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CASE STUDY

The impact of climate change on the development of water resources

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ABSTRACT

BACKGROUND AND OBJECTIVES: River basin ecology changes frequently when water resources are developed more. In order to meet human needs, the influence of climate change on river flow and hydrological structures should be understood. Population growth, corresponding economic expansion, and irrigation-related factors for food production all contribute to rising water demand. Consequently, the water availability becomes a scarce resource, when the water demand exceeds the supply. Hence, the understanding the interaction between water, ecosystem and society is a key factor in sustainable water resource development, management and utilization.

METHODS: This study evaluates the effects of climate change on the water resource development of the Dhidhessa River Basin. The degree of hydrologic modification was estimated using the Indicator of Hydrologic modification programs. Based on the analysis, the study looked into how variations in rainfall and temperature might affect the river's flow and Dhidhessa basin. Stakeholder analysis was used to identify seven types of stakeholders who expressed interest in the Dhidhessa sub basin.

FINDINGS: The results indicate that the basin experienced a decrease in water level and river flow as a result of climate change. This drop-in water level and river flow can be attributed to the anticipated change in climate caused by variations in rainfall. The Dhidhessa River Basin, located near the Dembi gauge station, was particularly vulnerable to these changes in flow. Interestingly, the degree of flow alteration was found to be relatively low throughout most of the months. In terms of stakeholder distribution, municipal and community governments accounted for 17.3 percent and 25.4 percent, respectively. Additionally, organizations with investors, ministries, and certain government agencies represented 37.4 percent of the articles, while foreign actors and religious organizations accounted for 19.9 percent.

CONCLUSION: The research findings indicate that the water balance in the Dhidhessa basin may be affected by climate change in the coming century. Thus, the variation in rainfall and temperature might affect the river flow. However, it is impossible to determine this change's direction definitively until the model results are assessed under various scenarios. Therefore, the virtual future of socio-hydrologic assessment and better integration of stakeholders is needed to understand the dynamics in the basin for sustainable water resource development and management.

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INTRODUCTION

The increasing concentration of atmospheric carbon dioxide has led to a global concern regarding climate change. (Florides *et al.,* 2009; Kellogg, 2019; Dawit *et al.,* 2020). Climate change is primarily responsible for the fluctuations in water levels and modifications in the flow of river basins. (Arnell, 1999; Bekele *et al.,* 2021). Expanding water resource development to meet human demands, however, contributes to the increase in rainfall variability. (Asfaw *et al*., 2019; Dawit *et al*., 2020). It may affect runoff, the severity of floods, the availability of irrigation water, soil moisture, and drought (Changnon *et al*., 2000; Cao *et al*., 2010; Belay *et al*., 2017). Constructing irrigation systems is crucial for providing food security, combating climate change, and raising household incomes (Burnham *et al.,* 2016; Dawit *et al.,* 2019). Nevertheless, the nation's potential has remained unrealized until now, primarily due to managerial, technical, financial, and various other challenges. (Arnell, 1999; Easterling *et al.,* 2000). The biggest obstacles to inclusive irrigation growth include high structural failure rates and environmental issues (Fischer *et al.,* 2007; Haddeland *et al.,* 2014; Krause *et al.,* 2019). Rivers serve as the main water supply for domestic, agricultural, and various other purposes. (Araya *et al.,* 2015; Aldababseh, 2018). Rivers and lakes are generated from rainfall originally formed by the rainfall-runoff process connected to climate change and its influence (Ayers *et al.,* 1985; Belay *et al.,* 2017). Furthermore, the hydrologic cycle and watershed hydrology can be influenced by factors such as plantation practices, soil properties, land utilization patterns, and their interplay with climatic conditions. (Keane *et al.,* 2009; Lemessa *et al.,* 2019). The hydrological cycle's effects on the availability, demand, and supply of water resources, especially the agricultural farming system, could have a significant impact due to climate change (Akıncı *et al.,* 2013; Van Emmerik *et al.,* 2014; Aldababseh, 2018). Climate change is a pressing concern that alters hydrological reactions and has a detrimental impact on the functioning of lakes in arid regions. This includes variations in temperature and precipitation patterns, which significantly influence the hydrological responses and overall performance of these water bodies. (Kumar, 2012; Ravikumar *et al.,* 2017; Woldegebriel *et al.,* 2022). It is difficult to adapt to these problems, particularly in arid and semi-arid areas (Watts *et al.,* 2015; Dawit *et al.,* 2020). Consequently, the future of water resource availability is expected to be unclear due to increased water resource development and management, particularly the effects of climate change (Burnham and Ma, 2016; Dechassa *et al.,* 2020). Additionally, research revealed that climate change may impact the water supplies used for agriculture, urbanization, and the environment (Panwar *et al.,* 2013; Teklewold *et al.,* 2017; Ndulue *et al.,* 2019). In order to grasp the uncertainties associated with future water resource plans and requirements, numerous decisions have been imperative in determining the approach to examine the impacts of climate change on global water resource management and its accessibility. (Bekele *et al.,* 2021; Degife *et al.,* 2021). The vulnerability of groundwater and surface water to climate change and variability will be greatest in semi-arid and arid regions (Egan, 2011; Obeysekera *et al.,* 2011; Taylor *et al.,* 2013). Since climate change can be exacerbated by human interference, such as irrigation and land use change, various studies suggest that the emphasis placed on assessing change in the water resource is limited to this phenomenon (Taylor *et al.,* 2013; Yihdego *et al.,* 2017; Balehegn *et al.,* 2019). However, due to the low capacity to adapt, particularly in underdeveloped nations, the socio-ecological systems and water resources are severely impacted by climate change (Treidel *et al.,* 2011; Burnham and Ma, 2016; Wang *et al.,* 2020). A lack of food was also caused by poor water resource management decisions, which contributed to population expansion and the need to meet livelihood demands in emerging nations (López-Carr *et al.,* 2013; Dorling, 2021; World Bank, 2022). Because there are insufficient protein sources, cattle farming production cannot meet market demand and must thus be increased (Awulachew *et al.,* 2005; Lee *et al.,* 2020; Nichols *et al.,* 2022). Furthermore, the fresh produce experienced a surge in market prices as a result of the imbalance between the availability and the demand, rendering them financially inaccessible for households with lower incomes. (Nelson *et al.,* 2010; Schmitz *et al.,* 2014; Nichols *et al.,* 2022). The current study examined the possible consequences of climate change on the water resources of Ethiopia's Dhidhessa Basin. To assess the anticipated alterations in the region, the Indicator of Hydrologic modification programs was employed, comparing projected shifts in temperature and precipitation. Consequently, the study aimed to ascertain the potential impact of daily temperature and precipitation fluctuations on stream flow and other hydrological components. The objectives of the ongoing study are as understanding how different factors (i.e. institutional, governance, environmental, human and hydrological) interact through water, and to determine outcomes that help to develop sustainable ecosystem. This study has been carried out in Ethiopia, Dhidhessa River Basin in 2023.

MATERIALS AND METHODS

Study area

This study was conducted in the Dhidhess River Basin, which is the tributary of the Abay/Nile basin. The Nile River is around 6,825 kilometres (km) long. Understandably, the discharge per square kilometre (km^2) is lower than that of other major rivers globally (Teweldebrihan *et al.,* 2021). The river embarks on a journey through diverse regions, spanning from Lake Victoria to the Mediterranean Sea, encompassing a range of geological formations, relief patterns, and weather conditions. Its primary sources are the Ethiopian Highlands and the plateau of equatorial lakes. Flowing in a sequential order from the Ethiopian Highlands, the Baro Akobo River, the Blue Nile River (also known as Abbay), and the Tekeze-Atbara River serve as the three main tributaries. Among these, the Abbay Basin holds immense significance in Ethiopia. It accounts for approximately 25 percent (%) of the country's population, covers 17.5% of its geographical area, and possesses 50% of its annual surface water resources. Consequently, the Abbay River contributes an average of 62% of the Nile river flows in the Aswan dam.The Dhidhessa sub-basin is responsible for roughly 25 - 26% of the Abbay flows near the boundary (Fig. 1). Hydrologically, the Dhidhessa sub-basin is crucial since the Abbay River originates in this area and contributes significantly to flow. It drains a region of almost 34,000 km^2, including tributaries like the Wama, Dabana, and Angar, all of which have previously been looked into for large-scale irrigation and power projects by various study groups (MoA, 2017; Wedajo *et al.,* 2019; Teweldebrihan *et al.,* 2020). This is a result of the hydrological virtues associated with this sub-basin.

Agro-climate

The Arjo Dhidhessa catchment's climate results from its geographic location and elevation: 1300–3012 meters (m). Factors such as the monthly mean temperature, relative humidity, wind speed, and sunshine hours (h) are significant inputs to estimate the crop water requirements for irrigation development. Climate data for the project area has been collected

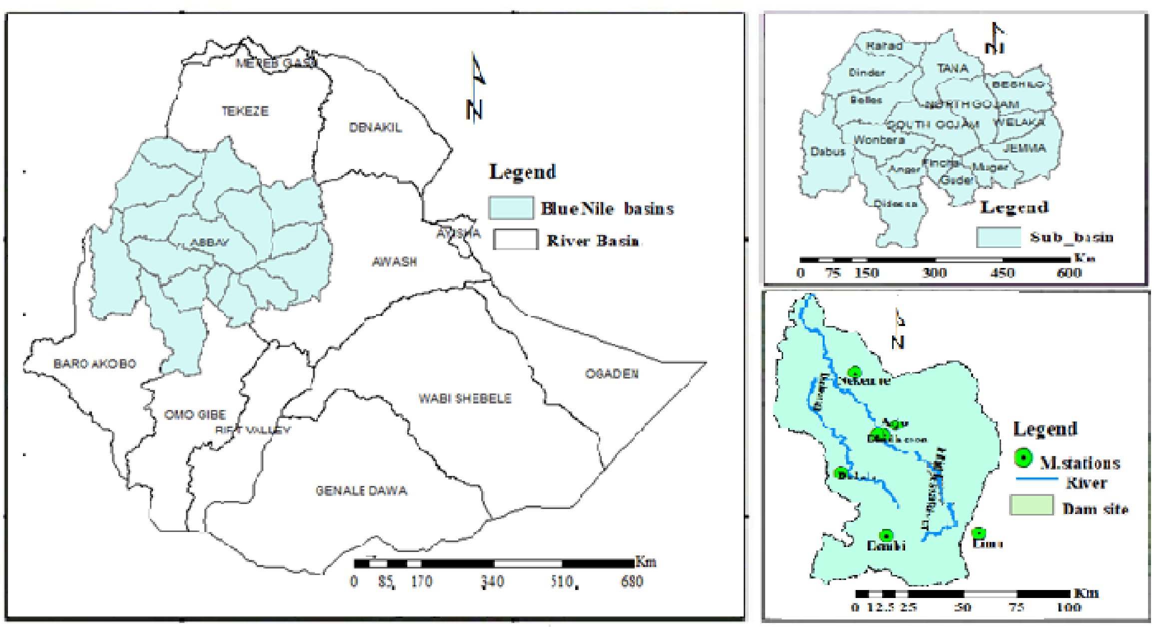

Fig. 1: Geographic location of the study area in the Dhidhess River Basin of the Abay/Nile basin in Ethiopia

and analyzed, encompassing information on temperature, relative humidity, sunlight duration, wind speed, and rainfall. To address any missing data, interpolation and correlation techniques have been employed. Additionally, consistency checks, data rectification, and other necessary adjustments have been implemented.. The Food and Agriculture Organization (FAO) Penman-Monteith method was used for the calculation of crop reference evapotranspiration (ETo) from meteorological data. Computer modeling has been used to calculate the evapotranspiration ETo. The FAO Penman-Monteith equation is employed to calculate evapotranspiration, utilizing a hypothetical grass reference surface. The Arjo-Dhidhessa project command area offers a standard for comparing evapotranspiration for different crops. Evapotranspiration calculations require a range of climatological and physical characteristics derived from meteorological data. Meteorological stations provide direct measurements for some of these data points. However, other factors can be determined through direct measurements or empirical relationships based on frequently observed data. In the investigation of rainfall for irrigation purposes, the most reliable and relevant climatological data were obtained from the Bedele, Dhidhessa, and Jimma stations. The Bedele station is the closest to the command area. The elevation of Dhidhessa station and the command area are the same as1330 metre above mean sea level (m.a.s.l.). The Arjo Dhidhessa watershed and command area's missing and short-term meteorological data have been extrapolated using Jimma station (Class I), which has the longest track record of all the stations nearby.

Air temperature

The mean monthly temperature in the project farm area varies slightly from 20.0 degree Celsius (°C) in December to 25.4 °C in March 2023. Fig. 2 shows a graphic representation of the command area's mean monthly temperatures.

Air humidity

The average humidity levels vary from 57% in March to 89% in September. Graphs depict the mean monthly humidity in the command areas. The collected humidity data was utilized to determine the evapotranspiration rates of reference crops. (Fig. 3).

Wind speed

The wind speed measurements exhibited variations ranging from 0.5 meters per second (m/s) in November to 0.8 m/s in April. The data on monthly wind velocity were gathered from the designated region to assess the extent of these fluctuations. (Fig. 4).

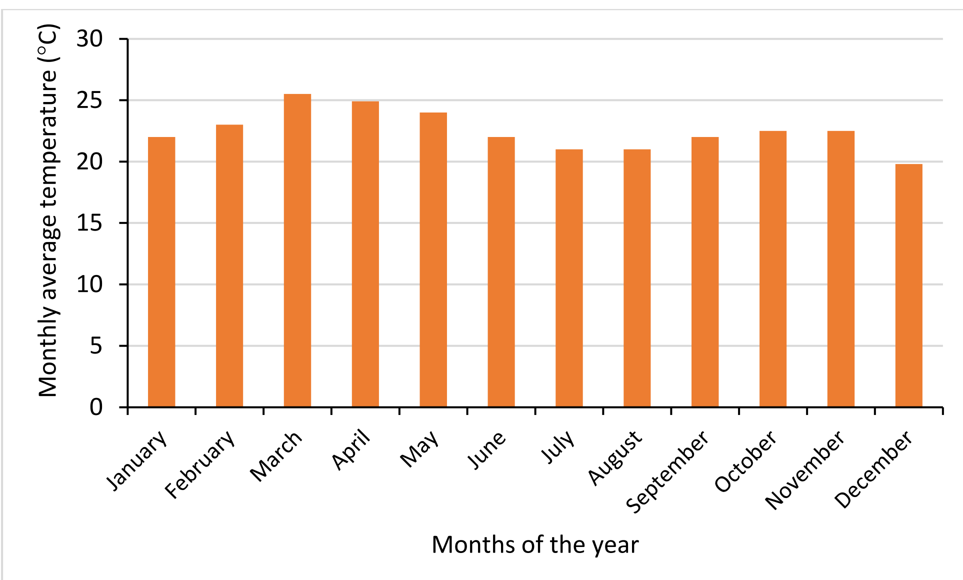

Fig. 2: The Monthly average air temperature across Dhidhessa River Sub-Basin

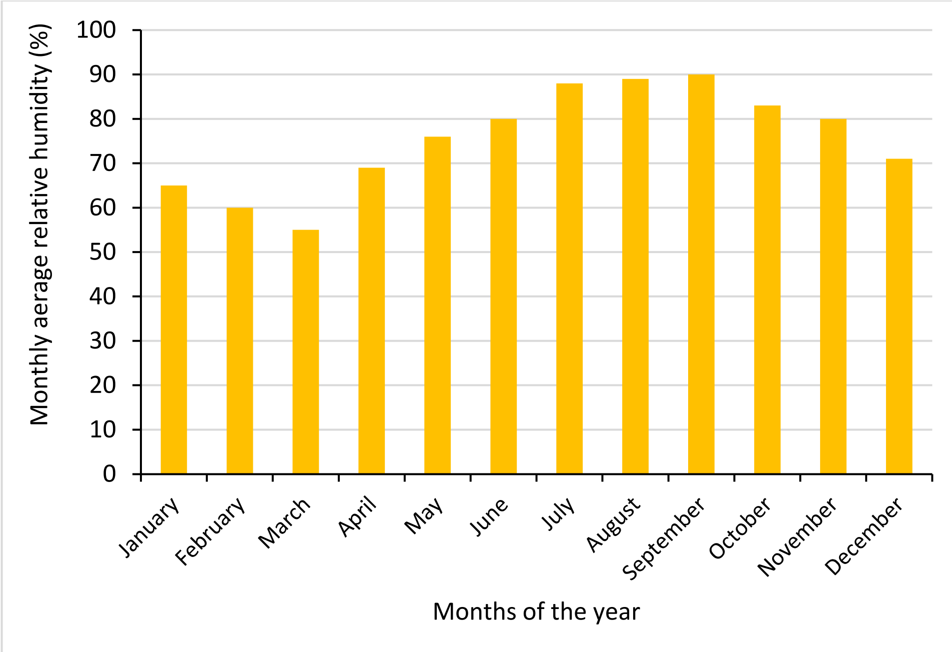

Fig. 3: The Monthly average air humidity across Dhidhessa River Sub-Basin

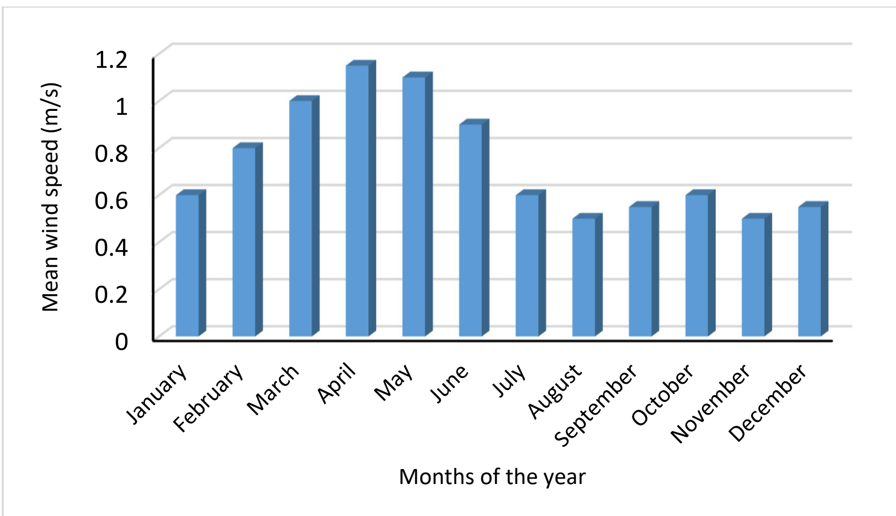

Fig. 4: The Monthly average wind speed across Dhidhessa River Sub-Basin

Solar radiation

The monthly duration of sunlight in the command area is typically 8.3 hours in December, but this figure decreases to 3.7 hours in July. Consequently, the estimation of evapotranspiration rates from reference crops has been based on data regarding the number of sunshine hours. (Fig. 5).

Rainfall

The rainfall resulted in 1453 millimetre (mm)

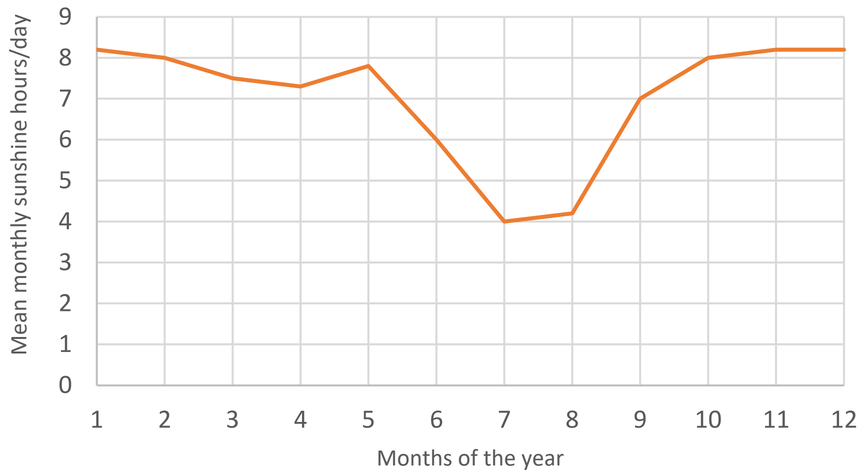

Fig. 5: The Monthly average solar radiation across Dhidhessa River Sub-Basin

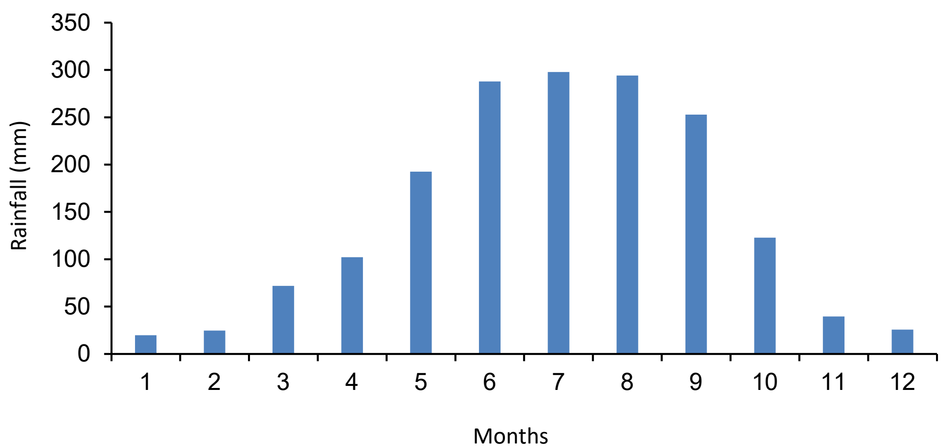

Fig. 6: The Monthly average rainfall distribution across Dhidhessa River Sub-Basin

over its watershed, varying from 2013 mm at Dembi Station to 1417 mm at Agaro stations. Five meteorological stations' daily rainfall, maximum, and lowest temperature values were used. The study's rainfall estimations were produced by regionalization and meticulous statistical analysis. The stations' data from Jimma, Dhidhessa, Bedelle, Dembi, and Agaro were suitably included after being subjected to consistency tests and other checks for length and quality. The mean annual rainfall mentioned above is recorded as 1148 mm, 1090 mm, and 951 mm for years (y) with notable exceedance probability levels of 75%, 80%, and 90% respectively. This rainfall follows a unimodal temporal distribution pattern. Due to the fact that 63% of the total rainfall occurs within a concentrated period of 5 months (July to November 2023), the planned dam will have sufficient water storage capacity to carry over from one season to another. The annual rainfall of the study area ranges from 1300 - 2200 millimeter per year (mm/y) with an average of about 1775 mm/y. Fig. 6 indicates that most of the rainfall occurs from June – September every year. Time-series plots were utilized to conduct a graphical analysis of the rainfall data, specifically focusing on the monthly rainfall data from various meteorological data stations within the river basin. It was observed that all stations exhibited comparable periodic patterns across all recorded data.

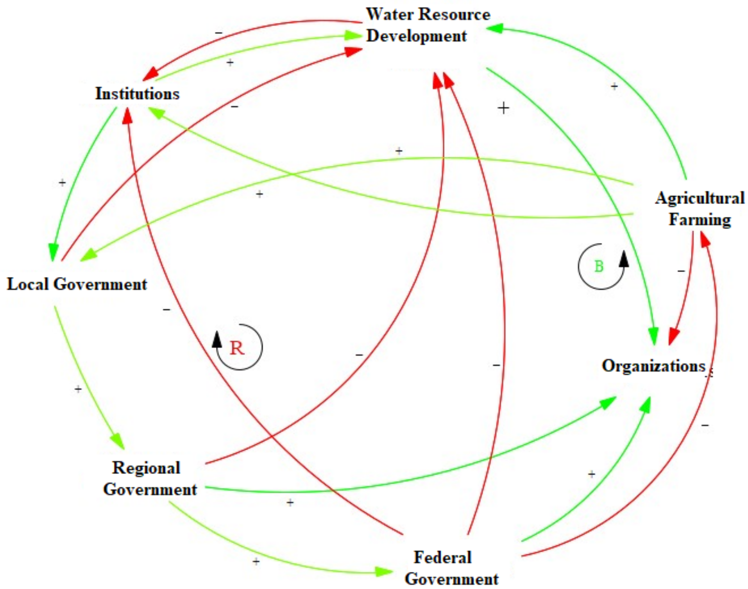

Fig. 7: Stakeholder analysis feedback loop

Water resources

Due to the strong database availability in Dhidhessa and the surrounding sub-basins, the monthly time series spanning 45 years (960 - 2005) was used. Data from stations including Dhidhessa at Arjo, higher Dhidhessa at Dembi, Dabana close to Abasina, Gilgel Ghibe close to Ascendabo, and Gojeb close to Shebe all contributed to a reliable database for statistical analysis used to estimate the time series of flows at the proposed Arjo dam site.

Hydrological modelling

Survey and analysis

After gathering secondary and primary data for analysis, interviews and focus group discussions were carried out. The investigation aimed to explore the involvement, perspectives, and practical positions of stakeholders in the development of water resources. The examination encompassed the evaluation of stakeholders' standards and significant roles. To gain a comprehensive understanding and identify the key contributors in the study area, an inclusive stakeholder analysis was conducted. Furthermore, the study acknowledged both the direct and indirect roles played by these stakeholders.

RESULTS AND DISCUSSION

Stakeholder's role in water resource development

The study employed both secondary and primary data, which were then supplemented by interviews and focus group discussions. The research aimed to examine the participation, viewpoints, and practical positions of stakeholders in the field of water resource development. The significance and primary responsibilities of stakeholders were thoroughly examined. Consequently, a comprehensive stakeholder analysis was conducted to gain insights into and recognize the principal actors within the water resource development sector. The stakeholders' direct and indirect roles were also identified (Fig. 7). Seven kinds of stakeholders were identified through the stakeholder analysis as having expressed interest in the Dhidhessa sub-basin. The community, local government, regional government, organizations, institutions, the federal government, and researchers constitute the seven categories. Most stakeholders, including municipal and community governments, comprised of 17.3% and 25.4%, respectively. Organizations with investors, ministries, and some government agencies make up of 37.4% of the articles, followed by those with foreign actors and religious organizations at 19.9%.

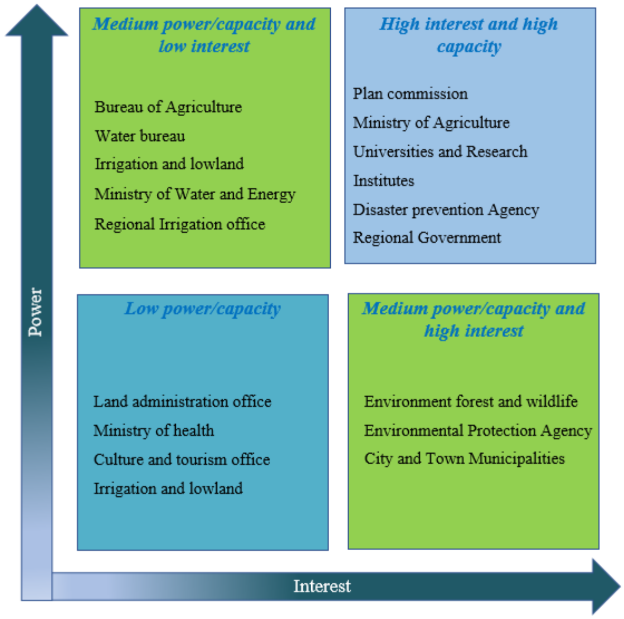

Fig. 8: Stakeholder power-interest quadrant

The study undertakes an analysis of the key actors involved in formulating strategic plans and establishing a comprehensive framework for the utilization of water resources, considering the existing challenges. To gain insights into stakeholder perspectives, levels of interest, capacities, and roles pertaining to water resource development, a focus group discussion was organized. A selection was made of a group of significant informants and stakeholders who are closely linked to the study due to their designated duties and close proximity. It is imperative for government institutions to assume the role of facilitators, empowering stakeholders to carry out their tasks in alignment with their individual viewpoints. As a result, the coordination process among stakeholders is difficult and cannot be achieved without coordination, which requires the creation of an enabling environment. In order to achieve the strategic objectives and effectively harness the capabilities of stakeholders at every level, it is imperative to ensure that their roles and coordination are geared towards conflict prevention. Moreover, the level of interest, influence, and implementation capacity possessed by each stakeholder plays a crucial role in determining the overall coordination and effectiveness within the stakeholder framework. The quadrant displays the degree of stakeholder influence, power, and coordination interest (Fig. 8).

Ecological response to flow alteration

The indicator of hydrological alteration (IHA) assesses various aspects of ecosystems' flow components, encompassing extremely low flows, low flows, large flow pulses, small floods, and significant floods. Among the 34 criteria that IHA considers, these factors play a crucial role in evaluating hydrological changes and their impact on the environment. (Fig. 9). The unique fluxes of these individual components possess a significant ecological value. The ecological reactions (such as abundance, diversity, and demographic characteristics) to the modified river flow are influenced by the affected components of the river flow. By integrating with ecological models, the IHA facilitates the establishment of flow-ecology theories in a more convenient manner. The flow duration curve, a graphic representation of cumulative frequency showing the percentage of time-defined discharges surpassed during a certain period, further illustrates the specified flow regimes. The flow duration curve illustrates the relationship between stream-flow magnitude and frequency for a certain river basin. The form of the curves of the flow period defines the flow characteristics of the flow regimes. The flow duration curve's shape reveals the drainage

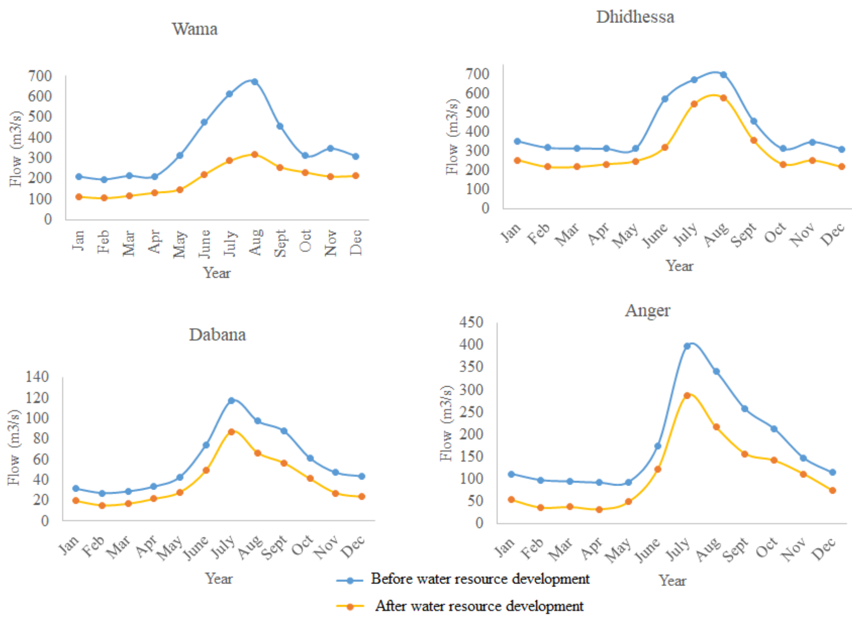

Fig. 9: Hydrologic alteration before and after dam construction

area's hydrological characteristics. The slope of the flow period curves reveals the range of flows in the stream. The steeper and flatter the slope, the more variety there is, claim (Berhanu *et al.,* 2015). Various methods can be employed to evaluate environmental flow, such as hydrologic analysis, hydraulic rating, habitat modeling, and holistic approaches. These techniques require extensive knowledge and effort, which are beyond the scope of this text. Therefore, a straightforward IHA is used to assess how dams in the upper portion of the Cauvery basin have altered the flow regime. The analysis reveals that the operations carried out in the reservoir and the subsequent withdrawal of water have had a substantial impact on the average monthly flow of the basin. (Fig. 5). It is undeniable that the reduced flow of water in the lower stream during the majority of months can be attributed to the implementation of more stringent water restrictions throughout different seasons. In direct opposition to its original flow pattern, the operations of reservoirs lead to a consistent decrease in monthly water flow across all sub-basins throughout the year.

CONCLUSIONS

Following the expansion of water resources and the effects of climate change, the study looked at how stream and river flow had changed in the basin. The hydrological model was employed to assess the consequences of water resource development and flow modification. The monthly average flow exhibited a considerable magnitude during certain months at the stations, whereas it was generally low in most months based on the IHA parameters. This was observed both before and after the impacts at Dhidhessa near Arjo and Dhidhessa near Dembi gauge station, as well as in the river flow components. Due to changes in precipitation and temperature patterns, it is projected that the intensity of rainfall will rise, whereas the stream flow is predicted to decline. The alterations in water availability and the hydrologic cycle are believed to be attributed to the impacts of climate change. The susceptibility to flow alteration differs between the Dhidhessa near Arjo station and the Dhidhessa near Dembi station. Consequently, the study primarily concentrated on examining the extent to which water resource development and climate change affect the sensitivity of the river basin flow in the latter location. The investigation involved analyzing various scenarios of forecasted changes in seasonal precipitation, including both increases and decreases. Each examined period of precipitation exhibited notable alterations in the accessibility of water resources and the climate.

Consequently, shifts in the direction of stream flow generally mirrored changes in rainfall patterns, indicating that the availability of water resources and river flow in the basin could be influenced by climate change. Consequently, the heightened utilization of water resources and the repercussions of climate change possess the capacity to diminish agricultural productivity, thereby causing a shift in river flow. The study excluded demand sites, such as industrial, institutional, and commercial water requirements, from the analysis of flow alteration due to data deficiencies. Consequently, it is highly recommended that assessments of rainfall intensity changes, which encompass all essential data for hydrological impact evaluations and consider the combined influence of climate and land use change on water resource availability, be carried out.

AUTHOR CONTRIBUTIONS

M.D. Teweldebrihan performed the literature review, initial investigation, compiled data, experimental design, analysed and interpreted the data, prepared the manuscript text, manuscript preparation and manuscript edition. M.O. Dinka performed the review, supervision, validation and manuscript preparation.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest 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, were observed by the authors.

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ABBREVIATIONS	DEFINITION
%	Percent
°C	Degree Celsius
FAO	Food and Agriculture Organization
Fig.	Figure
h	Hour
ETo	Evapotranspiration
km	Kilometer
km^2	square kilometre
m.a.s.l.	metre above mean sea level
m	Meter
mm	Millimeter
m/s	Metre per second
m^3/s	Cubic meter per second
mm/y	Millimeter per year
y	Year

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