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Reviewing Assessment of Surface Water Potential and Irrigation Development in Ethiopia: Opportunities and Challenges in Harnessing Water Resources for Agricultural Development

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ABSTRACT

This manuscript examines the critical role of sustainable water resource utilization for agricultural development, with a particular focus on surface water potential in Africa, notably Ethiopia. The investigation encompasses a multifaceted analysis that includes evaluating surface water availability, assessing land suitability, employing advanced hydrological modeling techniques, and scrutinizing the influential factors affecting irrigation development. The findings shed light on the opportunities and challenges faced in harnessing surface water resources for irrigation purposes, ultimately contributing to agricultural development. The Review highlights the significance of understanding surface water availability and employing advanced hydrological modeling techniques to assess water resources and identify suitable areas for irrigation projects. Additionally, it addresses the key factors influencing irrigation development in Africa and focusing on Ethiopia. Ethiopia is one of the countries which have enormous surface and ground water potential in East Africa. However, the surface water potential of the country has not yet fully understood. There are potential rivers, tributaries, springs and other water sources which flow throughout the year; there is no clear statistics which shows about the amount of available water resources and the irrigation water demand at catchment level. Recently, the rain fed based agriculture practice has become challenged by the rainfall distribution and variability, and resulted severely impedes agricultural productivity. So, maximize the use of irrigation could be a solution in a changing climate. In order to plan, develop, and promote the use of irrigation system, knowledge of the available water and irrigable land resources potential is a necessary step for a sustainable irrigation project. The overall objective of this Review is to assess surface water potential and irrigation development. Hence, assessment of land suitability, surface water availability, and are the specific tasks for irrigation development.

Introduction

The responsible use of water resources for the development of agriculture is crucial in the global context. Supplying enough food gets more difficult as the world's population continues to increase. In locations where rainfall patterns are unpredictable or insufficient, effective water management techniques and the utilization of irrigation technologies are essential for supplying the expanding global demand for food. (FAO, 2018). In the face of water shortage and climate change, we can improve global food security and advance sustainable development by utilizing water resources for agriculture. Surface water provides tremendous potential for irrigation in many areas of the African continent, including Ethiopia (FAO, 2018). Irrigation may help with food security, the elimination of poverty, and general economic growth. But to use surface water resources for irrigation effectively and sustainably, one must have a complete grasp of their availability, distribution, and potential (Meja, Bassa, & Mirkeno, 2020). The immense surface water potential of the African continent is a result of the abundance of its river basins. These river basins, which are distinguished by their size, hydrological patterns, and geographic distribution, are essential for maintaining water resources for a variety of uses, such as irrigation, home use, industrial processes, and hydropower generation. The Nile River Basin, which crosses multiple nations, including Ethiopia, Sudan, Egypt, and Uganda, is one of the major river basins in Africa. The potential for surface water on the continent is largely contributed by the Nile Basin. The Congo River Basin, Niger River Basin, Zambezi River Basin, and the Orange River Basin are just a few of the continent of Africa's other significant river basins. Each of these river basins has distinctive qualities and water potential that add to the continent of Africa's overall surface water availability. It is important to note that the potential for surface water in African river basins is currently underutilized (Mukosa and Mwiinga 2018). (NEPAD, 2012). Despite the continent's abundant water supplies, leveraging this potential for irrigation expansion and other water-dependent industries is difficult. Africa only has 185 million ha of its total land area under cultivation, and 12 million ha, or 7% of that, is irrigated. This suggests a tremendous opportunity for enhancing irrigation infrastructure and water usage effectiveness to maximize the agricultural potential of the continent (NEPAD, 2012). These difficulties include a lack of infrastructure, a lack of storage space, ineffective methods of managing the water, and conflicting water demands. These issues must be resolved in order to promote the sustainable use of surface water resources. To do this, integrated approaches to managing water resources, legislative changes, and investments in water infrastructure are necessary. Ethiopia, a country in the Horn of Africa, is distinguished by a variety of agro-ecological zones and an abundance of water resources, including several rivers, lakes, and reservoirs (Dereje M. and Desale K., 2016; Desale K., et al, 2014). As a result of its fast rising population and predominately agrarian economy, the nation has realized the value of improving its irrigation infrastructure to boost food security and agricultural output. A thorough understanding of a variety of elements, including hydrological patterns, climatic fluctuations, water availability, and the socioeconomic and environmental ramifications of such projects, is necessary for the best use of surface water resources for irrigation development. (Kasa, A. K., Haile, G. G., & (2015). The country has a yearly capacity of 123 billion m3 for surface water from its twelve river basins, and a potential of 2.6 to 13.5 billion m3 for groundwater (MoWIE, 2011). However, the country's irrigation potential is currently underutilized. The primary master plan studies and official documents that have thus far been utilized to assess Ethiopia's irrigation potential are (Awulachew et al., 2010) and FAO (2016). Estimates of Ethiopia's capability for irrigation differ from one source to another, despite the country's abundance of available land and water resources. The country's overall irrigable land area was assessed by the Ministry of Agriculture to be 2.3 million hectares in 1986, according to Kebede Ganole in 2010. On the other side, 2.8 million ha are offered by the International Fund for Agricultural Development (IFAD, 1987). Ethiopia has 3.7 million acres of potentially irrigable land, according to (MoWR, 2002). There is currently a lack of thorough research on the water potential and irrigation potential perspectives in the Ethiopian context because there are no defined or widely acknowledged standards for calculating the nation's irrigation potential (Haile and Kassa, 2015). Our understanding of the country's groundwater, surface water, and arable land is relatively constrained as one proceeds from zonal to lower administrative layers. This assessment of the literature will draw on a variety of academic papers, news pieces, and research projects carried out in Africa, with a focus on Ethiopia. This literature review ultimately aims to contribute to the understanding of surface water potential and irrigation development with a specific focus on Ethiopia in the broader context of the African continent. It will explore key themes and topics, such as hydrological modeling techniques, water availability assessments, land suitability, irrigation potential, and factors of Irrigation Development. This study intends to give useful insights for policymakers, water resource managers, researchers, and development practitioners engaged in the planning, implementation, and evaluation of irrigation projects in Ethiopia and other African nations by combining and assessing existing literature.

Availability of Surface Water

The total amount of water on Earth is roughly 1.36 108 million hectares-meters (ha-m). While just 2.8% of these resources are freshwater that may be found on the world, 97.2% of them are salty, mostly located in oceans. 2.2% of this 2.8% of freshwater is surface water, roughly speaking. (UN,2015). With 45% of the world's total freshwater resources, America has the highest share, followed by Asia with 28% and Europe with 15%. The water issue that the global village is currently facing has been partially caused by this natural distribution of water as well as a number of manmade factors (UNEP, 2010). Surface waters continuously exchange mass with the atmosphere and oceans, making them a vital part of the climate system and its variability. As a result, they play a significant role in the global water cycle (Mekuria, W., & Tegegne, 2022). We still have a limited understanding of freshwater storage, flux, and spatial distribution, particularly in many parts of the world (Rodell et al. 2018). The creation of efficient and sustainable water resource management plans is hampered by this knowledge gap. According to Aldorf and colleagues (2007), the current level of uncertainty raises important concerns about the availability of water across land areas, including the amount of freshwater stored on continents and the spatiotemporal dynamics of surface freshwater, including how it interacts with climatic variability and human activity. In the context of Africa, the second-largest continent in terms of both size and population, these problems are especially crucial. As of 2022, there will be almost 1.4 billion people living in Africa, which will make up about 18% of the world's population. Africa has an area of around 30 million km2. According to projections, Africa's population will double by 2050, with its proportion of the world's population rising to 26% in 2050 and perhaps as high as 40% by 2100 (United Nations 2019). Because of this, it is crucial to understand how Africa's water resources are distributed in order to manage this precious resource sustainably. According to the data that is currently available, Africa uses between 1,700 and 2,200 billion cubic meters (BCM) of surface water annually for a variety of purposes, including domestic, industrial, and agricultural use. This amounts to a small portion of the total annual renewable surface that is expected to be 4,079 BCM (FAO Aquastat, 2020). It's vital to emphasize that different African nations and areas might utilize surface water resources very differently. Some nations, like Egypt and Sudan, use a comparatively bigger proportion of the available surface water than other nations with high water demands and significant irrigation systems Multsch, S., Elshamy, M., Batarseh, S., Seid, A., Frede, H. G., & Breuer, L. (2017). At the continental level, Africa has the lowest percentage of fresh water at 9% (UNEP, 2012). The enhancement of water governance and the promotion of sustainable water management techniques are among the actions being taken to increase the exploitation of surface water resources in Africa. With these programs, the potential of the continent's surface water resources for food security, economic growth, and agricultural productivity will be fully realized. The headwaters of various Trans-Boundary Rivers, including the Nile, can be found in Ethiopia, a country with an abundance of water resources. Ethiopia, meanwhile, appears to be experiencing water stress, according to key measures. The total annual renewable water resources per person are 1,162 m 3, which is slightly above the 1,000 m 3 threshold for water scarcity and below the 1,700 m 3 threshold for the Falkenmark Water Stress Index (FAO Aquastat, 2020). Based on the information that is currently available, Ethiopia uses a significant amount of surface water for irrigation. To compare the precise amount of surface water used for irrigation to the overall surface water potential, however, exact numbers are not easily accessible. With an estimated 2.7 million hectares of potential irrigable land, Ethiopia's total annual renewable surface water resources are estimated to be around 122 billion cubic meters (BCM) (Berhanu, Seleshi, and Melesse, 2014; Berhanu & Hatiye, 2020). Ethiopia manages its surface water resources through a system of 12 basins, four of which are trans-boundary: the Nile, Rift Valley, Shebelle-Juba, and the Blue Ni Other than the Nile Basin, all of Ethiopia's river basins are experiencing water scarcities, and reliable surface water is particularly hard to come by below 1,500 meters in much of eastern Ethiopia (FAO Aquastat, 2016). Seventy percent of Ethiopia's renewable surface water comes from the western Abay (Blue Nile), Baro-Akobo, Mereb, and Setit-Tekeze/Atbara Basins, which are all a component of the Nile Basin (FAO Aquastat, 2016; Berhanu et al., 2014). According to Abtew and Dessu (2019), these basins together provide 86% of the Nile River's yearly flow. Over 20% of Ethiopia's surface water resources are found in the central and northeastern Afar-Denakil, Awash, Omo-Gibe, and Rift Valley Basins, which are a component of the Rift Valley Basin spanning across East Africa. Due to the low average annual precipitation, the Awash Basin has a restricted supply and a high demand for water, which is concentrated in the southern Omo-Gibe and Rift Valley Basins (FAO, 2020). Eight percent of Ethiopia's surface water resources are found in the eastern Wabi-Shebelle and Genale-Dawa basins, which are a portion of the Shebelle-Juba Basin (Berhanu et al., 2014). The Ogaden and Aysha, which are considered dry basins with rivers that flow only after rainfall (FAO Aquastat, 2016), are included in the North East Coast Basin. 22 lakes can be found in Ethiopia, the largest of which, Lake Tana in the Abay Basin, is a vital supply of water for the Nile River. Numerous sizable lakes exist in the Rift Valley Basin, the majority of which are saltwater bodies (Aquastat, 2016; Berhanu et al., 2014), and they provide over 30% of crop production (MoWIE, 2011)..

Table 1: Surface water potential and coverage area of Ethiopian river basin Source: (Seleshi et al, 2010)

River Basin	Area (Km^2)	Surface runoff (Bm^3)	River Basin	Area (Km^2)	Surface runoff (Bm^3)
Takeze	82,350	8.2	Denkil	74,002	0.86
Abbay	199,812	54.8	Awash	112,696	4.9
Baro	75,912	22.6	Aysha	2,223	-
Oma-gibe	79,000	16.6	Ogaden	77,121	-
Rift-valley	52,739	5.6	Wabi-Saballe	202,697	3.16
Mereb	5,900	0.65	Genale Dawa	171,042	5.88

Most of the time, data on water availability are only available at a single measurement point, like a gauging station, and there are no data on runoff at other locations within the sub-basin. As a result, methodologies for runoff estimation for various sub-river basins are required. The feasibility of sub-river basin outflow locations was initially determined by the possibilities for irrigation development both within and outside of each individual sub-river basin. Gonfa, B. D., Hatiye, S. D., and Finssa, M. M., 2021

Techniques for Hydrological Modeling

Utilizing a system of mathematical equations, hydrological models are used to simulate the water cycle and other hydrological functional phenomena computationally. Hydrological modeling can be thought of as a method of quantitative prediction for decision-making since it depicts the processes involved in the conversion of rainfall into runoff through channels that occur at the ground surface (Tshimanga, 2022). There are numerous frameworks for hydrological modeling that can be used right now, each with a different level of process description, conceptualization, data needs, and geographical and temporal resolutions. Utilizing or adapting existing model frameworks that have shown some promise in other contexts is now standard practice in the field of hydrological modeling. As a result, many global or land surface models have been used in Africa under different circumstances and for various goals (Trambauer et al., 2013; Hughes et al., 2015; Boone et al., 2009; Grippa et al., 2017; Getirana et al., 2017b). However, a thorough classification of these hydrological models is outside the purview of this debate. Please consult the sources cited for more detailed information about their classification. Here are a few hydrological models that have been employed to evaluate the prospective surface water availability in various Ethiopian basins.

SWAT:

Strengths: SWAT is recognized for its versatility and robustness, capable of simulating various hydrological processes and incorporating spatially distributed data (Hailu Gisha Kuma et al., 2023; Husen Maru et al., 2023; Megersa Adugna et al., 2023; Shiferaw E et al., 2021; Daniel Bekele et al., 2021; Woldesenbet, T.A., et al., 2018; Mekonnen, D.G., et al., 2019).

Applications: Its applications extend to water yield assessment, surface runoff modeling, sediment transport simulation, land use change impacts, and climate change assessments.

HEC-HMS:

Strengths: HEC-HMS is well-established and widely used, specializing in simulating runoff and streamflow, making it highly suitable for engineering applications (Demlie G. et al., 2020; Yilma K. et al., 2022; Proloy Deb & Anthony S. Kiem, 2020; Nickson T. et al., 2022).

Applications: It finds utility in surface water potential assessment, water resource management, and engineering hydrology studies.

Variable Infiltration Capacity (VIC):

Strengths: VIC employs a distributed modeling approach and effectively simulates water balance components, including evapotranspiration, runoff, and soil moisture (Desta, G., and Guzman, C.D., 2014; Girma, A.T., van et al., 2016).

Applications: Its widespread usage extends to simulating various hydrological processes, such as evapotranspiration, infiltration, runoff, and soil moisture dynamics.

GR4J Model:

Strengths: The GR4J model specializes in rainfall-runoff modeling and excels in regions with limited data, rendering it suitable for water resource management and flood forecasting (Gaba, E. Alamou, et al., 2017).

Applications: It serves the purpose of assessing water availability, designing water resource systems, and analyzing the impacts of land use changes or climate variability on streamflow.

HBV Model:

Strengths: The HBV model is characterized by its simplicity, computational efficiency, and adaptability to different climatic and hydrological conditions, making it an excellent choice for long-term streamflow simulations (Melsew A. et al., 2022; Adimasu Woldesenbet et al., 2022; Asfaw Kebede et al., 2014; C. Gaba, E. et al., 2017; A.Y. Jillo, et al., 2017; Alemseged T. et al., 2017; Kasye S. & Shimelis B., 2023).

Applications: It is widely used for water resources assessment and management, flood studies, and climate change impact assessments.

Hydrological models used to analyze soil moisture dynamics, runoff, and surface water availability. Overall, despite the wide variety of hydrological modeling tools available, the best option will be determined by the particular study questions and objectives. It's crucial to pick a modeling tool that is appropriate for the research topic and goals because different modeling tools each have their own advantages and disadvantages.

Suitable Land for Irrigation

The viability of agricultural projects and food security can be impacted by the appropriateness of the land for irrigation development. Numerous elements, including soil quality, topography, climate, and water availability, must be considered in order to assess a piece of land's potential. About 307.6 million hectares of land are supplied with irrigation systems worldwide. About 69 percent of this total comes from Asia, with the remainder coming from America (17 percent), Europe (8 percent), Africa (4 percent), and Oceania (2 percent). China has the most land that is irrigated globally, with 62.4 million hectares, followed closely by India with 61.9 million hectares and the United States of America with 28. Sub-Saharan Africa, South Asia, and the Middle East are the areas that require irrigation development the most globally, according to the UN. Water, UN (2018). Due to the rapid population increase and water shortage problems in these areas, irrigation development is a crucial component of their agricultural development plans. However, obstacles like market accessibility, infrastructure, and challenges with land tenure may restrict the potential for irrigated expansion. Governments and international organizations must collaborate to give these regions with the right policies and resources in order to overcome these obstacles. According to geography, there are significant differences in the suitability of land in Africa for irrigation development (FAO and IFAD, 2019). While some areas are arid or semi-arid and have low soil quality, others have an abundance of water resources and good soils. Land appropriateness for irrigation development is essential in nations like Ethiopia, where a sizable rural population depends on agriculture for a living. The nation has a significant amount of potential for irrigation development due to its numerous rivers and lakes, notably Lake Tana, which is the source of the Blue Nile River (Awulachew & Ayana, 2011; You et al., 2011). Due to a lack of infrastructure and investment in the industry, the nation is having trouble developing natural resources. You et al. (2011); Awulachew et al. (2010). depending on. There are a few crucial procedures that must be followed in order to obtain land suitability for irrigation development, according to (Assefa et al., 2018) and Kipkoech et al. (2018). First, the necessary legal and policy frameworks must be established to support sustainable and inclusive agricultural development. These frameworks should support smallholder farmers and promote the use of sustainable farming methods. Second, funds must be invested in infrastructure including irrigation systems, warehouses, and transportation networks. Thirdly, a focus on farmer capacity-building is required to guarantee that they have the abilities and information required to execute sustainable agricultural methods. Finally, international alliances and partnerships can support the development of supply chains for agriculture that are more resilient and sustainable. A variety of research techniques have been employed to evaluate suitable irrigation land. The use of GIS and MCE is widespread, though (Adhikary et al., 2015; Akinci et al., 2013; Assefa et al., 2018; Elsheik et al., 2010; Hussien et al., 2019; Jha et al., 2010; Latinopoulos et al., 2011; Nasir et al., 2019; Wale et al. Studies revealed that GIS and MCE approach of irrigation suitability analysis is efficient in handling multicriteria and providing better results (Adhikary et al., 2015;Akinci et al., 2013;Assefa et al., 2018;Elsheik et al., 2010;Jha et al., 2010;Latinopoulos et al., 2011;Teshome & Halefom, 2020;Worqlul et al., 2015). Therefore, to explore the current study, remote sensing and GIS-based MCE approaches were employed. The AHP technique was utilized to evaluate several criteria, rank options, and make judgments using MCE models. The AHP approach is efficient and widely used in water resource studies (Chen et al., 2010; Mendas & Delali, 2012). Various methods have been used in the field of irrigation land evaluation to determine if a piece of land is suitable for irrigation. Among these methods, Geographic Information Systems (GIS) and Multicriteria Evaluation (MCE) have emerged as commonly utilized techniques (Adhikary et al., 2015;Akinci et al., 2013;Assefa et al., 2018;Elsheik et al., 2010;Hussien et al., 2019;Jha et al., 2010;Latinopoulos et al., 2011;Nasir et al., 2019;Wale et al., 2013;Worqlul et al., 2017). Adhikary et al. (2015), Akinci et al. (2013), Assefa et al. (2018), Elsheik et al. (2010), Jha et al. (2010), Latinopoulos et al. (2011), Teshome & Hale fom (2020), and Worqlul et al. (2015) have all underlined the value of using GIS and MCE tools to evaluate potential irrigation land. These techniques examine the suitability of land for irrigation using geospatial analysis and remote sensing data within a GIS framework. Analytic Hierarchy Process (AHP)-integrated MCE models are used to evaluate several criteria, rank options, and support decision-making. The AHP method, which is frequently employed in studies of water resources, works well for determining the suitability of irrigation (Chen et al., 2010; Mendas & Delali, 2012). Due to their capacity to manage many variables and produce precise findings, GIS and MCE techniques offer a number of advantages in the evaluation of potential irrigation property. These methods entail integrating geospatial analysis tools and remote sensing data into a GIS context, allowing for thorough research and evaluation of many parameters determining irrigation appropriateness. The capacity of GIS to effectively handle and analyze spatial data is one of its main advantages. GIS offers a comprehensive evaluation of irrigation potential by integrating several information such as topography, soil properties, climate, land cover, and hydrological factors. By merging and overlaying these datasets, GIS may use spatial analytic techniques to find eligible sites, creating maps that show the best places for irrigation development. MCE and GIS improve the evaluation process by combining many factors into the decision-making process. The use of MCE enables the integration and evaluation of a number of variables, such as soil fertility, water availability, slope, drainage, and infrastructure accessibility, that affect the suitability of irrigation. MCE permits the ranking of options and the identification of the most advantageous places for irrigation construction by giving weights to each criterion. The AHP approach, which is frequently applied within MCE frameworks, is crucial in determining irrigation suitability. Through pairwise comparisons, the AHP technique makes it easier to compare and prioritize criteria in a systematic manner. Each criterion's relative relevance is determined by experts who provide subjective judgements, which are then mathematically calculated to create priority scores. By offering a quantitative basis for choosing the best sites for irrigation development, these scores support decision-making. Several research (Adhikary et al., 2015; Akinci et al., 2013; Assefa et al., 2018; Elsheik et al.) have shown the usefulness and efficiency of GIS and MCE techniques in irrigation suitability assessments.

Table 2: Potential suitable land area in the major river basins of Ethiopia

River basin	Basin area (km^2)	Potential irrigable land (km^2)	Percent potential	River basin

Abbay	198,891	21,186	11	Abbay
Denakil	63,853	523	1	Afar/Denakil
Awash	110,439	7331	7	Awash
Aysha	4321	–	–	Aysha
Baro-Akobo	76,203	2603	3	Baro-Akobo
Genale-Dawa	172,133	2056	1	Genale-Dawa
Mereb	5965	208	3	Mereb
Ogaden	80,009	720	1	Ogaden
Omo-Ghibe	78,189	8235	11	Omo-Ghibe
Rift Valley	51,989	10,512	20	Rift Valley
Tekeze	86,455	1782	2	Tekeze
Wabi-Shebelle	202,219	4868	2	Wabi-Shebelle
Total	1,130,666	60,024	5.3	Total

Irrigation Development

Agriculture is the backbone of many African economies, accounting for a significant portion of their GDP and employing millions of people. Irrigation is critical for increasing agricultural productivity and food security, yet the practice remains underutilized in many parts of the continent. In this paper will explore the current status of irrigation development in Africa, the challenges that impede its progress, and the solutions that are being implemented to overcome these obstacles. The Current Status of Irrigation Development in Africa: According to the Food and Agriculture Organization (FAO,2018), only 7% of arable land in Africa is equipped for irrigation, compared to the global average of 20%. The majority of irrigated land in the continent is located in north and southern Africa, whereas countries in sub-Saharan Africa have relatively low irrigation coverage. According to the Food and Agriculture Organization (FAO), about 16% of the world's land area is classified as suitable for irrigation, which represents approximately 279 million hectares (FAO, 2018).

In Ethiopia, where smallholder farmers provide around 95% of the nation's agricultural production, agriculture is a key component of the economy (Dagninet A. and Adugnaw A.,2019). The country has 12 river basins with a combined annual runoff volume of 122 billion m3 of water and an estimated 2.6-2.65 billion m3 of potential groundwater (Gebremedhin G. and Asfaw K.,2015). Ethiopia has been known as Africa's water tower as because of this (Godswill M. and Dawit K.,2017).About 12 million hectares (Godswill M.e, Regassa N.,2011)of Ethiopia's land is now being used for agriculture. Additionally, even though the exact amount of irrigated land is not known (Mehretie B. and Woldeamlak B.,2013),estimates of irrigable land in Ethiopia range from 1.5 to 4.3 million hectares (Mha), with an average of about 3.5 Mha (Haile G. G.,2015),. It is incredible however, since less than 5% of the nation's irrigable land is currently believed to be under irrigation, representing a total of 160,000 to 200,000 hectares (Dagninet A. and Adugnaw A.,2019).However, according to (Yilma,Z., G.B.,2011) both traditional and modern irrigation systems are being used to produce between 8 and 12 percent of the total irrigable potential. Also, differences in irrigation potentials and actually irrigated lands, for instance 3.7 Million ha and 197,000 ha according to (Haile & Kassa, 2015;Awulachew and Ayana, 2011; Gebremedhin G. and Asfaw K.,2015)'s and 3.5 Million ha and 626,116 ha as reported by (Godswill M. and Dawit K.,2017)'s respectively, are indicated differences in the same class. Therefore, there is no reliable and consistent assessment of potentials connected to irrigation and water in the Ethiopian setting that has been thoroughly researched and documented. This demonstrates that there aren't many study specifics in the field.

Not only Ethiopia, some African countries have a lower level of irrigation development and utilization compared to their irrigation potential. This suggests that there is room for further development and utilization of irrigation resources in these countries. Based on the data from FAO Aquastat some of African countries irrigation development is very low.

Table 3: the irrigation potential and current irrigation extent for selected countries in Africa:

Country	Irrigation Potential (hectares)	Current Irrigated Area (hectares)	Percentage of Irrigated Area
Egypt	3,450,000	3,100,000	89.86%
Sudan	12,800,000	2,710,000	21.17%
Morocco	5,000,000	1,400,000	28.00%
Algeria	5,700,000	1,500,000	26.32%
Nigeria	9,000,000	250,000	2.78%
Ethiopia	3,510,000	294,000	8.36%
South Africa	1,250,000	600,000	48.00%
Kenya	1,080,000	110,000	10.19%
Tanzania	1,150,000	400,000	34.78%
Senegal	500,000	206,000	41.20%

Source: (FAO Aquastat, Global Map of Irrigation Areas (GMIA), 2013)

However, it is important to note that this observation cannot be applied uniformly to all African countries. Africa is a diverse continent with varying geographical, climatic, and socio-economic conditions, leading to variations in the availability and utilization of irrigation resources.

Factors such as access to water sources, infrastructure, agricultural practices, government policies, and economic conditions can significantly influence the level of irrigation development and utilization in each country. Therefore, it is essential to consider the specific circumstances and factors unique to each country when assessing their irrigation practices.

(Makombe G, Namara R, Hagos F,2011) noted that irrigation development is a key for sustainable and reliable agricultural development which leads to overall development in Ethiopia. Irrigated agriculture is being practiced under smallholders, medium and large-scale farming. Many authors such as (Godswill M., Regassa N., 2011) used government-based irrigation schemes classification systems for their description during their studies. According to Ministry of Water Resources of Ethiopia (Makombe G, Namara R, Hagos F, 2011), irrigation development in Ethiopia is classified based on the size of the command area, in three types:

Table 4: Summary of typologies of irrigation schemes in Ethiopia (Haile G. G., 2015)

Typology	Size of scheme (ha)	Infrastructure	Water Management scheme (ha)
Small scale	< 200	Fixed or improved water control and diversion structures made	Water users' association or irrigation cooperatives. Local water users' association
Medium scale	200-3000	Fixed or improved water control and diversion structures.	Water users' association/ irrigation. cooperatives or state
Large scale	>3000	Fixed or improved water control and diversion structures	Mostly state enterprises

This classification system is the most common in Ethiopia. Accordingly, 46% of proposed irrigation developments are in the small-scale irrigation category (Makombe et al., 2011; Haile & Kassa, 2015) and the remaining portion is allocated to medium- and large-scale irrigation. However, there is a significant lack of detailed information regarding these projects, and it is crucial for future research and updates to address this issue

4.1. Irrigation technology adoption

Irrigation technology adoption in developed and developing countries can vary widely based on factors such as available resources, infrastructure, and local agricultural needs. However, there are several irrigation technologies and practices that have been utilized and promoted in many developed and developing countries to enhance agricultural productivity and water resource management. Here are some technologies commonly used or promoted:

Developed Countries:

Israel:

Drip Irrigation: Israel is a pioneer in the use of drip irrigation technology. The country's arid climate and limited water resources prompted the development and widespread adoption of drip irrigation systems. These systems allow precise water delivery directly to the plant's root zone, maximizing water-use efficiency. (Tal, A. 2016).

United States:

Precision Agriculture: In the United States, precision agriculture technologies are extensively used. Farmers employ GPS-guided tractors and equipment, drones for aerial monitoring, and soil sensors for data-driven decision-making. These technologies optimize irrigation practices, reduce water wastage, and increase crop yields. (Sanders, C. E., Gibson, K. E., & Lamm, A. J.,2022).

Netherlands:

- Hydroponics and Greenhouse Farming: The Netherlands is known for its advanced greenhouse farming practices, which often incorporate hydroponics. These controlled environment systems allow for highly efficient water and nutrient management, making it possible to grow crops with minimal water usage. (Opitz, I., Berges, R., Piorr, A., & Krikser, T.,2015)

Developing Countries:

India:

Drip Irrigation: India has been promoting drip irrigation among its farmers, especially for cash crops like sugarcane and cotton. Government subsidies and support have led to increased adoption, helping conserve water and improve crop yields. (Kumawat, Priyanka & Yadav, L & Jajoria, Dinesh & Kumari, Varsha & Meena, Bolta.2022).

Kenya:

Solar-Powered Irrigation: In Kenya, solar-powered irrigation systems are being deployed to provide off-grid solutions for smallholder farmers. These systems help farmers access water for their crops without relying on expensive diesel pumps or grid electricity.

Bangladesh:

Community-Based Irrigation: Bangladesh has a long history of community-based irrigation systems managed by local Water User Associations. These systems involve local participation in managing and maintaining irrigation infrastructure, ensuring equitable water distribution. (Mottaleb et al., 2019)

It's important to note that while developed countries often lead in the adoption of cutting-edge irrigation technologies, developing countries are increasingly finding innovative and context-specific solutions to address their unique challenges, such as limited resources and infrastructure constraints. The choice of technology often depends on factors like available resources, government policies, and local agricultural needs.

Factors Affecting the Development of Irrigation

Millions of people around the world depend on irrigation development operations to ensure their livelihoods and access to food, particularly in arid and semi-arid regions where rainfall is unpredictable or insufficient to sustain agriculture. However, a number of variables that differ between locations and nations affect how irrigation projects are implemented. The factors influencing irrigation development activities worldwide, in Africa, and in Ethiopia are examined in this essay. Irrigation development efforts are hampered by scarce water supplies, poor infrastructure, a lack of funding, and ineffective management procedures in many parts of the world (Jayawardena et al., 2019). These difficulties are particularly noticeable in poorer nations where a lack of water is a widespread problem. In Africa, irrigation development activities are also hampered by a number of factors including limited financial resources, insufficient technical expertise, poor infrastructure, climate change, and political instability (Alemu et al., 2017). The World Bank estimates that more than 1.2 billion people live in areas with insufficient water supply for agriculture and human consumption (World Bank, 2019). Due in part to these difficulties, just about 7% of sub-Saharan Africa's arable land is currently irrigated, compared to 40% in Asia (FAO, 2018). The absence of proper finance from governments and development partners is another factor contributing to the delay in irrigation development. Irrigation only receives a minor portion of this allocation in the majority of African nations, which spend less than 5% of their national budgets on agriculture. Insufficient funding has resulted in outdated infrastructure, poorly maintained irrigation systems, and restricted access to new technology. (UNDP, 2010). A number of obstacles, including the land tenure system, a lack of human and financial resources, inadequate infrastructure, and weak institutional support, have had an impact on the growth of irrigation activities in Ethiopia (Tadele & Duijn, 2017). Ethiopia's population depends to a degree of about 90% on rainfed agriculture, which is susceptible to droughts and climate change. In order to increase food security and reduce poverty, the Ethiopian government has given irrigation development efforts top priority. In conclusion, several locations and nations experience considerable differences in the factors influencing irrigation development operations. The solution to these problems requires a multifaceted strategy that includes the distribution of sufficient funds, investments in infrastructure growth, and enhanced management procedures. Irrigation development initiatives can greatly increase agricultural output, contribute to food security, and lessen poverty by addressing these issues. The irrigation subsector in Ethiopia has experienced tremendous growth, fueled by a number of causes. These factors include the immense untapped irrigation potential of the nation, the need to feed and sustain the nation's sizable and growing population, and the improving business climate. Both domestic and foreign investors are given incentives to stimulate investment, such as the duty-free importation of manufacturing equipment and an income tax holiday, particularly for founding export-oriented horticulture businesses. With an average yearly economic growth rate of 10.6 percent between 2007 and 2012, Ethiopia made significant economic and development success. Nevertheless, the nation continues to rely heavily on food assistance, receiving 25% of all international food aid to Sub-Saharan Africa. There is an urgent need to invest in irrigated agriculture in order to provide food security for a population of over 100 million people. The government is taking on a bigger role in commercializing the agriculture sector, along with programs funded by donors. Ethiopia's agricultural industry has experienced significant expansion, but a number of obstacles prevent commercialization and modernization. The lack of funding is a significant obstacle that is made worse by problems like unclear land access procedures, restricted access to inputs and financing, inadequate farming skills, a lack of resources for maintaining irrigation structures, reluctance on the part of traditional farmers to adopt new technologies and crops, and risk aversion among Ethiopian farmers (N. T. Henkaro, 2012; Meja, M., Bassa, & Mirkeno, T. (2020)). Other challenges include subpar agricultural extension services, insufficient irrigation water management assistance for small-scale farmers, frequent droughts contributing to the depletion of water resources, limited access to technical and market information leading to high transaction costs, inadequate rural infrastructure, including power supply, depletion of water resources impacting ecological systems, conflicts between different stakeholders, flood and erosion challenges, drainage issues, and (Meja, M., Bassa, M., & Mirkeno, T. Addressing these challenges is crucial for the sustainable development of irrigation in Ethiopia. Efforts should be directed towards improving financing mechanisms, enhancing land access procedures, providing adequate support services and resources for farmers, strengthening agricultural extension and irrigation water management, and investing in rural infrastructure. Additionally, effective measures should be implemented to mitigate ecological risks, resolve conflicts, tackle drainage and maintenance issues, and address market price fluctuations and pestrelated threats. By addressing these constraints and promoting sustainable practices, Ethiopia can unlock its vast irrigation potential, ensure food security, and propel the agricultural sector towards greater productivity and resilience. To overcome these challenges, initiatives at the continental and national levels aim to enhance investment in irrigation infrastructure, improve water management and governance, and provide training and technical assistance to farmers. Innovative approaches such as small-scale farmer-led schemes, solar-powered irrigation, and the use of mobile technology for water management are being explored to expand irrigation coverage and promote sustainable practices. In a global context, it is evident that Africa, including countries like Ethiopia, possesses advantageous circumstances for irrigation. However, it is imperative to acknowledge the importance of overcoming the obstacles and making substantial investments in irrigation infrastructure to attain agricultural productivity, ensure food security, and foster rural development in these regions. This recognition holds significance not only for the local context but also for the overall global efforts in addressing agricultural challenges and promoting sustainable development.

Conclusion

In summary, this article review has offered valuable perspectives on the potential of surface water and irrigation development, with a specific focus on Ethiopia within the broader context of Africa and the world.. This seminar underscores the crucial role of surface water resources in promoting agricultural growth and food security in the region. The assessment of surface water availability revealed both opportunities and limitations in harnessing water resources for irrigation purposes. By employing sophisticated hydrological modeling techniques, researchers have been able to accurately estimate the water potential and identify areas suitable for irrigation development. Furthermore, the review highlighted various factors influencing irrigation development in Africa, with a specific emphasis on Ethiopia. These factors encompassed both technical and nontechnical aspects, including infrastructure requirements, funding mechanisms, institutional frameworks, and socio-economic considerations. The analysis underscored the need for comprehensive planning, multi-stakeholder involvement, and policy interventions to address the challenges and maximize the benefits of irrigation projects. In light of the findings, it is evident that sustainable water management practices and policy interventions are essential for successful irrigation development in Africa, particularly in Ethiopia. Governments, international organizations, and local communities should collaborate to promote the efficient and equitable use of surface water resources for irrigation, while ensuring environmental sustainability and social inclusivity. The review concludes by emphasizing the need for continued research, knowledge sharing, and capacity building to further enhance surface water potential and irrigation development in Africa, thereby fostering agricultural productivity and economic growth.

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