively; the maximum and minimum values of total dissolved solids were 478 and 11.80 mg/L respectively, and the maximum and minimum values of the sodium adsorption ratio were 1.72 and 0.01 mEq/L, respectively.
CONCLUSION: Cation and anion concentrations were within the limits allowed by the Food and Agriculture Organization and the WHO. According to the irrigation water classification diagram, the waters were classified as C1S1 and C2S1, which implies that there are no restrictions for their use in irrigation systems, water type (I) and type (II).

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INTRODUCTION

Developing countries are vulnerable to issues related to water pollution, mainly due to bad habits in the use of water resources and to rapid industrialization (Faye, 2019; Kushal, 2015). Traditionally, farmers irrigate using surface water, and it is estimated that the irrigation of farmlands consumes between 33 and 90% of the world's water sources, which makes irrigation an activity that affects water availability (Betancourt Aguilar *et al*., 2017). According to the Intergovernmental Panel on Climate Change (IPCC), agriculture uses 70% of fresh water worldwide (IPCC, 2019; Yan *et al*., 2021); and in countries such as Colombia, water consumption in agricultural activities (IDEAM, 2012), and especially in irrigation systems, accounts for 50-74% of the total (FAO, 2015). Water used for irrigation systems depends on its quality (Gómez *et al*., 2015), which implies that it is necessary to assess its physical, chemical, and biological parameters to determine whether it is appropriate for use in the soils (Douti *et al*., 2021). It is extremely recommended that continuous monitoring of physico-chemical parameters in order to generate useful data and information to be used as a future basis in management actions that would help in mitigating problems in water resource (Douti *et al*., 2021; Dumago *et al*., 2018). Monitoring of irrigation water quality is essential for the sustainability of crop production and productivity. Despite this, not much information is available on the quality of the water used for irrigation in tropical areas that are vulnerable to the effects of climate change and with few management activities, mainly on the effects that the salinity and sodicity of the water used for irrigation may have, which is associated with high levels of electrical conductivity (EC) and a high sodium adsorption ratio (SAR). In general, salinity and sodicity produce abiotic stress, which affects morphological, physiological, and biochemical processes, including seed germination, growth, and water and mineral absorption, which reduce plant yields, quality, and productivity. It additionally affects the osmotic potential of soils, which produces hydric tress and toxic effects on plants, giving rise to metabolic and nutritional disorders, and in certain conditions of soil texture in may produce reduced yields, lower water infiltration, the formation of crusts on the surface and clogging of pores, which may end up degrading the soil and increasing runoff (Bauder *et al*., 2019; Li and Kang, 2020; Sekhon *et al*., 2020; Taghizadehghasab *et al*., 2021). Regardless of its source, irrigation water contains some dissolved salts. Medina Valdovinos *et al*. (2016) and Zaman *et al.* (2018) indicate that water quality for irrigation is determined by the nature, quantity, and proportion of ions present. Also, the suitability of water for irrigation is determined not only by the quantity of salts present, but also by the type of salts (Valles-Aragón *et al*., 2017; Zaman *et al.*, 2018). Several authors have defined the main variables that should be taken into consideration to classify the quality of water for irrigation systems from an agricultural perspective, some of the most important of which include: the concentration of soluble salts, the relative concentration of sodium (Na) with respect to other cations, the concentration of boron (B) or other elements that may be toxic under certain conditions, and the concentration of bicarbonates in relation to the concentration of calcium (Ca) and magnesium (Mg) (Gómez *et al*., 2015; Haritash *et al*., 2016; Zaman *et al*., 2018). Also, water used for irrigation is exposed to pollution from runoff, industrial discharges, use of agricultural chemicals and infiltration, among others, which may have significant short-term effects on the physicochemical characteristics of the water, and in turn on soil productivity and crop quality (Douti *et al*., 2021; Kushal, 2015); and in the long term may produce changes in the edaphic properties of soil, possibly to the point of making lands unsuitable for agriculture (Bortolini *et al*., 2018). On the other hand, water quality can have a negative effect on the performance of an irrigation system due to plugging of emitters and sprinklers. Problems can be caused by inorganic solids (silt and sand), organic solids (algae, bacteria, and slime) and dissolved solids (calcium, iron, and manganese). Potential problems can be minimized by testing the water quality to avoid potential issues (Lamont, 2012). As a tool to assess the suitability of water quality for irrigation, irrigation and water resource authorities from several countries and international organizations such as the FAO have proposed classification and monitoring methodologies (Adeyemi *et al*., 2017). FAO is currently developing a tool monitor water and soil based on field data, models, and satellite images. The tool will help countries monitor indicators of the Sustainable Development Goals (SDGs) associated with water quality (FAO, 2021). Additionally, each country has regulations on the use of water for irrigation, supported by international standards. In Colombia, the water quality of irrigation systems is determined based on the parameters established in decree 1076/2015, the Single Regulatory Decree of the Environment and Sustainable Development Sector, which establishes certain water quality parameters for use in agricultural activities (MINIAMBIENTE, 2015). However, this decree is insufficient for determining the water quality for irrigation, because at present the water used for irrigation is from different sources, including underground and surface waters. Due to the above, most studies in Colombia rely on international standards (Guerrero Guio *et al*., 2021), which contain threshold values based on criteria such as optimal crop yields, crop quality, suitability of the soil and irrigation equipment maintenance (Afed Ullah *et al.,* 2018). Even though such standards are specific for defined areas, they are the only points of reference available in the literature. Based on the above, the need arises to set clear and precise parameters to determine the maximum and minimum values of minerals, metals, pH, EC, and SAR that water used for irrigation in Colombia should have, to contribute the required nutrients to both the crops and the soils to achieve good yields and productivity, and to help mitigate the effects of climate change. Only a handful of studies have been made in Colombia and no studies have been carried out in the northern region of the country (Caribbean region). One noteworthy study was carried out on the plateau surrounding Bogotá (Colombia's capital), which determined the water quality for irrigation in horticulture crops around influence of the Bogotá River, one of the most polluted rivers in Colombia (Miranda *et al*., 2008). González Castillo *et al*. (2020) carried out the characterization of irrigation water at 90 farms in Norte de Santander (northeastern Colombia), which were proposed for the establishment of 18 agro-ecological models. Lastly, Guerrero Guio *et al*. (2021) assessed the quality of irrigation in eight municipalities in Boyacá (in eastern Colombia) at 60 ecological farms. In this sense, studies are required to establish a baseline for the development of agricultural policies and the establishment of management actions that promote the sustainable development and food security of small farmers. The aims of the current study is to determine physicochemical water quality and assess its suitability for irrigation. This study has been carried out in irrigation systems at 141 properties owned by small farmers in the department of Sucre (northern Colombia) in five prioritized municipalities (San Onofre, San Marcos, Morroa, Corozal and Majagual). The field measurements and laboratory analysis were carried out in 2020.

MATERIALS AND METHODS

Survey design and data collection

The department of Sucre is one of the 32 departments in Colombia (South America). It is located in the northwest of the country in the Caribbean region. It limits to the north with the department of Bolívar, to the south with the department of Córdoba and to the east with the Caribbean Sea (Fig. 1). Sucre has an area of 10917 Km^2 and a population of 949252 (Bustamante *et al*., 2016), of which 37.7% are small farmers. The agricultural production of small producers in the department of Sucre is carried out under limited management practices, they carry out manual tillage, have little soil management and make an inappropriate use of agrochemicals (DNP, 2003). Additionally, small producers do not document the frequency, quantity and agrochemicals used. Common crops in the study area include corn, cassava, yams, and plantains. The department of Sucre has 26 municipalities that make up five sub-region (Table 1).

Five municipalities were selected in the study namely, Corozal, Morroa, San Onofre, San Marcos, and Majagual for the subregions of savanna, Montes de Maria, Golfo de Morrosquillo, San Jorge, and Mojana, respectively (Fig. 1). The water used for irrigation in the subregions comes from artificial ponds, which are supplied by runoff from rainwater. The commonly used irrigation methods is sprinkler irrigation. The five sub-regions were selected taking as criteria the number of farms, the number of inhabitants and the representativeness of the main crops of the Department. Likewise, easy road access was considered. The selected municipalities have the minimum access roads required for the transportation of supplies, as well as for accessibility for monitoring and collecting samples. It should be noted that the department of Sucre has deficient road infrastructure due to the serious social and economic problems caused by the conflict and violence (Lissbrant *et al*., 2018). In the selected municipalities, assessments were carried using 22 variables of analysis of the

Table 1: Characteristics of the five sub-regions of the department of Sucre, in northern Colombia.

Subregion/Area	Municipality	Average Temperature (°C)	Annual Precipitation (mm)	Location	Vegetation
Montes de María ($6466\ km^2$)	Morroa	26.8	1000 – 1200	9° 20′ N, 75° 18′ W	Tropical dry forest area, mountain landscape
Sabana ($2101\ km^2$)	Corozal	27	990 – 1275	9° 9′ N, 75° 18′W	Tropical dry forest area, hills landscapes
Golfo de Morrosquillo ($1886\ km^2$)	San Onofre	27.4	900 – 1200	9° 8′ N, 75° 31′ W	Tropical dry forest area
San Jorge ($2934\ km^2$)	San Marcos	28	1300 –2300	8° 40′ N, 75° 8′ W	Zone of tropical humid forest, tropical dry forest, tropical very dry forest, and natural savanna
Mojana ($2337\ km^2$)	Majagual	28	2800	8° 32′ N 74° 37′ W	Tropical humid forest area

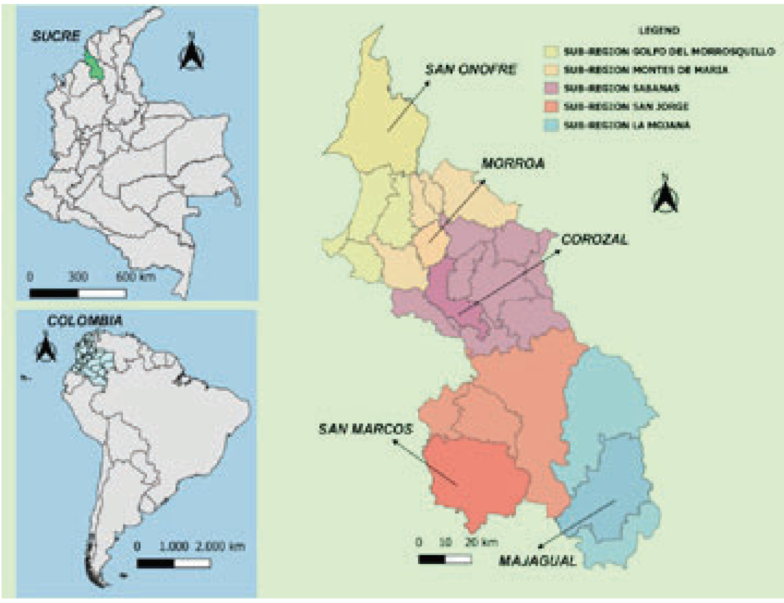

Fig. 1: Geographic location of the study area in the Department of Sucre in Northern Colombia

water used for irrigation at 141 farms.

The 141 surface water samples were gathered at the five prioritized municipalities with the following distribution: 34 samples from San Onofre, 30 samples from Morroa, 38 samples from Corozal, 17 samples from San Marcos and 22 samples from Majagual. For the sampling sites selection, the Guide for monitoring of discharges, surface and groundwater was used (IDEAM, 2002), in which the factors and criteria for sampling sites location in surface water bodies are established. The samples were gathered by the environmental laboratory Zonas Costeras S.A.S., which has been certified for environmental characterizations by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, by its acronym in Spanish). The water samples were taken in a 200 ml clear and water-right plastic container. All *in-situ* measurements and laboratory analysis were performed using standard methods (APHA, 2017). All the samples were collected by triplicate to determine the precision of tests and sample handling. The *in-situ* temperature was measured using the method

SM 2550 B/ electrometric, electrical conductivity (EC) was measured using the method SM 2510B/ electrometric, and pH was measured using the method SM 4500 H^+B/ electrometric.

Water quality laboratory analysis

Total dissolved solids (TDS) were determined using the method SM 2540C/ gravimetric by drying at 180°C. Total suspended solids (TSS) and total solids (TS) were determined using the methods SM 2540D and SM2540B / gravimetric by drying at 103°C – 105°C, respectively, chlorides by the method SM 4500-Cl-B /Argentometric, sulfates by the method SM 4500-SO_4^{2-}E/ Turbidimetric. For nutrients: nitrates by the method SM 4500-NO_3E/ Reduction with Cadmium, ammoniacal nitrogen by the method SM 4500-NH_3B, C/Distillation – volumetric and total phosphorus by the method SM 4500- P B, E/Digestion (sulfuric acid – nitric acid)/ ascorbic acid – Spectrophotometry. For cations: total aluminum through an internal method, equivalent to SM 3500-Al B/ photometric; for boron, silicon, magnesium, total lead and total cadmium using the method SM 3120 B / ICP-OES. For total iron, the method used was Spectroquant Merck test Iron 114761 / photometric, hexavalent chromium by the internal method equivalent to SM 3500-Cr B/ Photometric. The sodium adsorption ratio (SAR) was obtained in relation to total calcium by SM 3500-Ca B/volumetric with EDTA, magnesium SM3500-MGB / Calculation and total sodium by EPA 6010 D /ICP- OES. All the analyses were made at the environmental laboratory Zonas Costeras, certified by IDEAM.

Analytical framework

Correlation analysis was performed to determine the level of correlation between the analyzed physicochemical parameters. Additionally, the salinity and sodicity analysis was performed based on the values obtained for EC and SAR (Tartabull Puñales and Betancourt Aguilar, 2016). Lastly, a classification diagram of irrigation water was made (Shahid and Mahmoudi, 2014). The data in this work were analyzed by using R software (R Core Team, 2020).

RESULTS AND DISCUSSION

Physicochemical water quality parameters

The water temperature at the studied farms showed a maximum value of 38.2°C and a minimum value of 19.4°C, with an average value of 31.07 ± 2.32 °C. pH displayed alkaline values, with average value of 6.87 ± 0.72, which indicates that the water had acid values, but within allowable limits for agricultural use (WHO, 2016). In a case studied carried out by the office of the governor of Karf El – Sheikh, Egypt, the average value of pH was 7.88, i.e., alkaline water that was within the threshold range established by the FAO (Jahin *et al.*, 2020), which is consistent with data obtained by other authors for the largest dam in Algeria (Bini Haroun damn), with an average value of 7.81, in general determining that the pH of water used for irrigation was between neutral and slightly alkaline (Bouaroudj *et al.*, 2019). In Colombia, in a study carried out in the department of Boyacá at 60 ecological farms, pH displayed values between 6.5 and 7.5 (Guerrero Guio *et al.*, 2021). It should be noted that several authors indicate that even though pH is not one of the main factors for determining water quality, it is useful for determining the concentrations of species dissolved in carbon, and the availability of plant nutrients (Medina Valdovinos *et al.*, 2016). However, it should be pointed out that very low pH values may produce accelerated corrosion of the irrigation systems, and very high pH values above 8.5 are often caused by high levels of bicarbonates and carbonates (Bauder *et al.*, 2019). The EC of the water displayed an average value of 171.40 ± 134.45 µS/cm. These values are within the threshold range (WHO, 2016), and are classified as water of excellent quality. However, waters with low salinity, i.e., with EC values below (200 µS /cm), can give rise to infiltration problems because they tend to wash off the soluble salts in the soil, especially Ca, and may cause degradation of the soil structure, produce crusts and a reduction in water penetration (Zaman *et al.*, 2018). In a study carried out in the geothermic provinces of Konkan, Maharashtra, India, an assessment was performed of surface, underground and thermal spring waters, which displayed maximum and minimum EC values of 3960 - 160.4 µS/cm respectively, and an average value of 1469 µS/cm, concluding that the assessed waters were within all classes of water, which indicates a high level of water fluctuation (Shah *et al.*, 2019). TDS displayed an average value of 115.36 ± 86.92 mg/L, i.e., moderate concentration. TSS and TS displayed an average value of 34.29 ± 35.07 mg/L and 152.40 ± 96.31 mg/L, respectively (Table 2). According to the classification by the FAO, the assessed waters are classified as of low to moderate hazard (INTAGRI, 2018), which makes them suitable for use in irrigation.

Contrary to the findings of this study, a study carried out in the district of Mathura, the average TDS value was 4963 mg/L, which is above the allowed limit >50%. This value was attributed to high concentrations of sodium, magnesium, calcium (Ahmed *et al*., 2020), bicarbonates, sulfurs, and chlorides (Valles-Aragón *et al*., 2017). Values close to those reported in this study were found in a study carried out in Jamalpur Sadar, Bangladesh, in underground and surface waters (162.2 and 287.8 mg/L, respectively) (Zakir *et al*., 2020). TDS are thought to be consequential from runoffs, agricultural practices, deforestation activities, sewage discharges and other sources (Dumago *et al*., 2018). Cl^- displayed an average value of (10.78 ± 9.06 mg/L), the concentrations of SO_4 and N-NO_3 displayed values of (106.86 ± 58.25 mg/L and 0.69 ± 0.16 mg/L, respectively), and N-NH_3 (4.70 ± 0.59 mg/L). Additionally, concentrations of P displayed an average value of 0.20 ± 0.26 mg/L. Aluminum concentration displayed an average value of (1.85 ± 1.84 mg/ L). Si concentrations averaged (5.35 ± 4.96 mg/L), and the average value of Fe concentration was (2.70 ± 1.85 mg/L). Irrigation water with Fe levels above 0.10 mg/L may cause clogging of drip irrigation emitters and above 0.30 mg/L may lead to Fe rust stains, and discoloration on foliage plants in overhead irrigation applications. These levels are generally below the levels that cause toxicities in plant tissue except when iron levels exceed 4 mg/L or when the root medium pH is below 5.5 (Saaltink *et al*., 2017). The average values of Mn and B concentration were 0.13 ± 0.20 mg/L and 0.05 ± 0.03 mg/L, respectively. The concentrations of Pb, Cr and Cd displayed average values of 0.02 ± 0.008 mg/L, 0.07 ± 0.01 mg/L and 0.002 ± 0.001 mg/L, respectively, while the average values of the concentrations of Ca^{2+}, Mg^{2+} and Na were 18.52 ± 22.01 mg /L, 12.91 ± 7.73 mg/L and 3.22 ± 7.12 mg/L, respectively. Lastly, the average value of SAR was 0.14 ±0.21 mEq/L. This value is within the allowable range, with the assessed waters classified as suitable for irrigation (Arhad and Shakoor, 2017; Zaman *et al*., 2018). SAR represents the adsorption of sodium in irrigation water and reflects the possible influence of sodium in the soil; it also has a dispersing effect on colloids in the soil and may affect soil permeability (Zaman *et al*., 2018). The FAO states that SAR <3 does not cause problems to the crops and soils (Shahid *et al*., 2018). Consistent with the values found in this study, a study carried out in southern Iraq (Al-Gharraf channel), with assistance from a software program named Irrigation Water Guide (IWGV.1), the average value of SAR was: 1.96 mEq/L, which indicates that the channel's water has

Table 2: Results for the physicochemical parameters analyzed in water used for irrigation in the department of Sucre, in northern Colombia

Parameter	Maximum	Minimum	Mean ± SD
T (°C)	38.20	23.90	31.07 ± 2.32
pH	9.32	4.40	6.87 ± 0.72
EC (µS/cm)	669	19.80	171.40 ± 134.45
TDS (mg/L)	478	11.80	115.36 ± 86.92
TSS (mg/L)	287	3.80	34.29 ± 35.07
TS (mg /L)	574	25	152.40 ± 96.31
Cl (mg/L)	54.80	2.40	10.78 ± 9.06
SO_4 (mg/L)	625	4.30	106.86 ± 58.25
N-NO_3 (mg/L)	1.01	0.50	0.69 ± 0.16
N-NH_3 (mg/L)	6.35	3.05	4.70 ± 0.59
P (mg/L)	1.42	0.02	0.20 ± 0.26
Al (mg/L)	11.3	0.16	1.85 ± 1.84
Si (mg/L)	33.2	0.71	5.35 ± 4.96
Fe (mg/L)	8.56	0.23	2.70 ± 1.85
Mn (mg/L)	1.62	0.002	0.13 ± 0.20
B (mg/L)	0.29	0.01	0.05 ± 0.03
Pb (mg/L)	0.05	0.01	0.02 ± 0.008
Cr^{+6} (mg/L)	0.07	0.05	0.07 ± 0.01
Cd (mg/L)	0.005	0.001	0.002 ± 0.001
Ca^{2+} (mg/L)	210	3.06	18.52 ± 22.01
Mg^{2+} (mg/L)	59.30	3.95	12.91 ± 7.73
Na (mg/L)	51.30	0.30	3.22 ± 7.12
SAR (mEq/L)	1.72	0.01	0.14 ± 0.21

low risk for irrigation (Ewaid *et al*., 2019). Meanwhile, a study carried out in Colombia at 60 ecological farms in 4 municipalities of the department of Boyacá, SAR displayed concentrations of 0.16 mEq/L for farm 4 of model 1 (Guerrero Guio *et al*., 2021).

The correlation analysis indicated statistically significant correlations between the analyzed variables (*p-value* ≤ 0.05) (Table 3), except for TSS and pH, which displayed no correlation with the other water quality variables. Only P displayed correlation with TSS (*p-value* ≤ 0.05), while Al only displayed correlation with temperature (*p-value* ≤ 0.05). P and Al had low negative correlation with B, Mn, Na, Cr and SAR. Even though SAR was correlated with almost all the chemical variables, it only displayed high positive correlation with Mn. Cl had high negative correlation with P and low negative correlation with Al. The correlation analysis indicates high positive correlations between the variables EC – TDS (r = 0.969), TDS – TS (r= 0,924), Cd – P (r = 0. 989), Mg – Ca^{2+} (r=0.964), Na – Mn (r=0.996), P – NH_3 (r= 0.995), Si – Cl (r= 0.995) and Na – SAR (r = 0. 919), and high negative correlation between EC – Fe (r = -0.084), Ca^{+2} – P (r = - 0.085), Mg^{+2} – Al (r = -0.084) and Cd – Mn (r =0.082). The most highly correlated variables were pH, EC, TDS, Cl, SO_4, Ca^{2+}, Mg^{2+} and B. The variable associated with the cations, anions, pH, TDS, EC, and TS was SAR (*p-value* ≤ 0.05); P was only associated with TSS, and Al only with temperature (*p-value* ≤ 0.05). In a study carried out at the largest dam in Algeria (Beni Haroun dam), 112 correlation tests were statistically significant, most of them positive, between Na, EC, Cl, K, SAR, Na% and other parameters (e.g., HCO_3). Additionally, the correlation indicated that water temperature was negatively correlated with pH, EC, Ca, Mg, Na, Cl, HCO_3, and NO_3 (Bouaroudj *et al*., 2019). As in the case of this study, most correlations were positive. A study carried out in the geothermal provinces of Konkan, Maharashtra, India, by means of a correlation matrix it was determined that strong positive correlation exists between Cl and Na (r = 0.973), Cl and EC (r=0. 994), Cl and Ca (r=0.917); TDS displayed high correlation with EC, Na, Ca, Cl, Br, indicating that it is probable that they are derived from the same water source, but displayed negative correlation with Mg and HCO_3. SO_4 displayed poor correlation with most ions and negative correlation with Mg and HCO_3 (Shah *et al*., 2019). The correlation between EC values and Ca^{2+}, Mg^{2+} and Cl reflects the large contribution of these ions to the salinity of the water assessed in the department of Sucre. Additionally, the correlation between Ca^{2+}, Mg^{2+}, Cl and Na indicates that these ions contribute in a natural manner to the salinity of the water and that they represent most of the soluble salts in the water (Jahin *et al*., 2020).

Classification of the assessed water for irrigation

Most values for electrical conductivity were below 250 µS/cm at the assessed farm units, which implies that the water is of excellent quality for use in irrigation. Values above 250 µS/cm were only found in the municipalities of Morroa and San Onofre, associated with medium water quality (Fig. 2A). Based on the sodicity found in the water for irrigation at the farm units, there is no risk of sodization, because the SAR values were <10 mEq/L, i.e., water classified as of excellent or good quality for this parameter (Fig. 2B). Most of the assessed waters from the farm units were classified as C1S1 (good water quality) and C2S1 (medium hazard water), which puts the sampled water in the category of type (I) and type (II) (Fig. 2C). C1 water can be used for most crops and most soils with low probability of developing salinity in the soil. C2 water can be used, though it may produce moderate amounts of lixiviates. It can be used for plants with moderate tolerance for salt and can be used for most crops without the need for special practices to control salinity. S1 water can be used for irrigation of almost all types of soil, without the risk of developing harmful levels of exchangeable sodium in the soil. S2 waters pose a significant sodium hazard in soils of fine texture and high capacity to exchange cations, especially in soils with low lixiviation conditions. This type of water can be used in thick texture soils or organic soils with good permeability (Zaman *et al*., 2018). Several studies on surface waters in different areas of the world display results that are consistent with or differ from the results obtained for the waters assessed in the department of Sucre. In a study carried out in Ecuador at a sustainable quinoa crop by the Togllahuayco stream, the waters were classified as C1S1, C1S2, and C2S2 (Quinteros Carabalí *et al*., 2019), which partially coincides with the classification reported in this study. Unlike the above results, a study carried out in Tunisia on the Medjerda River reported classifications of water for irrigation of C1S1, C2S1, waters with low risk of salinity, C3S3 and C4S3, waters with high risk of alkalinity and high to very high salinity, and C4S2, waters with medium sodium risk associated with very high salinity (Etteieb *et al*., 2017).

Table 3: Correlation between the assessed physicochemical properties in water used for irrigation in the department of Sucre, in northern Colombia

Parameter		pH	T	EC	TDS	TSS	TS	Cl^-	SO_4	NO_3	NH_3	Ca^{2+}	Mg^{2+}	P	Al	Fe	B	Cd	Mn	Na	Pb	Si	Cr	SAR
		p - value																						
pH	Correlation coefficient		0.000	0.000	0.000	0.934	0.000	0.087	0.095	0.573	0.736	0.003	0.071	0.465	0.060	0.182	0.043	0.000	0.581	0.014	0.022	0.217	0.779	0.005
T		0.357		0.001	0.001	0.945	0.001	0.365	0.846	0.235	0.901	0.144	0.228	0.435	0.000	0.414	0.442	0.000	0.718	0.321	0.076	0.330	0.293	0.255
EC		0.347	0.290		0.000	0.811	0.000	0.001	0.000	0.004	0.001	0.000	0.000	0.785	0.567	0.321	0.000	0.000	0.132	0.000	0.000	0.000	0.035	0.000
TDS		0.357	0.273	0.969		0.612	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.866	0.483	0.716	0.000	0.000	0.058	0.000	0.000	0.000	0.025	0.000
TSS		0.007	0.006	0.021	0.045		0.000	0.593	0.801	0.680	0.217	0.708	0.314	0.000	0.062	0.018	0.499	0.377	0.017	0.214	0.851	0.108	0.430	0.320
TS		0.337	0.266	0.884	0.924	0.412		0.005	0.000	0.002	0.000	0.000	0.000	0.120	0.135	0.640	0.000	0.000	0.005	0.000	0.000	0.000	0.064	0.000
Cl^-		0.225	-0.120	0.434	0.398	-0.074	0.362		0.060	0.400	0.631	0.066	0.006	0.338	0.736	0.124	0.000	0.044	0.665	0.002	0.343	0.995	0.008	0.007
SO_4		0.141	0.017	0.577	0.620	-0.022	0.601	0.247		0.595	0.000	0.000	0.000	0.604	0.447	0.499	0.000	0.000	0.104	0.000	0.000	0.037	0.295	0.002
NO_3		-0.048	0.101	0.243	0.310	-0.036	0.255	-0.112	0.045		0.825	0.013	0.339	0.634	0.510	0.286	0.823	0.781	0.323	0.830	0.463	0.731	0.770	0.640
NH_3		-0.029	0.011	0.290	0.324	0.108	0.334	-0.064	0.335	-0.019		0.060	0.171	0.995	0.699	0.152	0.812	0.162	0.000	0.857	0.545	0.214	0.860	0.677
Ca^{2+}		0.263	0.133	0.795	0.795	-0.035	0.727	0.248	0.836	0.225	0.171		0.000	0.365	0.621	0.064	0.000	0.000	0.964	0.000	0.000	0.007	0.698	0.000
Mg^{2+}		0.156	0.105	0.726	0.652	-0.090	0.578	0.364	0.745	0.083	0.119	0.805		0.454	0.335	0.052	0.000	0.000	0.517	0.000	0.000	0.000	0.358	0.000
P		-0.065	-0.069	-0.024	-0.015	0.411	0.138	-0.131	-0.046	0.042	-0.001	-0.085	-0.068		0.534	0.007	0.661	0.989	0.958	0.275	0.627	0.593	0.506	0.383
Al		0.066	0.306	0.049	0.060	0.163	0.127	-0.045	-0.065	0.056	-0.033	-0.045	-0.084	0.055		0.000	0.682	0.371	0.763	0.339	0.562	0.848	0.614	0.515
Fe		-0.113	0.069	-0.084	-0.031	0.205	0.040	-0.202	-0.057	-0.091	0.121	-0.168	-0.168	0.236	0.610		0.019	0.247	0.274	0.015	0.874	0.817	0.405	0.020
B		0.240	0.093	0.653	0.585	-0.083	0.528	0.475	0.762	0.027	0.029	0.871	0.809	-0.054	-0.050	-0.277		0.000	0.529	0.000	0.000	0.730	0.499	0.013
Cd		0.399	0.334	0.589	0.569	0.088	0.571	0.266	0.438	0.027	0.134	0.579	0.492	0.001	0.086	-0.111	0.673		0.397	0.000	0.000	0.134	0.032	0.000
Mn		0.047	-0.031	0.128	0.161	0.207	0.234	0.058	0.137	-0.084	0.440	0.004	0.056	-0.005	-0.026	0.093	-0.076	-0.082		0.996	0.240	0.230	0.896	0.877
Na		0.210	0.085	0.650	0.554	-0.110	0.455	0.399	0.526	-0.018	-0.016	0.607	0.803	-0.097	-0.082	-0.207	0.550	0.434	0.000		0.000	0.000	0.291	0.000
Pb		0.345	0.271	0.691	0.674	-0.031	0.653	0.190	0.768	0.114	0.094	0.904	0.769	-0.076	0.090	-0.025	0.837	0.584	0.181	0.624		0.002	0.812	0.008
Si		0.105	0.083	0.375	0.392	0.140	0.361	0.001	0.175	0.029	0.105	0.242	0.337	0.048	0.016	0.020	0.042	0.144	0.102	0.379	0.461		0.616	0.000
Cr		0.024	-0.089	0.178	0.190	-0.069	0.157	0.343	0.089	-0.025	-0.015	0.036	0.080	-0.059	-0.043	-0.071	0.082	0.205	-0.011	0.091	0.037	0.043		0.326
SAR		0.238	0.097	0.583	0.501	-0.087	0.413	0.348	0.263	-0.040	-0.035	0.340	0.575	-0.077	-0.055	-0.196	0.293	0.329	0.013	0.919	0.398	0.393	0.083	

EC= Electrical conductivity; T= Temperature; TDS= Total Dissolved Solids; TSS= Total Suspended Solids; TS=Total Solids; SAR= Sodium Adsorption Ratio.

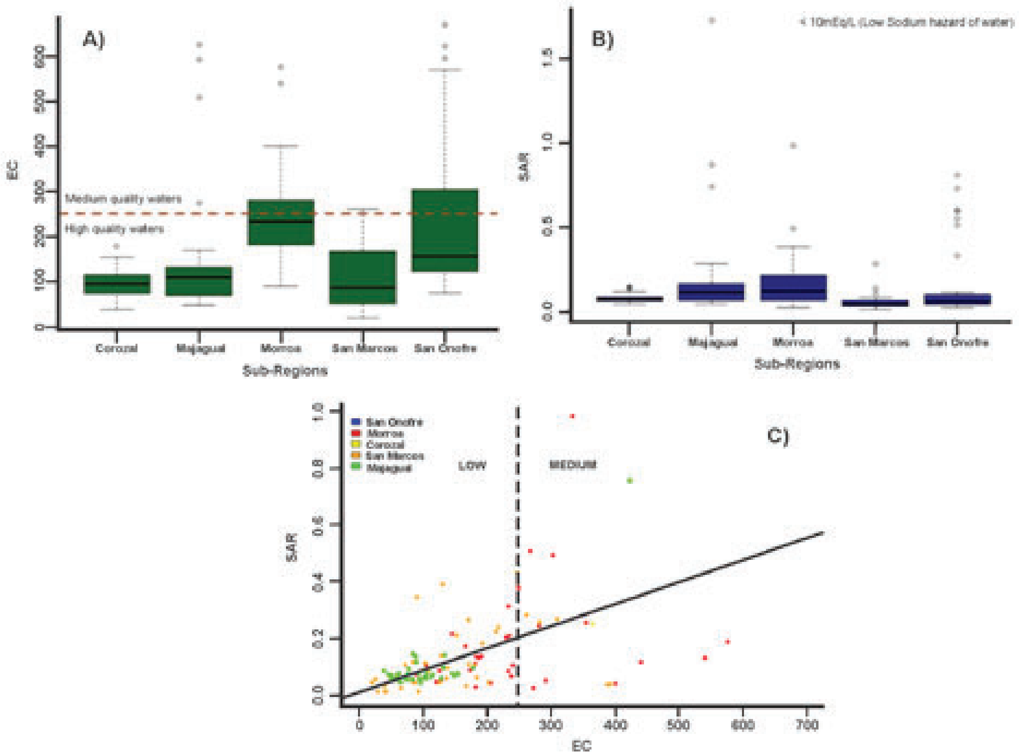

Fig. 2: A) Hazard level according to electrical conductivity. B) Sodization level. C) Sodium adsorption ratio (SAR) vs electrical conductivity (EC)

CONCLUSION

Irrigation systems depends on water quality, which implies that it is necessary to assess its physical, chemical, and biological parameters to determine whether it is appropriate for use in the soils. This study highlighted the need to evaluate the quality of irrigation systems water for crop and soil health, and to guide farmers on the implications of use of low-quality irrigation water. The surface waters assessed at the 141 farm units of the prioritized municipalities of the department of Sucre, Colombia, are waters that are suitable for use in irrigation systems, because according to the FAO and WHO they are waters that are within the established thresholds for use in agriculture, without producing harm to the crops and the soils. The concentrations of cations and anions in the water, such as Na, SO_4, Cl, Ca^{2+}, Mg^{2+}, which are generally associated with increased salinity, were within the allowed ranges, which implies that the water is suitable for irrigation. The concentrations of EC and SAR associated with salinity and sodicity displayed optimal levels, based on which they were classified as C1S1 and C2S1 waters. Some EC results displayed very low levels, due to which it is advisable to monitor these waters to avoid possible future problems for the soils and crops. Additionally, the correlation between EC values and Ca^{2+}, Mg^{2+} and Cl reflects the large contribution of these ions to the salinity of the water assessed in the department of Sucre. However, the irrigation water had an average Fe value above 0.30 mg/L. The study revealed that important concentration levels and composition of dissolved constituents in water which determine its quality for irrigation use were found within the permissible limits for irrigation water. It is recommended to perform periodic testing of the water, because external factors and chemical agents may change the composition of the water, directly affecting the crops and agricultural soils. Based on the sodicity found in the water for irrigation at the farm units, there is no risk of sodization, because the SAR values were <10 mEq/L, i.e., water classified as of excellent or good quality for this parameter. The FAO states that SAR <3 does not cause problems to the crops and soils. Lastly, this study establishes a baseline for the development of agricultural policies and the establishment of actions that promote the sustainable development and food security of small farmers in tropical zones that are vulnerable to the effects of climate change and with few management activities.

AUTHOR CONTRIBUTION

B. Guerra Tamara performed the literature review, experimental design, analyzed and interpreted the data, prepared the original draft. A.C. Torregroza-Espinosa performed analyzed and interpreted the data, writing - original draft, writing - review & editing. D. Pinto Osorio helped in the contextualization and prepared the original draft. M.I. Moreno Pallares performed literature review, experimental design, analyzed and interpreted the data, writing - original draft, writing - review & editing. A. Corrales Paternina helped in the contextualization and prepared the original draft. A. Echeverría-González helped in the contextualization and prepared the original draft.

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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.

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ABBREVIATIONS

Al	Total Aluminum
B	Boron
Br	Bromide
°C	Degree Celsius
Ca	Calcium
C1	Low salinity water
C2	Medium salinity water
C3	High salinity water
C4	Very high salinity water
Ca^2	Total calcium
Cd	Total cadmium
Cl	chlorides
Cr	Hexavalent chromium
C1S1	Good water quality
C2S1	Low sodium water
C2S2	Medium salinity water
C3S3	High sodium water
C4S3	Very high sodium water
EC	Electrical conductivity
FAO	Food and Agriculture Organization
Fe	Iron
HCO_3	baking soda
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies
IWGV.1	Irrigation water guide
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
Mg^2	Magnesium
Mg/L	Milligrams per liter
mEg/L	Milliequivalents per liter
mm	millimeter
Mn	Magnesium
Na	sodium
N-No3	Nitrates
$N\text{-}NH_3$	Ammoniacal nitrogen
ODS	Sustainable Development Goals
P	Total phosphorus
Pb	Total lead
pH	Hydrogen potential
µS/cm	Microsiemens per centimeter
S1	Low sodium water
S2	Medium sodium water
S3	High sodium water
S4	Very high sodium water
SAR	Sodium adsorption ratio
Si	Silicon
SO_4	Sulfate
SM2550B/ electrometric	Standard Method for the analysis of water and wastewater
SM/2510B/ electrometric	Standard Method for the analysis of water wastewater

SM/4500/H+B/ electrometric	Standard Method for measuring the pH value in water by potentiometry using a standard hydrogen electrode
SM/2540C/ gravimetric	Standard Methods: Total Dissolved solids dried at 180 °C
SM/2540D/ gravimetric	Standard Methods: Total Suspended solids dried at 103-105 °C
SM/2540B/ gravimetric	Standard Method: Total Suspended solids dried at 103 -105°C
SM4500-Cl-B Argentometric	Standard Methods: Chloride by argentometric method
SM4500 SO42 – E turbidimetric	Standard Methods: sulfate
SM 4500-NO3 E/ Reduction with Cadmium	Standard Methods: Nitrate in Water After Cadmium Reduction
SM 4500-NH3B, C/Distillation – volumetric	Standard Methods: nitrogen (ammonia)
SM 4500- P B, E/ Digestion (sulfuric acid – nitric acid)/ ascorbic acid – Spectrophotometry	Standard Methods: phosphorus
SM 3500-Al B/ photometric	Standard Methods: Aluminum by Eriochrome Cyanine R Method
SM 3120 B / ICP-OES	Standard Methods: Metals by plasma emission spectroscopy
SM 3500-Cr B/ Photometric	Standard Methods: Chromium
SM 3500-Ca B/ volumetric with EDTA	Standard Methods: Calcium by EDTA
SM3500-MGB / Calculation and total sodium	Standard Methods: Calculation and total sodium
TDS	Total dissolved solids
TSS	Total suspended solids
TS	Total solids
WHO	World Health Organization

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CASE STUDY

Environmental awareness factor of used cell phones

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ABSTRACT

BACKGROUND AND OBJECTIVES: Electronic equipment production is one of the major industrial sectors in Indonesia, as it also contributes to Indonesia's export commodities, which increase because of rapid technological developments. Cell phones, which have considerable potential to become electronic waste, recorded the enormous escalation in electronic production. This research aimed to increase community involvement and the collection of used cell phones from households in e-waste management in Indonesia. A survey was conducted to explore a household's environmental awareness and willingness to recycle based on sociodemographics, environmental hazard awareness, and used cell phone usage in Jabodetabek, Indonesia.
METHODS: In this research, a peer questionnaire was used and organized into five sections: The first section contained the sociodemographic details of the respondents. The second section comprised multiple concerns that relate to recycling and environmental awareness. The third section contained the family cell phone information. The fourth section determined the cell phone consumer behavior. The fifth section consisted of willingness to recycle. Statistical correlations between variables were assessed, and the chi-square independence test was used to evaluate the statistical correlations.
FINDINGS: Mostly the households will replace their used cell phone if there is damage (66.84%) and keep the used cell phone at home (59.5%), thus becoming an obstacle in applying the appropriate recycling system and a circular economy. The average cell phone ownership in Jabodetabek is 1.28 units, and the average cell phone life span of people in Jabodetabek is 2.6 years. The Environmental Hazard Awareness variable has significant differences with occupation and income level (p-value = 0.028 and 0.046), Used Cellphone Usage variable has significant differences with the income level variable (p-value = 0.024). The others, a statistically significant difference between sociodemographic variable and Willingness to Recycle was observed; p-value = 0.003 for age and p-value = 0.034 for occupation.
CONCLUSION: This paper showed that Environmental Hazard Awareness and Willingness to Recycle have an important role in increasing the collection of used cell phones from households. . This study assessed community-based factors located in urban areas. The factors could encourage their participation in collection activities, obtain information on the preferred collection channels of residents, and provide a perspective for managing cell phones through an analysis of the improvements and influences of Indonesia's current e-waste recycling program. Therefore, to develop a new strategy, the findings of this study can provide insights into the e-waste problem and citizen's awareness of e-waste management.

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NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
52	6	2

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INTRODUCTION

Electrical and electronic equipment waste (e-waste) is one of the fastest-growing waste sources globally, as fast as technological development and electronic product replacement (Baldé *et al.*, 2017). Moreover, e-waste is one of the materials that contain the most harmful substances in domestic waste (Król *et al.*, 2016). Hsu *et al.* (2019) reported that the global e-waste in 2016 amounted to 44.7 million tons, expected to reach 50 million tons in 2021 and 100 million t in 2030 (Tiwary *et al.*, 2017). Members of society now need to discuss e-waste with precise planning to avoid environmental damage (Babayemi *et al.*, 2017). Indonesia is an archipelago country that is located on the Asian continent. Indonesia is the fifth country with the largest population, reaching 270 million people, with an annual population growth of 1.25% or approximately 3.37 million people/year (*Statistics Indonesia*, 2021). The total population in large cities, such as Jakarta, Bogor, Tangerang, Depok, Bekasi, Bandung, Semarang, Surabaya, Medan, and Palembang, reaches 50.7% of the total population of Indonesia. About 58% of this population is concentrated in Java Island. The electrical and electronics market is currently dominated by smartphones, computers, and some electrical and electronic equipment at low import prices (Honda *et al.*, 2016). Used cell phones are one type of e-waste that deserves special attention, as it has a growth rate of more than 40% each year (Xu *et al.*, 2016). Consequently, more than 40 million end-of-life cell phone units are predicted to be produced by Indonesia in 2028 (Santoso *et al.*, 2019). Thus, this case study focused on cell phones. The number of cell phone products in Indonesia increases every year, with 46.9 million units circulating in Indonesia in 2003, 333.9 million units in 2015, and 435 million units in 2017 (ITU-D, 2020). The rapid technological development has also caused an increase in the number of cell phone products in Indonesia, thus increasing e-waste originating from cell phones (Andarani and Goto, 2014). Concerning economic conditions affecting e-waste collection, Li (2017) indicated that cell phones are the most dominant type of e-waste with many precious metals and nonmetals. Therefore, Zeng *et al.* (2018) stated that conventional mining is less cost-effective than urban mining. The Life Cycle Cost assessment was conducted to investigate the cost of recycling waste cell phones and the contained precious metal by considering the material flow from waste cell phone collection to waste material disposal after mineral extraction (He *et al.*, 2019). Liu *et al.* (2020) reported that the hydrometallurgical process for cell phone e-waste was environmentally and economically viable. The process had a 29 % return on investment (ROI), indicating that it could ensure a self-sustaining business. Ghodrat *et al.* (2016) described the process used to model the economic feasibility of e-waste using copper smelter and determined that the minimum capacity to be still economically feasible is 30,000 t/year. However, the main strategy that creates economic benefits is the optimization of the production of precious metals from cell phones. Babayemi *et al.* (2017) suggested that three years is the average usage time of cell phones in Nigeria. Mishima *et al.* (2016) estimated that the use time of cell phones is three years from the increase in the annual production of cell phones in Japan. According to Yin *et al.* (2014), customers replaced their cell phones for less than three years for various reasons. The level of toxicity in Asian, African, and European nations is used to reference that the end of life of cell phones is faster in some countries nowadays, which is in one or two years (Sarath *et al.*, 2015). Based on numerous previous research findings, most customers replace their used cell phone in just 1–3 years, shorter than the cell phone’s life span because of improved features, newer versions, and lower prices. Many used cell phones that users in their households keep because of the small shape and small space occupied is another problem in the collection process, thus becoming a barrier to the implementation of the recycling system (Wilson *et al.*, 2017; Ylä-Mella *et al.*, 2015). Echegaray and Hansstein (2017) suggested that socioeconomic and demographic factors greatly influence the success of the recycling process carried out in Brazil. Additionally, consumer awareness is critical to any successful e-waste control efforts (Awasthi and Li, 2018). Martinho *et al.* (2017) stated that gender, mainly male, employment level, and families, affected the desire to recycle for cell phone customers in Portugal. Song *et al.* (2012) studied that educational level can play a significant role in willingness to pay on cell phone consumers in Macau. The most frequently cited barrier to residents returning cell phones was a lack of formal collection channels (Tan *et al.*, 2018). Liang and Sharp (2016) referred to age and gender as the deciding factors that influence recycling programs. Yin *et al*. (2014) determined that family and educational background had the most significant effect on customer disposal actions. The selling of e-wastes by households to smugglers is one of the main obstacles to e-waste collection (Wang *et al*., 2017). At the same time, Liang and Sharp (2017) indicated strong associations between higher financial and literacy levels of users of e-waste and their experiences on e-waste and its environmental implications in several Asian countries. Previous studies showed that various factors, including demographic factors (such as age, gender, and educational level) and environmental awareness, likely influence consumers' decisions on different disposal options. The most significant factor in achieving a successful collection rate of e-waste tends to be customer interest. Several studies have examined e-waste management in Indonesian cities. Panambunan-Ferse and Breiter (2013) described the state of e-waste management in Manado City, Indonesia, where e-waste will be disposed of in the landfill due to the government's lack of rules and monitoring systems, which has resulted in a lack of public awareness of e-waste. Informal actors were the most dominant influence throughout the collecting and sorting of e-waste from households in Indonesia. It is necessary to include the informal sector in the regulations made by the government (Rochman *et al*., 2017). Maheswari *et al*. (2017) suggested the Quatro helix model where producers, government, takeback operators, and the community work together to implement reverse logistics for e-waste properly. Pandebesie *et al.* (2019) studied the behavior of the residents of Surabaya, Indonesia, when dealing with e-waste. They found that willingness to pay may also be a source of e-waste management financing. Although certain cities in Indonesia have performed studies on e-waste management, there is still limited research on the environmental awareness and willingness to recycle e-waste streams. This research aimed to increase community involvement and the collection of used cell phones from households in e-waste management in Indonesia. The research finds out the characteristics of the JABODETABEK households and finds the main factors influencing community involvement in e-waste management in Indonesia. We intend to identify the reasons of residents are unwilling to turn their cell phones off the shelf. Also, the factors that could encourage their participation in collection activities and provide a perspective for managing cell phones through an analysis of the improvements and influences of Indonesia's current e-waste recycling program. Furthermore, the findings of this research will assist the government in improving e-waste management strategies. The novelty was the relationship model between the sociodemographic of the Jabodetabek community with environmental awareness and willingness to recycle to improve e-waste management in Indonesia. In order to achieve this objective, an experimental online questionnaire survey was undertaken to examine residents' actions and preferences regarding cell phone disposal in Jabodetabek, Indonesia, in 2020. The streams of cell phones used in this region have also been monitored.

MATERIALS AND METHODS

This study conducted a household questionnaire utilizing questionnaires to gather information on people's environmental awareness and willingness to recycle e-waste. The questionnaire contained 31 questions, including yes or no questions, single or multiple answer questions, and statements graded on a five-point Likert scale. The questionnaire refers to previous research on consumer behavior toward electronic equipment, and a peer questionnaire was used and organized into five sections: The first section contained the sociodemographic details of the respondents, including gender, age, education, jobs, income, and area (Islam *et al.*, 2016; Song *et al*., 2012). The second section comprised multiple concerns related to recycling, knowledge, and environmental awareness (Afroz *et al.*, 2013; Islam *et al.*, 2016). The third section contained the family cell phone information (Martinho *et al.*, 2017). The fourth section determined the cell phone consumer behavior (Yin *et al.*, 2014). The fifth section consisted of willingness to recycle (Tan *et al.*, 2018; Yin *et al.*, 2014). Significant differences hypotheses between Environmental Hazard Awareness (EHA), Used Cell phone Usage (UCU), Willingness to Recycle (WTR) within household sociodemographic variables were developed. In order to support the validation and clarification of our findings while also supplementing current theory on e-waste management in the research region. During the survey, information on the sociodemographic characteristics of residents, cell phone usage, and replacement behavior was also collected. Statistical correlations between variables were assessed, and the nonparametric statistical method of the chi-square (χ^2) test for independence was used to evaluate the statistical correlations between variables.

Microsoft Excel was used to evaluate the questionnaires, and Minitab17 was used to do statistical analysis.

Survey design and data collection

This research used chain referral sampling for the survey (Johnson, 2014). Emails were sent to the family members, acquaintances, and colleagues of the authors. Sixty people, who were, in turn, asked to invite as many people as possible. The emails included a link to the online questionnaire developed using Google Forms. When sending the questionnaire link to acquaintances and colleagues, the authors ask for their help in redistributing it. The respondent's requirement is family-based; only one family member can fill out the questionnaire in that family. Another requirement is that the questionnaire was distributed in different regions and age ranges so that the respondents obtained will be more diverse. Chain referral sampling (also known as snowball sampling) provides functional advantages for exploratory research, such as the easy selection of participants, high response rate, and relatively low cost (Baltar and Brunet, 2012; Johnson, 2014). Panambunan-Ferse and Breiter (2013) studied an overview of e-waste management in Indonesia using snowball sampling. In comparison, exploring the latest smartphone and tablet consumer consumption and recycling behavior by Martinho *et al.* (2017) and an examination of household e-waste management strategies by Tiep *et al.* (2015). Based on the input from users, the questionnaire was refined. We applied the chi-square (χ^2) test whether there were any significant variations in the respondents' sociodemographic factors with the other awareness factors. We provided a short description of the idea of e-waste and that of a formal concept of a collection system to prevent possible confusion. The survey was available from October 22nd, 2020, to November 14th, 2020, and 394 responses were received. As a result, 389 questionnaires were appropriate to households living in nine urban districts and cities shown in Fig. 1. The reason why Jabodetabek was chosen as a survey

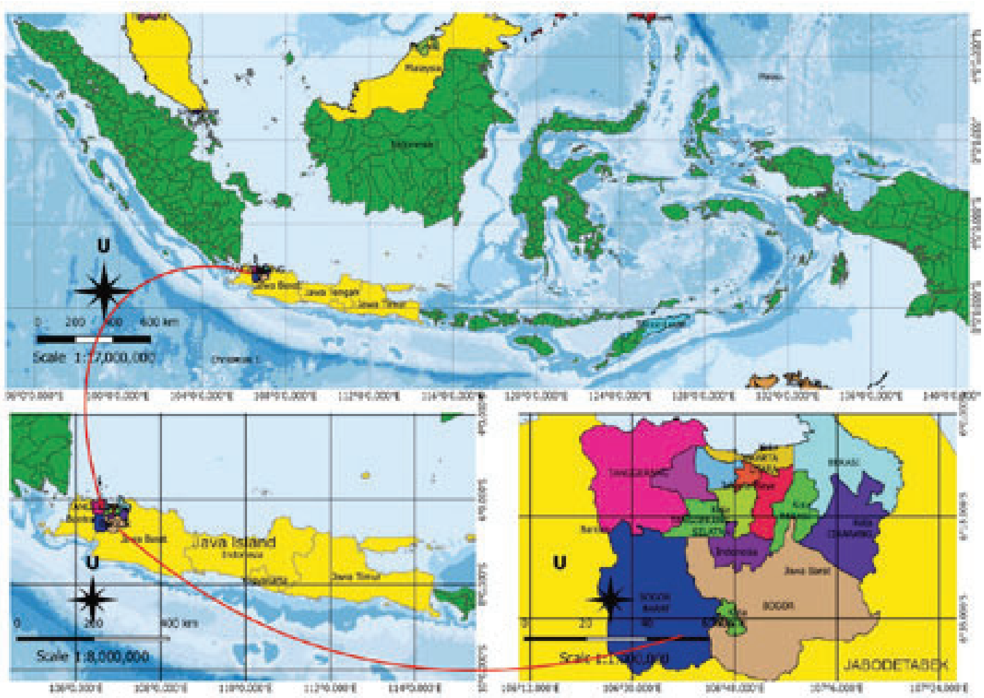

Fig. 1: Geographic location of the study area in Indonesia, Java Island and Jabodetabek

location is due to the fact that the total population in large cities, such as Jakarta, Bogor, Tangerang, Depok, Bekasi, Bandung, Semarang, Surabaya, Medan, and Palembang, reaches 50.7% of the total population of Indonesia. About 58% of this population is concentrated in Java Island; the electrical and electronics market is currently dominated by smartphones, computers, and some electrical and electronic equipment at low import prices (Honda *et al.*, 2016).

Analytical framework

Jabodetabek has grown into a more extensive and more integrated megacity from the boundaries of different city regions. This area comprises Jakarta as the business district and its satellite cities, namely Bogor, Depok, Tangerang, and Bekasi. Jabodetabek has become Indonesia's largest megacity with an important role in social, political, and economic aspects. Jabodetabek has a land area of approximately 7,000 km^2. In 2010, Jabodetabek's population was more than 26.7 million and contributed 25.52% to Indonesia's GDP (Rustiadi *et al.*, 2015). According to the calculated number of households in Jabodetabek (i.e., approximately 460,000), the sample size is set as 384 (CRS, 2016; Islam *et al.*, 2016). The total number of valid respondents that we have in this research is 389 samples. Thus, the number of sample respondents has exceeded the sample size set based on the previously presented calculations. The behavioral patterns of residents regarding the disposal of their out-of-use cell phones and their attitudes toward cell phone collection activities were considered. Their perceptions of selling their waste cell phones and their priorities were examined in the settings and modes of the collection infrastructure.

RESULTS AND DISCUSSION

Residents' sociodemographic Characteristics

According to the respondents' sociodemographic characteristics, the mean age was 34.90, and 42.93% of the respondents were male. The majority of the respondents held a bachelor's degree (i.e., 46.53%). The average individual earnings were Rp 6.4 million/month. The top three areas of concern and involvement that respondents were most interested in were study principles, government employees, and businesses or services. These topics were the top priorities of 25.71%, 20.31%, and 18.51% of respondents, respectively. The sociodemographic build of the resident is shown in Table 1.

The other survey results showed that most

Table 1: Sociodemographic build of the resident

Characteristics	N (number)	%
Sex		
Male	167	42.93
Female	222	57.07
Age		
18 - 24	118	30.33
25 - 29	54	13.88
30 - 39	64	16.46
> 40	153	39.33
Occupation		
Business & Services	72	18.51
Government Employee	79	20.31
Corporate employee	138	35.48
Student	100	25.71
Education Level		
High School and associate degree	143	36.76
Bachelor Degree	181	46.53
Master and above	65	16.71
Monthly Income (Rp)		
2 - 3.5 million	116	29.82
3.5 - 5 million	35	9.0
5 - 7 million	50	12.85
7 - 10 million	57	14.65
>10 million	131	33.68

respondents had one cell phone (i.e., 72.24%), whereas 23.65% had two cell phones, 2.31% had three cell phones, and 1.8% had more than three cell phones. Thus, the total number of cell phones owned by a Jabodetabek respondent was more than 1.28 units. This number is slightly lower than the average number of cell phone owners in Indonesia, which is 1.4 units with 371.4 million cellphone users out of a total population of 262 million (Kemp, 2017).

Life span and reasons for cell phone replacement

The average life span of cell phone use in our study is 2.6 years (Fig. 2). Based on the respondents' data, most people in Jabodetabek (i.e., 48.59%) still use their cell phones for more than three years. Among the respondents, 30.33% continued to use the same cell phones for three years, and 14.4% of the respondents changed their cell phones when they reached 1.5–2 years old. The average life span of cell phones in the study conducted by Polák and Drápalová (2012) was 4.35 years. Two years later, Yin *et al.* (2014) determined that the average life span of a cell phone was shortened to 2.9 years. During its development, the cell phone was initially an electronic product with a slow turnaround; it became an electronic product with a fast turnaround because of the rapid growth of functions, technologies, and sales strategies that pushed new products to the market every year. The average cell phone usage time was 2.61 years in the study conducted by Bai *et al.* (2018), and the average use of cell phones was 1.9 years in the study conducted by Tan *et al.*

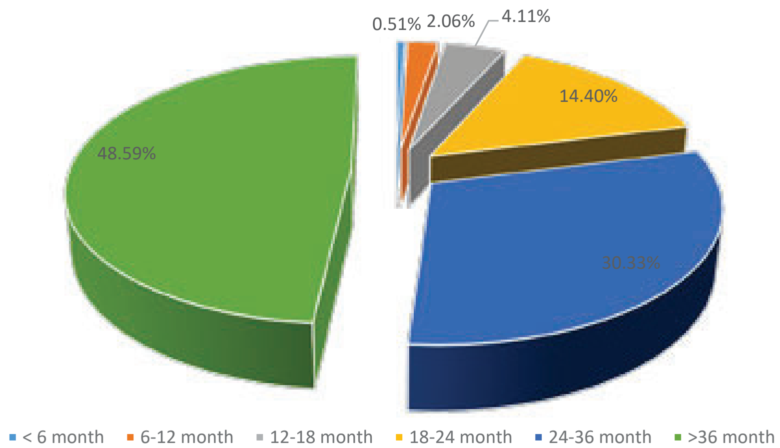

Fig. 2: Households' cell phone replacement frequency

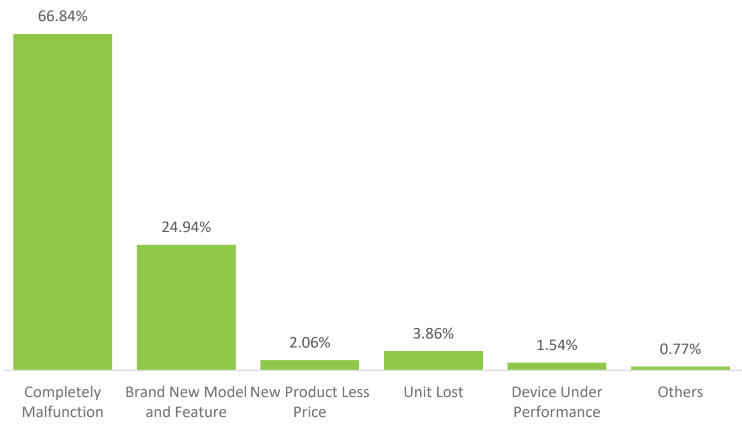

Fig. 3: Households' cell phone reason for replacement

(2018). These studies further proved that cell phones have developed into electronic products with a fast turnaround. Differences between the results depended on the level of income of the respondents in the survey. The users' reasons for replacing cell phones showed that users would replace cell phones if the cell phones are damaged (66.84%) or if their models and features are out of date (24.94%) (Fig. 3). Ylä-Mella *et al.* (2015) showed that 72% of the respondents would replace their cell phones if it is no longer working fine, and 32% of the respondents were driven to change their cell phones by the innovative features of the newer products. Through this research, the finding is quite similar.

Resident's used cell phones treatment methods

Based on the survey results, Fig. 4 shows that most respondents (i.e., 59.9%) keep unused cell phones at home compared their behavior toward other large household appliances, such as televisions, computers, and refrigerators. Only approximately 17% of the respondents keep large household appliances at home after they no longer use them (Islam *et al.*, 2016). The high-level storage of unused cell phones is due to their small size and small space occupied at home. Moreover, a large amount of personal

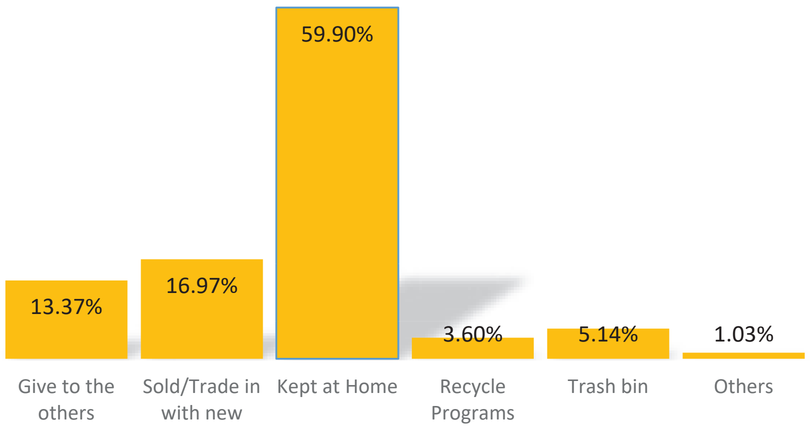

Fig. 4: Household behavior toward used cell phones

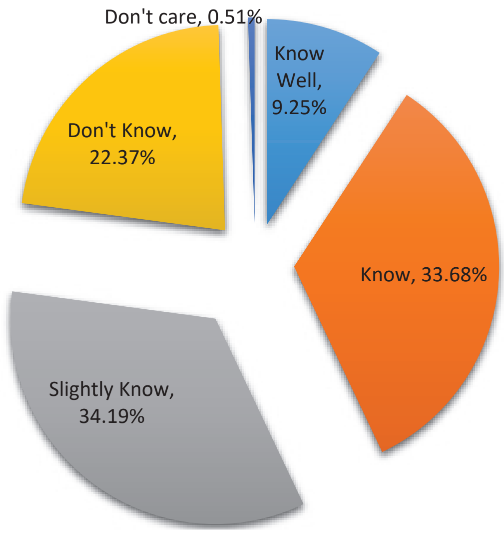

Fig. 5: Household knowledge of used cell phone hazards

information is stored in cell phones, making residents more careful in disposing of used cell phones. There were also significant differences in each country or city to hold used cell phones in the other studies. The research conducted by Ylä-Mella *et al.* (2015) in Oulu, Finland, showed that 85% of cell phone users keep their used cell phones at home. Meanwhile, the research conducted by Martinho *et al.* (2017) in Portugal showed that 36% of the respondents choose to keep their used cell phones. Similarly, the research conducted by Yin *et al.* (2014) and Bai *et al.* (2018) in China showed that the proportion of respondents that store used cell phones at home is 47% and 79%, respectively. These differences were the various income levels of the population in the cities studies were conducted. However, keeping used cell phones at home to a certain extent will prevent re-use and recycling activities. Because for the operation of an economical processing facility, the minimum number of used cell phones collected is required (Tan *et al.,* 2018). Therefore, changing people's attitudes toward the choice of disposing of used cell phones is a fundamental requirement to solve environmental problems related to used cell phones.

Resident's knowledge about e-waste

The results obtained in the survey of household awareness of environmental hazards associated with used cell phones and respondents' attitudes toward the collection process are shown in Fig. 5. The results showed that approximately 77.12% of the respondents knew that used cell phones could harm the environment, 9.25% were aware of the specific effects of the hazards, and the remaining 22.88% did not know or did not even care. Regarding households' attitudes toward used cell phone collection activities, approximately 52.7% of the respondents were willing to give their used cell phones and support the collection activities. Compared to other studies, Kuala Lumpur, Malaysia, appears to have a tiny proportion of e-waste awareness than Indonesia. Only 59 % of households know that e-waste is harmful to the environment (Afroz *et al*., 2013). Another study of residences in Surabaya, Indonesia, found that just 35% of the population is aware that electronic waste is classified as a hazardous substance (Pandebesie *et al*., 2019). Contrast findings in Bangladesh, just 9% of citizens worry about e-waste, and 68% of community members are ignorant of the issue (Islam *et al*., 2016). The studies show that public understanding of e-waste has a wide range of features, including substantial variances between areas in Indonesia. These might be due to community education and e-waste management strategy in each region. The other variables, such as education level and employment, which differ throughout regions, can also affect differences in knowledge between areas. It is critical to establish the development and enforcement of laws to be aware of the proper handling of e-waste.

Relationship between variables

This study used the chi-square (χ^2) test to analyze and determine whether there are significant

Table 2: Chi-square independence test results

Variable A	Variable B	x^2	$p - value$	Result
Gender	EHA	0.009	0.926	Independent
	UCU	0.457	0.796	Independent
	WTR	2.44	0.785	Independent
Age	EHA	7.119	0.068	Independent
	UCU	1.412	0.703	Independent
	WTR	24.855	0.003	Dependent
Occupation	EHA	9.102	0.028	Dependent
	UCU	2.976	0.395	Independent
	WTR	22.297	0.034	Dependent
Educational Level	EHA	2.512	0.285	Independent
	UCU	1.143	0.565	Independent
	WTR	13.207	0.105	Independent
Income Level	EHA	9.708	0.046	Dependent
	UCU	7.452	0.024	Dependent
	WTR	16.129	0.185	Independent

differences. The variables tested were EHA, UCU, WTR variables, and sociodemographic variables of the respondents, i.e., gender, age, educational level, occupation, and income. Pearson's (χ^2) test is usually appropriate as long as no more than 20% of events are required to have frequencies less than 5; some categories of variables have been merged to enhance the findings (Sheskin, 2011). Table 2 shows all the results of the χ^2 calculation that examines the differences between sociodemographic and environmental awareness variables. Significant differences were observed between occupation and income categories toward the EHA variable (p-value = 0.028 and 0.046). Work in businesses and services shows more EHA and a higher income (>IDR 10 million), paying more attention to environmental issues when buying new electronic products (p-value = 0.046). Islam *et al.* (2021) reported that age, family size, and income level influence people's awareness of e-waste, where respondents with an income level above US$156,000/year have a deep concern for e-waste. In contrast, Martinho *et al.* (2017) founded that age above 35 years and occupation have significant differences with awareness behavior, where students and employees have high environmental awareness compared to others. Furthermore, Tan *et al.* (2018) showed that educational level and occupation area had significant differences with public awareness in China. The other significant differences between the UCU variable and the variable income level on the manner of cell phone acquisition (p-value = 0.024). The differences between sociodemographic and WTR also show significant differences between age and occupation on the number of damaged cell phones but kept (p-value = 0.003 and 0.034). The minimum number of cell phones that are damaged but kept is as much as two units for each family, whereas the minimum number of cell phones that are usable and kept is 4–5 units for each head of the family. These findings are consistent with Pandebesie *et al.*

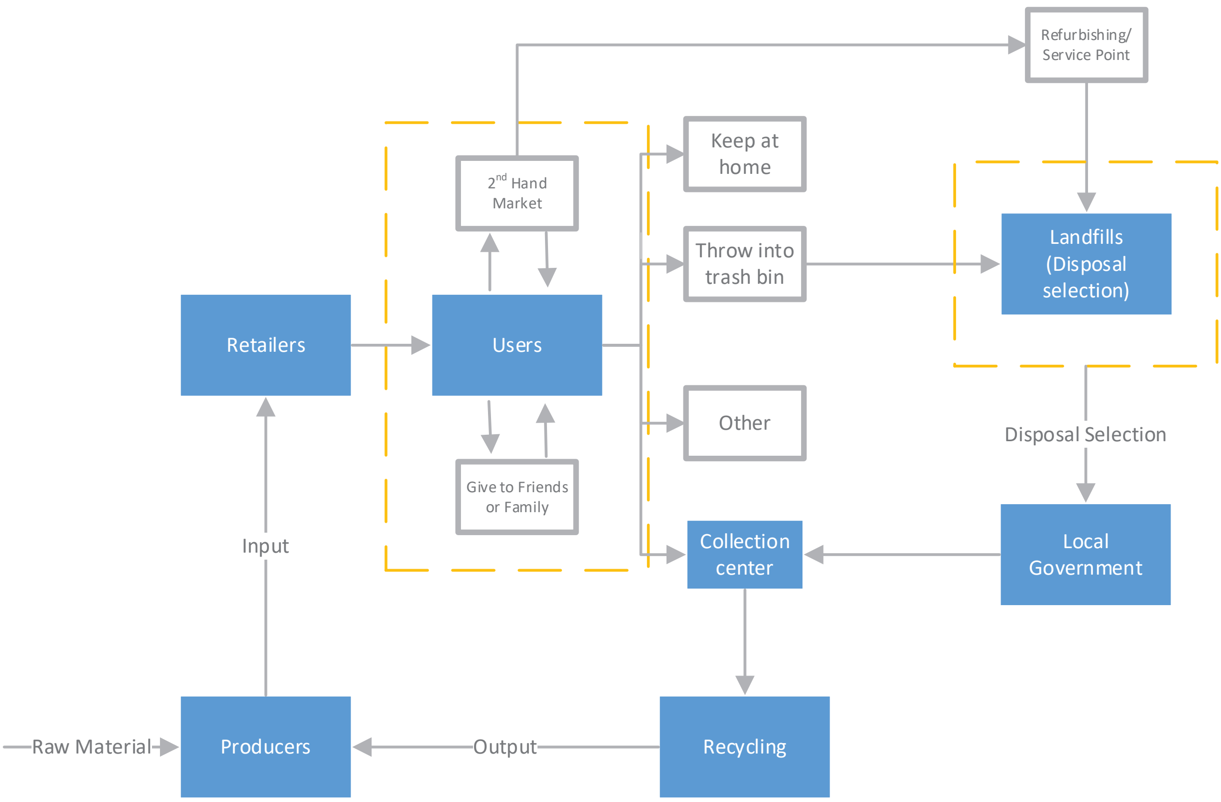

Fig. 6: Used cellphone flow in Jabodetabek

(2019), who found that age and education level had a strong indirect influence on respondent's willingness to manage their waste. Dwivedy and Mittal (2013) demonstrated different results in which the variable income level impacts people's willingness in Indian variables. According to Miner *et al*. (2020), there are no significant differences in participants' desire to cooperate in e-waste management according to their sociodemographic backgrounds.

E-Waste management in Indonesia

Indonesia currently has no specific regulations governing the management of electronic waste. Law no. 8 of 2008 concerning waste management and Law no. 32 of 2009 concerning environmental protection and management is currently used as the legal basis for regulations used in electronic waste management. Technical regulations in implementing the Law are regulated in Government Regulations No. 101 of 2014 concerning hazardous and toxic waste management. It explains the use of this waste, including recycling, recovery, re-use, which are important links. Government Regulations No. 81 of 2012 concerning household waste management in which electronic waste is included in its classification. The hazardous and toxic waste regulation originated from Indonesia's participation in the Basel convention on hazardous waste as regulated in Presidential Decree No. 61 of 1993 concerning the ratification of the Basel Convention on the control of transboundary movements of hazardous wastes and their disposal, which Presidential Regulation further amended No. 47 of 2005. Hazardous and toxic waste, according to Government Regulations No. 101 of 2014 section 1, is the remainder of a business and activity containing substances, energy, and other components which, due to their nature, concentration, and amount, either directly or indirectly, can pollute and damage the environment life, and endanger the environment, health, and the survival of humans and other living creatures. Section 53, written in Government Regulations No. 101 of 2014, requires hazardous and toxic waste for people who produce hazardous and toxic waste. If it cannot be done alone, it can be given to hazardous and toxic waste users. Section 54 states that hazardous and toxic waste is used as raw material, energy substitution, and raw material substitution, whose utilization is under the development of science and technology. Indonesia's current regulations are still in the early stages (Andarani and Goto., 2014). It is undeniable that it will be a challenge for the government to manage e-waste. There are still valuable metals that have economic value in e-waste (Tesfaye *et al*., 2017). Urban Mining can be one of the strategies that can be applied to overcome the problems in handling e-waste in Indonesia. It can also increase competitiveness in the e-waste management industry's sustainability because there is a large potential for added value (Arora *et al*., 2017). Reducing the amount of e-waste is one of the options that Indonesia can do. Extended Producer responsibility (EPR) is a potential option where producers must be responsible for the e-waste produced from their products (Afroz *et al*., 2013). Indonesia needs to reformulate regulations covering the informal sector in e-waste management because the informal sector is an essential part of Indonesia's e-waste management success (Rochman *et al.*, 2017). According to Song *et al*. (2012), households in developed nations must pay for e-waste collection, and their behaviors and attitudes are critical to the successful collection of home e-wastes. Wang *et al*. (2017) formulated financing assistance for e-waste management, proper advice and standards for domestic e-waste collection systems, and tax advantage encourage formal collecting companies as essential roles in excellent e-waste management that should be considered.

The flow of e-waste

No regulations for monitoring e-waste from households, either at the national or regional level, have been established. The Ministry of Environment in Jakarta is the principal agency responsible for waste management in Indonesia. In several cases, diverted e-waste, which was illegally imported using several methods, such as being declared as raw, reprocessed/re-used, or donated materials, was discovered by the government (Panambunan-Ferse and Breiter, 2013). As a result, the central government has adopted the extended producer responsibility method since 2008. However, the regulations are still being formulated at the time of this research. In an interview with the Head of the DKI Jakarta Provincial Environmental Service, e-waste management and regulations were confirmed to be nonexistent in the Jakarta region.

Moreover, the initiative from the local government simply sorts electronic equipment from the local people and disposes it into landfills. Afterward, the sorted wastes are taken to the collection points in each subdistrict or district, then send to the DKI Jakarta Provincial Environmental Service warehouse. E-waste management in Jakarta is illustrated in Fig 6. The DKI Jakarta Provincial Environmental Service has an e-waste dropbox program at car-free day areas or other public places so that people can dispose of their e-waste into e-waste drop boxes. Another program currently being implemented is a service to pick up e-waste from people's residences with a minimum requirement of 5 kg of e-waste. Residents living in Jakarta can use this service for free. E-waste is stored in the DKI Jakarta Provincial Environmental Service warehouse, which the e-waste recycling industry will then utilize. However, consumers are not enthusiastic about this program. Thus, this program does not run as it is desired initially.

CONCLUSION

This study aims to increase the role of the Jabodetabek community and the collection of used cell phones to participate in the success of e-waste management in Indonesia. Sociodemographic characteristics of the people in Jabodetabek, Indonesia were taken for 389 samples of respondents dominated by women (55%), age range > 40 years (39.33%), corporate employees (35.48%), Bachelor Degree educational level (46.53%) with monthly income above IDR 10 million/month (33.68%). This research also identifies reasons residents are unwilling to recycle their cell phones. The households were asked how long it took consumers to replace their cell phones, the reasons for replacing their old cell phones, and how to treat their used cell phones. Based on research, the average cell phone ownership in Jabodetabek is 1.28 units, and the average cell phone life span of people in Jabodetabek is 2.6 years. Mostly the households will replace their used cell phone if there is damage (66.84%) and keep the used cell phone at home (59.5%), thus becoming an obstacle in applying the appropriate recycling system and a circular economy. The significant differences between environmental awareness (i.e., EHA, UCU, and WTR variables) and sociodemographics of households were observed. The EHA variable has significant differences with occupation and income level (p-value = 0.028 and 0.046), UCU variable has significant differences with the income level variable (p-value = 0.024). The others, a statistically significant difference between sociodemographic variable (age, occupation) and WTR was observed; p-value = 0.003 for age and p-value = 0.034 for occupation. This paper showed that EHA and WTR have an important role in increasing the collection of used cell phones from households. Therefore, to develop a new strategy, the findings of this study can provide insights into the e-waste problem and citizen's awareness of e-waste management. The relationship model between sociodemographic and EHA and WTR as the knowledge contribution helped determine the right characteristics in e-waste management in Indonesia in the future. We believe that these findings will help strengthen decision-making steps to assist formal and informal e-waste recycling activities in Jabodetabek. Either to ensure the success of used cell phone collection activities, the EHA and WTR of the community need to be considered. This study is limited to cell phones in Indonesia's e-waste so that the characteristics of users are limited. The huge potential of e-waste and other types of e-waste such as television, air conditioning, and washing machines also have different user characteristics. The future research for e-waste management with the user characteristics in other countries needs to be compared would be beneficial. It will be interesting if research on e-waste management is carried out with various types of e-waste and various user characteristics because e-waste disposal and consumers' behavior and awareness are dynamically different. Furthermore, a replication of this study in other countries could be beneficial in determining whether cultural differences influence consumers' attitudes toward small electronic equipment repair and resale.

AUTHOR CONTRIBUTIONS

N. Wibowo carried out the literature review, study research, data analysis and interpretation, manuscript text preparation, and manuscript editing. R. Nurcahyo supervised the research, assisted in obtaining the study funding and have granted final approval to the published version. D.S. Gabriel have been evaluated and collaborated in the comprehensive revision of it for important defining substance.

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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

%	Percent
DKI	Special Area of the Capital
E- waste	Electronic waste
EHA	Environmental hazard awareness
Fig	Figure
GDP	Gross domestic product
IDR	Indonesian rupiah
i.e	That is
Jabodetabek	Jakarta, Bogor, Depok, Tangerang, Bekasi Cities
Kg	Kilograms
Km^2	Square kilometers
t	tonnes
t/year	Ton/year
p-value	Probability value
ROI	Return on investment
UCU	Used cell phones usage
WTR	Willingness to recycle
X^2	Chi-square test

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REVIEW PAPER

Effectiveness of natural coagulants in water and wastewater treatment

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ABSTRACT

Natural waterways are contaminated due to industrialization, urbanization, population growth etc., degrading their quality. Contaminated waterways cause numerous health and environmental hazards. Therefore, it is imperative to remove contaminants. Coagulation is one of the efficient primary chemical treatment methods that could be used to treat such contaminants. Natural coagulants have gained popularity in the water and wastewater treatment industry due to their advantage over chemical coagulants. Natural coagulants are derived from either plants, animals, or microorganisms. This study has elaborated on the nature and mechanisms, and types of natural coagulants. In this review work, many studies have proposed several types of natural coagulants. However, plant-based natural coagulants extracted from different plant components have been extensively discussed and compared based on their application and efficiency in water and waste treatment. The primary purpose of this review is to refine the knowledge on the potential use and optimization of the effectiveness of eco-friendly and sustainable natural coagulants. Besides, the development efforts and the barriers reported by recent findings for the commercialization of natural coagulants are also discussed. Further, few modified natural coagulants have also been presented for exploring the other possible approaches to promote their usage in water and wastewater treatment in the future studies..

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INTRODUCTION

Water is the fundamental requirement for all human activities and biological activities. It is the main component in the hydrological cycle. The water resources are continuously decreasing around the world due to various environmental degradation activities, climate change (Konapala *et al*., 2020), population growth (Zubaidi *et al.*, 2020), and increasing standards of living and urbanization (Wu *et al*., 2013). Rapid population growth and haphazard waste disposal have resulted in the impending water crisis. In order to sustain the water requirements, various processes and technologies are being researched to improve the quality of water (Ullah *et al*., 2020). These technologies fall into three main categories, namely physical, chemical, and biological treatment methods. Physical methods include settling, media, and membrane filtration (Obotey Ezugbe and Rathilal, 2020), adsorption (Ali and Gupta, 2006), and UV processes (O'Malley *et al*., 2020). Coagulation (Alibeigi-Beni *et al*., 2021), disinfection (Collivignarelli *et al*., 2017), ion exchange (Ergunova *et al*., 2017), catalytic reduction (Guo *et al*., 2020; Sivakumar, 2015), oxidation (Gogate and Pandit, 2004), and softening processes (Brastad and He, 2013) are some of the chemical methods used in the wastewater treatment. Biological methods include microbial biodegradation (Huang *et al*., 2018), phytoremediation (Hu *et al*., 2020), bioreactor processes (Neoh *et al*., 2016), constructed wetlands (Wu *et al*., 2015) etc. Moreover, some processes are combined with others to improve efficiency (Ang and Mohammad, 2020). One of the most widely used processes in water and wastewater's primary treatment is coagulation for removing suspended particulate matter and colloids in wastewater (Staicu *et al*., 2015). Coagulation is considered one of the simple methods to remove suspended solids and impurities in water efficiently. Successful coagulation can be attained by using either chemical-based (inorganic and synthetic organic) coagulants or natural coagulants (de Paula *et al*., 2018). Natural coagulants have been recognized for their traditional local water purification (Choy *et al*., 2014; Dorea, 2006). Naturally occurring coagulants are sustainable, environmentally friendly, and less toxic than chemical coagulants (Teh *et al*., 2014). Natural coagulants have grasped the scientific community's attention in the past decades due to their significant health and environmental benefits, and it solves most of the common problems associated with chemical coagulants. Natural coagulants are produced or extracted from different sources such as microorganisms, animals, or plants (non-plant-based and plant-based). Now, several effective coagulants which have plant origin are being identified. Some of the common ones include *Hibiscus sabdariffa* (Roselle seeds) (Mohd-Esa *et al*., 2010), *Dolichos lablab* (Hyacinth bean) (Daverey *et al*., 2019), *Moringa oliefera* (Nonfodji *et al*., 2020), Nirmali seeds (Prabhakaran *et al*., 2020) watermelon seeds (Bhattacharjee *et al*., 2020) and cactus species (Rebah and Siddeeg, 2017). The drawbacks of chemical coagulants have resulted in the search for eco-friendly and sustainable natural coagulants in their usage and production. The main advantages of natural coagulants are renewability, biodegradability, nontoxicity, and cost-effectiveness. These studies have already proved the effectiveness of natural coagulants in wastewater treatment applications (Choy *et al*., 2014; Yin, 2010). However, the industrial usage of natural coagulants in wastewater treatment applications is limited. This is mainly due to the processing cost and the performance consistency of the extracted compounds from natural sources. Due to this, researchers tend to focus on modifying natural coagulants to get the maximum benefits (Muruganandam *et al*., 2017; Ahmed *et al*., 2016). This study aims to identify potential research gaps to refine the knowledge on natural coagulants and summarize the optimization methods for coagulants for improving their efficiency in water and wastewater treatment. This study also showcases the application of these coagulants for large-scale commercial usages and may assist in future studies. These will be discussed in sections as follows: the need for natural coagulants, mechanisms of natural coagulants, types of natural coagulants, barriers in the commercialization of natural coagulants, and examples of modified or blended natural coagulants. This study has been carried out in Colombo, Sri Lanka, in 2021.

Need for natural coagulants

Chemical coagulant used has raised controversial issues due to its toxic nature for living organisms and can be categorized into three types: hydrolyzing metallic salts, pre-hydrolyzing metallic salts, and synthetic cationic polymers (Freitas *et al*., 2018; Verma *et al*., 2012). Due to the low cost, easy handling, storage, and high availability, chemical coagulants are more prevalent in wastewater treatment processes.

$Al_2(SO_4)_3$, $Fe_2(SO_4)_3$, $AlCl_3$ and $FeCl_3$ are the most commonly used coagulant salts (Freitas *et al.*, 2018; Matilainen *et al.*, 2010; Sher *et al.*, 2013). Despite the availability, low cost etc.; chemical coagulants are far behind in green chemistry due to high residual concentrations of aluminum found in treated wastewater (Freitas *et al.*, 2018; Matilainen *et al.*, 2010). According to Freitas *et al.*, 2018; McLachlan 1995; Polizzi *et al*. 2002, Alzheimer's disease is linked with the neurotoxicity of aluminum. Synthetic polymer coagulants form hazardous secondary products such as acrylamide which is carcinogenic and neurotoxic, and also synthetic polymers have low biodegradability (Freitas *et al*., 2018; Kurniawan *et al*., 2020). Excessive concentrations of chemical coagulants such as aluminum reduce the pH of water tends and also, they can be accumulated to food chains (Kurniawan *et al*., 2020). Improper disposal of toxic sludge pollutes the groundwater and soil. Accumulation of toxic sludge, such as aluminum, iron etc., in natural water bodies causes adverse effects on aquatic organisms and plant species (Kurniawan *et al*., 2020). Hence there is a need for the efficient utilization of natural coagulants for water and wastewater treatment.

Mechanism of coagulation by natural coagulants

Coagulation occurs between the coagulant added, the impurities, and the alkalinity of the water, resulting in the formation of insoluble flocs. Flocs are the agglomerations of particulate suspended matter in the raw water, reaction products of the added chemicals, colloidal and dissolved matter from the water adsorbed by these reaction products. Unprocessed water from the reservoir contains organic and inorganic impurities, such as silt, rotten substance, alga, bacterium, etc. Hence coagulation is the essential step in water purification. In addition, coagulants make suspensions in water to gather and reduce the turbidity of water (Z. Song *et al.*, 2009). The successful coagulation of natural coagulants (Ang *et al*., 2020) stands on these three pillars: characteristics of coagulant used, characteristics of water to be treated, characteristics of mixing process (Ang *et al.*, 2020; Kumar *et al.*, 2017). As Fig. 1 shows, these coagulation factors play a significant role in determining the most efficient coagulant required for the treatment. Coagulants' molecular weight (Ang *et al*., 2020; Gautam and Saini, 2020), types of equipment and reagents used, chemical and physical properties of the pollutants such as zeta potential (Ang *et al.*, 2020), color, the concentration of the colloidal particles, the presence or absence of impurities (trace elements and dissolved salts (ions and chemicals) also affect the coagulation process (Ang *et al*., 2020; Kumar *et al*., 2017; Muruganandam *et al*., 2017). If the natural coagulant contain positive surface charge, its coagulation activity against negatively charged suspended particles will be higher and vice versa for negatively charged natural coagulants with positively charged suspended particles. Functional groups also contribute to surface charge (Ang *et al.*, 2020). Molecular weight of natural coagulant is very important in particle bridging. If the molecular weight of natural coagulant is higher, it can form strong bridges with the particles and it leads to the formation of strong flocs and improve settling (Ang *et al*., 2020). Mixing is another critical step in the coagulation process. Fast mixing increases the interactions between coagulants and suspended particles and forms micro flocs. Slow mixing leads to the aggregation of micro flocs into large flocs (Kurniawan *et al.*, 2020). Coagulation also affects the other steps of the treatment process. An efficient and effective coagulation process favors the microbiological quality (Kumar *et al.*, 2017) of the end product and increases the lifetime of filters (Kumar et al., 2017), reducing the total cost of treated water.

Natural coagulants are composed of carbohydrates, protein, and lipids. The primary building blocks are the polymer of polysaccharides and amino acids. According to the previous research, the main mechanisms governing coagulation activity are charge neutralization and polymer bridging.

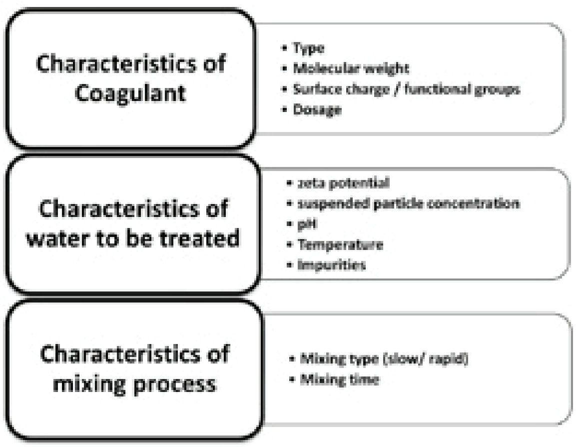

Fig. 1: Factors affecting coagulation
(Ang *et al*., 2020; Gautam and Saini, 2020; Kumar *et al*., 2017)

Polymer bridging is preceded by polymer adsorption. Because of the affinity between long-chain polymers and colloidal particles, long-chained polymers can attach to the colloidal particle's surface. A part of the polymer is attached to the particle while the other parts form loops and tails. These loops and tails are the main structure of polymer bridging loops, and tails allow attaching to other colloidal particles and form larger flocs. The basis of charge neutralization is known as the electrostatic patch mechanism. The patches of positive and negative regions on the particle's surface cause the additional attraction between particles. Ionizable polymer (polyelectrolytes) is used as a coagulant in the charge neutralization mechanism. It stabilizes the negatively charged colloidal particles. Polycation is used to stabilize the particles, gaining near to zero zeta potential. The optimum dosage of polyelectrolyte needed will be determined by the charge density of the polyelectrolyte (Amran *et al*., 2018; Yin, 2010). Natural coagulants have varied mechanisms of action. Let us consider some of the coagulation mechanisms of natural coagulants.

As shown in Table 1 Chitin is a cellulose-like biopolymer. It is found in fungi, marine invertebrates, yeasts, and insects. Chitosan is formed by the deacetylation of chitin (Hassan *et al*., 2009; Saranya *et al*., 2014). It is efficient in cold waters at low concentrations, producing less sludge and sludge degraded by microorganisms. Both charge neutralization (has positively charged amino group) and bridging are the two coagulation mechanisms identified. Chitosan is a potential substitute for metallic salts and synthetic polyelectrolytes used in wastewater treatment (Nechita, 2017). Chitosan has a high content of amino groups. It provides a cationic charge at acidic pH, supports the destabilization of colloidal suspension, and promotes rapid-settling, large floc. Since Chitosan is a long-chain polymer with positive charges, it can also coagulate negatively charged particulate and colloidal materials via adsorption and hydrophobic flocculation (Roussy *et al*., 2005; Saranya *et al*., 2014; Karbassi and Heidari, 2015). Seed extracts of Nirmali (*Strychnos potatorum*) are anionic polyelectrolytes. It can destabilize the particles in water via inter-particle chemical bridges. Nirmali seed extract contains lipids, carbohydrates, and alkaloids. Hydroxyl groups found in the polymer chain provide adsorption sites for forming chemical bridges (Theodoro *et al*., 2013; Yin, 2010) and –COOH and free –OH surface groups increase the coagulation competency (Yin, 2010). Polysaccharides mixtures of galactanii and galactomannani extracted from *Strychnos potatorum* seeds can reduce turbidity up to 80% (Adinolfi *et al*., 1994). According to the study carried out by Ndabigengesere *et al*., 1995, Moringa extracts consist of water-soluble cationic coagulant proteins. Coagulation activity is carried out via the mechanism of charge neutralization and adsorption (Ndabigengesere *et al*., 1995; Theodoro *et al*., 2013;

Table 1: Summary of functional groups and mechanism proposed for natural coagulants

Natural coagulant	Source of extraction	Mechanism proposed	Functional groups	Reference
Moringa oleifera	leaves, flowers, seeds, roots, bark	Adsorption and charge neutralization	Starch, cationic protein, fatty acids, phenolic compounds Amines, glucose, alcoholic compounds, and carboxylate groups	Kumar *et al*., 2017; Kurniawan *et al*., 2020; Yin, 2010
Nirmali (*Strychnos potatorum*)	seeds	Inter-particle bridging	galactan and galactomannan	Vijayaraghavan *et al*., 2011
Cactus Musilage	Cactus pads	adsorption and bridging coagulation method	D-xylose, galacturonic acid, l-arabinose, l-rhamnose, and d-galactose.	Vijayaraghavan *et al*., 2011; Yin, 2010
Chitosan	fungi, marine invertebrates, yeasts	Charge neutralization and bridging	N-acetyl-D-glucosamine (acetylated unit), β-(1-4)-linked D-glucosamine (deacetylated unit)	Saranya *et al*., 2014
Tannins	Castanea, Acacia, or Schinopsis	Adsorption and charge neutralization	polyphenol compounds	Vijayaraghavan *et al*., 2011; Yin, 2010

Yin, 2010). Tannins are secondary metabolites of plants, produced from the barks, leaves, fruits, seeds regarded as a potential natural coagulant for water and wastewater treatment (Yin, 2010; Grenda *et al*., 2020). These polyphenol compounds are obtained from Castanea, Acacia, or Schinopsis plants. Tannins contain phenolic groups of anionic nature. These phenolic groups can be deprotonated, and form phenoxide stabilized resonance, allowing coagulation (Özacar and Şengil, 2003; Yin, 2010). The effectiveness of tannin as an eco-friendly coagulant depends on the chemical structure of the extracted tannins and their degree of modification. If more phenolic groups are available in a tannin structure, the coagulation capability will increase (Yin, 2010). The high coagulation ability of the cactus is due to the presence of mucilage. It assumes as sticky and complex carbohydrates. Surface cactus pads have high water retention capability. Cactus mucilage is made up of galacturonic acid, galactose, arabinose, xylose, and irhamnose. It is stored in internal and external parts of the cactus (Sáenz *et al*., 2004; Theodoro *et al*., 2013). According to Miller *et al*., 2008, cactus mucilage coagulation occurs by forming chemical bridges via hydrogen bonds or dipole interactions. Polygalacturonic acid present in mucilage is responsible for forming chemical bridges (Miller *et al*., 2008). Polygalacturonic acid structure consisted of an anionic chain, Chemisorption is involved between the charged particles and –OH and –COOH groups due to their partial de-protonation in aqueous solutions (Theodoro *et al*., 2013; Yin, 2010).

Types of natural coagulants

The natural coagulants have characteristics that are not noxious to an aquatic environment. It includes microbial polysaccharides (Saleem and Bachmann, 2019), bio-wastes (Atchudan *et al*., 2020), alginate, gelatin, cellulose-based materials, and Chitosan (Vigneshwaran *et al*., 2020). Most of the natural coagulants are polysaccharides; hence they are also termed polymeric coagulants. According to the origin, natural coagulants can be divided into three categories, as shown in Table 2.

Animal-based natural coagulants

Chitosan (CS) is a linear copolymer produced by the deacetylation of chitin (Verma *et al*., 2012). Chitosan offers several advantages over traditional compounds. For example, it is widely available (higher after cellulose), sustainable, cost-effective, non-toxic, biodegradable, biocompatible, soluble in weak acids, pH-sensitive (Martău *et al*., 2019; Pontius, 2016), better biosorption, no secondary pollution, sludge can reuse as agricultural fertilizer etc. (Abreu *et al*., 2020; Huang *et al*., 2000). In addition, Chitosan is efficient in reducing chemical oxygen demand, suspended solids, and turbidity (Abdullah and Jaeel, 2019).

Plant-based natural coagulants

The use of natural plant extracts dates back to 2000 BC, where Egyptians have inscribed the evidence of plant materials used for water treatment (Sivaranjani and Rakshit, 2016). According to Fatombi *et al*., 2013, it is clear that nuts such as beans, almonds, and *Strychnos potatorum* were used in Sudan, Egypt, and India, respectively. These nuts are reported to stimulate the coagulation of turbid waters (Fatombi *et al*., 2013). Since the late 1970s, various plant-based polyelectrolytes and polymers have been researched as coagulants. Plant-based coagulants are generally derived from the various parts of the plants and are organic, water-soluble, ionic, and non-ionic polymers in nature (Bodlund *et al*., 2014; Dezfooli *et al*., 2016; Fatombi *et al*., 2013). In the colloid-free aqueous state and the colloidal particle solution consisting of restricted irreversible loop arrangements, they maintain random configurations and help in destabilization by forming micro or macro flocs through charge neutralization (Hameed *et al*., 2016). Some plant-based materials may also behave as flocculant by strengthening the flocs for better settleability (Al-Hamadani *et al*., 2011; Awang and Aziz, 2012). Several works of literature have reported applying plant-based coagulants for water and wastewater treatment (Kansal and Kumari, 2014; Kristianto, 2017; Oladoja *et al*., 2017). Most of the investigated coagulants are from family *Fabacea*, primarily extracted from the leaves (Rak *et al*., 2012)

Table 2: Types of natural coagulants

Plant-based	Animal-based	Microorganism-based
Moringa Oleifera	Chitosan	Xanthan gum
Cactus	Alginate	*Aspergillus sp.*
Nirmali seeds	Chitin	*Enterobacter*
Tannin		*Streptomonas*
Potato starch		
Banana peel		
Common beans		
Tamarind seeds		

and seeds (Jayalakshmi *et al*., 2017). One of the most popular and extensively researched plant-based coagulants is *Moringa oleifera* belonging to the family *Moringaceae* (Baptista *et al.,* 2017; Camacho *et al*., 2017). The other common coagulants are Nirmali seeds, Tannins, Roselle seeds, Hyacinth bean etc, which have been studied for turbidity reduction (Saharudin *et al*., 2014; Fermino *et al*., 2017; Choubey *et al*., 2012). As in Table 3 is shown, they are low cost, non-toxic, locally available, readily implementable, and show great potential. Plant-based coagulants are advantageous because i) They are not dependent on chemicals; ii) they generate smaller amounts of sludge and biodegradable; and (iii) less toxic and not corrosive (Rocha *et al*., 2019).

Many wastewater treatments have substituted chemical coagulants with plant-based coagulants because of their low price, abundant source, multi-purpose, and biodegradability (Othmani *et al*., 2020).

Comparison of natural coagulants efficiency

The list of plant-based coagulants studied as natural coagulants are summarized in Table 4, with brief accounts of their optimal conditions, applications, and efficiencies. Roselle seeds (*Hibiscus sabdariffa)* were high in proteins (28 %) and soluble in water. When in solution, they carry an overall positive charge. These positively charged proteins bind to the turbidity causing negatively charged particles in the solution. According to the research, roselle seeds' highest turbidity removal efficiency is within 77 % - 87 % for synthetic wastewater at pH 10 and 81 % - 93 % at pH 4 (Saharudin and Nithyanandam, 2014). *Moringa oleifera* has been one of the best plant extracts for water purification. It is effective in removing Biological Oxygen Demand (BOD), turbidity, Chemical Oxygen Demand (COD), total coliforms removal, algal removal, Hardness, Total dissolved solids (TDS), and Total suspended solids (TSS) etc. According to the research carried out by (Choubey *et al*., 2012), *Moringa oleifera* removes turbidity from 100 NTU to 5.9 NTU and after dosing, and filtration to 5 NTU and total coliform remove by 96 % in synthetic raw water. Furthermore, in laundry, wastewater turbidity removed by 84 % and COD by 46% (Al-Gheethi *et al*., 2017). In Municipal wastewater, the reduction of turbidity, COD, BOD, hardness, TSS, and TDS are found to be 61 %, 65 %, 55 %, 25 %, 69 %, and 68%, respectively (Kumar Kaushal and Goyal, 2019). Hyacinth bean (*Dolichos lablab*) peels are characterized for usage as a protein source. Hyacinth bean peels have a moderate concentration of protein. Turbidity removal efficiency is 99% with the dosage of 20 mg/L in synthetic water (Bs and Papegowda, 2012). With the 200 mg/500 ml dosage, turbidity removes from 100 NTU (Nephelometric Turbidity Units) to 11.1 NTU and after dosing, filtration to 9.5 NTU, and total coliform removal 89% in synthetic water (Choubey *et al*., 2012). *Cactus* is another efficient natural coagulant. According to various research studies, cactus species prove efficient in removing turbidity, COD, and color. For example, in textile wastewaters, cactus removes turbidity by 92 %, COD by 89 %, and color by 99 % at the dosage of 40 mg/L and pH 7.25 (Bouatay and Mhenni, 2014). *Nirmali seeds* are another crucial natural coagulant used to remove turbidity and total suspended solids (TSS). It removes TSS by 76%, turbidity by 96% in laundry wastewater (Mohan, 2014). *Watermelon (Citrullus lanatus)* is the latest approach in developing an effective natural coagulant. The efficiency of turbidity removal was 88 % for the tannery effluent and 98% for synthetic wastewater. The other physicochemical parameters of tannery wastewater, such as TSS, BOD, and COD, were also reduced significantly. The COD removal efficiency was 50%, and the BOD of the wastewater was reduced by 55%. When employed as a coagulant, the watermelon seeds significantly decrease the synthetic wastewater's TSS, turbidity, BOD, and COD, and the tannery effluent (Sathish *et al*., 2018). Table 4 summarizes the facts on potential applications of plant-based materials that can be used as natural coagulants. This is significant in developing new mixed natural coagulants which deliver maximum efficiency.

Table 3: Characteristics of natural coagulants

Parameters	Characteristics
Carbon footprint	Environmentally friendly
Toxicity	Less toxic
Heavy Metals	Settling will occur along with the coagulation process
Sludge	Sludge volume/amount reduction, Low sludge handling cost, and treatment cost with good biodegradability

Therefore, it can be said that natural coagulants have found their diverse application not only for physical and biological water and wastewater treatment but also as a disinfectant. From a

Table 4: Summary of the removal efficiencies of some natural coagulants for water and wastewater treatment

Natural coagulant	Wastewater source	Optimal Conditions		Performance		References
		Dosage	pH	Parameters	Removal Efficiencies	
Industrial wastewater						
Hibiscus sabdariffa (Roselle seed extract)	Glove manufacturing wastewater	60 mg/L	10 ≤	Turbidity	87%	Saharudin and Nithyanandam, 2014
Moringa oleifera (Drumstick Tree)	Laundry wastewater	120 mg/L	5.7	COD Turbidity	43% 84%	Al-Gheethi *et al.*, 2017
Opuntia ficus indica (Cactus species)	Textile wastewater	40 mg/L	7.25	Turbidity COD Color	92% 89% 99%	Bouatay and Mhenni, 2014
Citrullus lanatus (Seeds of Water Melon)	Tannery wastewater	2000 mg/L	-	Turbidity BOD COD TSS	87% 55% 50% 69%	Sathish *et al.*, 2018
Strychnos potatorum (Nirmali seeds)	Laundry wastewater	8000 mg/L	-	Turbidity TSS	96% 76%	Mohan, 2014
Ocimum basilicum (Basil)	Textile wastewater	1600 mg/L	8.5	COD Color	62% 69%	Shamsnejati *et al.*, 2015
Corchorus Olitorius L. (Jute mallow)	Agricultural wastewater	3 mg/ L	-	Turbidity TOC (Total organic carbon)	95% 100%	Altaher *et al.*, 2016
Bamboo (*Bambusa vulgaris*)	Electroplating industry wastewater	1500 mg/L	5.5	BOD COD Cl- Sulphate TDS Ni	95 % 88 % 90 % 93 % 97 % 99 %	Sivakumar *et al.*, 2018
Cassia obtusifolia (Sickle pod seed gum)	Raw pulp and paper mill effluent	750 mg/L	5	TSS COD	87% 36%	Subramonian *et al.*, 2014
Pectin of orange peel pith	Surfactant	8000 mg/L	-	Turbidity TSS	90% 82%	Mohan, 2014
Dragon fruit foliage	Concentrated latex effluent	800 mg/L	10	Turbidity COD TSS	99% 95% 89%	Idris *et al.*, 2012
Papaya Seed	Textile wastewater	570 mg/L	2	Color	85%	Kristianto *et al.*, 2018
Chitosan	Olive mill wastewater	400 mg/L	-	TSS Turbidity	81 % 84 %	Rizzo *et al.*, 2008
	Paper and pulp wastewater	1800 mg/L	- - -	BOD COD Turbidity	90% 93 % 95 %	Thirugnanasambandham *et al.*, 2014
	Brewery wastewater	120 mg/L	-	COD	50% 73%	Gautam and Saini, 2020
	Textile wastewater	30 mg/L	- -	Turbidity COD	95% 65%	Hassan *et al.*, 2009
Aspergillus niger	Tannery industry wastewater	4.0 g	3	Cr(VI) TDS TS COD BOD Sulphates	96 % 92 % 98 % 85 % 90 % 94 %	Sivakumar, 2016
Municipal wastewater						
Moringa oleifera (Drumstick Tree)	sewage, gray water (water from sinks and showers)	-	-	Turbidity COD BOD TSS TDS Hardness	61% 65% 55% 69% 68% 25%	Kumar Kaushal and Goyal, 2019
Citrullus lanatus (Seeds of Water Melon)	Sewage wastewater	72.3 mg/L	5	BOD TSS	92% 93%	Joaquin *et al.*, 2021
Cucumis melo (Cantaloupe seeds)		76.7 mg/L	7	BOD TSS	80% 88%	
Okra seeds (ladies' fingers) coagulant	sewage, gray water (water	-	-	Turbidity BOD	65% 56%	Kumar Kaushal and Goyal, 2019

Continued Table 4: Summary of the removal efficiencies of some natural coagulants for water and wastewater treatment

	from sinks and showers)			COD TDS TSS Hardness	67% 69% 72% 30%	
			Synthetic water			
Moringa oleifera (Drumstick Tree)	Raw water synthetic	100 mg/L	10 ≤	Turbidity Total coliforms	94 % 96%	Choubey *et al*., 2012
Dolichos lablab (Hyacinth bean)	Turbid water (synthetic)	400 mg/L	-	Turbidity Total coliforms	89 % 89%	Choubey *et al*., 2012
	River water (Synthetic)	20 mg/L	-	Turbidity	99%	Bs and Papegowda,
Cicer arietinum (Chickpea)	Turbid water (synthetic)	400 mg/L	-	Turbidity Total coliforms	96 % 90%	Choubey *et al*., 2012
Opuntia ficus indica (Cactus species)	River water (Synthetic)	20 mg/L	-	Turbidity	99%	Bs and Papegowda, 2012
Mango pith	Turbid water (Synthetic)	500 mg/L	13	Turbidity	98%	Qureshi *et al*., 2011
Trigonella foenum-graecum (Fenugreek seeds)	Turbid water (synthetic)	300 mg/L	8.0	Turbidity	98%	ELsayed *et al*., 2020
Citrullus lanatus (Seeds of Water Melon)	Turbid water (Synthetic)	2000 mg/L	-	Turbidity	98%	Sathish *et al*., 2018
Jatropha curcas seed	Turbid water (Synthetic)	120 mg/L	3	Turbidity	96%	Abidin *et al*., 2011
Lens culinaris (Red lentil)	Turbid water (Synthetic)	26.3 mg/L	4	Turbidity	99%	Chua *et al*., 2019
Cassia fistula (Golden shower)	Synthetic paint industry wastewater	160 mg/L	8.4	Color Turbidity	96% 98%	Vishali *et al*., 2020
Alginate	Turbid water synthetic	10 mg/L	-	Turbidity	98%	Devrimci *et al*., 2012
			Surface water			
Moringa oleifera (Drumstick Tree)	Raw surface water	150 mg/L	7	Algal removal	65%	Ali *et al*., 2008
	Surface water	150 mg/L	7.5	Turbidity	97%	Pritchard *et al*., 2010
Cassia alata (Christmas candles)	Raw surface water	1000 mg/L	-	Turbidity	93%	Rak and Ismail, 2012
Opuntia dillenii (Cactus species)	Highly turbid lake water	1000 mg/L	-	Suspended solids Turbidity Color Suspended solids	56% 93% 15% 89%	Nougbodé *et al*., 2013
Prunus armeniaca (Apricot)	Raw surface water	30 mg/L	7	Algal Removal	55%	Ali *et al*., 2008
Mangifera indica, (Mango)	Raw surface water	30 mg/L	7	Algal Removal	68%	Ali *et al*., 2008
Tannin	Surface water	30 mg/L	9	Turbidity	80%	Sánchez-Martín *et al*., 2010
Banana pith	Polluted river water	100 mg/L	4	Turbidity COD Suspended Solids Sulphates Nitrates Cu Cr Fe Zn Pb Mn	99% 54% 96% 99% 89% 100% 100% 92% 81% 100% 60%	Kakoi *et al*., 2016; Karbassi and Pazoki, 2015

disinfection point of view, comparing the chemical and natural coagulants is interesting, considering their different parameters during usage. The natural coagulants are biodegradable and have no toxic effect on the receiving water bodies, which is a significant issue for chemically disinfected waters. Moreover, compared to chemical coagulants, the natural coagulants generally are readily available and generally sourced from the local areas making an attractive alternative as a disinfectant, which eliminates the need for storage in a controlled room. A study by Amran *et al*. (2018) has also emphasized on the need to conduct more detailed studies on the efficiency of plant-based coagulants for water and wastewater treatment. Therefore, detailed studies are required to explore its possibilities as a disinfectant for commercial purposes.

Natural coagulants - barriers for the commercialization

Most natural extracts have proven their coagulation capabilities in removing COD, BOD, TSS, turbidity, etc.; not many have accepted and reached commercialization. Four main barriers hinder commercialization: Financial capability, regulatory approval, market awareness, and research development (Choy *et al*., 2014). Another study by Saleem and Bachmann (2019) has highlighted the coagulants' cationic, anionic, and non-ionic nature and explored its application and commercialization constraints. The existing research outcomes are mostly confined to laboratory scale, lacking in real industrial applications. Lacking financial freedom and understanding about the market hinder the investors from investing in a new product. Economically feasible extraction methods are essential for successful commercialization. Comprehensive studies on the coagulation mechanism are also limited. Approval from the local government authorities and other regulatory authorities must be granted to launch any new products successfully. Obtaining approval is not easy without ensuring product compliance to the respective standards. Strong motivation for green chemistry concepts and cleaner production of the investors are crucial for the natural coagulant development and their applications. Table 5 summarizes the barriers that affect the successful commercialization of natural coagulants.

The main barrier for the commercialization of natural coagulants is difficulty in bulk production of raw materials; plant species. Raw materials used to produce chemical coagulants such as aluminum, iron are abundant in nature. For a successful and realistic application, raw materials required to produce natural coagulant should be available in large scale. Technical support, expert support and new equipment are necessary in sustainable implementation of natural coagulants so that production cost will ultimately increase. In short run this is not very economical so that market acceptance will be less. Hence the absence of mass plantation of recourses hiders steady supply of raw materials and the long term applications (Kurniawan *et al*., 2020). As Table 5 shows, natural coagulants are not readily available. Plant materials pass few stages before convert in to a plant-based

Table 5: Barriers in the commercialization of natural coagulants

Environmental and Technical Constraints	Economic and Social Constraints
• Complex extraction process	• Lack of money and time to invest in research and development.
• Absence of mass plantation for bulk processing	• Lack of maintaining a steady supply of raw materials. • Lack of meeting the minimum quality requirement.
• Due to the organic properties of natural coagulants, COD levels might increase.	• Lack of regulatory approvals on plant-based coagulants.
• Lack of toxicological studies for purified coagulants.	• Lack of awareness and market interest.
• Seasonal variations in some plant resources. (Cactus grow in hot seasons)	• Well established, competitive market.
• Lack of research regarding the practical usage and issues occurring during the operations within the plant	• High initial establishment cost.
• Lack of proper arrangements for storage of the natural coagulants in stock.	• Industrial acceptance
• Improper estimation of the quality characteristics of the treated water	• Lack of knowledge on health improvements

natural coagulant. These stages includes: extraction of active compound, purification etc. Extraction processes are different form plant- based to animal-based coagulants. Hence these processes should be carefully analyzed and should produce simplified and economically feasible processing steps. So that further studies needed to be carried out to analyze the converting and handling of powdered forms of coagulants, storing and preservation as well as toxicity (Kurniawan *et al*., 2020). Therefore commercialization process is costly as well as may take more time than expected. As mentioned in Fig. 1 coagulation process depends on coagulant type and dosage, pH, temperature etc. Hence these parameters should be optimized before implementing to the industry and it is more time consuming so that it will be difficult to cope with the competitive market (Kurniawan *et al*., 2020). Government and non-government regulatory bodies should encourage the industry to use natural coagulants in wastewater treatment process by implementing environmental rules (Freitas *et al*., 2018; Kurniawan *et al*., 2020) and reducing tax payments (Kurniawan *et al*., 2020), introduce new loan schemes to cover the initial implementation costs, linking the connection between research organization and industry and give recognition for the use of natural coagulants. Due to the use of high optimal dosages of natural coagulants, high amounts of residual organic matter (Freitas *et al*., 2018; Oladoja, 2016) is found in treated wastewater hence the COD levels will increase. This will ultimately increase the microbial activity leading to change in color and emission of unpleasant odors (Kurniawan *et al*., 2020; Oladoja, 2015). When selecting a plant species as raw material for the production of natural coagulants, it is important to consider their seasonal variations and availability (Kurniawan *et al*., 2020). Hence research and development studies should be conducted to identify best, economically productive natural coagulants and also to identify feasible combinations of chemical and natural coagulants.

Modified natural coagulants

A breakthrough in the commercial profit-oriented market can be made by emphasizing the need for blended coagulants. Lately, Mohd-Salleh *et al*., (2019) indicated natural materials as aids for future coagulant production and discussed the potential to develop composite coagulants that are sustainable. Natural coagulants can be used in conjunction with modifying agents. Table 6 shows some of the modifying agents used in combination with natural coagulants. Many of them are also active as flocculants when combined with a modifying agent. Chitosan is biodegradable and eco-friendly in comparison with traditional coagulants and acts as a bio-flocculant. It is used as a substitute for conventional coagulants in water treatment. Chitosan has primary amino groups; these amino groups can remove various contaminants. Previous studies have shown that Chitosan removed around 99% of *Microcystis aeruginosa* cells. However, its low production yield leading to a high cost of operation has hindered its application as a sole coagulant in practical scenarios (Ma *et al*., 2016). Due to its insolubility in neutral and alkaline conditions, the application of Chitosan is usually limited. Chemically modified chitosan materials have been manufactured to overcome this issue (Dharani and Balasubramanian, 2015; Zhang *et al*., 2014). According to the study (Vigneshwaran *et al*., 2020), Moringa seeds are considered natural coagulants/flocculents. It is mainly comprised of lipids and protein. The protein molecules of moringa seeds can bridge $–NH_2$ groups and –OH groups present in the chitosan molecule. Bridging will leads to the destabilization and aggregation of the small stable colloidal impurities into larger particle units. Hence, it is known as floc. The floc can remove through several physicochemical processes such as solid-liquid separation, slow mixing, and rapid mixing (Vigneshwaran *et al*., 2020). Recently, natural polymeric coagulants, such as cellulose, Chitosan, starch, have drawn more attention due to their advantages of low price, biodegradability, vast resources, and low toxicity. In addition, attention was focused on starch-based coagulants because starch is one of the most abundant natural polymers globally and has been applied in various fields (Li *et al*., 2015).

According to Ma *et al*., 2016 dual coagulant prepared by using chitosan and aluminum chloride is efficient in removing toxic cyanobacteria *Microcystis aeruginosa* found in water bodies. This novel mixed coagulant shows a strong bridging ability and high adsorption. This study suggests that CTASC is efficient, cost-effective, specific, and safe in removing *Microcystis aeruginosa.* Zhang *et al*., 2014, mentioned chitosan-based flocculent N-carboxyethylated chitosan (CEC) is eco-friendly coagulant produced by chitosan and acrylic acid. It flocculates copper (II) and tetracycline (TC). The advantages are in the aspects of optimal dosage,

Table 6: Summary of the literary works on the modified natural coagulants

Natural coagulants	Modifying agent	Wastewater source	Parameter	Optimal conditions		Removal efficiency (%)	References
				Dosage (mg/L)	pH		
Chitosan (CTS)	Aluminum chloride (AC)	Drinking water treatment	*(Microcystis aeruginosa) cyanobacteria removal*	2.6 CS + 7.5 AC	-	98	Ma *et al.*, 2016
	Acrylic acid	Livestock wastewater	Copper (II) removal	50	8	98	Zhang *et al.*, 2014
	Mercaptoacetic acid	Turbid water (Synthetic)	Turbidity	50	5	100	Zhang *et al.*, 2015
			Copper ((II) removal	50	7.3	90	
	N-methyl piperazinium chloride	Tannery effluent	BOD	5	6.7	86	Dharani and Balasubramanian, 2015
			COD	5	6.7	96	
	Moringa oleifera	Turbid water (Synthetic)	Turbidity	200	8	84	Vigneshwaran *et al.*, 2020
Starch	(2-hydroxypropyl) trimethylammonium chloride	Synthetic wastewater	Kaolin suspension removal	1000	4	93 %	Li *et al.*, 2015

lowest residual concentrations, and floc properties. The charge neutralization mechanism is used for the removal of copper (II), and TC makes a coordination complex with copper(II) hydroxides and eliminates with copper (II) at pH 9. Mercapto - acetyl chitosan (MAC) is prepared by combining mercaptoacetic acid and chitosan. It has the ability of adsorption bridging so that water solubility is high (Zhang *et al.*, 2015). Turbidity is removed by electrical neutralization of the turbidity substances. Heavy metal ions produce coordination complexes or chelate with MAC and form flocs (Zhang *et al.*, 2015). According to Dharani and Balasubramanian, 2015 study, Chitosan-g-N-MPC is prepared by grafting N-methyl piperazinium chloride to chitosan. Flocculation mechanisms are charge neutralization and bridging. Due to the considerable molecular weight and high charge density, it requires low optimal dosages. According to Vigneshwaran *et al.*, 2020, acid-treated carbonized chitosan-*Moringa oleifera* (ACCM) shows better adsorption ability, high coagulation capability, low sludge formation and low leaching level. Coagulation mechanisms are charge neutralization and adsorption. Li *et al.*, 2015 discussed two kinds of starch-based flocculants. Though they have the same chemically modified functional groups, substitution degrees are different. CMS-CTA-P and CMS-CTA-N have opposite surface charge properties in water. CMS-CTA-N is efficient in the hematite suspension at neutral conditions. CMS-CTA-P shows a better flocculation activity in the kaolin suspension at neutral and acidic conditions. Patching, bridging, and charge neutralization are found as flocculation mechanisms.

CONCLUSION

Coagulants obtained from many natural sources have found their place in the water and wastewater industry world and are widely being used as primary coagulants or coagulant aids. Natural coagulants are environmentally friendly, inexpensive, less hazardous to human beings, and viable alternatives to chemical coagulants. Plant-based, animal-based, and microorganism-based coagulants have been researched for ages and have become popular in developing countries. This review summarized the efficiencies of common natural coagulants such as Roselle seeds, *Moringa oleifera*, Hyacinth bean, Cactus, Nirmali, Chitosan, Tannins and Watermelon seeds etc., used in the water and wastewater treatment and suggested that plant-based species showed good efficiencies in removing turbidity, color, organic matters as well as pathogens. It was noticed that many studies had investigated the application of plant-based coagulants in the primary treatment for turbidity removal and secondary treatment for organic pollutant (TSS, BOD, and COD) removal. However, its disinfection aspect is not well explored. Studying the plant-based coagulants or plant species for the tertiary treatment of water and wastewater could be an exciting area for future research. Further, plant-based coagulants are advantageous due to their low toxicity and eco-friendly sludge production. Despite having significant benefits, some crucial barriers to the commercialization of natural coagulants are identified in this review. The significant barriers are environmental, technical, economic, and social challenges. However, there have been efforts made to commercialize natural coagulants through modified natural coagulants. There are two modified coagulants summarized in this work: Chitosan and starch, which are considered an alternative way to enhance the efficiency of the coagulants and increase its market demand. The concept of modified or composite coagulants could be taken as an indirect example for tackling these constraints. However, there are limited studies on these barriers, and this review recommends that more investigations and assessment methods are required to find the origin of these constraints and solve it through more scientific approaches. Further, from a sustainability perspective, the demand for natural coagulants is destined to increase. Therefore, more researches in the modified coagulants hold promising prospects.

AUTHOR CONTRIBUTIONS

S. Nimesha has done most of the writing and preparing the manuscript. C. Hewawasam has done some part of writing, editing and supervision of works of first author. D.J. Jayasanka has done some part of writing, editing and supervision of works of first author. Y. Murakami is the advisor for the writing this review. N. Araki is the advisor for this research work. N. Maharjan has given significant intellectual inputs and supervised this work.

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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 falsification, double publication and submission, and redundancy, have been entirely witnessed by the authors.

ABBREVIATIONS

AC	Aluminum chloride
ACCM	Acid treated carbonized chitosan-*Moringa oleifera*
AD	Alzheimer’s disease
BOD	Biological oxygen demand
CEC	Carboxy-ethyl Chitosan
Chitosan-g-N MPC	N-methyl piperazinium chloride grafted Chitosan
CMS-CTA-P / CMS-CTA-N	(2 hydroxypropyls) trimethylammonium chloride etherified carboxymethyl starch (two different substitution degrees)
COD	Chemical oxygen demand
-COOH	Carboxyl group
Cr	Chromium
CS	Chitosan
CTS	Chitosan to be modified
CTS- AC	Chitosan -aluminum chloride

Cu	Copper
Fe	Iron
g	Grams
MAC	Mercapto - acetyl chitosan
mg/L	Miligrams per liter
Mn	Manganese
-NH_2	Amine group
Ni	Nickel
NTU	Nephelometric turbidity units
-OH	Hydroxyl group
Pb	Lead
pH	Potential (power) of hydrogen
TC	Tetracycline
TDS	Total dissolved solids
TOC	Total organic carbon
TS	Total solids
TSS	Total suspended solids
Zn	Zinc
%	Percentage sign

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CASE STUDY

Green tourism business as marketing perspective in environmental management

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ABSTRACT

BACKGROUND AND OBJECTIVES: Environmental guidelines and principles of sustainable development are becoming increasingly popular and are a priority for most business areas. One of the widely developing eco-destinations is green tourism, which is gaining a profitable and priority status, especially for lower middle-income countries. The purpose of the article is to determine the strategic marketing support for the development of green tourism on the example of Ukraine and its regions based on an approach to its assessment in terms of environmental and tourism competitiveness.

METHODS: The authors used general scientific and specific methods: comparative, critical and system analysis, synthesis to search and group indicators of ecological and tourism competitiveness. Distance method, ranking, economic and statistical analysis were implemented to analyze the green tourism potential in each region in Ukraine and reveal the leaders and outsiders among them. For the accumulation, processing, visualization of data and forming the matrix of green tourism, based on data for 2015-2019, potential Microsoft Excel, Figma and Canva tools, Harrington scale were applied.

FINDINGS: The approach to estimate the green tourism potential based on the ecological and tourism regional competitiveness according to the author's list of 37 indicators were proposed, the matrixes of green tourism potential of Ukrainian regions in 2019 and 2020 were developed, and strategic marketing support according to sustainable development for green tourism business were proposed. Strategic marketing support of green tourism development in Ukrainian regions was defined based on ecological and marketing strategies.

CONCLUSION: The author's approach makes it possible to systematically assess the potential of green tourism using up-to-date statistical information. According to the tourism and environmental competitiveness rating, the regions with the most significant and worst potential were found. The positive dynamics of the development of green tourism in 2019-2020 were revealed. The results are the basis for providing comprehensive environmental and marketing support to ensure sustainable development and gain additional competitive advantages in the green tourism business.

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INTRODUCTION

Environmental guidelines and principles of sustainable development are becoming increasingly popular and are a priority for most business areas. The latest analytical reports from the WTO show a rapid increase in the number of consumers, for whom the level of environmental friendliness is becoming an important factor when choosing a travel service (WTO, 2021). Green offices, green marketing, green tourism, all these areas are promising and widely implemented in many developing and developed countries. Every year, for more and more consumers, the level of environmental friendliness becomes an important factor in choosing a product or service. So green tourism is not the exception and has the status of the profitable and priority area. It combines the ideas of effective tourism and environmental protection. More than twenty years ago, scientists paid attention to the issue of the implementation of green tourism principles in the framework of sustainable development. In particular, Fennell (1999) introduces the key foundations, concepts, and issues related to ecotourism based on international case studies. Subsequently, many attempts were made to formalize the concept of Ecotourism. Wearing *et al.* (1999) considered ecotourism as a wide range of elements: a form of 'alternative tourism' opposed to mass tourism; a particular philosophical orientation towards nature; a strategy for sustainable development. Cheia (2013) provided a survey on the theoretical notions about ecotourism and compares the most important attempts to define it. Lee *et al.* (2016) considered green tourism as a term relating to the natural environment and cultural heritage of an area or undertaking good environmental management (or green) practice. Tang *et al.* (2017) believed it is a kind of tourist activity that pays attention to resources and protects ecology and a mode of tourism economic development that advocates recycling. Obviously, such a popular direction requires market research. In this regard, many researchers focused their attention on the behavioral aspects of international tourists concerning the sustainability of green tourism, using the extended framework of the theory of planned behavior (Ibnou-Laaroussi *et al.*, 2020). Thus, ecotourism explores the natural area's ecological, cultural, historical, and archaeological treasures while preserving its integrity and enhancing economic development opportunities for local communities (Shah, 2017). Shabbir *et al.* (2020) analyze "the main green marketing approaches and their impact on consumer behavior towards the environment in the United Arab Emirates". They reviewed "the current consumption patterns of green products using a questionnaire approach". In addition, another important direction of ecotourism is considered in the scientific literature. According to the Low Carbon Green Growth Roadmap, ecotourism is positioned as one of the most important green adjustments on the way to low carbon green growth, which is considered a promising development direction in the tourism industry (LCGGRAP, 2012). Tsung *et al.* (2019) have provided complex research of low-carbon tourism experience from the perspective of nature-based tourism and, as a result, formed the recommendations to advance tourism management. For example, Povodör *et al.* (2013) investigate "the demand by office managers on Green Office standard, structured EU Green Office trainings and also for tools to measure office's environmental impact". They determine European Green Office Principles, improve the European Green Office program and Environmental Management System, propose the criteria used for identifying "greener" goods based on a life cycle approach. Aroonsrimorakot (2018) describes "the purpose, principles, features, procedure for setting up, and management of green office standard in Thailand with the main aim of describing the growing importance of green office due to the impact of climate change". The interests of some academic economists gradually focused on issues related to the commercialization and profitability of the direction. Park and Kim (2020) provide "an overview of green banking as an emerging area of creating competitive advantages and new business opportunities for private sector banks and expanding the mandate of central banks and supervisors to protect the financial system and manage risks of individual financial institutions". Every year, for more and more consumers, environmental friendliness becomes an important factor in choosing a product or service. The provisions of sustainable development have been included in the strategic goals of many enterprises. Following the global trends of sustainable development and green initiatives, Ukrainian scientists are also researching eco-responsible tourism, regional potential. Thus, according to the purpose of this study the following studies were highlighted. Pidgornyi and Mylashko (2014) study the areas of statistical research of tourist flows, costs, and consumption, providing methods to analyze the quantified phenomena in tourism. Danylko (2014) explores the role of information resources for the successful implementation of rural green tourism in Ukraine to increase the rural population's employment and reduce labour migration. He emphasizes the need to form a system of statistical monitoring, using the whole set of statistical methods in assessing the state and trends in the services of the tourism market. Panyuk and Lukomska (2016) analyze the current state of the tourism industry in Ukraine and the relationship of rural green tourism development with the tourism industry in the macroeconomic aspect. They prove the importance of developing green tourism, through which it is possible to solve social and economic problems of rural areas. Babenko *et al*., (2020) study the development of the processes of regional integration of Ukraine to ensure sustainable economic development regarding ecotourism and determine the priority direction of its regional integration. Bilovodska *et al*. (2020) analyze the eco-trends in packaging and the Ukrainian market of organic products. The authors form the scientific and practical approach to the development of environmental packaging based on evaluating consumers', manufacturers', intermediaries' perspectives, considering the principles of eco-oriented logistic management in trade and innovative entrepreneurship. The COVID-19 pandemic significantly affected the development of tourism. Scientists analyze the impact on the tourism industry and overall economic performance. For example, Vărzaru *et al*. (2021) listed measures to ensure the tourism sector's resilience during the COVID-19 pandemic. Orîndaru *et al*. (2021) examine "the fluctuating tourist perceptions on travelling and tourism industry expenditure and understand consumers' expectations and criteria to reconsider purchasing such services as to provide a clear background for appropriate strategies and response measures for the T&T industry recovery". Yustisia *et al*. (2021) explain the adaptation strategies of tourism industry stakeholders destinations during the COVID-19 pandemic. For many countries, green tourism not only protects the environment but is also a source of significant revenue. In countries such as Costa Rica, Ecuador, Nepal, Kenya, Madagascar, ecotourism is one of the main areas of economic development and financial stability. An insignificant number of organizations present green tourism in Ukraine, but more and more people choose this type of tourist activity every year. Moreover, there is an increase in the popularity of atypical destinations for travel. The vast majority of ecotourism fans still prefer the Carpathians. Still, the number of visitors to small hotels in picturesque parts of other regions of Ukraine is growing (e.g., in the village of Koropoven (Kharkiv region), the "wild" beaches along the Black Sea in the Kherson region, etc.). The COVID-19 pandemic exacerbates these trends. However, the existing approaches to the formation and assessment of the potential of green tourism for such countries are mostly fragmented. This does not allow for comprehensive, objective calculations for development in the regional context and the creation of applicable marketing recommendations. Consequently, given the above, the purpose of the study is to determine the strategic marketing support for the development of green tourism on the example of Ukraine and its regions based on an approach to its assessment in terms of environmental and tourism competitiveness. The objectives of the current study are:1) to investigate the indicators of tourism and environmental competitiveness of Ukrainian regions before and during the pandemic COVID-19; 2) to develop a matrix of green tourism potential of Ukrainian regions in 2019 and 2020 based on the ecological and tourism regional competitiveness according to the author's list of 37 indicators; 3) to define ecological and marketing strategies for different types of regions according to the level of green tourism (sufficient, satisfactory and unsatisfactory). This study has been carried out in Ukrainian regions as a case study in 2021.

MATERIALS AND METHODS

According to "Sustainable Development Goals: Ukraine" national report (NBR, 2017) provided by the Ministry of Economic Development and Trade of Ukraine, "Monitoring Report" developed by the State Statistics Service of Ukraine (MR, 2019; MR, 2020) with the support of UNICEF in Ukraine and UN RCO benchmarks for Ukraine to achieve the sustainable development goal up to 2030 are identified. Obviously, tourism is considered a constituent of the Ukrainian sustainable development strategy. However, despite the considerable interest in ecological initiatives and developments, the issues of the development of the Ukrainian tourism business based on sustainable principles remained insufficiently disclosed. The deliverables of foreign researches without proper adaptation to the conditions of Ukraine will not lead to the desired result. It should also be mentioned that the developments of Ukrainian research are incomplete; they are limited to specific aspects. It is not enough to simply analyze the amount of revenue or expenditure by industry. Thus, to determine the strategic marketing support of green tourism, it was proposed to use statistical indicators grouped to characterize tourism and ecological potentials (WTO, 2018). Many categories can be identified by characterising the Ukrainian regions' potentials, so the analysis will be conducted according to the distance method to estimate competitiveness (WEF, 2021). In this method, the indicator of comprehensive assessment considers the absolute values of the compared indicators and their proximity to the best values (UNRISD, 2021). The following mathematical analogy is used to calculate the value of the integrated assessment. Each region is considered as a point in the *n*-dimensional Euclidean space. Coordinates of the point are the values of comparative indicators. The concept of the benchmark is introduced as a region with all the best values of indicators among the regions (Screemoyee, 2021). The closer is the region to the benchmark, the smaller is its distance to it, and the higher is the ranking. The region with the minimum value of a comprehensive assessment has the highest ranking.

The study involves N regions, and the metric distance between the elements (indicators) of the set is determined by the function $Int\,Ind_N(x;y)$, the objective function of maximum proximity is using Eq. 1.

$$F = Int\,Ind_N(x;y) \rightarrow min, \qquad (1)$$

where; $(x;y)$ – elements (indicators) of the set or their coordinates.

To study the analytical indicators of the region competitiveness, a matrix of elements was made where the rows determine the number of the corresponding tourism and ecological competitiveness indicators of the region, and the columns - the number of the corresponding regions of evaluation. That is, the sample consists of objects (regions) characterized by the most detailed indicators of the ranking of the object. Ranking assessment is carried out according to the weight of indicators. The value of its ranking according to the author's list of indicators is determined for each analyzed region. The coordinates of the points of the matrix are standardized indicators of the *i*-th region. It is determined by the ratio of the actual values of each indicator with the benchmark. The calculating of an integral indicator (both for tourism competitiveness and ecological competitiveness) the following approach was implemented using Eqs. 2 and 3.

$$Int\,Ind_N = \sum_{i=1}^{n} W_i \times (1 - Sub\,Ind\,Value_i), \qquad (2)$$

$$Sub\,Ind\,Value_i = \frac{C_i}{C_{max}} \text{ or}$$

$$Sub\,Ind\,Value_i = \frac{C_{min}}{C_i} \qquad (3)$$

W_i – the weight of the indicator i; n – a total number of indicators; C_i – an actual value of the indicator i; C_{max} – a maximum value of the indicator i among all investigated regions; C_{min} – a minimum value of the indicator i among all investigated regions.

It was proposed to include the following indicators of tourist activity: 1) income from the provision of tourist services (excluding VAT, excise duties and similar mandatory payments) - for legal entities and natural persons-entrepreneurs; 2) the amount of costs of tourism entities; 3) cost of realized tourist vouchers - by tour operators and travel agencies within Ukraine;4) number of tourists served by tour operators; 5) number of collective accommodation facilities (legal entities) - total number of collective accommodation facilities (CAF) in Ukraine, hotels and similar accommodation facilities, tourist bases and mountain shelters, etc., specialized accommodation facilities, recreation facilities, etc.; 6) number of collective accommodation facilities (natural persons-entrepreneurs) - total number of CAF, number of hotels; 7) capacity of hotels and similar accommodation facilities (legal entities / natural persons-entrepreneurs) - total number of places, number of places in hotels, in tourist bases and mountain shelters, etc. To determine the ecological competition, the main indicators were included: 1) atmospheric emissions from stationary sources of pollution, namely: emissions of pollutants, ammonia, non-methane volatile organic compounds, carbon monoxide, methane, suspended solids, sulfur dioxide, nitrogen dioxide, carbon dioxide; 2) generation and management of waste by region, namely: the amount of formed, disposed of, incinerated, deleted in specially designated places or objects; 3) the total amount of waste accumulated during operation, in specially designated places or facilities (waste disposal sites); 4) land area of reserves and national nature parks; 5) capacity of treatment facilities; 6) capital investments in environmental protection; 7) current costs of environmental protection. The total of indicators in each Ukrainian region was received. All weight indicators are the same. For the accumulation, processing, ranking, visualization of data and forming the matrix of green tourism potential Microsoft Excel, Figma and Canva tools, Harrington scale were applied.

RESULTS AND DISCUSSIONS

Research of green tourism development prospects in Ukraine

Ukrainian tourism has always been divided into summer recreation (by the river or at sea) and winter (in the mountains) at the level of stereotypes. However, the country's tourism potential does not end there, and every year the industry develops more and more and expands its product portfolio. In recent years, the parliament has drawn attention to the need to develop the tourism sector, which in Ukraine is under the jurisdiction of the Ministry of Economic Development and Trade. In early spring 2017, the Cabinet of Ministers approved a strategy for the development of tourism and resorts until 2026. According to this document, conditions must be created for comfortable, safe, and diverse tourism in Ukraine. These include changes to the relevant laws and the creation of additional legislative acts. The financial support for tourism development was planned. Furthermore, the recent global coronavirus crisis will significantly influence those strategic plans. Therefore, the announced growth of indicators for the next ten years can already be questioned. The first is an increasing the number of foreign tourists. The indicators of 2015 were taken as a basis. Then 12.9 million foreigners came to Ukraine. The prognoses for 2026 was about 32.25 million people. The Ministry of Ecology and Natural Resources of Ukraine has been saying that it is necessary to increase the lands of the nature protection fund. This is important for a post-industrial country (TPU, 2020). It should be understood that it is not only about the restoration of forests, many of which were artificially planted in the 1950-60s but also about preserving natural landscapes, including swamps, steppes, estuaries and even the desert in the Khersonska region. People's access to the territory of nature and biosphere reserves is quite limited, which is not the case with national parks, where tourists can enter freely, but to use the resources of areas that belong to the nature reserve is prohibited. In 2017, for the first time in three years, the budget included funds for tourism development - 30 million UAH. But this is ten times less than neighboring countries receive as state support for the tourism sector. These funds are planned to spend on information, marketing support of the tourism sector, and Internet resources creation. A significant effort should also be focused on the emerge from the shadow. Despite the turmoil in the economic sector, green ideas are gaining more and more popularity among both producers and consumers. Concerns in society are growing every day due to many problems related to human health and the environment. Humankind has begun to realize that the greening of any activity is the only right choice of society. Therefore, under the pressure of a socially responsible population, new types of products were created (the so-called "green" products), which cause minor damage to the environment. Creating demand, sales promotion, and business planning considering environmental aspects are urgent problems in the current development of sustainable production and consumption in Ukraine. Ukrainian consumers are mostly aware of today's most important environmental problems, understand the need to overcome them, and are willing to pay a surcharge for environmental goods and services. Today to be a "green" businessperson means you are in trend. Words such as "environmentally friendly", "organic", "natural" are quite clearly engraved in the everyday language of consumers and producers. One of the challenges that green leaders face is closer attention from consumers and contact audiences. Balancing between environmental goals and business profitability (which is ultimately needed to keep business viable), they must find ways to sustain the company's existence, even if the business is perceived as "not green enough" in some of its decisions. It was decided to build a matrix that would combine environmental and tourism factors to analyze the potential for introducing elements of green tourism. All information for the study was taken from the survey issued by the State Statistics Service of Ukraine in 2017 and 2019. Separately, the tourist and ecological condition of the regions of Ukraine was analyzed by the method of determining competitiveness and by the method of additional analysis of secondary information. The indicators of the green tourism development level are presented in Fig. 1.

Today many players of the tourism market in Ukraine understand the importance of eco-component. However, it should be noted that the share of entrepreneurs aware of the principles of the concept of "eco-tourism" or "green tourism" is relatively small. It should be noted that it couldn't follow the trend because no data for green tourism was available after 2017. Luckily, the World Economic Forum has released the travel and tourism rankings for countries across the world in 2017 and 2019 (Table 1).

According to The Travel and Tourism Competitiveness Index methodology (TTCR, 2017; TTCR, 2019), the natural resources pillar measures the available natural capital and the development of outdoor tourism activities. Natural capital is defined in terms of landscape, natural parks, and the richness of the fauna. The key feature of Ukrainian green tourism is a unique tourist lifestyle, which is based on implementing the entrepreneurial potential of the rural population to improve their welfare in the future. The overall dynamics of green tourism development in Ukraine is acceptable. Also, considering the global COVID 19 crisis that

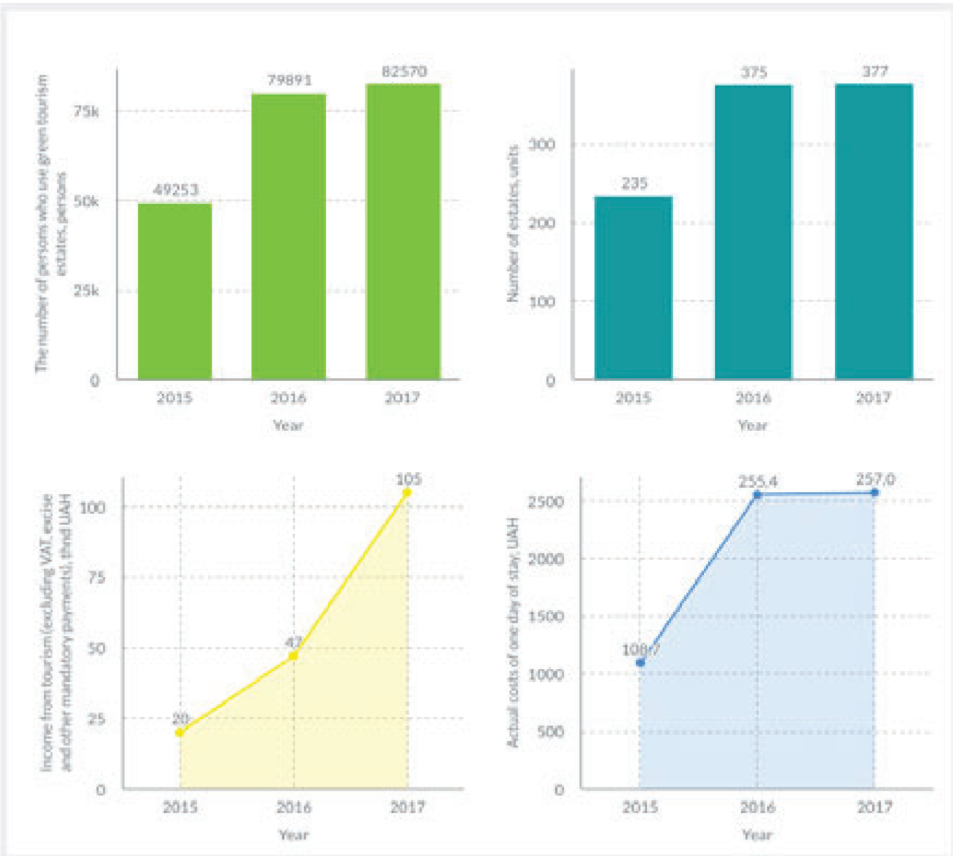

Fig. 1: The indicators of the green tourism development level of Ukraine in 2015-2017 (SSSU, 2020)

Table 1: Ukraine profile in the travel and tourism competitiveness index report (TTCR, 2017; TTCR, 2019)

Component	Value			Rank		Europe average	Global average
	2019	2017	Trend	2019 (out of 140)	2017 (out of 136)	2019	2019
Travel and Tourism Competitiveness Index	3.7	3.5	↑	78	88	4.3	3.8
1. Enabling environment sub-index	5.0	4.6	↑	65	78	5.4	4.8
Business environment	4.1	3.7	↑	103	124	4.7	4.5
Safety and security	4.8	3.5	↑	107	127	5.8	5.3
Health and hygiene	6.5	6.6	↓	11	8	6.2	5.1
Human resources and labor market	4.8	4.9	↓	48	41	5.0	4.5
ICT readiness	4.5	4.2	↑	78	81	5.4	4.6
2. T and T policy and enabling conditions sub-index	4.5	4.1	↑	70	85	4.6	4.4
Prioritization of Travel and Tourism	4.3	4.3	=	92	90	4.9	4.6
International Openness	3.7	2.9	↑	55	78	3.7	3.3
Price competitiveness	5.9	5.2	↑	19	45	5.1	5.3
Environmental sustainability	3.9	3.9	=	114	97	4.7	4.3
3. Infrastructure sub-index	3.4	3.1	↑	73	79	4.2	3.5
Air transport infrastructure	2.7	2.4	↑	71	79	3.6	3.1
Ground and port infrastructure	3.1	3.0	↑	77	81	4.1	3.5
Tourist service infrastructure	4.3	4.0	↑	65	71	4.9	4.0
4. Natural and cultural resources sub-index	2.1	2.2	↓	89	88	2.9	2.7
Natural resources	2.2	2.3	↓	116	115	3.1	3.1
Cultural resources and business travel	1.9	2.1	↓	55	51	2.6	2.2

Table 2: The ecological and tourism competitiveness of Ukrainian regions

Region	An integral indicator of the tourism competitiveness					An integral indicator of the ecological competitiveness				
	2019	Rank 2019	2020	Rank 2020	Trend 2020/2019	2019	Rank 2019	2020	Rank 2020	Trend 2020/2019
Vinnytsia	0.8496	16	0.9074	18	Negative	0.8356	15	0.8868	16	Negative
Volyn	0.8462	14	0.7806	11	Positive	0.8331	14	0.9176	19	Negative
Dnipropetrovsk	0.7876	10	0.6857	9	Positive	0.7084	7	0.7083	8	Positive
Donetsk	0.9877	24	0.9734	24	Positive	0.9942	24	0.9467	24	Positive
Zhytomyr	0.8389	13	0.6589	6	Positive	0.7192	9	0.7526	9	Negative
Zakarpattya	0.4650	1	0.6845	8	Negative	0.6415	5	0.5398	3	Positive
Zaporizhzhya	0.8467	15	0.8466	14	Positive	0.5561	4	0.5496	4	Positive
Ivano-Frankivsk	0.5466	2	0.5565	2	Negative	0.5445	3	0.5257	2	Positive
Kyiv	0.7151	6	0.9181	20	Negative	0.8287	13	0.8245	15	Positive
Kirovohrad	0.7213	7	0.7214	10	Negative	0.8594	17	0.9190	20	Negative
Luhansk	0.9211	19	0.9699	23	Negative	0.6869	6	0.6868	7	Positive
Lviv	0.5783	4	0.5774	3	Positive	0.3114	1	0.2897	1	Positive
Mykolaiv	0.9791	23	0.8769	16	Positive	0.7174	8	0.6485	6	Positive
Odesa	0.7864	9	0.5190	1	Positive	0.4974	2	0.5794	5	Negative
Poltava	0.9548	22	0.8400	13	Positive	0.8724	18	0.8876	17	Negative
Rivne	0.8868	18	0.9512	22	Negative	0.9620	23	0.9203	22	Positive
Sumy	0.8315	11	0.8313	12	Negative	0.9206	22	0.9205	23	Positive
Ternopil	0.7284	8	0.9108	19	Negative	0.8145	12	0.8094	13	Positive
Kharkiv	0.9385	21	0.9383	21	Positive	0.7778	10	0.7618	10	Positive
Kherson	0.6785	5	0.6734	7	Positive	0.7845	11	0.7844	11	Positive
Khmelnytsk	0.8715	17	0.8758	15	Negative	0.9027	21	0.9190	21	Negative
Cherkasy	0.9275	20	0.6039	5	Positive	0.8899	20	0.9166	19	Negative
Zaporizhzhya	0.5664	3	0.5832	4	Negative	0.8877	19	0.8155	14	Positive
Chernihiv	0.8342	12	0.8840	17	Negative	0.8384	16	0.8026	12	Positive

significantly affects the tourism business worldwide, the internal demand for Ukrainian sights might increase. But the demand growth doesn't always mean getting a long-term effect. Once the borders open, tourist flows will be redistributed in traditional pre-pandemic destinations. However, it should be noted that safety issues and standards of tourist services will be significantly tightened.

Matrix approach to estimating the potential of green tourism in Ukraine's regions

A matrix combines two integral indicators: ecological competitiveness and tourism competitiveness (Table 2).

An example of calculations of the integral indicator of the tourism competitiveness: Dnipropetrovsk region case in 2020 is provided in Table 3. The others calculations for each region were performed similarly.

An example of calculations of the integral indicator of the ecological competitiveness: Cherkasy region case in 2020 is provided in Table 4. The others calculations for each region were performed similarly.

As it comes from Table 2, according to the ranking results of the Ukrainian regions, five Ukrainian regions can be recognized as leaders by the level of ecological competitiveness in 2019: Lviv, Odesa, Ivano-Frankivsk, Zaporizhzhya, Zakarpattya. Donetsk (the part of the region under Ukrainian control), Rivne, Sumy, Khmelnytsk and Cherkasy regions are outsiders in terms of environmental competitiveness. In terms of tourism competitiveness in 2019, the leaders were Zakarpattya, Ivano-Frankivska, Chernivetska, Lvivska and Khersonska regions, and the outsiders were Donetsk (the part of the region that is under Ukrainian control), Mykolaiv, Poltava, Kharkiv and Cherkasy regions. According to the level of ecological competitiveness, Lviv, Ivano-Frankivsk, Zakarpattya, Zaporizhzhya and Odesa regions were leading in 2020. Donetsk (the part of the region under Ukrainian control), Sumy, Rivne, Khmelnytsk, Kirovohradsk regions are the outsiders. As to the tourism competitiveness Odesa, Ivano-Frankivsk, Lviv, Chernivtsi, Cherkasy regions are the leaders, and Donetsk (the part of the region that is under Ukrainian control), Luhanska (the part of the region that is under Ukrainian control), Rivne, Kharkiv and Kyiv regions are the outsiders (Table 2). It should be noted that from 2019 till 2020, the same regions remain the leaders by the level of ecological competitiveness; Ivano-Frankivsk, Chernivtsi and Lviv regions – according to the level of tourism competitiveness. Only Cherkasy region stopped being in 2020 among outsiders by the ecological competitiveness. Unfortunately, Donetsk (the part of the region under Ukrainian control) and Kharkivska regions were the outsiders in 2019 and 2020 by the tourism competitiveness. Also, Odesa and Cherkasy regions have significantly improved their tourism competitiveness. Vice versa, Rivnenska and Kyivska regions deteriorated and got to outsiders by the tourism competitiveness. It is also worth noting the high density of obtained results for the rest of the Ukrainian regions that can be qualified as lower than the average. Obviously, the COVID-19 pandemic significantly affects the development of tourism. It is also positive for the development of green tourism. According to Table 2, the ecological competitiveness increased in twelve regions (Volyn, Dnipropetrovsk, Donetsk, Zhytomyrska, Zaporizka, Lvivska, Mykolaivska, Odesa, Poltava, Kharkiv, Kherson, Cherkasy regions) and tourism competitiveness – in 16 regions (Dnipropetrovsk, Donetsk (the part of the region under Ukrainian control), Zakarpattya, Zaporizhzhya, Ivano-Frankivsk, Kyiv, Luhansk, Lviv, Mykolaiv, Rivne, Sumy, Ternopil, Kharkiv, Kherson, Chernivtsi, Chernihiv. The matrix was constructed using the ranking results To combine the both components (ecological and tourism competitiveness). The X-axis of a matrix shows an integral indicator of the ecological competitiveness, and the Y-axis shows an integral indicator of the tourism competitiveness (the closer the region's coordinates are to 0, the greater the potential of green tourism it has). Figs. 2 and 3 provide the visualization of the obtained results.

Strategic marketing support of green tourism in Ukraine's regions

To determine the strategic marketing support of green tourism in Ukraine's regions it was defined ecological and marketing strategies of each region. While the ecological strategy has a close relationship with marketing, and together presents the first as an advantage of the tourism product and enshrines in the minds of consumers. All regions were divided into three types according to the level of green tourism: 1 – sufficient; 2 – satisfactory; 3 – unsatisfactory (Table 5).

Table 3: Calculations of the integral indicator of the tourism competitiveness: Dnipropetrovsk region casein 2020

Component			Value	Weight	Target value: Trend to	Target value: Best case	Sub indicator value	Integral indicator
The subjects of tourist activity - legal entities	Income from tourism (excluding VAT, excise tax and similar mandatory payments)		23567.5	0.052631	max	380990.5	0.061858	0.049375
The subjects of tourist activity - individual entrepreneurs	Income from tourism (excluding VAT, excise tax and similar mandatory payments)		42703.5	0.052631	max	167153.7	0.255474	0.039185
The cost of tourist activity in the service of other organizations that are used in the production of the tourist product			5942.3	0.052631	min	126.4	0.021271	0.051511
The cost of travel packages sold to customers	By tour operators		56308.5	0.052631	max	561549.0	0.100274	0.047354
	By travel agents inside Ukraine		14364.3	0.052631	max	119113.9	0.120593	0.046284
Number of tourists served by tour operators and travel agents			29440	0.052631	max	122485.0	0.240356	0.039981
Number of collective accommodation facilities by types of facilities (Legal entities)			159	0.052631	max	228	0.697368	0.015928
Among them	Hotels and similar accommodation facilities		63	0.052631	max	135	0.466667	0.02807
	Among them	Tourist bases, mountain shelters, student summer camps, other places for temporary accommodation	8	0.052631	max	25	0.32	0.035789
	Specialized accommodation facilities		96	0.052631	max	148	0.648649	0.018492
	Among them	Recreation centers, other recreation facilities (except camp sites)	66	0.052631	max	111	0.594595	0.021337
Number of collective accommodation facilities by types of facilities (Individual entrepreneurs)			69	0.052631	max	301	0.229236	0.040566
Among them		Hotels	42	0.052631	max	109	0.385321	0.032351
Capacity of hotels and similar accommodation points by type of accommodation (Legal entities)			6218	0.052631	max	13933	0.446279	0.029143
Among them		Hotels	4685	0.052631	max	11321	0.413833	0.030851
		Tourist bases, mountain shelters, student summer camps, other places for temporary accommodation	788	0.052631	max	2138	0.368569	0.033233
Capacity of hotels and similar accommodation points by type of accommodation (Individual entrepreneurs)			1540	0.052631	max	6538	0.235546	0.040234
Among them		Hotels	1263	0.052631	max	4007	0.315198	0.036042
		Tourist bases, mountain shelters, student summer camps, other places for temporary accommodation	101	0.052631	max	2065	0.04891	0.050057
In total								0.685782

Table 4: Calculations of the integral indicator of the ecological competitiveness: Cherkaska region casein 2020

Component		Value	Weight	Target value: Trend to	Target value: Best case	Sub indicator value	Integral indicator
Atmospheric emissions from stationary sources of pollution	Volumes of pollutant emissions	48.3	0.055555	min	3.2	0.066253	0.051874
	Ammonia emissions	5.5	0.055555	min	0.01	0.001818	0.055454
	Emissions of non-methane volatile organic compounds	1.5	0.055555	min	0.2	0.133333	0.048148
	Carbon monoxide emissions	2.9	0.055555	min	0.9	0.310345	0.038314
	Methane emissions	13.8	0.055555	min	0.3	0.021739	0.054347
	Suspended solids emissions	8.8	0.055555	min	0.4	0.045454	0.053029
	Sulfur dioxide emissions	5.0	0.055555	min	0.01	0.002	0.055444
	Nitrogen dioxide emissions	10.0	0.055555	min	0.3	0.03	0.053888
	Carbon dioxide emissions	2422.1	0.055555	min	147.4	0.060856	0.052174
Waste generation and management	Formed	1295.1	0.055555	min	173.4	0.133889	0.048117
	Disposed of	766.9	0.055555	max	83802.1	0.009151	0.055046
	Incinerated	11.7	0.055555	min	3.3	0.282051	0.039886
	Deleted in specially designated places or objects	267.9	0.055555	min	29.2	0.108996	0.049499
The total amount of waste accumulated during operation in specially designated places or facilities (waste disposal sites)		6257.8	0.055555	min	522.9	0.08356	0.050913
Land area of reserves and national nature parks		19862.1	0.055555	max	290602.3	0.068348	0.051758
Capacity of treatment facilities		83	0.055555	max	897	0.092531	0.050414
Capital investments in environmental protection		22.5	0.055555	max	4088.5	0,005503	0.055249
Current costs of environmental protection		254.1	0.055555	max	5533.5	0.04592	0.0530034
In total							0.916560

According to Table 5, there are no regions in the sufficient zone. But the Lviv region may move to this zone in the near future because the integral indicator of ecological competitiveness was 0.2897 in 2020. It demonstrated a positive trend by both components (ecological and tourism competitiveness). Summarizing the above, it is quite appropriate to identify green tourism with sustainable development, as the main task of green tourism is to achieve the maximum level of existence of intact natural and cultural resources. The combination of sustainable development principles implementation and opportunities for green tourism contributes to optimising the economic potential of rural areas and justifies the need to diversify the economy. Green tourism meets the needs of tourists and host regions, protecting and expanding opportunities for the future generation. Resources are used in such a way that to meet economic, social and aesthetic needs, preserving cultural integrity, necessary ecological processes, biological diversity and life support systems. Since the direction of green tourism has already penetrated the Ukrainian market and improves its performance every year, its positive impact on the ecological condition of the territories has been proven. It is advisable to develop a marketing policy to promote it. Ukraine has great potential in this direction, taking all protected areas, lakes, reserves, and more into account. In addition, the development of this area should increase the level of environmental and socially responsible literacy of the population,

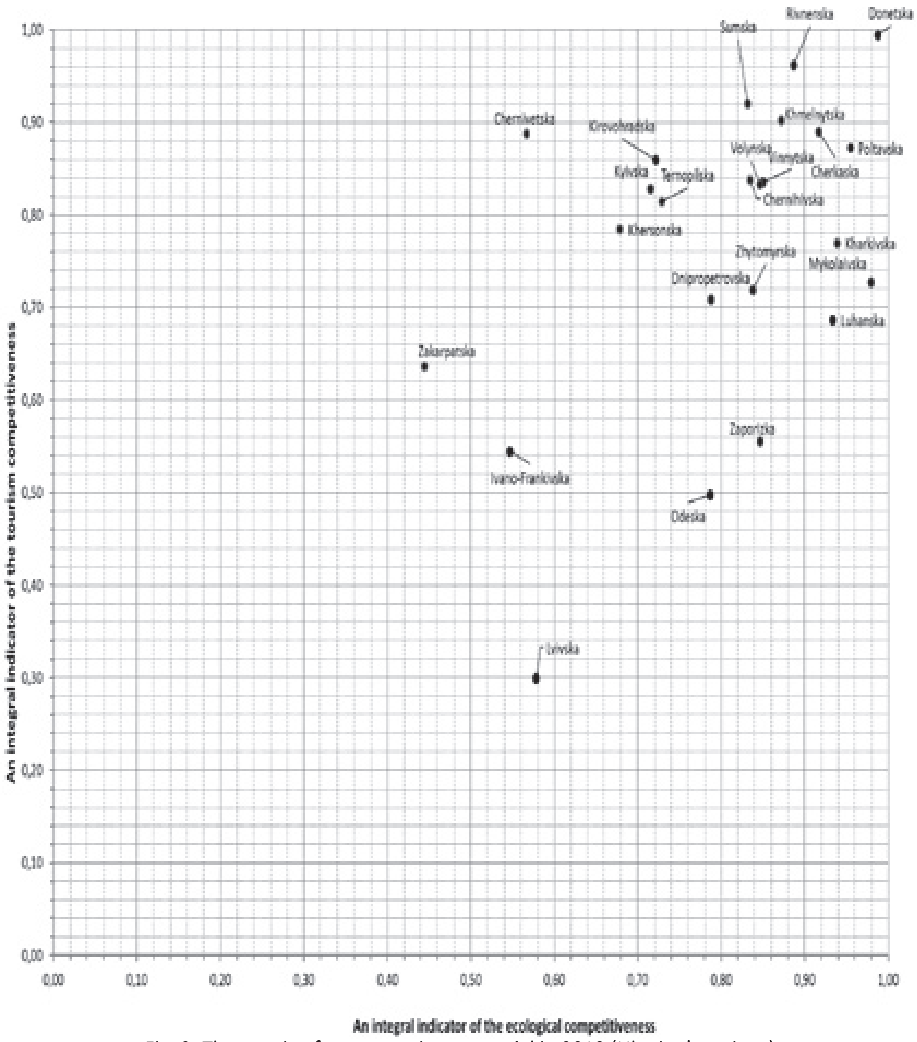

Fig. 2: The matrix of green tourism potential in 2019 (Ukraine's regions)

improve environmental performance and image of the territories reduce the level of urbanization. The key feature of Ukrainian green tourism is a unique tourist lifestyle, which is based on the implementation of the entrepreneurial potential of the rural population regions), such as «Grunivska Sych», «Khortytsia», "Askaniia Nova" and others. The purpose of the study presented here is to determine the strategic marketing support for the development of green tourism on the example of Ukraine and its regions based on an approach to its assessment in terms of environmental and tourism competitiveness. The practical guidance was presented on assessing green tourism potential using relevant objective statistical information and developing strategic marketing recommendations for supporting the development of different Ukraine's regions on this basis. This approach provides complex environmental and marketing support to ensure sustainable development and gain additional competitive advantages by green tourism entrepreneurs. Previous researches discussed the selection of the most suitable methods for assessment of tourism potential based on cluster model (Boshota *et al*., 2017; Boiko *et al*., 2017; Dokai *et al*., 2018), factorial approach (Yukhnovska. 2019; Lee, 2016), scoring (Gerasymenko *et al*., 2017; Ramamoorty *et al*., 2020). Results of the analysis

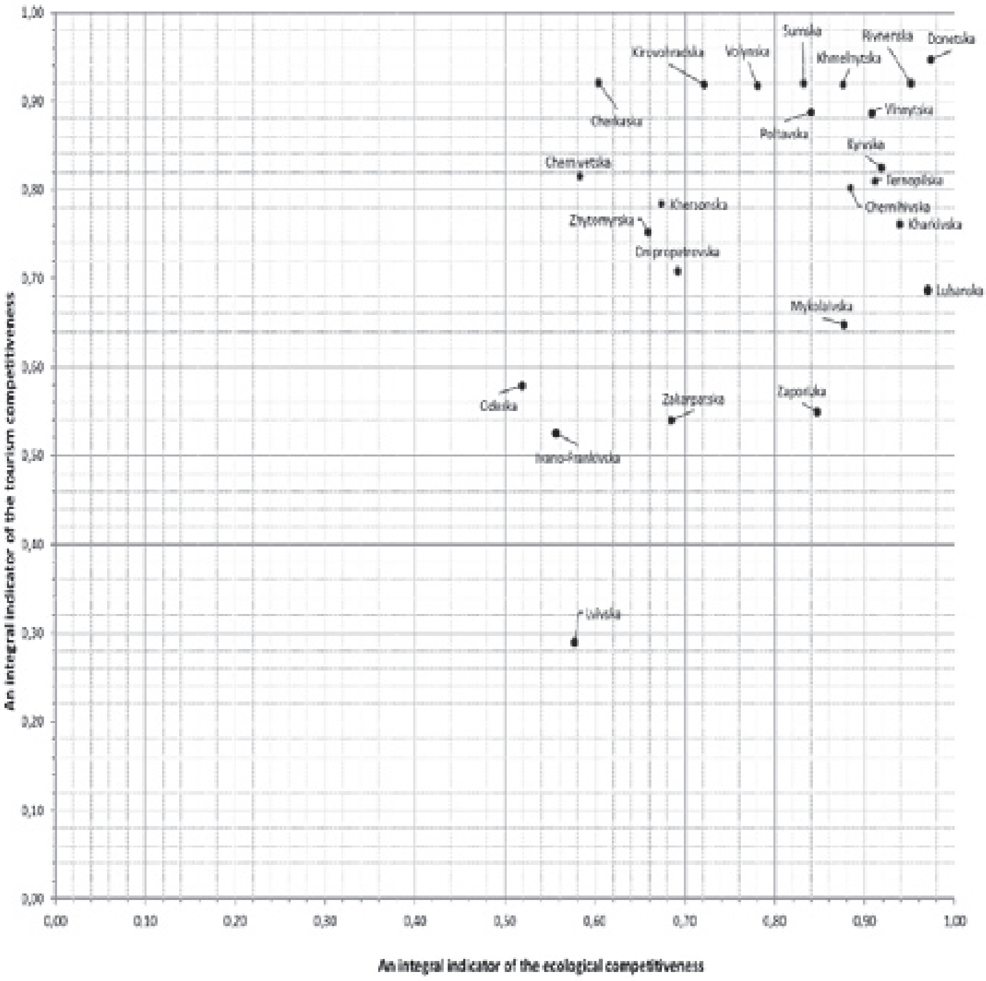

Fig. 3: The matrix of green tourism potential in 2020 (Ukraine's regions)

show that more than half of the analyzed studies used or referred to behavioural theory from either the field of economics, sociology, or marketing. Regarding the formation of marketing support for the development of tourism business revealed that it is not based on objective statistical information and relevant indicators mostly. Furthermore, it was observed that although many studies dedicated the forming of marketing strategy through digital tools and interdisciplinary approaches, typically, one discipline is most developed (Sofronov, 2019; Eshtaev, 2017; Prokopenko *et al*., 2019; Danylyshyn *et al*., 2021 and others). For example, Sofronov (2019) studied the *"variety of communications strategies and techniques to promote areas and destinations"*. Eshtaev (2017) composed "parts of innovational marketing strategies and possible usage of these strategies at the tourism market". In addition, it is possible to state the limited research on assessing the potential of green tourism in the regional context. These positions became the basis for determining the purpose of this study. To analyze the level of green tourism development in the regions of Ukraine quantitatively, it was identified the components and key indicators that will most objectively reflect the current state of green tourism development and allow a comprehensive assessment and establish the imbalances of such development. Note that the range of indicators is not exhaustive in our study. Their number may vary and supplement depending on the task of a detailed statistical analysis.

Table 5: Ecological and marketing strategy for the development of green tourism potential (case in 2020)

Level of ecological and tourism competitiveness	Regions	Type of ecological strategy	Type of regional marketing strategy
Sufficient [0-0.37]	-	Proactive sufficiency strategies (voluntary restriction of consumption and, accordingly, lifestyle changes), balanced nature management	Image marketing
Satisfactory (0.37-0.63]	Lviv, Odesa, Ivano-Frankivsk	Compensation strategies, strategies aimed at improving resource efficiency (eco-efficiency strategies), effective environmental management	Attractiveness marketing
Unsatisfactory (0.63-1.0]	Cherkasy, Chernivtsi, Zakarpattya, Zaporizhzhya, Mykolaiv, Vinnytsia, Volyn, Dnipropetrovsk, Donetsk, Luhansk, Zhytomyr, Kyiv, Kirovohrad, Luhansk, Poltava, Rivne, Sumy, Ternopil, Kharkiv, Kherson, Khmelnytsk, Chernihiv	Protective strategies, strategies aimed at comprehensive solutions to environmental problems (strategy of environmental modernization), regulatory environmental management	Marketing of the population and infrastructure

CONCLUSION

One of the results of implementing the green marketing provisions in the tourism industry is the development of green tourism. Green tourism involves recreation in ecologically clean natural areas or regions, combined with visits to scientific, educational, cultural, cognitive places and activities. However, this activity contributes to maintaining and increasing the level of ecological potential of the environment and increasing the population's welfare. Based on this study, the following main conclusions can be made: 1) the authors developed an approach based on assessing the tourism and ecological component by determining the competitiveness of regions. It covers the most relevant array of statistics and makes a representative assessment of the current state of green tourism potential; 2) according to the ranking of tourism and ecological competitiveness, the regions with the greatest and the worst potentials were clarified, and positive dynamics of green tourism development in 2019-2020 was found. Thus, Lvivska, Ivano-Frankivska and Odeska regions were the leaders before and during the pandemic COVID-19. The ecological competitiveness increased in twelve regions and tourism competitiveness – in 16 regions of Ukraine in 2020; 3) the authors developed a matrix that reflects the grouping of Ukrainian regions by the level of green tourism potential in 2019 and 2020. Strategic marketing support of green tourism development in Ukrainian regions was defined based on ecological and marketing strategies. The obtained results confirm that vast majority of regions is in the unsatisfactory area. So, marketing support for the development of the green tourism industry should be based on the improvement of the marketing complex 5P (taking into account the specialization in the field of services, it is advisable to add five components "people" to the complex). It is crucial to increase consumer awareness about the functioning of green tourism institutions, their competitive advantages and make this trend. It is necessary to focus on legal support and developed training facilities (how to be profitable in this area, promote travel company, the importance of certification, etc.). This will help guide existing service providers and attract even more people willing to start a business in this area. To gain additional competitive advantages and increase trust among the population, the green tourism enterprise also has the opportunity to improve the level of recreational facilities by obtaining "green certification"; and building a communication policy on this basis.

AUTHOR CONTRIBUTIONS

O. Gryshchenko analyzed and interpreted the data, prepared the manuscript text. V. Babenko helped in the literature review, manuscript preparation and edition. O. Bilovodska performed the literature review, compiled the data and manuscript edition. T. Voronkova performed the literature review and some of the remained analyses. I. Ponomarenko helped in manuscript preparation, formed visualization and supervised data, completed the marketing recomendations. Z. Shatskaya performed some of the remained analyses and helped in visualization and data curation.

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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/or falsification, double publication and/or submission, and redundancy.

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ABBREVIATIONS

%	percent
&	and
e.g.	exempli gratia, for example
et al.	others
etc.	et cetĕra, and so on
Fig.	Figure
GT	green tourism
i.e.	id est, in other words
CAF	collective accommodation facilities
LCGGRAP	Low carbon green growth roadmap for Asia and the Pacific
MR	Monitoring Report
NBR	National baseline report
NGOs	non-governmental organizations
SMEs	small and medium-sized entities
SB	Statistical bulletin
SSSU	State Statistics Service of Ukraine
TPU	Tourism potential of Ukraine
TTCR	The travel and tourism competitiveness report
TTST	Tourism teacher: Sustainable tourism
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNRISD	United Nations Research Institute for Social Development
UNICEF	United Nations International Children's Emergency Fund
UN RCO	United Nations Resident Coordinator Office
USAID	United States Agency for International Development
WEF	World Economic Forum
WTO	World Trade Organization

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REVIEW PAPER

Converting the cigarette butts into valuable products using the pyrolysis process

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Waste recycling

ABSTRACT

More than 5.5 trillion cigarettes are manufactured, and approximately 4.5 trillion cigarette butts are being scattered across the globe per year. These cigarette butts are considered as one of the most hazardous wastes and environmental threats in the world. Thermochemical techniques can be used to turn biomass and solid wastes into valuable final products. Pyrolysis is a comfortable thermochemical technique for turning biomass into biochars, biofuels, briquette solid fuels, and further valuable products such as activated carbons, carbon black, and printing ink. In this study, it was attempted to review the available researches about pyrolysis of cigarette butts with an emphasis on transforming them into carbonated solid and liquid products. It was found that, in addition to the process variables, the type of cigarette butts treatment has a significant effect on the yield and quality of the finished goods. Further studies on the pyrolysis of cigarette butts, especially microwave-assisted pyrolysis and hybrid waste pyrolysis, seemed to be necessary. Solving the technical issues associated with the pyrolysis of cigarette butts to produce the value-added goods would contribute to their application in waste disposal and recycling of other resources. Future studies should focus on the separation methods with the help of gas products to provide the heat required in the reactor. Moreover, mixing the sewage sludge material, as a feed, with cigarette butts and application of appropriate models and experiments to attain the products with specific properties are recommended. The results of this study can be used to eliminate the hazards of the cigarette butts scattered in the environment and create the added value for the pyrolysis process.

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INTRODUCTION

Large amounts of pollutants in the world threaten the humans, animals, and plants life. The World Health Organization (WHO, 2017) has reported that tobacco and related products threaten many resources on the Earth. According to the WHO, there are many pollutants that pose damage to the environmnt during the tobacco product life cycle. Although tobacco processing and production take place in particular regions of the world, its use and waste are widely dispersed around the globe. Since the produced wastes can be found in everywhere, their collection and disposal are considered a complex problem. Approximately, 967 million smokers in the world used 6.25 trillion cigarettes in 2012 (Ng *et al.,* 2014). However, the smoked cigarettes were reported to be decreased to 5.7 trillion in 2016. Considereing the rapid development of this market, this rate is expected to rise to 9 trillion by 2025 (Mackay *et al.,* 2006). Cigarette butts (CBs) are the main residue of tobacco around the world, and they account for a large share of pollutants collected in urban clean-ups (Curtis *et al.,* 2017, Conservancy 2018). The cigarette consumption waste in the world is estimated to be 340–680 million kg. Approximately, 2 million tons of ink, paper, foil, cellophane, and glue are used for cigarettes packaging. The CBs have a sahre of over 40% in urban clean-up items (Novotny and Slaughter 2014, Bonanomi *et al.,* 2015). According to WHO (2017), around 2/3 of the CBs are left in the environment. Moreover, Patel et al. (2013) reported the exact number of the left CBs as 76%. The uncontrolled distribution of CBs is a bigger problem because they are not biodegradable and release more than 7,000 toxic chemicals into the environment (Marinello *et al.,* 2020). While the adverse impacts of smoking on human's body are widely studied, the negative effects of tobacco on the environment are not well understood. The use of insufficient land and water for tobacco farming, application of hazardous pesticides in tobacco plantation, erosion, carbon pollution from manufacturing and processing systems, and production of toxic and non-biodegradable waste are among these negative effects. Inappropriate CBs dumping has led to a number of domestic and wildland fires with disastrous consequences (Kadir and Sarani 2015). Many countries ratify some rules against using tobacco and advocate the policies on raising the price of the tobacco-based products (Smith and McDaniel 2011). Considering the inefficiency of the conventional disposal techniques, such as landfilling and incineration which are not feasible for CBs, an effective solution for management and disposal of this waste seems to be essential (Barnes 2011, Bandi *et al.,* 2018). An efficient disposal method for this waste could reduce the release of toxic chemicals into the environment and lead to some benefits such as energy supply from the huge volume of waste material. There are several methods for recycling and reusing the CBs to ensure a hazardless procedure for their life cycle. CBs are mainly made up of cellulose acetate which has attracted the attention of many researchers. A single cigarette filter contains about 12,000 fibers of cellulose acetate (Novotny *et al.,* 2009). These fibers consist titanium dioxide and are connected together by a triacetin (glycerol triacetate) surfactant (Kabir and Hameed 2017). The molecular formula of cellulose acetate is $C_{76}H_{114}O_{49}$ and its average molecular weight is 1,811.7 g/mol (Sayers *et al.,* 2010). High amounts of carbon atoms in the cellulose acetate structure make it a good candidate to be used as a raw material for producing the porous carbon derivatives. The primary element of CBs, cellulose acetate, is a desirable organic carbon source for conversion into useful liquid finished goods using the thermal cracking techniques (Lam *et al.,* 2017). The pyrolysis method has been successfully used for degradation of cellulose to furans, (Long *et al.,* 2017), carboxylic acid and aldehydes (Al Shra'ah and Helleur 2014), and hydrocarbons/aromatics (Zhang *et al.,* 2011, Karanjkar *et al.,* 2014). The main goal of these conversions is to achieve sustainable energy from waste. The direct combustion of raw materials to provide heating energy is called thermal combustion which is usually performed to generate steam and electricity. The main principle of gasification technology is producing synthetic fuel gas to be combusted for heat generation or used as a turbine or engine fuel for electricity generation. The liquid fuel produced byu the pyrolysis method can be used as a fuel oil in static heating and applied for electricity generation. Interestigly, pyrolysis can directly produce a liquid fuel which is a good option when the resources are far from the energy-required place. Pyrolysis process has received much attention due to its ability to produce high amount of liquid oil (up to 80 wt%) at moderate temperature of about 500 °C. Moreover, it is very flexible as its parameters can be manipulated to optimize the product yield based on preferences. The liquid oil produced can be used in furnaces, boilers, turbines and diesel engines without any upgrading or treatment. The oil produced by biomass pyrolysis is considered as a highly environmentally friendly fuel because it contributes to the reduction of CO_2 in the atmosphere (Sharuddin *et al.,* 2018). Although many studies have focused on the risk of CBs being released into the environment, a few studies have been done on converting the CBs into valuable products through the pyrolysis process. In this study, it has been attempted to give a short review of CBs and the pyrolysis method for recycling and converting them to sustainable energy. The review is focused on distribution, structure, and toxicity of the CBs. It also covers the methods for recycling of CBs, a brief review of pyrolysis technology, and a comparative discussion on the pyrolysis methods used for the disposal and recycling of CBs. The obtained results can be used by researchers and industries to perform an optimized method for controlling this waste. This study has been carried out in Biofuel Research Laboratory, Caspian Faculty of Engineering, College of Engineering, University of Tehran, Rezvanshahr, Iran during 2019-2021.

Cigarette butts

Distribution

CBs production is directly affected by the production of tobacco and its use. China has the highest share in this industry around the world. The CBs account for about 22-46% of visible wastes in the municipal discharges (González Alonso *et al.,* 2012) and have a variable distribution in all the urban areas. A study performed in Berlin indicated that different areas had different concentrations of the CBs. The maximum and the minimum mean values were 5.2 CBs/m^2 0.29 CBs/m^2, respectively. In the mentioned study, the maximum value of CBs concentration (about 48.8 CBs/m^2) belonged to a nearby train station (Green *et al.,* 2014). In another study in San Diego, Marah and Novotny (2011) investigated the probability of the CBs existence in different places. They reported the mean values of 38.1 CBs/m^2 and 4.8 CBs/m^2 for the highest and the lowest probabilities, respectively. They finally showd that only 6 places were devoid of CBs contamination (Marah and Novotny 2011). There are some correlations between the concentration of CBs and the parameters such as density of population and cigarette market availability (Araújo and Costa 2019). The places around the malls, bars, restaurants, gas stations, grocery stores, liquor stores, cafés, traffic signals, and convenience stores have a higher probability of CBs existence (Green *et al.,* 2014). Marah and Novotny (2011) reported that the CBs concentration around the venues was nearly 8 times higher than their concentration in other places. They applied the graphic information system to indicate the CBs distribution density in municipal fields. In another conducted study by Asensio-Montesinos *et al.* (2019), 56 Mediterranean coastal sites were selected the CBs density measurement. They found different CBs concentration in various beach topologies. This value was measured as 54 CBs per 100 m of the beach, 67 CBs per 100 of village areas, and 121 CBs per 100 of urban areas (Elliott 2014, Asensio-Montesinos *et al.,* 2019). In different seasons, there are different numbers of CBs in a single area, especially touristic regions. However, there is no data about the specified correlation between these parameters (Green *et al.,* 2014). In another coastal area, the tourism season showed 46% growth in CBs pollution, which was two times greater than the same value in other seasons (Martinez-Ribes *et al.,* 2007). Another study showed that the CB contaminants were significantly higher in summer than in fall (Simeonova *et al.,* 2017). Evaluation of the pollutants collected from Bulgaria indicated that CBs (with total amount of 4496) had the highest share in the detected litter and accounted for 29.7% of the total waste. However, a significat variation in the amount of these CBs was observed in different seasons. For instance, in the study area, 2637, 1072, 454, and 333 CBs were detected in summer, autumn, winter, and spring respectively (Simeonova and Chuturkova 2019). Consumption rate and presence of people in public spaces can also affect the volume of the waste. The amount of CBs on public beaches was greater than other sites (Taffs and Cullen 2005). Moreover, the rate of the disposed CBs could vary among different points in different times of the week. Volume of CBs/m^2 in the studied areas was twice in vacations (Oigman-

Pszczol and Creed 2007). Patel *et al.* (2013) found that the majority of the 219 smokers littered their cigarette butts. Butt littering was more common among those who did not extinguish their cigarette (94.4% vs 4.5%, p=0.003). It was also more common in the evening than in the lunchtime periods (85.8% vs 68.1%, p=0.002, logistic regression analysis). Most of the smokers (73.5%) did not extinguish their butts and some of them threw their lit butts into the trash bins (Patel *et al.,* 2013).

Structure of cigarette butts

CB is a cigarette filter which has some tobacco with some chemical compounds and contaminants (Parker and Rayburn 2017). The key material used in the CBs is cellulose acetate which is resistant to biodegradation compounds (Ariza *et al.,* 2008, Velzeboer *et al.,* 2014) and remains undegraded in the environment for 18 months in usual conditions (Novotny and Zhao 1999). While it is non-biodegradable, it can be converted to lighter elements under ultraviolet (UV) irradiaiton, remaining for 10-15 years (Dieng *et al.,* 2013). To create a cigarette cartridge, titanium dioxide is exposed to the cellulose acetate fibers with a thickness of about 20 mm and 15,000 of them are densely packed along with glycerol triacetate as a binder (Slaughter *et al.,* 2011). Production of cellulose acetate by acetylation (combination of acetic acid and acetic anhydride) is quite well known. Plasticizers (e.g. polyethylene glycol) may be applied before the treatment. Although cellulose has a low capacity for biodegradation owing to the chemical alteration of the materials, it is effectively digested by the cellulase enzyme. The conversion of synthetic cigarette filters is inhibited by the extreme compactness of the fiber and additives (Araújo and Costa 2019). Such factors make the CBs a potential candidate for environmentally harmful problems (Ariza and Leatherman 2012). Although each CB's pollution is not significant due its tiny size and distribution, it has the potential to cause local contamination (van Dijk *et al.,* 2011). The effect of CB pollutants on aquatic life has been studied and approved (Slaughter *et al.,* 2011). The CBs in the public areas, if swallowed, can cause health problems in children, birds, and animals (Novotny *et al.,* 2011). The harmful chemicals in CBs have encouraged the researchers to track and validate their influence on such species (Dieng *et al.,* 2013).

Cigarette butt contaminants

CB contamination in various places induces the environmental hazards and introduces toxins into the ecosystem (Moerman and Potts 2011). 75 % of cigarette smoke compounds are verified to be gaseous, with the rest being in the tar form (Aeslina and Mohajerani 2012). Nitrates, hydrogen cyanide, polycyclic aromatic hydrocarbons (PAHs), acetaldehyde, N-nitrosamines, ammonia, carbon monoxide, formaldehyde, phenol, benzene, pyridine, aromatic amines, and metal ions like chromium, nickel, cadmium, and arsenic are some of the contaminants in cigarette smoke (Micevska *et al.,* 2006) and all of them are trapped in the filter (Dieng *et al.,* 2013). CB is one of the key sources of pollution in urban areas and it can disperse many pollutants, including toxic metal ions, into the marine ecosystem (Dobaradaran *et al.,* 2017). Due to the penetration of such pollutants into the freshwater supplies, CB has been classified as a hazard to marine life and environment (Patel *et al.,* 2013). Since CB contains cadmium, tar, arsenic and lead, it can pose a serious threat to ecosystems and marine species (Pon and Becherucci 2012). Metal ions are among the most significant pollutants discovered in CBs and they can cause pollution in the aquatic species, if discharged into the marine ecosystems (Dobaradaran *et al.,* 2017). The value of heavy metal ions, such as arsenic, nickel, cadmium, lead, zinc and copper, in CBs is known to be from some µg/g to many hundred g/g (Chevalier *et al.,* 2018). Extraction of the heavy metals packed within CBs could be occurred by penetration into the ecosystem (Aeslina and Mohajerani 2012). The leakage of heavy metals from CB in roadways with an estimate of 150 butt/km/month was calculated as 0.02–1.7 mg/km/month. Cadmium, lead, copper, arsenic and chromium leaks, for example, were recorded to be 0.02, 0.59, 1.7, 0.81 and 0.15 mg/km/month (Moriwaki *et al.,* 2009). Fig. 1 illustrates the different heavy metal ions existing in the CBs.

CBs have a capability to release PAHs which can cause cancer in the living organisms in the ecosystem. In a roadway survey, although the volume of each PAH in a CB was 0.0065 to 0.0078 mg/kg and the overall volume PAHs in all the CBs was 0.039 mg/kg, the mean probable exposure of

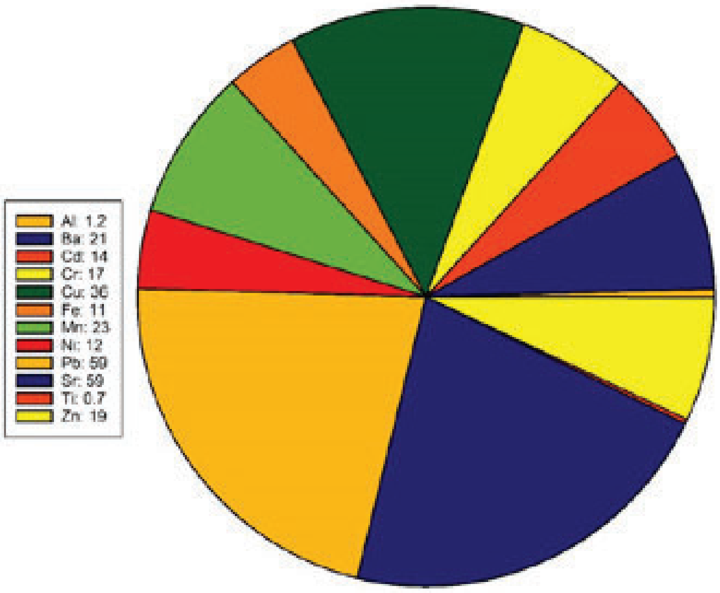

Fig. 1: The leakage percentage rate of different heavy metals from cigarette butts (Moerman and Potts 2011)

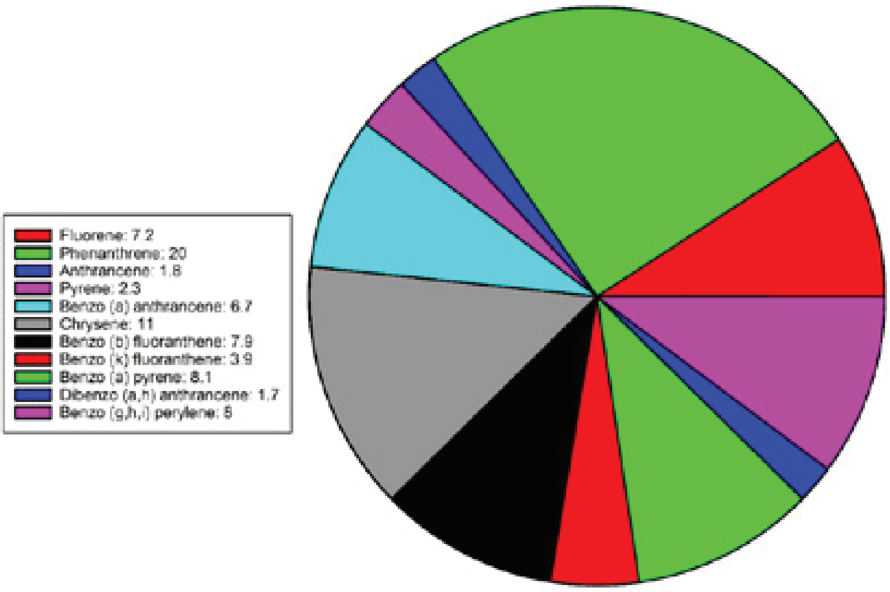

Fig. 2: The percentage of polycyclic aromatic hydrocarbons in cigarette butts (Moriwaki *et al.* 2009)

PAHs in the littered CBs was 0.032 mg/km/month. In the mentioned survay, the factors such as weather and wind were found to be effective in determining the concentration of such contaminants (Moriwaki *et al.,* 2009). Various amounts of PAHs are detected in CBs. In a CB, the maximum PAH rate is related to phenanthrene with a frequency of 20% and the minimum PAH rate belongs to anthracene and dibenzoanthracene with less than 2% (Fig. 2).

CBs also include polycyclic aromatic compounds

(PACs), such as nicotine, which have an adverse effect on humans (Green *et al.,* 2014). The nicotine leaked from CB into the water resources can be immediately absorbed by skin, small intestine, bladder and lung alveoli, potentially causing heart failure and neurological effects. Nicotine leakage from CBs into aquatic environments happens very quickly, and this applies to both precipitation on CBs and submersion of CBs in the marine environment. When a cigarette is washed in standing water, nicotine rapidly starts to leach [7.3 mg/g (equivalent to 2.5 mg/L) leaking exceeded 1,440 min], half and 90% of which occur in the first 26 min and 651 min respectively. An average of 3.8 mg/g nicotine exposure was observed in a 21.6-mm accumulation substrate, and almost half of this amount leached with 1.6 mm of precipitation from the soil (Green *et al.,* 2014). The fast nicotine release into the aqueous medium is attributed to its interaction and dosage left in the structure. Other factors, such as chemical composition of the soil and filtration of the bed, can influence the level of nicotine leakage into the water supplies. The amounts of nicotine and other toxins, which are basically determined by smokers, can be influenced by the characteristics (mass and amount of total tobacco) of the dispersed CBs. Each cigarette can contaminate 1000 liters of water (Green *et al.,* 2014). The nicotine leaking level as been registered as 3.8 mg/L. The precise release of nicotine by natural runoff and the species' response to it have not been determined, but its hazard has been well studied (Moriwaki *et al.,* 2009). Considering the huge volume of discarded CBs, their potentially poisonous and environmentally harmful compounds should be taken seriously. The toxic effects of this waste on fish and other aquatic organisms have been already identified, and the adverse effects of cigarettes have been approved by many studies (Lee and Lee 2015, Dobaradaran *et al.,* 2019). For example, 100% of Aedes aegypti died after 24 h during the first period of larvae due to the CB toxicity in 100 ml of water (Dieng *et al.,* 2013). CB termination in the larval step for Aedes albopictus and its impact on the decomposition of Aedes aegypti were also observed (Dieng *et al.,* 2014). Moreover, the effectiveness of CB on Aedes albopictus, the risk of fish mortality owing to the toxins in CB (86), the antibacterial activity in the

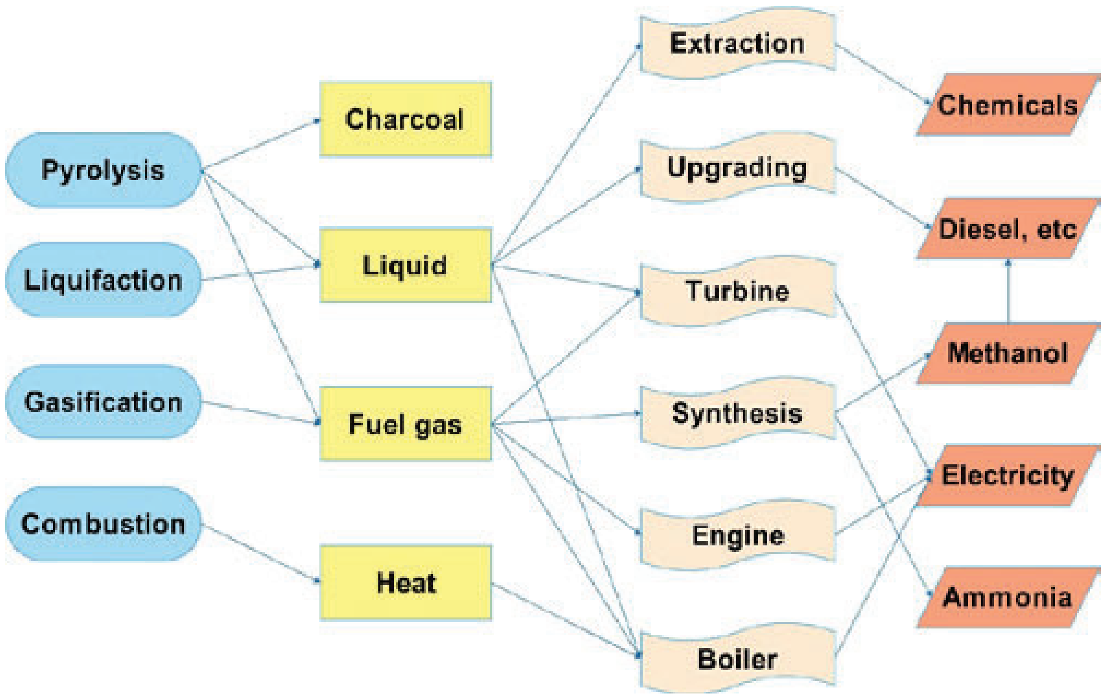

Fig. 3: Thermochemical biomass processes and products (Bridgwater and Peacocke, 2000)

Aedes aegypti larval time, and the impact of CB on Dafina and Daphnia Magna water flea were reported (Dieng *et al.,* 2013). Three types of CB were studied for their potential hazards by Rebischung *et al.* (2018). These hazards were labled as HP 4 (irritant – skin irritation and eye injuries), HP 5 (particular target area toxicity/aspiration toxicity), HP 6 (acute toxicity), HP 7 (cancer causing), HP 8 (irritant), HP 10 (toxic to recombination), HP 11 (mutagenic), and HP 13 (sensitizing). The CBs' nicotine has been reported as the main hazard corresponding to HP 6 (acute toxicity) (Rebischung *et al.,* 2018).

Methods for cigarette butts recycling

The researchers efforts to recycle CBs were influenced by the physical structure and chemical properties of CBs. CB recycling processes are examined in brick manufacturing, cement production, mosquito handling, porous carbon and absorbent production, voice insulating materials, paper performance, and biofilm drivers in wastewater treatment. CB refining is not requires in some fields such as bricks or asphalt manufacturing, and cigarette could be used in the original form. CB, however, needs to be processed by extraction procedure, pyrolysis, and filter rod extraction for other purposes. Fig. 3 illustrates some conventional thermal conversion methods for producing energy from biomass.

In most of the studies, CBs are disinfected and

Table 1: The CBs recycling methods

Recycling method	Process	References
Vector control	Doping CB for 24 h in 100 mL of deionized water and using the substances discharged from it	(Dieng *et al.,* 2013)
	Dope the CB in tap water within 1, 2, 3, 4 , 5 , 6, 7 , 8, 9 and 10 days	(Dieng *et al.,* 2011)
	Doping CB for 24 h in 100 mL of deionized water and using the compounds leaked from it	(Dieng *et al.,* 2014)
	Doping 5 g CB in 250 mL of distilled water for 24 hours, then centrifuging the solution and using the supernatant	(Mondal *et al.,* 2015)
	Using the CB extract for constructing nano silver structures in the presence of $AgNO_3$ solution	(Murugan *et al.,* 2018)
Asphalt production	Encapsulated in paraffin and bitumen	(Mohajerani *et al.,* 2017)
	Without process	(Kadir and Mohajerani 2011)
	Without process	(Mohajerani 2012)
Production of clay brick		
	Without process	(Kadir *et al.,* 2015)
	Without process	(Mohajerani *et al.,* 2016)
	Without process	(Sarani 2013)
Activated carbon	Heating in vacuum at 230 °C for 3 h and pouring out the carbon to 100 µm	(Masoudi Soltani *et al.,* 2015)
	Simple pyrolysis with 900 °C for 3 h and with a continuous nitrogen gas equivalent to 100 cm^3/min and 5 °C/min heating rate	
	Single-stage carbonisation with pyrolysis fuel equivalent to 900 °C for 1 h at 5 °C/min heating	(Yazdi *et al.,* 2012)
	Impregnated with NaOH, then pyrolysis	(Koochaki *et al.,* 2019)
Biofilm barrier application	The filter rod extracting	(Sabzali *et al.,* 2012)
	The filter rod extracting	(Sabzali *et al.,* 2011)
Production of super hydrophobic fibers	Doping the cigarette filters in NaOH solution and then in Hexadecyltrimethoxysilane-ethanol solution	(Ou *et al.,* 2016)
	Doping in about 4% hexane solution at room temperature	(Liu *et al.,* 2015)
Porous sound absorber	Cellulose acetate extracted manually from cigarette filter	(Murugan *et al.,* 2018)
	Without process	(Maderuelo-Sanz et al., 2018)
Paper pulp	Pulping the cigarette at boiling point for 3 h and with 1% NaOH	(Teixeira *et al.,* 2017)
Corrosion inhibitors for metal surface	Water extracts of CBs	(Lucatero *et al.,* 2016)
Application in lithium-ion batteries	Packaging and any remaining tobacco and chars were removed, and the cellulose acetate filters were soaked in purified water before being sonicated with ethanol using an ultrasonic UP400S	(Huang *et al.,* 2015)
Ester-rich bio-oil production	Microwave assisted pyrolysis	(Wang *et al.,* 2020)

dried before being used. CB reuse techniques and their products are presented in Table 1.

Reuse of CBs in various mechanisms can contribute to the production of functional items. It was proved that CBs contain a number of recyclable materials owing to their physicochemical properties. The use of CBs in some reusing techniques may have unvaforable impacts on the characteristics of the finished product as listed in Table 1. The data provided in Tables 1 and 3 indicate that it is necessary to recycle CB regardless of its structural properties or contaminants captured in its filter. While the usage of whole CBs in re-enactment without eliminating the components has been explored in a few processes, such as production of building products, application of the chemicals adsorbed onto CBs and also cellulose acetate are the most important methods for CBs recycling. Distilled water and chemical solvents may be used to remove the contaminants contained in the CB. Utilization of these chemical compounds for prevention of corrosion in metals and vectors needs some serious health and environmental attention (Mondal *et al.,* 2015). Upon clearance of contaminants without any physical deformation, tobacco cellulose acetate filters are used in supercapacitor industries. Cellulose acetate is chemically converted into pulp and adsorption products (Yazdi *et al.,* 2012), which eventually produce contaminant gases and wastewater emissions (Teixeira *et al.,* 2017). The quality of the final product is a key element in the CB reuse for development of construction materials such as bricks and asphalt. Application of CBs in the raw materials influences the finished product's properties including strength, density, porosity, and thermal conductivity (Murugan *et al.,* 2018). The variability of such features is beneficial, but the strength increase in bricks is known to be a negative property. The reuse cycle contributes to the development of high-quality materials under appropriate working conditions such as correct mixing period (Torkashvand *et al.,* 2020). While the application of CBs in raw resources, owing to their adsorption ability, decreases the heavy metals release in the manufacturing process of bricks, it induces pollutant emission in the gas or liquid phase in all the strategies for CBs re-utilizing. In some cases, researchers, despite using chemical treatment methods, could not reduce the contaminants from the wastewater produced by CBs processing to an appropriate degree (Teixeira *et al.,* 2017). A particular portion of CBs is removed in many systems, but some components remaine as waste and need maintenance. The trapped chemicals emitted from CBs could be applied in reuse operations for other purposes, such as management of vector and inhibitors for metal corrosion (Lucatero *et al.,* 2016). Many studies approve the high quality of the product obtained from the CB recycling processes (Dieng *et al.,* 2014). Pollutants existing in CBs, for example, are extremly good at controlling the vectors. In particular, the CB-derived carbons have a large number of active sites with a large surface area (600 m^2/g) which make them suitable for treatment of wastewater (Hamzah and Umar 2017). The efficiency of the CB reuse techniques is determined based on the effectiveness of their products (see Table 3). Despite the improvements in the consistency of bricks following the introduction of CBs and the modest adsorption capability of the carbon extracted from CBs compared to other adsorbents, these approaches may not have the ability to recycle CBs in a large scale. Superoleophilic/Superhydrophobic fiber processing can be a great option for CB reuse due to its product efficiency and no loss of output over many cycles among the suggested methods. CB recycling for manufacturing supercapacitors may also be deemed an appropriate process which can provided the product with consistency when it is incompatible with the commercial forms. Certain recycling procedures, including vector control, anticorrosion production, and paper production, may have some disadvantages due to the use of CB toxins or toxin release during the processing period. Problems of hazardous waste, such as CBs, should be deeply considered in sustainability programs in terms of environmental effects. It is claimed that Aedes aegypti has a higher propensity to spawn (egg-laying) in a water containing CBs than in a space lacking CBs, indicating that CBs do not affect the mosquito setting location (Dieng *et al.* 2014). Moreover, it was shown that the compounds derived from CBs did not decrease the reproductive behavior of Anopheles stephensi (Murugan *et al.* 2018). One of the effective procedures for CBs safe recycling is the application of cellulose acetate to produce sound absorbers or supercapacitors following the recovery of captured compounds for manufacturing corrosion inhibitors or for carrier protection purposes that minimize wastewater and hazardous waste (Torkashvand and Farzadkia 2019). CBs were also used as a strong basis for the development of activated carbons by pyrolysis procedures to create N-doped carbon materials (Lee *et al.,* 2014, Kim *et al.,* 2016). Since cellulose acetate is the key element of CBs, it was applied to manufacture nanocrystalline cellulose (Ogundare *et al.,* 2017) and cellulose-based membranes (Huang *et al.,* 2015). CBs treatments included several effective opportunities to recover them. Nevertheless, the CBs have always been a solid waste despite being utilized as absorbent products. Moreover, these recycled products need to be further destroyed to prevent the production of solid contaminants in an area. The main component of CBs, cellulose acetate, is a highly efficient natural carbon source and could be processed into highly valued liquid fuels using the efficient thermochemical processing techniques (Wang *et al.,* 2018). The pyrolysis process has been widely used for the conversion of cellulose to hydrocarbons/aromatics, furan substances (Mascal 2019), and other organic materials such as aldehydes, carboxylic acid and similar substances (Al Shra'ah and Helleur 2014). Microwave-assisted pyrolysis (MAP), due to its rapid temperature increase, targeted processing, volumetric and standard heating in growing heat flux, and improving the reaction efficiency, has advanced as a possible method to replace the regular pyrolysis (Zhao *et al.,* 2019). MAP of cellulose was conducted in earlier studies to produce the phenol-rich fuel (Wenliang *et al.,* 2018, Wang *et al.,* 2019). Some researchers (Nieva *et al.,* 2015) have also approved the efficiency of the MAP of cellulose in producing significant yields of useful liquid products (Veerabagu *et al.,* 2021).

Pyrolysis

Pyrolysis is a thermal disintegration of compounds where there is no oxygen or slightly less oxygen full combustion. A precise description of pyrolysis is difficult, particularly when it is applied to biomass. Earlier studies typically correlate pyrolysis with the carbonization process, of which a solid char is a primary ingredient. The term pyrolysis defines processes where oils are favored materials. In the latter procedure, the time period for pyrolysis is much faster. The generalized changes that happen during pyrolysis are as follows (Diebold and Bridgwater 1997).

1) Transfer of heat from a source of heat to raise the fuel temperature;
2) The initiation at high temperature of primary pyrolysis reactions produces volatile and charcoal elements;
3) Hot volatile flow to colder solids contributes to heat conversion between hot volatiles and colder unpyrolyzed fuel;
4) Tar is generated by the condensation of certain volatile matter in the cooler sections of the fuel, accompanied by side reactions;
5) In a competition, catalytic second pyrolysis reactions happen when primary pyrolysis process interactions take place simultaneously;
6) Residential cycle, dehydration, radical replication, water gas shift reaction, and reformation occur based on the time/temperature/pressure pattern of further thermal decomposition.

Groundbreaking investigations on flash or fast pyrolysis have demonstrated that carbon-based materials can yield significant amounts of dominant, non-equilibrium liquids and gases, including associated materials, useful materials, oils, and petrochemicals. The lower volume of solid char produced by traditional pyrolysis can have alternatives such as fuel gas with high value, fuel oil, or quick pyrolysis materials (Bridgewater *et al.,* 2001).

Types of pyrolysis

The pyrolysis method may be divided into various types according to the configurations of the process. The subsequent sections provide a description of gradual and rapid pyrolysis processes, since they are the most regular approaches. Different types of pyrolysis procedures have been described, and additional details about the pyrolysis cycle's approaches and reactors have been reported in many studies (Czajczyńska *et al.,* 2017, Zaman *et al.,* 2017). The method indicates reactor type which should be used in the process (Roy and Dias 2017). Drum, screw/auger and rotatory kilns are the reactors commonly used in simple pyrolysis. Spinning cones, fluidized beds, vacuum, entrained stream, and axial reactors are the reactors for rapid pyrolysis (Marshall and Eng 2013). Using auger-type reactors, both fast and slow pyrolysis processes could be handled.

Fast pyrolysis process

The "fast pyrolysis" term refers to heating carbon-based materials at a heating rate of 100-1300 °C/s for 1 to 10 s (Tripathi *et al.,* 2016). This process is typically applied for producing bio oil because the pyrolysis process oil content is significantly higher than the char and gas output. 60–75% liquid biooil, 10–20% volatile gas compounds, and 15–20% biochars are common commodity yields in rapid pyrolysis (Bridgwater 2003). The primary aim of the rapid pyrolysis procedure is to heat carbon-based feedstock to reach the thermal degradation, thus shortening the release time and facilitating the char forming (Mohan Jr *et al.,* 2006). Besides, by using high heating speeds through rapid pyrolysis to convert the feedstock into liquid biooil products, the unexpected generation of char is avoided.

Slow pyrolysis process

The standard form of pyrolysis is slow pyrolysis which usually requires low levels of heating and high periods of residency (Tripathi *et al.,* 2016). Approximately, a 400-500 °C average temperature, with a thermal intensity of 0.1-1 °C/s is used for 5-30 min as an optimal period. The slow pyrolysis cycle favors the carbonaceous char output but liquid, while gas fuel compounds are often generated in comparatively limited amounts (Demirbas and Arin 2002).

Pyrolysis; Benefits and Limitations

Pyrolysis is a more environmentally sustainable option compared to incineration. Compared to other thermo-chemical and biochemical processes, pyrolysis is often thought to be the best option for time saving and have the least environmental footprint (Jo *et al.,* 2017). The high capacity to manage all types of feedstock and manufacture a broad array of products is among the advantages of using the pyrolysis technique (Foust *et al.,* 2009). Unlike biochemical processes, the process needs less reaction time and can be quickly upgraded as short retention periods. Considering the disadvantages of using pyrolysis, it is possible to mitigate the wet and high moisture feedstock issue by integrating the low cost predrying methods before reaction which can be measured using the model and simulation. Sufficient sunlight and low humidity, especially in arid environments, allow the solar greenhouse methodologies to offer a low-cost pretreatment drying. Gasification and pyrolysis are the techniques for producing biochar, but pyrolysis generates greater biochar outputs and emits less toxic gases such as SO_x and NO_x (Tripathi *et al.,* 2016). Another advantage of pyrolysis versus gasification is its versatility in managing various raw materials and various operational situations which allows the final products to produce the necessary specifications. Comparison of the different processes of converting materials into energy sources is presented in Table 2.

Pyrolysis of cigarette butts

Some experiments are focused on the pyrolysis of CBs aiming to develope the valuable items such as biochars and fuel oils. Bio char is regularly used to modify the soil, and bio oil can be applied for energy supply and as additive in asphalt industries (Vakalis *et al.,* 2017). Biochar is an organic material

Table 2: Comparison of thermochemical conversion processes (Pourkarimi *et al.,* 2019)

Conversion Process	Temperature (ºC)	Pressure (MPa)	Liquid		Gas content (% dry wt.)	Solid content (% dry wt.)
			Content (wt.% dry)	HHV (MJ/ Kg)		
Gasification		-	13.74	15.18	28.08	58.18
Gasification	500	35	15	-	69	7
Liquefaction	350	36	43	39	-	-
Liquefaction	350		39.9	39.9	23.2	-
Pyrolysis	450	0.101	57.9	41	32	10.1
Pyrolysis	502	0.101	55.3	39.7	36.3	8.4

Table 3. The CBs pyrolysis methods and results

Objective of study	Product(s)	Highlights	Reference
Manufacture of ester-rich bio-oil by pyrolysis of used cigarette filters	Ester-rich bio-oil	• Due to the high heating frequency under MAP conditions, the pyrolysis output was greatly improved with the the help of microwave absorber silicon carbide in the reactor as well as the application of methanol to N_2 carrier gas; • MAP heating method led to 29.17% bio-oil from CBs compared to to the conventional tubular muffle furnace heating method which yields 0% of bio-oil. The bio-oil yield from CBs increased from 29.17% to 46.71% due to the introduction of methanol. • Gas chromatography/mass spectrometry findings showed that esters, particularly methyl acetate (over 12%). were the major components of bio-oils (over 40%) • The UCF bio-char showed mesoporous properties (e.g., over 500 m^2/g of specific surface area).	Wang *et al.*, 2020
Treatment of the recycled CBs to produce electrically conducted materials	Conducting material	• In a simple process, the conductive substances were produced through heat treatment of the recycled cigarette filters. • Since no pretreatment of the used cigarette filters was needed prior to the carbonization phase, it was cost-effective. • The current-voltage curve of the product showed a marked improvement in conductivity, supporting the application of the substance in electronic conduction.	Ghosh *et al.*, 2017
The effect of carbonization temperature of waste CBs on Na⁻storage capacity of N-doped hard carbon anode	N-doped hard carbon anode	• Waste CBs for the sodium ion battery anode was reused through the pyrolysis carbonization process at 700 °C and 800 °C. • The morphology and electrochemical efficiency of N-doped waste CBs hard carbon (NWHC) were influenced by the temperature of the carbonization process. • The reversible discharge power of NWHC-700 anode was 300 mAh/g at 25 mAh/g for 200 cycles and 135 mAh/g even at 1500 mAh/g for 2000 cycles, higher than 241 mAh/g and 105 mAh/g of NWHC-800 anode, respectively.	Hou *et al.*, 2019
Lead removal by charred carbon from the pyrolysis of used cigarette filters	Nitric acid modified charred carbon	• Charred carbon was produced by the simple pyrolysis of the CBs. • The effects of the pH of the lead solution, the adsorbent dosage, the initial lead concentration and the contact time of the two carbons were studied. • The adsorbent dosage impact was virtually equivalent for both modified and unmodified carbons with an average value of 0.1 g • The adsorption results were fitted with the Freundlich and Langmuir isothermic models. • The removal performances for non-modified and HNO_3-modified carbons were calculated at an initial lead concentration of 600 mg/L at 66 and 74.5 mg/g, respectively.	Masoudi Soltani *et al.*, 2015
Effects of pyrolysis conditions on the porous structure construction of mesoporous charred carbon from used cigarette filters	Mesoporous charred carbon	• One-step pyrolysis was used to synthesize mesoporous charred carbon from the used cigarettes filters. • Complete factorial configuration of experiments, including heating intensity, soaking period and pyrolysis temperature, was used at three rates for each factor. • The temperature and heating volume of the synthesized coal had the most important impact on the overall surface area. • At a pyrolysis temperature of 900 °C, the maximum surface area (597 m^2/g) was achieved when the substrate was heated at 5 °C/min and kept at this level for 3 h. • The N_2 adsorption – desorption isotherm generated showed some degree of mesoporosity in charred carbon at an average pore size of 3.32 nm.	Soltani *et al.*, 2014
The effect of pre-swelling on activated carbon from CBs	Activated carbon	• CBs were impregnated with various proportions of NaOH solutions and then pyrolyzed. • Phenol and carboxyl were evaluated using FTIR. • The activated carbon specific surface area was about < 900 m^2/g. • The iodine number verified the maximum activated carbon capacities (1143.34). • Tests revealed that filter fiber pre-swelling can raise the average activated carbon surface by 47%.	Koochaki *et al.*, 2019
Dry physical mixing of cigarette filters with KOH prior to porous carbon synthesis	Porous carbon	• This analysis measured the impact of physical mixing of cigarette filters with KOH powder on the final characteristics of carbonated porous carbon • Dry KOH functional mixing of cigarette filters has been observed to minimize the specific surface area of Brunauer, Emmet and Teller by about 79%. • This indicated that dry KOH impregnation to CBs as a carbon precursor for porous carbon synthesis would not be an acceptable method for achieving a higher surface area.	Soltani and Yazdi 2012

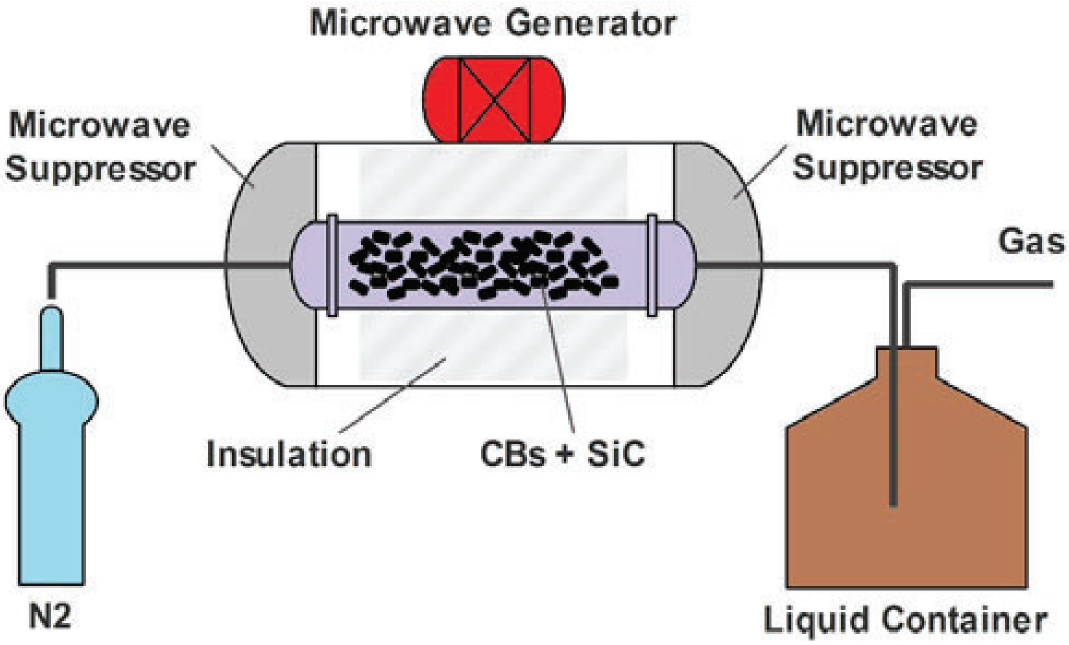

Fig. 4: The reactor of microwave-assisted pyrolysis (Wang *et al.,* 2020)

produced by pyrolyzing carbon-based feedstocks and is better characterized as a “soil conditioner.” The addition of biochar to soil would act as a carbon sink. The characteristics of biochar have been considered to be extremely heterogeneous, both inside the independent bio-char grains and among the biochars derived from different feedstocks and/or under different pyrolysis conditions. Bio-oil can be easily preserved and shipped as it is a green liquid fuel. It can be used as an alternative to fuel oil or diesel in a variety of stationary cases such as boilers, furnaces, generators, and electricity-generating turbines. Alternatively, the crude oil could be used to make adhesives, phenol-formaldehyde-type resins, wood flavors (Xiu and Shahbazi 2012). Table 3 provides a summary of the studies yet have been conducted on the pyrolysis of CBs, and elaborates on the methods, properties, yield, etc, related to the extraction of bio oil and biochar from CBs. The used cigarette filters (UCF) were utilized to produce ester-rich bio-oil via a cleaner production process, namely MAP. The pyrolysis efficiency was significantly enhanced owing to the high heating rate under MAP with the help of microwave absorber silicon carbide (SiC) in reactor and addition of methanol. Compared to the traditional tubular muffle furnace heating method yielding 0% of bio oil, the MAP heating method extracted 29.17% of bio oil from UCF. Using the MAP, the bio oil yield from UCF increased from 29.17% to 46.71% due to the introduction of methanol. N_2 with a flow rate of 800 mL/min was passed through the MAP reactor for 10 min at the beginning of the experiment. The heating was then achieved by a steady stream of 800 mL/min N_2 using a 1000 W microwave (about 80 °C/min). To complete the operation, the temperature was eventually increased to 600 °C and maintained at this temperature for 10 min. Fig. 4 shows a schema of the system employed for the pyrolysis method. The results of this study showed that by adding methanol to the mobile phase, the bio oil yield would be 17.54% higher. If the projected CBs are fully exploited, about 358065 m^3 of bio oil would be produced annually (Wang *et al.,* 2020).

The products of CBs pyrolysis, are mostly in solid-phase for different applications. The electrically conductive substrates (Ghosh *et al.,* 2017) were developed, and it has been shown that addition of

12 wt% of pyrolyzed CBs to DI water increases its conductivity by at least one order. The results of N-doped hard carbon anode preparation (Hou *et al.,* 2019) indicated that the reversible discharge power of NWHC-700 anode was 300 mAh/g at 25 mAh/g for 200 cycles and 135 mAh/g even at 1500 mAh/g for 2000 cycles, higher than 241 mAh/g and 105 mAh/g of NWHC-800 anode, respectively. Nitric acid-modified charred carbon (Masoudi Soltani *et al.,* 2015) was utilized to lead ion removal, and the results showed that at an initial lead concentration of 600 mg/L, the removal efficiencies were 66 74.5 mg/g and 74.5 mg/g for non-modified and HNO_3-modified carbons, respectively. Mesoporous charred carbon (Soltani *et al.,* 2014) was developed and at a pyrolysis temperature of 900 °C, the maximum surface area (597 m^2/g) was achieved when the substrate was heated at 5 °C/min and maintained at this level for 3 h. The generated N_2 adsorption–desorption isotherm showed some degree of mesoporosity in charred carbon at an average pore size of 3.32 nm. Moreover, pre-swelled activated carbon (Koochaki *et al.,* 2019), and KOH treated porous carbon ث were obtained as solid products by using the pyrolysis method for CBs recycling.

CONCLUSIONS

Compared to other biochemical and thermochem-ical methods, pyrolysis is an economically efficient alternative disposal system for biomass waste. Considering the large amount of CBs waste produced globally, the pyrolysis of CBs with the objective of generating different valuable items holds a promising potential. Biochars can be further processed into valuable materials such as activated carbons. System parameters and activation strategies have a significant impact on biochar properties and performance. A number of recent experiments have shown the advantages of using the pyrolysis of CBs for the development of valuable products, particularly biochars. Although the biggest problem of the pyrolysis process is the moisture of the input feed, its most important advantage is the conversion of feed into valuable materials in a one-step process at moderate temperatures. The following issues can be addressed as part of future study: a) the recycling and integration of the gas portion again into the pyrolysis reaction, including certain heat requirements for the thermal decomposition of CBs into biochar product can improve the efficiency of pyrolysis system and economic feasibility; b) the co-pyrolysis of CBs with various materials and biomass waste and their effects on the enhancement of the target product yield while reducing the production of undesirable products; c) further examination of the application of microwave-assisted technologies to transform CBs waste into high quality products such as liquid fuel oils; and d) using models and experiments to attain products with the specific properties and yielding required for the final potential use (e.g. capacitors, pollutant adsorbents) and enhancing the manufacturing structures and processes (such as pyrolysis pressure, temperature and retention time). Tackling the technical issues accossiated with the pyrolysis of CBs to produce valuable goods would help to develope its use in waste handeling and recycling of different compounds which can directly be used or converted into the other final products. Adequate economic and thermodynamic evaluation should also be done on methods of converting CBs into valuable products. The results of this study can mitigate the hazards of spreading CBs in the environment and create added value in the pyrolysis process.

AUTHOR CONTRIBUTIONS

M. Hazbehiean performed investigation, data collection, and also done the partial analysis. N. Mokhtarian and A. Hallajisani performed data analysis in the study. All authors contributed to literature, supervision, and writing the original draft. A. Hallajisani edited and corrected the manuscript.

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CONFLICT OF INTEREST

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

%	Percentage
°C	Degrees Celsius
°C /min	Degrees celsius per minute
°C /s	Degrees celsius per second
µg/g	Microgram per gram
$AgNO_3$	Silver nitrate
Butt/Km/ month	Cigarette butts per kilometer per month
CBs	Cigarette butts
CBs/m^2	Cigarette butts per square meter
Cl	Chlorine
Cm^3/min	Cubic centimeter per minute
et al.,	And others
FTIR	Fourier-transformed infrared spectroscopy
g/g	Gram per gram
g/mole	Gram per mole
h	Hour
HHV	High heat value
HNO_3	Nitric acid
HP	Hazardous properties
J/g	Joule per gram
Kg	Kilogram
KOH	Potassium hydroxide
L	Litre
m	meter
m^2/g	Square meter per gram
mAh/g	Milliamper hours per gram
MAP	Microwave assisted pyrolysis
mg/g	Miligram per gram
mg/Kg	Miligram per kilogram
mg/Kg/ month	Miligram per kilogram per month
mg/L	Miligram per litre
min	Minute
mL	Mililitre
mL/mm	Mililitre prt millimeter
mm	Milimeter
N_2	Nitrogen
NaOH	Sodium hydroxide
NO_x	Nitrogen oxides
nm	Nanometer
NWHC	N-doped waste cigarette butts hard carbon
PACs	Polycyclic aromatic compounds
PAHs	Polycyclic aromatic hydrocarbons
pH	Power of hydrogen
S	Second
SO_x	Sulfur oxides
UCF	Used cigarette filters
UV	Ultra violet
W	Watt
WHO	World Health Orcanization

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