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Research article

Overall performance assessment of selected small-scale irrigation schemes using internal and external performance indicators in West Hararghe Zone, Eastern Ethiopia

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ABSTRACT

This study was conducted to evaluate the overall performance of selected small-scale irrigation schemes using internal and external performance indicators. The performance of the irrigation schemes in relation to water balance was evaluated using three indicators. The results indicated that the relative water supply (RWS), relative irrigation supply (RIS), and field application ratio (FAR) of Midagdu irrigation scheme were 0.9, 1.3, and 0.75 respectively. This indicates that the water supply is not closely related to the water demand. However, for the Wadeti Irrigation scheme, the RWS, RIS, and FAR are 0.48, 0.35, and 2.83, respectively, indicating water stress. The Midagdu irrigation scheme shows 7496.75 birr/ha for both output per unit command area and output per unit cropped area. Output per unit irrigation water supply was 12.5 birr/m3, while output per unit water consumed was 4.4 birr/m3. For the Wadeti irrigation scheme, the values were 11,276.12 birr/ha, 11,276.12 birr/ha, 8.7 birr/m3, and 1.6 birr/m3, respectively. This study results showed that the Wadeti irrigation scheme is more land-efficient, while the Midagdu scheme is more water-efficient. The values of the hydraulic performance indicators Conveyance Efficiency (Ec), Water delivery capacity (WDC), and Delivery Performance Ratio (DPR), for the Midagdu irrigation scheme were 75 %, 0.45, and 0.8, respectively, while for the Wadeti irrigation scheme, the values were 42 %, 0.11, and 0.4, respectively. These results indicate that the water delivery performance of the two schemes was poor. Therefore, improving the hydraulic performance of the scheme requires minimizing water conveyance losses.

1. Introduction

1.1. Background

Water scarcity could be an obstacle to producing more food to meet the demands of an increasing world population. Improving the effectiveness existing irrigation schemes could be one strategy for conserving this valuable resource [1]. Farmers throughout the world have constructed their irrigation management methods. Depending on the field situation and resources available to farmers, their management criteria result in a range of performance levels [2].

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Increasing irrigation could serve as a viable solution to address the problem of food insecurity by increasing agricultural production [3]. Irrigation benefits the national economy by boosting agricultural production, improving food security, creating jobs, and fostering industrial growth through the production of exportable crops. Large investments in infrastructure for irrigation schemes over the last half century, after understanding its importance in increasing food production to feed the increasing population from year to year, have been undertaken in developing countries [4]. To increase sustainable production in irrigated agriculture, either new irrigation schemes can be constructed, or the performance of existing irrigation schemes can be evaluated and improved [5]. Irrigated agriculture in Ethiopia comprises only a small fraction of the total cultivated area. The estimated irrigation potential of Ethiopia is 4.3 million ha. The currently developed area with this potential is 247,470 ha. This area includes 138,339 ha (55.90 %) of traditional irrigation, 48, 074 ha (19.43 %) of modern small-scale irrigation and 61,057 ha (24.67 %) of modern medium- and large-scale irrigation [6].

Although the renewable surface area and groundwater of Ethiopia amount to 123 and 2.6 billion cubic meters per annum, respectively. And its distribution in terms of area and season does not provide adequate opportunities for sustainable economic growth. The severity of repeated droughts impacts the well-being of farming communities and the overall country's economy. Even in years with ample rainfall, floods can detrimentally affect the livelihoods of residents living near rivers and lakes due to the challenges they face in preventing or mitigating such events. As a result, irrigation projects are extensively examined, devised, and executed across the country from this significant perspective [7]. However, little or no attention has been given to monitoring and evaluating the performance of established irrigation schemes. Both traditional and contemporary irrigation systems are managed by public agencies or communities, and numerous existing irrigation systems are experiencing deterioration in physical infrastructure, operation and its management. Performance assessment is employed to ascertain the present condition of the schemes concerning the designated benchmarks and aids in uncovering the underlying reasons for its underperformance, thereby suggesting opportunities for enhancement. According to Ref. [8], two major approaches to performance evaluation are considered: how well service is being delivered and the outcomes of irrigation in terms of the efficiency and productivity of resource use. To measure these performances, a number of indicators have been proposed and tested in different parts of the world [9–14]. The majority of Ethiopian population lives in rural areas, and agriculture provides the majority of the country's income. The improvement of agricultural productivity can be caused by the use of farming lands for intensive and continual practices irrespective of season and affirmative land use methods. The Oromia Irrigation Development Authority is responsible for ensuring sustainable and reliable agriculture through the development of modern and improved irrigation schemes in the eastern and western Hararghe zones of the Oromia region [15].

In addition, due to the poor performance of irrigation schemes in Ethiopia, the performance assessment of small-scale irrigation systems is not common in the Oromia region, especially in the West Haraghe zone. Hence, this study attempts to introduce the concept of internal and external performance indicators to assess the performance of small-scale irrigation schemes in West Hararghe.

1.2. Problem statements

Water is a valuable resource for agricultural production. Life and sustainable development are seriously and increasingly threatened by water scarcity and misutilization. As water is the limiting factor in most of the world, increasing yields and sustaining food production depend mainly on irrigation. Therefore, the protection and development of water resources are crucial for irrigation facilities. The efficiency of numerous irrigation systems falls considerably short of their capacity as a result of various deficiencies, including inadequate design, construction, operation, and maintenance.

The head regulator and the sluice gate built on the weir do not provide proper functions. During the irrigation period, farmers use local materials to prevent water leakage through the sluice gate. Most canals found in the scheme are unlined and cause water losses during the irrigation period. This gave rise to problems of a shortage of water in the scheme. Farmers use traditional irrigation water delivery systems and irrigation frequently, which results in poor water management. More often, farmers spend their time in cleaning canals, which they have to do every season before irrigation starts. Most of the water control structures constructed in the scheme are not operational.

With a growing population and increasing demand for food, sustainable production increases from irrigated agriculture must be achieved. Barriers to the advancement and effectiveness of irrigation include inadequate availability of dependable hydrological and soil information, elevated expenses for investments and operations, water scarcity resulting from reduced water reservoir discharge, deficiencies in both design and execution, inadequate upkeep of infrastructure, and insufficient or substandard research on irrigated agriculture.

In Ethiopia, irrigation projects are extensively researched, planned, and carried out. However, no attention has been given to monitoring and evaluating the performance of established irrigation schemes. An irrigation system of approximately 0.7 Mha is currently being developed for Ethiopia, and the effectiveness of the current plans is not well known [16]. Irrigation schemes in the west Hararghe zone, which has poor irrigation system management, are compounded by competition for water access by crops, livestock, and small holders. No previous studies have investigated the performance of small-scale irrigation schemes in the Zone, so this research aimed to assess the overall performance of small-scale irrigation schemes in the West Hararghe Zone of the Oromia region using internal and external indicators.

Since, the main objectives of any irrigation system is crop production, land productivity, and water productivity, these factors must be regularly measured and monitored [17,18]. Also, the absence of reliable, location-specific data about irrigation performance including efficiency, consistency, sufficiency, and the extent of irrigated land is hampering the progress of current irrigation projects. This data gap prevents effective evaluation, hinders targeted improvements, and ultimately undermines the ability to optimize water resource management. When evaluating the performance of field-level irrigation schemes, only inputs (water, for example) should be taken into account. Moreover, Wadeti and Midagdu irrigation schemes face numerous challenges, including damaged infrastructure (broken division boxes and flow control gates), sedimentation buildup in canals, excessive vegetation and stagnant water in tertiary canals, inadequate operation and maintenance practices, poor water competition in fields, insufficient water measurement methods, and ineffective on-farm water management strategies.

In addition, farmers' interest in irrigation has grown recently, raising the need for water and, consequently, the pressure to enhance the efficiency of two irrigation schemes in order to guarantee the productivity of the land and water. Furthermore, it has been crucial to collect accurate information regarding the relative performance of different structures, the system that adapts better to the output of irrigated agriculture, and the extent to which irrigation schemes realize the predetermined and identified objectives.

2. Materials and methods

2.1. Description of the study area

2.1.1. Midagdu irrigation scheme

The Midagdu Irrigation Scheme is geographically located in the West Hararghe Zone Oda Bultum woreda. The beneficiaries are found in PA **Midagdu**. Distance from zone town_49 km_ and district town_10 km. Geographically, the district is located between 8035′00″ and 9000′00″ North Latitude and 40033′00″ and 41020′00″ East longitude and has an altitude of 1629 m above sea level (Fig. 1).

2.1.2. Wadeti irrigation scheme

This irrigation scheme is geographically located in the West Hararghe zone Chiro woreda. The site is geographically located between 9° 6′ 38.463″ W 121° 8′ 24.715‴ East and has an altitude of 1643 m above sea level (Fig. 2).

2.1.3. Topography

Oda Bultum District: Oda Bultum district is situated in the West Hararghe Zone. With an average altitude of 1770 m above sea level (m.a.s.l.), the district has an altitudinal range of 1040–2500 m. Regarding the district's total land area and terrain, 40 % is steep slope and 60 % is plain. Rainfall ranges from 900 to 1100 mm annually. 262,899 cattle, 96,220 goats, 23,234 sheep, 122,433 hens, 47,322 donkeys, 1873 horses, 1620 mules, and 19,324 camels make up the district's animal population. **Chiro District:** The elevation varies between 1501 and 2500 m above sea level, with 10 % weyna dega, 70 % dega, and 20 % kola. The average annual temperature is between 27.5 °C and 38.5 °C. On the other hand, the annual precipitation in highlands and lowlands varies from 600 to 1000 mm. The topography of the woreda is undulating, with steep characteristics, limited vegetation cover, and sparsely vegetated areas. The main problems to food security and sustainability are drought, water scarcity, soil erosion, flooding, lack of animal fodder, and lack of diversification in income.

2.2. Method of data collection

This study was carried out during the dry season (*known as Bega in local language),* while the crops has been irrigated. Ethiopian seasons has classified into three. The driest season is called *Bega* (October to January). Both primary and secondary data gathering methods were employed. Materials and instruments used were Auger, GPS (Global Positioning System), Seba hydrometer, current meter, partial fume, and measuring tape. Soil laboratory materials, core sampler, and weight balance were among the tools utilized.

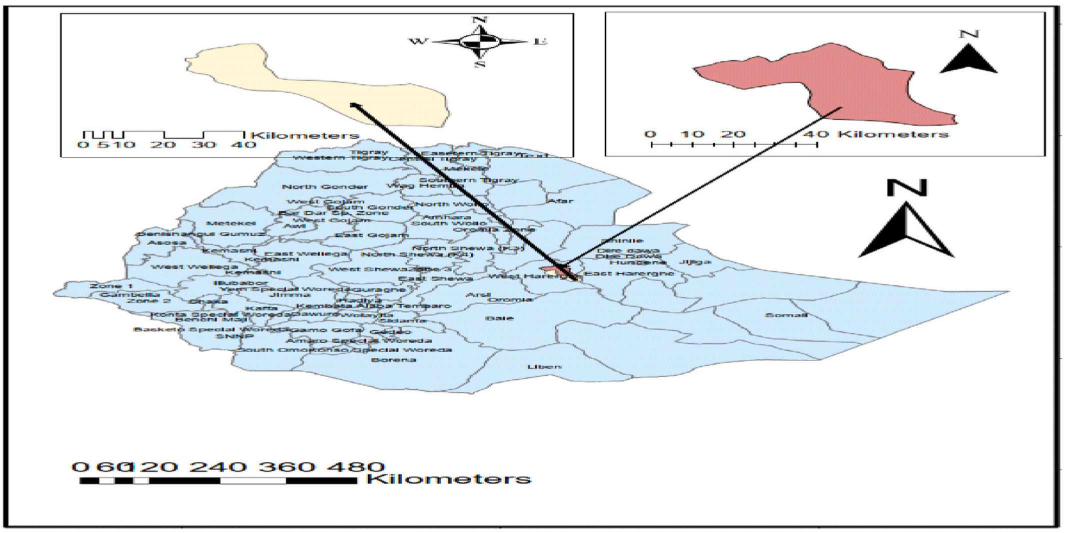

Fig. 1. Location of the Midagdu irrigation scheme.

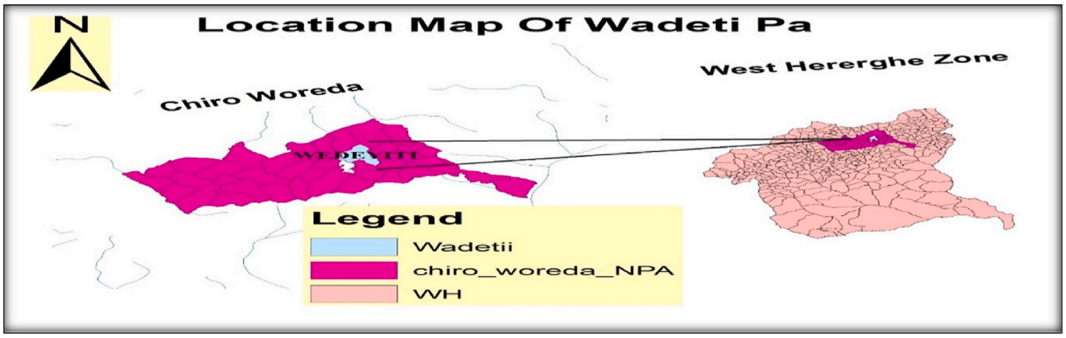

Fig. 2. Location of the Wadeti irrigation scheme.

2.2.1. *Primary data collection*

Both formal and informal survey methods have been employed for primary data collection. Canal water flow measurements to obtain discharge, the current price of irrigated crop production (sorghum, maize, Banana, papaya and khat) in kg or in quintal. Individual interviews from the market and frequent field observations to obtain overall information on the schemes and to cross-check the secondary data collected from the West Hararghe Agricultural and Natural Resource Office. For the purpose of flow measurement, the floating method was adopted. Canal flow measurements were taken upstream, middle stream and downstream for each months of the irrigation season (October–January).

2.2.2. *Secondary data collection*

2.2.2.1. Climate data. Climatic data such as rainfall (mm), temperature (^{o}C), humidity (%), wind speed (km/day) and sunshine hours (hour) for the research site were collected from the National meteorological Agency(NMA) of Ethiopia. CROPWAT model was used to determine crop water and irrigation water demand.

2.2.2.2. Agronomic data. Agronomic data such as crop type, planting date, harvesting date, productivity per hectare and production were collected from the West Hararghe Agricultural and Natural Resource Office.

2.2.2.3. Soil data. The soil types of the study area were collected from the design document of the schemes. Soil information such as infiltration rate, field capacity, and permanent wilting point, which is required for the CROPWAT 8 Model, was collected from Ref. [19] Training Manual-4 based on the soil types of the study area.

2.3. *Sampling technique*

Non-probability sampling (purposive sampling) techniques were used to determine Midagdu and wadeti irrigation schemes. Out of the total irrigation schemes found in seventeen districts in the West Hararghe Zone, Midagdu irrigation schemes were selected from Oda Bultum Woreda and Wadeti from Chiro Woreda irrigation schemes were purposively selected based on the availability of data and accessibility for transportation.

2.4. *Method of data analysis*

2.4.1. *The float method for flow measurement*

The scarcity of water resources brought on by climate change has made flow measurements more significant in recent decades [20]. According to Ref. [20] report, with an error of less than 2.5 percent, there was a good agreement between the integrating-float method findings and the results of velocities acquired using other measuring techniques. There are associated investment, operating, and facility maintenance costs for every unit of water that is admitted into the canal and transported to the field. So, reliable water measurement is the key to effective irrigation water use [21]. According to Ref. [22], the choice of a streamflow measurement technique may depend on the stream's volume, the method's accuracy, the terrain's accessibility, and the availability of both financial and material resources. Also indicate that due to its affordability and convenience of use, the float method is best in small streams on flat terrain. The topography of the command area of both irrigation scheme were flat and the flow in the canal were also small. So, based on the indicated criteria indicated by Ref. [22], the float method was selected and used for measuring flow in different locations of the irrigation canal.

According to Ref. [23], this method requires two types of information: the cross-sectional area of the water flowing in the irrigation canal and the speed at which the water flows. The floating bottle/material is timing its travel between two points at a known distance. The first step to consider is the cross-sectional area (csa) of the canal.

The part of the canal that is relatively straight and has a uniform cross section was selected. To determine the distance from the release point to the trajectory's end for the floating object, it is essential to ensure that the measuring location is consistently positioned downstream to avoid disrupting the water surface. The distance should be in meters. The cross-sectional area of the canal was measured by splitting it into several segments with at least 4 segments, as shown in Fig. 3. The cross-sectional area is calculated by using Equation (1) below.

$$A_n = L_n \times \frac{(d_{n-1} + d_n)}{2} \tag{1}$$

where, A_n is the cross-sectional area,

L is the length of segment

n, is the segment number, and d is the depth of the point.

The measurement position should always be downstream to avoid disturbing the water surface. When gauging the stream's depth, the measurement process should commence from the stream bed upwards to the water's surface. Following the completion of all necessary measurements, the subsequent step involves computing the area for each segment.

$$V_f = \frac{Distance}{Time}\left(\frac{meter}{Second}\right) \tag{2}$$

$$V_a = V_f \times c\left(\frac{m}{s}\right) \tag{3}$$

where v_f $= flow\ flocity, c$ $= correction\ factor,$

Finally, to determine a water flow by using

$$Q = V_a \times A\left(m^3 / s\right) \tag{4}$$

V_a = average velocity.

Q = discharge.

A = Area.

2.4.2. Water balance indicator

Reliable Water delivery performance could be assessed using Field application ratio (FAR), relative water supply (RWS), and relative irrigation supply (RIS) for effective irrigation management [18]. And also indicated RWS and RIS establish a relationship between supply and demand and provide information about the availability or scarcity of water as well as the degree to which supply and demand are balanced. Based on the collected data, the following three most common water balance indicators were used to assess the performance of the field application ratio (FAR), relative water supply (RWS) and relative irrigation supply (RIS) schemes, as indicated by Refs. [13,24] and as cited in Ref. [25]. The RWS indicator is a helpful tool for knowing how well irrigation systems operate as well as how the actions of the two main actors in the irrigation process—farmers and irrigation engineer's impact system performance [26]. The FAR. RWS and RIS were computed by using equations (5)–(7) respectively.

$$FAR = \frac{Volume\ of\ irrigation\ water\ needed}{Volume\ of\ irrigation\ water\ delivered} \tag{5}$$

$$RWS = \frac{Total\ water\ applied\ to\ the\ field}{Crop\ water\ demand} \tag{6}$$

$$RIS = \frac{Volume\ of\ irrigation\ water\ delivered}{Irrigation\ demand} \tag{7}$$

2.4.3. Comparative performance indicators

For the assessment of the selected irrigation schemes, four external indicators developed by the International Water Management Institute (IWMI) were used for the comparative performance analysis of the selected small-scale irrigation schemes (see Equations (8)–

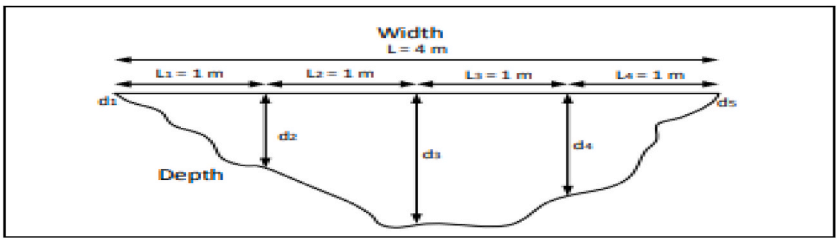

Fig. 3. Divided canal segments [23].

(10)). These four indicators relate the output (crop production) to unit land and water. These indicators allow the comparison of the performance of fundamentally different systems by standardizing the gross value of agricultural production. In areas facing water scarcity, the importance of the standardized gross value of production (SGVP) per volume of water utilized is particularly emphasized. Conversely, in regions where land availability is the limiting factor, the output per unit of controlled or cultivated land has greater significance.

$$Output\ per\ cropped\ area\frac{birr}{ha}=\frac{SGVP}{Irrigated\ cropped\ area} \tag{8}$$

$$Output\ per\ unit\ command\frac{birr}{ha}=\frac{SGVP}{Command\ area} \tag{9}$$

$$Out\ per\ unit\ irrigation\ supply\frac{birr}{m3}=\frac{SGVP}{Delivered\ irrigation\ supply} \tag{10}$$

$$Output\ per\ unit\ water\ consumed\frac{birr}{m3}=\frac{SGVP}{Volume\ of\ water\ consumed\ by\ ET} \tag{11}$$

2.4.3.1. Crop water requirement and irrigation water requirement analysis. Using the CROPWAT 8 model, the crop and irrigation water demand of the major crops grown in the small-scale irrigation schemes of Midhagdu and Wadeti were determined. And by using Equation— was used to determine the net crop and irrigation water requirements for the two seasons of the research year.

$$\mathrm{NCWR}=\boldsymbol{CWR_{Onion}}\times\boldsymbol{Area_{Onion}}/\boldsymbol{Area_{total}}+\boldsymbol{CWR_{Beetroot}}\times\boldsymbol{Area_{Beetroot}}/\boldsymbol{Area_{total}}+\boldsymbol{etc}—$$

$$NCWR=CWR_{crop-1}\times Area_{crop-1}/Area_{total}+CWR_{crop-2}\times Area_{crop-2}/Area_{total}\pm-----CWR_{crop-n}\times Area_{crop-n}/Area_{total} \tag{12}$$

$$NIWR=IWR_{crop-1}\times Area_{crop-1}/Area_{total}+IWR_{crop-2}\times Area_{crop-2}/Area_{total}\pm-----IWR_{crop-n}\times Area_{crop-n}/Area_{total} \tag{13}$$

Where.

NCWR = Net crop water requirement.

CWR = Crop water requirement.

IWR = Irrigation Water Requirement.

Crop-1 up to n = represents the types of crop grown in respective irrigation schemes of the study area.

2.4.4. Hydraulic performance indicator

Of the total hydraulic performance indicators, the three most common hydraulic performance indicators Delivery Performance Ratio (DPR), Conveyance Efficiency (Ec) and Water Delivery Capacity (WDC) were used due to limited data available to assess the hydraulic performance of irrigation canals. The delivery performance ratio is the simplest, yet probably the most important hydraulic performance indicator [27], as cited in Ref. [28]. The delivery performance ratio in irrigation systems indicates problems related to sediment deposits, scour, vegetation, etc., of some water conveyance structures. The DPR is the ratio of the amount of actual water delivered to the intended amount of water to be delivered or the gross irrigation water requirement.

$$DPR=\frac{Actualy\ delivered\ water\ to\ field(m^3)}{Amount\ of\ water\ intended\ to\ be\ delivered(m^3)} \tag{14}$$

When the delivery performance ratio approaches one, the irrigation canal maintains its operational conditions as designed [13] as cited in Ref. [28].

The water delivery capacity of the scheme indicates whether the peak crop water demand is fulfilled by the irrigation canal.

$$WDC=\frac{Actual\ canal\ capacity\ at\ scheme\ head}{Peak\ crop\ water\ requirement} \tag{15}$$

Conveyance efficiency (Ec*):* This is the total amount of water flowing into a canal system at a point divided by the amount of water reaching a certain distance downstream of the previous point.

$$E_c=\frac{Discharge\ measured\ at\ scheme\ head}{Measured\ discharge\ at\ tail\ of\ the\ scheme}\times 100 \tag{16}$$

3. Results and discussion

3.1. Irrigation water supply of Midagdu and Wadeti irrigation schemes

In Hararghe and other areas, irrigation water distribution is managed by the beneficiaries themselves. They appoint a local leader, known as Abba melka, to ensure fair and equitable water allocation to each user [16]. Beneficiary farmers manage irrigation practices based on informal agreements (by laws), but the Peasant Association administration plays a more active role in decision-making. The bylaws, agreed upon by the beneficiaries, establish a framework for individual rights and responsibilities, penalties for rule violations, and procedures for using irrigation water. Hence, every user or beneficiary has the right to use irrigation water as per the sequence of requests made to Abba Melka and his permission. The irrigation hour allocation depends on the size and requirements of the farm. On average, the duration of water application may be 10 h/day.

The canal flow measurements for this study were taken once per month during the irrigation season by using the floating method for the year of study. The canal flow was measured upstream or at the diversion outlet, midstream and downstream of the canal, and finally, the average was taken as the actual amount of water delivered to the whole cropped area of the scheme.

3.2. Midagdu irrigation scheme

3.2.1. Crop water demand (CWD) and irrigation water demand (IWD

To compute the comparative and internal indicators for the analysis of the data to determine the performance assessment of the scheme, the annual crop water demand and annual irrigation water demand of the major crops grown in the schemes during the irrigation season are the main parameters needed.

To determine the crop water Demand and irrigation water Demand of the irrigation scheme, the area coverage of the crop, planting and harvesting dates, and total growing days of each crop were collected. There are different major crop types cultivated under the Midagdu irrigation scheme. These crops have different crop water demands. The crop water demand of each crop was calculated by using the CROPWAT 8 model for the irrigation season (October–January) of the study period (2019). Fig. 4 and Table 1 shows the average monthly effective rainfall and ETO of the Midagdu irrigation scheme. The results indicated that, the months of January, November, and December reveal the lowest evapotranspiration (ETo) under the Midagdu irrigation scheme, whereas the months of May, June, and July show comparatively high values, more than 3.7 mm per day. The highest (ETo) implies that there is high temperature and sunshine hours in May, June and July months in the Midagdu irrigation scheme, and the reverse is true for the lowest values (Table 1). These periods coincide with the dry and rainy seasons. This gives the observed differences in meteorological parameters within one year. In the dry season, the resulting low relative humidity combined with high temperatures led to increased (ETo) during this period of a year. Conversely, the low ETo values in the rainy season can be attributed to the high frequency of precipitation in combination with high relative humidity and relatively low temperatures. The results of this finding agree with [29] showing that ETo was lowest during the wet season peak and highest during the dry season peak.

The seasonal crop water demand and irrigation water demand of the Midagdu irrigation schemes was summarized in Table 2. *As observed from Fig. 5 and Table 2 irrigation water demand were less than the crop water demand throughout the irrigation season. This indicated that the excess water were supplied from rainfall. The IWD is somewhat lower than the CWD when agriculture completely depends on irrigation and rainfall as rainfall supplies the excess water* [30]. The crop water demand and irrigation water demand of Cabbage, Tomato and Maize were 173.3, 130.4, 75.6 and 69.5, 56.9, 33.5 respectively. This value were small in relative to the other crops due to their short growing period and their difference were due to different development stage time. The higher crop water demand of the Onion was observed next to Khat throughout the irrigation season. This was due to its higher water requirement at initial, transplanting and bulb formation stage relative the other short growing crop [31].

3.3. Wadeti irrigation scheme

3.3.1. Crop water demand (CWD) and irrigation water demand (IWD

Table 3 and Fig. 6 summarizes the total rainfall, effective rainfall, and reference evapotranspiration at the Wadeti irrigation scheme. The result shows that, Wadeti irrigation scheme experienced its highest evapotranspiration rates in June, reaching 5.85 mm per day (Table 3). This high evapotranspiration, driven by elevated temperatures and sunshine hours, poses a challenge to agricultural production of the local area. To address this, improving irrigation water use efficiency and implementing climate adaptation strategies, such as soil and water conservation techniques and drought-tolerant crop varieties [32,33] are crucial for ensuring sustainable agriculture.

The annual crop water demand and irrigation water demand of the major crops grown in the scheme during the irrigation season are the main parameters needed. The same procedure as that used for Midagdu was used for this study to determine the crop water and irrigation water demand. The total CWR and IWR for major cultivated crops in Wadeti irrigation scheme, were analyzed using the CROPWAT 8 model. As observed from Fig. 7 and Table 4, the total CWR for the entire growing season for sorghum, maize, banana, papaya, guava, and khat was found to be 404.9, 453.6, 1257, 1743.7, and 1169.4 mm/season, respectively. However, the IWR for sorghum, maize, banana, papaya, guava, and khat for the entire growing season was found to be 266.4, 315.1, 440.6, 771.3, 328.2, and

Table 1
Average monthly effective rainfall and ETO of the Midagdu irrigation scheme.

Months of the year	Jan	Feb	Mar	April	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall(mm)	7.4	15.5	47.3	93.4	75.9	46.3	96	116.7	104	44	15.7	11
ETO(mm/day)	0.77	1.49	2.43	3.18	3.71	3.91	3.77	3.32	2.64	1.7	0.91	0.52
Effective RF(mm)	7.3	15.1	43.7	79.4	66.7	42.9	81.3	94.9	86.6	41	15.3	10.8

Table 2
The seasonal CWD and IWD of the Midagdu irrigation scheme.

Crop types	Area(ha)	CWD(mm/season)	IWD(mm/season)
Onion	16	243.4	38.4
Cabbage	26	173.3	69.5
Tomato	10	130.4	56.9
Maize	161	75.6	33.5
Khat	187	247.1	51.9
Total	400		

Note: CWR; Crop water Demand, IWD: Irrigation Water Demand.

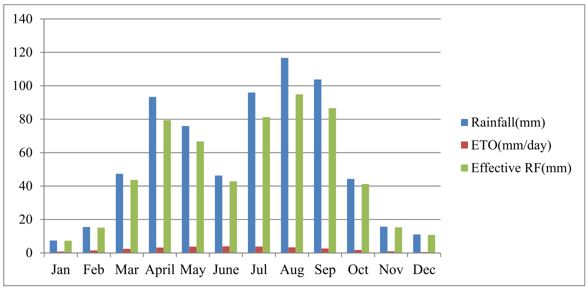

Fig. 4. Average effective rainfall and ETO of the Midagdu scheme.

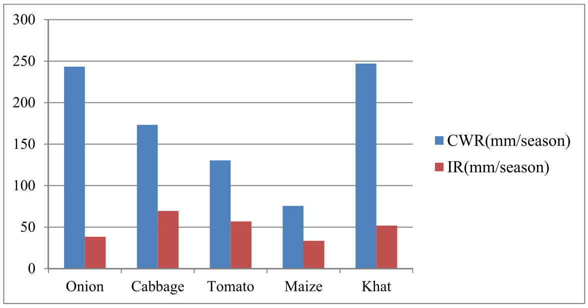

Fig. 5. Irrigation water and crop water demand of the Midagdu irrigation scheme.

Table 3
Average monthly effective rainfall and ETO of the Wadeti irrigation scheme.

Months	Jan	Feb	Mar	April	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall(mm)	28	29	79	199	105	129	237	165	184	69	51	19
ETO(mm/day)	4.15	4.37	4.81	5.02	5.04	5.85	4.94	4.49	4.95	4.91	4.49	4.16
Effective RF(mm)	26.7	27.7	69	135.6	87.4	102.4	147.1	121.4	130	61.4	46.8	18.4

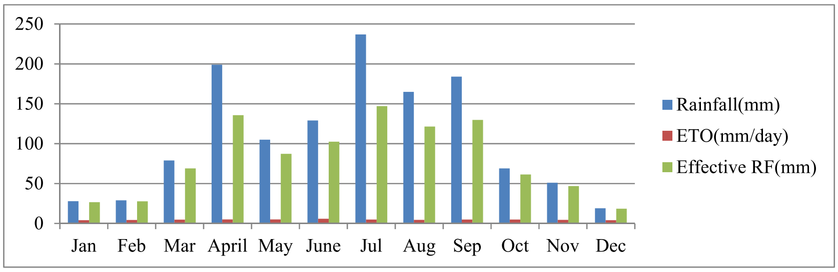

Fig. 6. Average monthly effective rainfall and ETO of the Wadeti irrigation scheme.

470.8 mm/season, respectively. It was found that crops with a longer growing period, such as sorghum, banana, papaya, guava, and khat, which occupy almost all the months of the year, consume abundant water. Therefore, this study result shows that, the crop with the most water required for the Wadeti irrigation scheme is papaya (1743.7 mm/season), and the lowest amount of water is required for sorghum (404.9 mm/season), as shown in Table 4 below. Moreover, those crops with shorter growth seasons, on the other hand, required less irrigation water. The results of a study conducted by Ref. [34] to determine the crop water requirements for banana in Hyderabad district of Pakistan is comparable to those for papaya, guava, banana, and khat in the current study. The comparability of the outcomes supports our conclusion.

3.4. Water balance indicators

3.4.1. Relative water supply (RWS) of Midagdu and Wadeti irrigation schemes

The relative water supply is one of the main indicator used to assess whether the water supply is suitable for agricultural production [18]. The ratio of the total amount of water supplied by irrigation and rainfall to the total amount of evapotranspiration required plus seepage and percolation losses is known as relative water supply [35]. Relative water supply of Midagdu and Wadeti irrigation schemes were indicated in Table 5 (see Fig. 8).

The finding of this study reveals that, the relative water supply of Midagdu and Wadeti irrigation schemes were 0.90 and 0.48, respectively. According to Ref. [36], as cited in Ref. [16], RWS values between 0.9 and 1.2 are adequate, 1.2–1.8 are excessive, and 1.8–2.5 are very excessive. Therefore, the amount of water supply in the Midagdu irrigation scheme was adequate to meet the crop water demand. Similar findings by Refs. [37–40], the RWS indicator attains greater average values, typically above 0.80, indicating that the requirement for evaporation can be satisfied over the entire cycle of crop development. However, the amount of water supply in the Wadeti irrigation scheme was inadequate to meet the crop water requirement. This shows that there is a miss much between the irrigation supply and crop water demand in scheme. When the crop water requirement is not fulfilled by the irrigation water supply, a condition of underirrigation occurs in irrigation scheme. Similar finding obtained by Refs. [18,41], were indicated that most of the farmers irrigated below the crop water requirements, showing RWS values less than the critical value, and there was great variability among irrigation farm.

3.4.2. Relative irrigation supply (RIS) of Midagdu and Wadeti irrigation scheme

The relative irrigation supply, or the ratio of water delivered to crop net irrigation demand, is one of the main performance indicator [42]. The irrigation water supply during the months of the irrigation season (October–January) under the Midagdu and Wadeti irrigation schemes are indicated in Table 6 and Fig. 9.

The result shows that, the Midagdu irrigation scheme had a relative water supply of 1.3, indicating an excess of irrigation water, while the Wadeti scheme had a lower supply of 0.35. This excess water in Midagdu has likely led to waterlogging and increased salinity, negatively impacting agricultural productivity. The high relative irrigation supply (RIS) value observed in the Midagdu scheme (1.3) aligns with studies conducted in other parts of Ethiopia [43–45], which reported RIS values of 1.27, 1.31, and 1.12, indicating excess irrigation in those areas. In contrast, the Wadeti scheme's lower RIS value of 0.35, supported by studies [18,46–48], suggests irrigation deficiencies as the mean RIS value is 0.60.

3.4.3. Field application ratio (FAR) indicator

This indicator reflects the water balance, and its value fluctuates based on the actual volume of water delivered to the irrigated field. It is calculated as the ratio between the difference in potential evapotranspiration and effective rainfall or irrigation water demand (measured in depth) and the volume of water delivered to the field. The target value for the field application ratio varies depending on the irrigation technology employed, the prevailing climate, and the type of crop being cultivated – whether dry-foot crops or ponded rice, as cited in Ref. [25]. By using equation (5), the field application ratios of the Midagdu and Wadeti irrigation schemes were estimated and are shown in Table 7 below.

The Midagdu irrigation scheme had a field application ratio (FAR) of 0.75, indicating excess water was delivered to the irrigated field. However, the Wadeti field application ratio (FAR) of 2.83 suggests significant water stress, shows more water needs to be

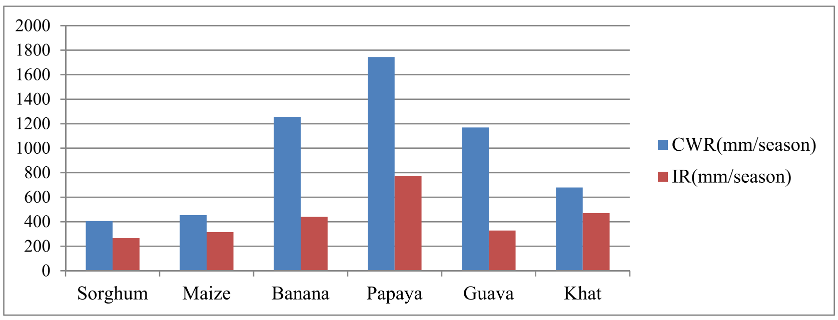

Fig. 7. Average monthly CWD and IWD of the Wadeti irrigation scheme.

Table 4
Average CWD and IWD of major cultivated crops in the Wadeti irrigation scheme in the study period of 2019.

Major crop types	Area(ha)	CWD(mm/season)	IWD(mm/season)
Sorghum	35	404.9	266.4
Maize	27	453.6	315.1
Banana	10	1257	440.6
Papaya	10	1743.7	771.3
Guava	6	1169.4	328.2
Khat	46	679.6	470.8
Total	134	5846.9	670.2

Table 5
The calculated relative water supply (RWS) of the Midagdu and Wadeti schemes.

Schemes	Irrigation water supply(mm)	CWR(mm)	IWR(mm)	Total Rf(mm)	RWS
Midagdu	59.94	170.21	45.22	93.6	0.90
Wadeti	141.045	706.74	399.8	196	0.48

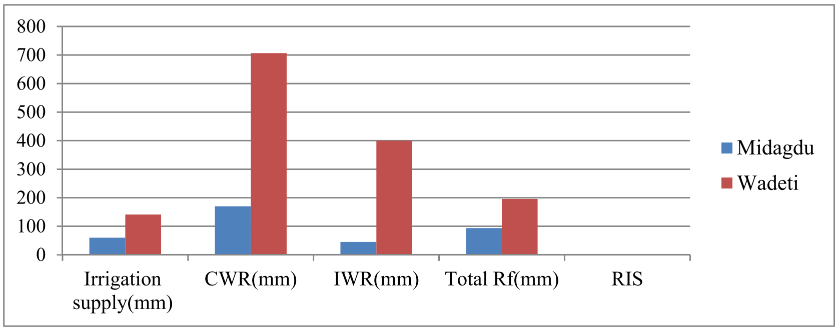

Fig. 8. Midagdu and Wadeti relative water supply values.

Table 6
The estimated values of the RIS of the Midagdu and Wadeti irrigation schemes.

Scheme	Irrigation supply(mm)	CWR(mm)	IWR(mm)	Tot.Rf(mm)	RIS
Midagdu	59.94	170.21	45.22	93.6	1.3
Wadeti	141.045	706.74	399.8	196	0.35

Table 7
The field application ratios of the Midagdu and Wadeti irrigation schemes.

Irrigation Schemes	Irrigation supply(m3)	IWR(m3)	FAR
Midagdu	239,760	180880	0.75
Wadeti	189,000	535732	2.83

IWR: Irrigation Water Requirement.

supplied from the canal to meet crop needs. As cited in Ref. [25], an FAR greater than one indicates water stress, suggesting the need for increased water allocation."

3.5. Comparative indicator

The comparative performance of the schemes was evaluated using selected comparative indicators, namely, agricultural and water use performance, as indicated by international water management institutes [9].

To compare the two irrigation schemes in terms of their output per area and water supply, four comparative indicators were used for this study. Those indicators are output per cropped area, output per unit command area, output per unit irrigation supply and output per unit water consumed. To determine the comparative performance indicators, crop water and irrigation water requirements per season were calculated by using the CROPWAT 8 model. By using equations (8) and (9), the outputs per command area and per

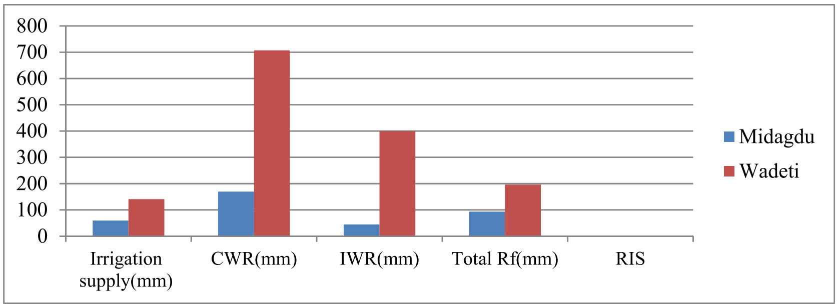

Fig. 9. The Midagdu and Wadeti relative irrigation supply values.

Table 8
Irrigated crop production of Wadeti in 2018 and 2019 of study period.

Crop types	2018				2019			
	Area (ha/yr)	Avg Yield (qt/ha/yr)	Unit. Price(birr/qt/season)	Total income (birr)	Area	Yield (kun/ha/yr	Unit price (birr/kg)	Total income
Sorghum	33.6	70	1500	105000	35	73	1500	105000
Maize	26.9	76	700	53200	27	80	700	53200
Banana	10.1	42	2000	84000	10	46	2000	84000
Papaya	10	22	2500	55000	10	29	2500	55000
Guava	6.7	11.5	1200	13800	6	13	1200	13800
Khat	40.4	526	190	99940	46	6400	187.5	1200000
Total	**128**			**410,940**	**134**			**1,511,000**

cropped area of the Midagdu and Wadeti irrigation schemes of the 2018 and 2019 reference period were calculated, and the results are shown in Table 8.

Fig. 10 shows the comparative performance indicators of the Midagdu and Wadeti irrigation schemes. Based on the results, the Midagdu irrigation scheme had a value of 2906.12 for output per cropped area and output per command area, suggesting an equal size for both. The Wadeti scheme, however, had a higher output per cropped area and output per command area of 3210.5, indicating better land productivity in 2018 (Table 9) (See Fig. 10 and Table 10).

Following equations (12) and (13), the net crop water requirements and irrigation water requirements of the cropping seasons of the Midagdu and Wadeti irrigation schemes were analyzed. To change the net depth of crop water requirements and irrigation water requirements by volume, it need to be multiplied by the irrigated area of the season. The net crop water and irrigation water requirements of the Midagdu and Wadeti irrigation schemes are summarized in Table 11. The result revealed that, the total crop water demand and irrigation water demand of the Midagdu irrigation scheme were 170.2 mm/season and 45.2 mm/season, respectively. Whereas, the crop water and irrigation water demands of the Wadeti irrigation scheme are 706.7 mm/season and 399.83 mm/season, respectively.

As shown in Table 12 and Fig. 11, Wadeti has higher output per cropped area and output per command area. This is due to the high perennial cropping intensity and type of crop grown in scheme. A higher output per irrigation supply and output per water consumed by the Midagdu irrigation scheme indicate that the Midagdu scheme is better at effectively utilizing water. Accordingly, the Wadeti irrigation scheme is better for land productivity, and the Midagdu scheme is better for water productivity.

3.6. Hydraulic performance indicator

There are different irrigation water delivery performance indicators [46]. However, due to limited data, only three indicators were used for this study: water delivery capacity (WDC), conveyance efficiency and delivery performance ratio (DPR). The delivery performance ratio, or the ratio of actual delivered discharge to intended discharge, is the most significant and straightforward performance indicator in the irrigation field [49]. As it seen from Table 13 and Fig. 12, the total monthly average irrigation water demand or gross irrigation demand in the cumecs of the Midagdu irrigation scheme was 0.048. Whereas, the monthly average total irrigation water demand or gross irrigation demand of the Wadeti irrigation scheme was 0.051 m^3/s. The actually delivered water (Qd) in the irrigation canals of the Midagdu and Wadeti irrigation schemes were measured at the head, middle and tail reaches of the schemes.

According to Ref. [16], the water delivery ratio compares the actual amount of water delivered to the irrigation scheme to the total amount needed. However, conveyance efficiency focuses on the canal system's ability to transport water, measuring the water loss as it travels from one point to another downstream.

The peak irrigation requirements of the Wadeti and Midagdu irrigation schemes are calculated from the cropping pattern, planting date of each crop and cropping intensity of each crop in the scheme by using the FAO CROPWAT 8 model, and the results are presented in Table 14. The results shows that the peak irrigation water requirement of the Wadeti irrigation scheme occurred on Feb, at 0.41 l/s/

Table 9
The calculated values of the comparative performance indicators of the Midagdu and Wadeti irrigation schemes.

Irrigation Schemes	Output per cropped area	Output per unit command area
Midagdu	2906.12	2906.12
Wadeti	3210.50	3210.50

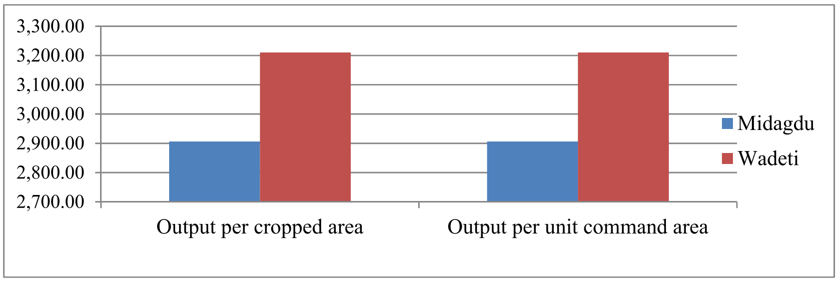

Fig. 10. The comparative performance indicator values in the 2018.

Table 10
Irrigated crops production of the Midagdu irrigation scheme in 2018 and 2019.

Types of Crop	2018				2019			
	Area (ha/yr)	Avg Yield (qt/ha/yr)	Unit. Price (birr/kun/yr)	Total income (birr)	Area (ha)	Yield (ku/ha/yr)	Unit.price (birr/kg)	Total income
Cabbage	25	260	900	234000	26	285	1200	342000
Maize	150	115	750	86250	161	123	1200	147600
Onion	20	292	2000	584000	16	305	2500	762500
Tomato	6	129	1100	141900	10	147	3000	441000
Khat	175	245	190	46550	187	256	47,872	1305600
Total	**376**			**1,092,700**	**400**			**2,998,700**

Table 11
The net CWD and IWD of the Midagdu and Wadeti irrigation schemes.

Irrigation Schemes	Area(ha)	NCWR (mm/season)	NCWR (mm3/season)	NIWR (mm/season)	NIWR (mm3/season
Midagdu	400	170.2	680800	45.2	180800
Wadeti	134	706.7	946978	399.83	535772.80

NCWR; Net Crop Water Demand, NIWR; Net Irrigation Water Requirement.

Table 12
The values of the comparative performance indicators of the Midagdu and Wadeti irrigation schemes.

Irrigation Schemes	Output per cropped area	Output per unit command area	Output per unit irrigation water supply	Output per unit water consumed
Midagdu	7496.75	7496.75	12.5	4.4
Wadeti	11,276.12	11,276.12	8.7	1.6

Table 13
The values of the delivered and required discharge of the Midagdu and Wadeti irrigation schemes.

Irrigation Schemes	Delivered Discharge (QD)	Required Discharge QR	DPR
Midagdu	0.039	0.048	0.8
Wadeti	0.02	0.051	0.4

DPR; Delivery Performance Ratio.

ha. The average water application time of the Wadeti irrigation scheme was 10 h/day.

Table 15 shows that the peak irrigation water requirement during the irrigation season (Oct to Jan) under the Midagdu irrigation scheme occurred in Jan and Feb, at 0.1 l/s/ha.

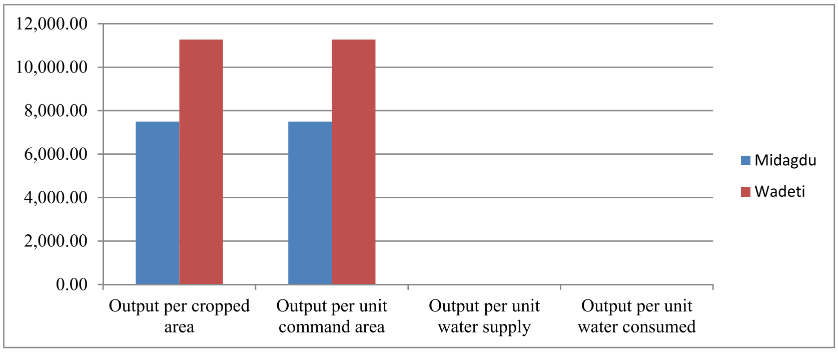

Fig. 11. Comparative performance indicators of the Midagdu and Wadeti irrigation schemes.

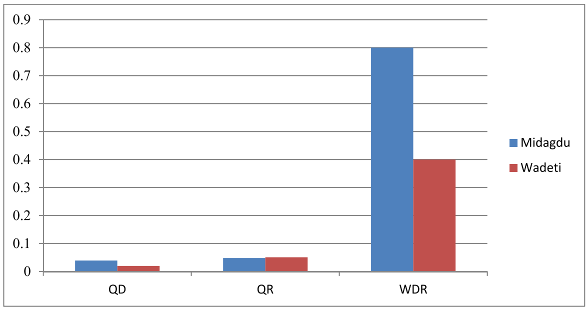

Fig. 12. The values of the delivered and required discharge of the Wadeti and Midagdu irrigation schemes.

Table 14
Peak irrigation water requirement values of the Wadeti irrigation scheme 2019.

Months of the year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Net scheme. irr.req (l/s/ha)	0.34	0.41	0.26	0.03	0.03	0	0.01	0.02	0.02	0.1	0.03	0.24

By using equation (9), the water delivery capacities of the Midagdu and Wadeti irrigation schemes are summarized in Table 16 below (see Fig. 13).

According to Ref. [50], a DPR value above one (>1) indicates that the outlets deliver more water than the required discharge, and reverse conditions occur when DPR values are less than one (<1). Fig. 14 shows that the delivery performance ratios of the Midagdu and Wadeti irrigation schemes were 0.8 and 0.4, respectively. This imply that there was water stress in Wadeti irrigation schemes and that the irrigation canal did not deliver the required discharge. However, in Midagdu irrigation scheme, the delivered water was almost balanced with required discharge water.

By using equation (16), the conveyance efficiency of the two schemes were calculated and are shown in Table 17. The result of the analysis show that, the conveyance efficiency of the Midagdu irrigation schemes was 75 %, implying that three-quarters of the water entering the canal system reaches the fields. This suggests the canal infrastructure is generally well-maintained, and there aren't major leakages or seepage issues. High value of water conveyance efficiency means more water reaches the fields, leading to improved water availability for crops, potentially increasing yields and agricultural production. Similar study conducted by Ref. [18] in Tanzania, the conveyance efficiency for the main canals and the field canals was 84 and 65 % during the dry season and 85 and 74 % during the wet season, respectively. The study examined the effectiveness of both improved and unimproved small-scale irrigation schemes.

Moreover, this study suggested that, the Wadeti irrigation scheme's conveyance efficiency is only 42 %, indicating uneven water distribution. This is primarily caused by water leakage and sedimentation in the canals, particularly in the longer, unlined sections. The irrigation scheme's low efficiency is due to silting by weeds and soil, narrow canals, and canal breaks, contributing to a large amount of water loss. As a result, it could influence local agricultural farms situated distant from water sources, where the main canals are lengthy

Table 15
The peak irrigation water requirements of the Midagdu irrigation scheme in the 2019.

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Net scheme.irr.req (l/s/ha)-2019	0.07	0.1	0.1	0.03	0	0	0	0	0	0	0	0.01

Table 16
The values of the water delivery capacity of the Midagdu and Wadeti irrigation schemes.

water delivery capacity (WDC)	Midagdu	Wadeti
actual delivered discharge at head (m3/s)	0.044	0.024
Peak irrigation. Requirement (m3/s)	0.0984	0.219
water delivery capacity (WDC)	0.45	0.11

Table 17
The values of the hydraulic performance indicators of the two irrigation schemes.

Irrigation Schemes	Ec(%)	WDC	DPR
Midagdu	75	0.45	0.8
Wadeti	42	0.11	0.4

Note: *Ec; conveyance efficiencies, WDC: Water delivery capacity, DPR; Delivery Performance Ratio.*

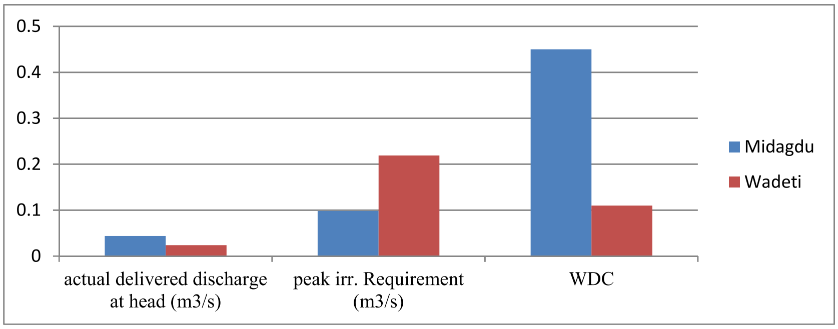

Fig. 13. The water delivery capacity of the Midagdu and Wadeti irrigation schemes.

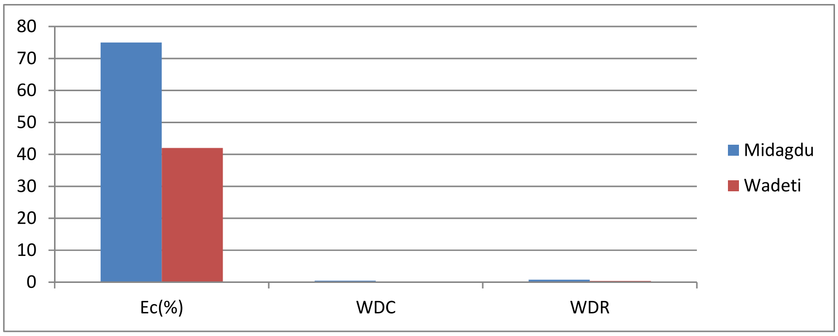

Fig. 14. The values of the hydraulic performance indicators under the Midagdu and Wadeti irrigation schemes.

and unlined, irrigation water losses in the conveyance system can account for a large portion of total water losses. The Bilate and Furfuro irrigation schemes in the Silti Zone, southern Ethiopia, were the subject of a similar study by Ref. [48] indicating the average conveyance efficiency was 53 % and concluded that the scheme was operating inefficiently and inadequately.

Table (17) shows that the water delivery capacities of the Midagdu and Wadeti irrigation schemes were 0.45 and 0.11, respectively. A lower value of this indicator in both schemes shows that canal capacity was more constrained to meet the maximum crop water demands. According to Ref. [9], if the value of WDC is less <1, there is a water constraint in the scheme.

4. Conclusion and recommendations

4.1. Conclusion

The evaluations of the two irrigation schemes were carried-out by using internal (hydraulic and water balance) indicators and external (agricultural) indicators for the overall performance assessment of the Midagdu and Wadeti irrigation schemes in west hararghe zone. The study revealed that, the overall relative water supplies of the Midagdu and Wadeti irrigation schemes were 0.90

and 0.48, respectively. Accordingly, the amount of water applied in the Midagdu irrigation scheme was adequate to meet the crop water demand, whereas the amount of water applied in the Wadeti irrigation scheme was inadequate to meet the crop water requirement. When the crop water requirement is not fulfilled by the irrigation water supply, a condition of underirrigation occurs with the irrigation scheme.

An RIS greater than one in the Midagdu irrigation scheme indicates that overirrigation occurred in the Midagdu irrigation scheme, which indicates that excess irrigation water was supplied. The relative irrigation supply is less than that in the Wadeti irrigation scheme, which shows that a condition of underirrigation occurs. This also indicates that less or less irrigation water was supplied to the irrigated field. The output per cropped area and the output per command area of the Midagdu and Wadeti irrigations are the same since the irrigated area and command area are equal. However, as observed from the above figure, the Wadeti irrigation scheme had better land productivity in the 2018.

Wadeti has a greater output per cropped area and output per command area. The main reasons might be due to the high perennial cropping intensity and type of crop grown in scheme. A higher output per irrigation supply and output per water consumed by the Midagdu irrigation scheme indicate that the Midagdu scheme is better at effectively utilizing water. Accordingly, the Wadeti irrigation scheme is better for land productivity, and the Midagdu scheme is better for water productivity. The delivery performance ratios of the Midagdu and Wadeti irrigation schemes were 0.8 and 0.4 respectively. This indicates that there was water stress in both irrigation schemes and that the irrigation canal did not deliver the required discharge. This indicates that there is no equitable distribution of water among the water users at the head and tail reaches for both the Midagdu and Wadeti irrigation schemes during the irrigation season and indicates that there is a problem of water leakage and sedimentation of soil in the irrigation canal. Comparatively, the conveyance efficiency of the Wadeti irrigation scheme was very small, at less than 50 %, which shows that there is high canal leakage due to canal breakage in the middle reach of the scheme. The water delivery capacities of the Midagdu and Wadeti irrigation schemes were 0.45 and 0.11, respectively. A lower value of this indicator in both schemes indicates that canal capacity was more constrained to meet the maximum crop water demands.

4.2. Recommendations

- ✓ Maintaining the existing irrigation canal is very important for reducing the conveyance loss rather than developing only a new irrigation scheme.
- ✓ Training farmers on irrigation schedules based on crop water demand is very important for reducing unequal water distributions and conflicts among water users at the head, middle and tail reaches for better water application efficiency.
- ✓ The water user association should be strengthened to improve irrigation water management.

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Data availability

Data will be available based on request from corresponding author.

Ethical issues

The Review Board at Oda Bultum University had provided all ethical approval before the research was carried out. The authors confirm that informed consent was obtained from all participants. Keenly aware of ethical issue, the authors adhered to key principles of research ethics including the purpose of the research to participants, seeking and obtaining informed consent, ensuring voluntary participation and confidentiality of participants. The participants were also informed about the anonymity of the data collected and these data would be used for scientific research only.

CRediT authorship contribution statement

Nade Nuru: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Ahmednasir Amin:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abdulaziz Husen:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Ahmed Jibril Usmail:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] M. Tebebal, M. Ayana, Hydraulic Performance Evaluation of Hare Community Managed Irrigation Scheme, Southern, Ethiopia, 2015.
[2] Z. Bekele, K. Tilahun, On-farm performance evaluation of improved traditional small-scale irrigation practices: a case study from Dire Dawa area, Ethiopia, Irrigation Drainage System 20 (2006) 83–98.
[3] Legesse Tamirayehu, Tadesse Amare, Evaluation of water delivery performance and conveyance efficiency in gatto small-scale irrigation scheme, southern, Ethiopia, J. Water Resour. Ocean Sci. 39 (2021).
[4] Florian Pius Makaka, Performance Evaluation of Dakawa Irrigation Scheme. Tanzania: Sokoine, 2020.
[5] M. Şener, A.N. Yüksel, F. Konukcu, Evaluation of hayrabolu irrigation scheme in Turkey, J. Tekirdag Agric. Fac. (2007) 43–44.
[6] I. Hussain, Direct and indirect benefits and potential disbenefits of irrigation: evidence and lessons, J. Int. Comm. Irrigat. Drainage 56 (2-3) (2007) 179–194.
[7] P. McCornick, Synthesis of research issues and capacity building in water and land resources management in Ethiopia, Integrated water and land management research and capacity building priorities for Ethiopia 204 (2003).
[8] A.J. Clemmens, D.J. Moldens, Water uses and productivity of irrigation systems. Water productivity: science and practice, Irrigat. Sci. 2007 (25) (2007) 247–261, https://doi.org/10.1007/s00271-007-0067-y.
[9] D.J. Molden, R. Sakthivadivel, C.J. Perry, C. De Fraiture, Indicators for comparing performance of irrigated agricultural systems 20 (1998). Iwmi.
[10] W.H. Kloezen, Water markets between Mexican water user associations, Water Pol. 1 (4) (1998) 437–455.
[11] M.W. Burton, S.L. Small, S.E. Blumstein, The role of segmentation in phonological processing: an fMRI investigation, J. Cognit. Neurosci. 12 (4) (2000) 679–690.
[12] I.J. Lorite, L. Mateos, E. Fereres, Evaluating irrigation performance in a Mediterranean environment: II. Variability among crops and farmers, Irrigat. Sci. 23 (2004) 85–92.
[13] M.G. Bos, M.A. Burton, D.J. Molden, Irrigation and Drainage Performance Assessment: Practical Guidelines (Pp. Viii+-158), 2005.
[14] F.H. Koppens, C. Buizert, K.J. Tielrooij, I.T. Vink, K.C. Nowack, T. Meunier, L.M.K. Vandersypen, Driven coherent oscillations of a single electron spin in a quantum dot, Nature 442 (7104) (2006) 766–771.
[15] West Hararghe Irrigation Development Authority Office (WHIDAO), Design Document of the Midagdu and Wadeti Irrigation Schemes (Unpublished), 2010.
[16] S.B. Awulachew, M. Ayana, Performance of irrigation: an assessment at different scales in Ethiopia, Exp. Agric. 47 (S1) (2011) 57–69.
[17] Tamiru Haile Alemseged, Alemayehu Mussie, Rientjes Tom, Nakawuka Prossie, Evaluating irrigation scheduling and application efficiency: baseline to revitalize Meki-Ziway irrigation scheme, Ethiopia, SN Appl. Sci. 2 (2020) 1710, https://doi.org/10.1007/s42452-020-03226-8.
[18] M.F. Moges, Indicators for evaluating the performance of small scale irrigationschemes in bahir dar, Northern Ethiopia, Journal of Agricultural Science and Botany (2022), https://doi.org/10.35841/2591-7897-6.8.136.
[19] FAO, Guidelines for Designing and Evaluating Surface Irrigation Systems, 1989. Irrigation and drainage paper 45. Rome.
[20] B.S. Abed, Flow measurements in open channels using integrating-floats, J. Eng. (2021) 130–144, https://doi.org/10.31026/j.eng.2021.1.09.
[21] U.C. Chaube, A. Pandey, V.P. Singh, Measurement of flow and sediment in canals, in: Canal Irrigation Systems in India. Water Science and Technology Library, vol. 126, Springer, Cham, 2023, https://doi.org/10.1007/978-3-031-42812-8_10.
[22] P. Dobriyal, R. Badola, C. Tuboi, et al., A review of methods for monitoring streamflow for sustainable water resource management, Appl. Water Sci. 7 (2017) 2617–2628, https://doi.org/10.1007/s13201-016-0488-y.
[23] Sony A. Affandy, Adhi Kurniawan, Renanto Handogo, Juwari P. Sutikn, I-Lung Chien, Technical and economic evaluation of triethylene glycol regeneration process using flash gas as stripping gas in a domestic natural gas dehydration unit, Engineering Reports 2 (5) (2020).
[24] A.P. Boss, Giant planet formation by gravitational instability, Science 276 (5320) (1997) 1836–1839.
[25] Z. Renthlei, M.D. Denis, R. Kumar, M. Kumar, S. Srivastava, A. Denis, S. Suryavanshi, A. Yadav, Irrigation performance assessment of a canal irrigated area: a case study of samrakalwana village in allahabad, J. Indian Water Resour. Soc., J. Indian Water Resour. Soc. 37 (2017). Vol. 37. India.
[26] M.S.M. Amin, M.K. Rowshon, W. Aimru, Paddy Water Management for Precision Farming of Rice. InTech, 2011, https://doi.org/10.5772/28883.
[27] R.R.M. Bos, F.B. Rozema, G. Boering, A.J. Nijenhius, A.J. Pennings, A.B. Verwey, H.W.B. Jansen, Degradation of and tissue reaction to biodegradable poly (L-lactide) for use as internal fixation of fractures: a study in rats, Biomaterials 12 (1) (1991) 32–36.
[28] Habtamu Alemu Werkneh, Investigation of Flooding Problems in Urban Drainage System: the Case at Zenebe Werk in Addis Abeba, School of Civil and Environmental Engineering. Addis Ababa University, Ethiopia, 2017.
[29] K.A. Adeniran, M.F. Amodu, M.O. Amodu, F.A. Adeniji, Water requirements of some selected crops in Kampe dam irrigation project, Australia Journal of Agriculture Engineering 1 (4) (2010) 119–125.
[30] Shumaila Soomroa, Ghulam Shabir Solang, Altaf Ali Siyal, Asad Golo, Nabi Bux Bhattic, Abdul Ghani Soomrod, Aneela Hameem Memone, Sallahuddin Panhwarf, Hareef Ahmed Keeriog, Estimation of irrigation water requirement and irrigation scheduling for major crops using the CROPWAT Model and climate data, Water Pract. Technol. 9 (2023).
[31] M. Pérez-Ortolá, J.W. Knox, Water relations and irrigation requirements of onion, Exprimental Agriculture (2015) 210–231.
[32] A.G. Tirfi, A.S. Oyekale, Analysis of trends and variability of climatic parameters in Teff growing belts of Ethiopia, Open Agric. J. 7 (2022) 541–553.
[33] A.J. Usmail, M.M. Maja, A.A. Lakew, Farmers' perceptions of climate variability and adaptation strategies in the rural areas of Dire Dawa administration, eastern Ethiopia, Heliyon 9 (2023) e15868.
[34] S. Soomro, G.S. Solangi, A.A. Siyal, A. Golo, N.B. Bhatti, A.G. Soomro, H.A. Keerio, Estimation of irrigation water requirement and irrigation scheduling for major crops using the CROPWAT model and climatic data in Hyderabad district of Pakistan, Water Pract. Technol. 18 (3) (2023) 685–700.
[35] M.K. Rowshon, C.Y. Kwok, Teang Shui Lee, GIS-based scheduling and monitoring irrigation delivery for rice irrigation system: Part II. Monitoring, Agric. Water Manag. (2003) 117–126.
[36] P.G. Pérez-González, G.H. Rieke, E. Egami, A. Alonso-Herrero, H. Dole, C. Papovich, C. Martin, Spitzer view on the evolution of star-forming galaxies from z= 0 to z∼ 3, Astrophys. J. 630 (1) (2005) 82.
[37] Y. Dembélé, S. Ouattara, A. Keïta, Application of the indicators "relative water supply" and "water productivity" to the analysis of performance of small irrigated areas in Burkina Faso, Irrigat. Drain. (2001) 309–321.
[38] Wenceslas Somda, Bernhard Tischbein, Janos Bogardi, Water use inside inland valleys agro-systems in the dano basin, Burkina Faso, Water Cycle (2020) 88–97.
[39] Nguyen Thi Ngoc Uyen, Schneider Karl, Ribber Lars, Nauditt Alexandra, V.N.D. Phuoc, Assessing the performance of irrigation system in the dominant paddy rice region of the vu gia thu bon delta, International Scientific Publications (2019) 1314–8591.
[40] K.M. Chandran, G.K. Ambili, Evaluation of minor irrigation schemes using performance indicators: case studies from South India, Sustain. Water Resour. Manag (2016) 431–437.
[41] Herminia Puerto, Miguel Mora, Bernat Roig-Merino, Ricardo Abadía-Sánchez, José María Cámara-Zapata, Ricardo Suay, Carmen Rocamora, Orchard level assessment of irrigation performance and water productivity of an irrigation community in eastern Spain, Agronomy (2021) 1109–1829.
[42] Juan Benavides, Eva Hernández-Plaza, Luciano Mateos, Elías Fereres, A global analysis of irrigation scheme water supplies in relation to requirements, Agric. Water Manag. (2021) 378–3774.

[43] C. Santos, I.J. Lorite, M. Tasumi, Performance assessment of an irrigation scheme using indicators determined with remote sensing techniques. Southern Spain, Irrigat. Sci. 28 (2010) 461–477.
[44] A.S. Manaze, Performance assessment irrigation schemes according to comparative indicators: a case study of shina-hamusit and selamko, Ethiopia, International Journal of Scientific and Research Publications. (2015) 2250–3153.
[45] M. Aseres, M.A. Moges, S. Tilahun, B. Geremew, D. Geletaw, E. Bekele, Performance evaluation and assessment of quashni small scale irrigation scheme, in: Amhara Region (Ed.), Advances of Science and Technology, Springer, Cham, 2020, pp. 126–147.
[46] M. Fátima Moreno-Pérez, José Roldán-Cañas, Assessment of irrigation water management in the Genil-Cabra (Córdoba, Spain) irrigation district using irrigation indicator, Agric. Water Manag. (2013) 98–106.
[47] Ignacio J. Lorite, Luciano Mateos, E. Fereres, Evaluating irrigation performance in a Mediterranean environment: I. Model and general assessment of an irrigation scheme in Andalusia, southern Spain, Irrigat. Sci. (2004) 77–84.
[48] Mulugeta Abebo Abo, Shemelies Assefa, Abraham W/Michael, Performance evaluation of the bilate and Furfuro irrigation schemes in Silti zone, southern Ethiopia, J. Eng. Appl. Sci. 71 (2024) 88.
[49] K. Abera, M. Mehari, Performance evaluation of pressurized irrigation system (A case of kobo girana irrigation system, Ethiopia), in: Advances of Science and Technology: 8th EAI International Conference, ICAST 2020, Bahir Dar, Ethiopia, October 2-4, 2020, Proceedings, Part II 8 (Pp. 85–97), Springer International Publishing, 2021.
[50] J.S. Maatooq, Hydraulic characteristics and discharge of canal sluice gate: practical approach, J. Eng. 22 (11) (2016) 16–35.