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*Research Article*

# Assessment of Irrigation Water Management Performance Indicators and Mitigation Measure in Arba Minch Irrigation Scheme, Ethiopia

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Irrigated agriculture has been practiced in Ethiopia for several centuries and performance of scheme was poor due to inadequate irrigation water management practices. This study was conducted to evaluate irrigation water management indicators and to suggest possible mitigation measure for Arba Minch irrigation scheme. Primary data such as field and canal flow, soil moisture content, and canal slope were measured on field and soil physical properties were evaluated in the laboratory. Utilizing climate and crop data, the CropWat 8 model was employed to estimate seasonal crop water requirements, while furrow and border irrigation dimensions were designed using SURDEV software. The average field application efficiency (30%), storage efficiency (76%), percolation losses (66%), and overall efficiency (25%). The average relative water and irrigation supply in the scheme were 1.7 and 3.3, respectively. The mean water and land productivity of the wheat, onion, pepper, watermelon, and maize of the Arba Minch irrigation scheme were 0.1 kg/m$^3$ and 0.5 ton/ha, 0.9 kg/m$^3$ and 4.9 ton/ha, 1.5 kg/m$^3$ and 6.2 ton/ha, 0.5 kg/m$^3$ and 0.6 ton/ha, and 0.9 kg/m$^3$ and 4.2 ton/ha, respectively. Watermelon had the highest net returns per hectare ($1,693), followed by onion ($1,829), pepper ($1,221), and wheat ($1,057). In terms of net returns per cubic meter of water, onion led with $0.3, followed by watermelon ($0.2), pepper and wheat with the lowest at $0.1 (top of form). The average value conveyance efficiency, water surface elevation ratio and manning coefficient were 82%, 42%, and 0.06%, respectively. The existing, and corrected length were 843 and 135 m (border irrigation) and 20 and 595 m (furrow irrigation), respectively. In conclusion, the Arba Minch irrigation scheme was very poor performance and low efficiency. To address these issues, farmers and irrigation authorities implement improved irrigation water management practices. Policymakers should promote sustainable water management and explore crops with higher water productivity for overall scheme improvement.

## 1. Introduction

Irrigated agriculture has been practiced in Ethiopia for several centuries and has remained an essential mode of agriculture in the country [1]. Ethiopia has an estimated 1.5 million hectares of irrigable land considering water availability from rivers, groundwater, and water harvesting from rainfall [2]. Modern irrigation began in Ethiopia in the 1950s through private and government-owned schemes in the middle Awash Valley, where large sugar, fruit, and cotton state farms were established [3]. Surface irrigation methods such as furrow, border, and basin irrigation have primarily been used [4]. However, irrigation water management and utilization have received insufficient attention and irrigation practices have resulted in various adverse consequences. Water logging [5], soil salinity [6], lower productivity, and water scarcity [7] are the most problems of irrigation scheme.

Irrigation water management is the act of timing and regulating irrigation water [8], system operation, and maintenance [9] and holding the required water level in the root zone [10]. Appropriate and or/better irrigation water management practices increase land and water productivity by ensuring higher system efficiency [11]. Small-scale irrigation schemes in Ethiopia like Gery Kilty, Gibe Lemu, and Sanka are under poor performance status [12]. This poor scheme condition resulted from shortcomings in infrastructure design, construction, operation and maintenance [13], and the absence of strictly controlled water management practices [14]. Additionally, irrigation schemes will fail due to insufficient technical skills to manage available irrigation water [15] and sedimentation of the weir and canal structure [16]. Improving irrigation efficiencies along the distribution system and at the farm level is an important water management goal to reduce the wastage of water [17]. Performance assessment in irrigation is used to support the planning and implementation of any development project [18] and to identify the present status of the scheme based on the selected indicators [19]. Proposed standard efficiency terms for irrigation system evaluation are conveyance efficiencies, delivery capacity, application efficiencies, storage efficiencies, and percolation loss which help to realize how well-irrigated agriculture is performing at the different scheme levels [20]. Good maintenance enables to keeping of water control infrastructure in good working condition and this maintenance indicators are assessed through effectiveness of infrastructure and water surface elevation ratio [21].

Canal conveyance efficiencies and delivery capacity indicate the ability of the canal to carry the required discharge with a minimum loss [22]. Application and storage efficiency, and percolation are essential parameters to measure the effectiveness of irrigation water application and the quantity of water stored in the crop root zone [23]. Effectiveness of infrastructure measure status of functional and nonfunctional infrastructure in the scheme whereas water surface elevation ratios also evaluate change of canal bed due to siltation and weeding problem [24]. Water supply indicators (such as relative water and irrigation supply) are used to describe how supply and irrigation demands are matched [16]. Irrigation water loss along the canal system can be minimized by providing lined canals using various materials like concrete, asphaltic concrete, flexible membranes [25], compacted earth, and soil cement mixture [26]. Successful irrigation schedules or calendars, land leveling, and selection of the best irrigation methods and improvements are used to improve on-farm irrigation efficiencies [27] that increase (water) crop productivity within a limited area and water availability [28].The efficient mitigation measure helps to increase the life span of water distribution structure in the irrigation schemes [29].

Arba Minch irrigation scheme was located in Rift Valley Lakes Basin in southern parts of Ethiopia and it was started around 1958 Ethiopian calender (E.C) to introduce mechanized agriculture practice. During that period, the scheme was called Arba Minch state farm and it had 62 ha of land covered by dwarf Cavendish banana. The adapted irrigation methods in the scheme were traditionally graded furrow and border surface irrigation and the water diversion structure across the Kulfo River was simple intake. Currently, a simple diversion structure across the river is not functional and irrigation water from the sources is diverted by using a temporary structure that constructs from local materials such as stone, mud, and woods. The scheme was subject to several problems like excess water loss, crop wilting, and unfair irrigation water distribution with downstream users. This problem may be due to poor irrigation management practice and irrigation control structure, insufficient technical skill, and institutional setup.

The main canal conveyance efficiency and delivery capacity of Hare community-managed irrigation system that found near the Arba Minch irrigation scheme were 58% and 1.07%, respectively [4]. However, no research was conducted on the Arba Minch irrigation scheme to assess irrigation system performance. The research focuses on evaluating, improving, and optimizing the Arba Minch irrigation scheme in Ethiopia. It aims to enhance crop water efficiency, economic returns, and overall performance by addressing existing inefficiencies. The significance lies in providing insights and recommendations for improved irrigation practices, sustainable water management, and exploring high-productivity crops to benefit agriculture in the region.

## 2. Material and Methodology

*2.1. Description of the Study Area.* Arba Minch state farm is located between 6°3′18” North latitude and 37°54′40” East longitude of Gamo zone, south nation, nationality and people's regional state, Ethiopia. The average elevation of the scheme is 1,198–1,204 m above the mean sea level. The schemes have one main canal of 2,953 m in length and a three-branch canal with 6,400 m in total length. Gross command area of the Arba Minch irrigation scheme was 842 ha and the major crop patterns of scheme were wheat, onion, pepper, watermelon, and maize irrigated alternatively and permanent banana. Plots of soil sampling and irrigation water measurement along the canal and on field were selected along the study area as describe in Figure 1.

*2.2. Climate Description.* The average minimum and maximum temperature of the study area were 18 and 29°C, respectively (Figure 2). Monthly reference evapotranspiration also varied from 3.45 to 5.04 mm/day with a 4.25 mm/day average value and the maximum and minimum values of reference evapotranspiration were observed in April and December, respectively. Rainfall distribution season of the area was bimodal type. These rainy seasons were from April to June and October to December as presented in Figure 2, and the total received average annual rainfall was 904 mm. The water source of the Arba Minch irrigation scheme is Kulfo River and the minimum and maximum flow of the river were 2.35 and 50.73 $m^3/s$, respectively. Minimum temperature (min_temp), maximum temperature (max_temp), and average monthly rainfall are presented in Figure 2.

*2.3. Data Collection and Analysis*

*2.3.1. Soil Physiochemical Properties.* Sizes of sampling plots were fixed 30 m × 40 m, 20 m × 50 m, and 10 m × 90 m for the wheat, maize, and onion crops, respectively. The average furrow area of watermelon and pepper was 15.8 and 3.7 $m^2$ with 20 and 6 m furrow length, respectively. Composite soil samples were collected at 90 cm soil depth with 30 cm depth interval by using Auger Hole Device. Soil texture, bulk

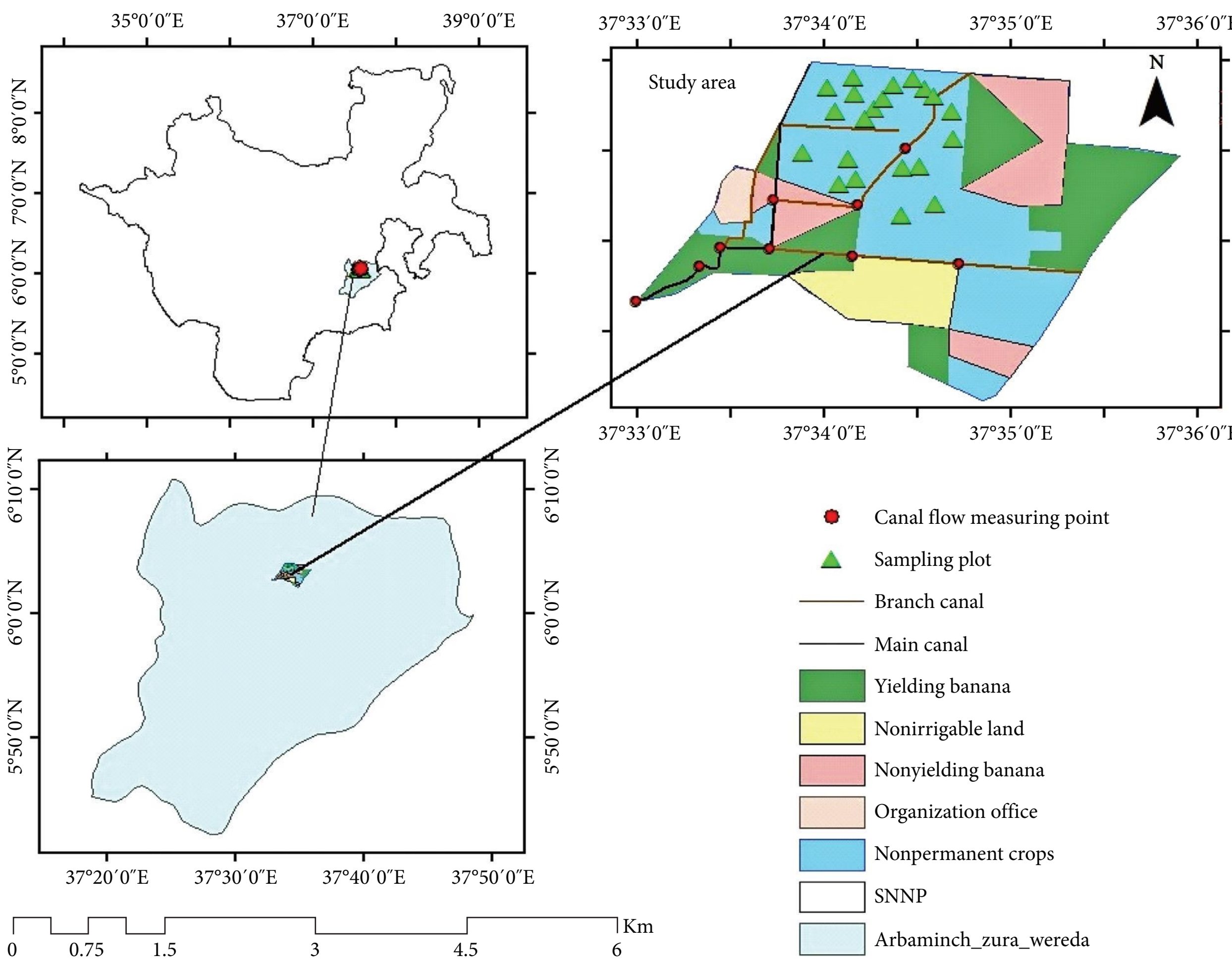


Figure 1: Study area location.

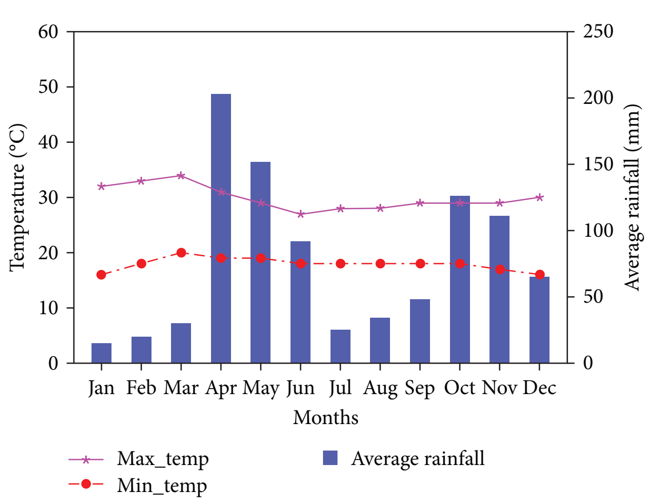


Figure 2: Average monthly minimum temperature, maximum temperature, and rainfall.

density, and plastic and liquid limit were evaluated by hydrometer test, oven dry method, and Atterberg limit test, respectively. Field capacity and permanent wilting point were determined in laboratory by using pressure plate apparatus. Field capacity and permanent wilting point are used to monitor the irrigation schedule in the scheme. Infiltration rate characteristics of soil were determined initially at the start of the experiment using a double ring Infiltrometer and that was used as input for the CropWat model. Based on the effective root depth of the crop, soil water content before and after irrigation on crop irrigated land was estimated indirectly with calibrated time-domain reflectometer (TDR) as presented in Figure 3 and soil water content after irrigation was collected in 24–72 hr. Those estimated values were used to fix the amount of depth of irrigation and soil water storage after irrigation [30]. Soil moisture depletion (SMD) is the difference between field capacity and the actual moisture in the soil root zone at any given time before irrigation [31].

$$\mathrm{SMD} = \sum_{i=1}^{n} \left( \frac{\theta_{\mathrm{c}} - \theta_{\mathrm{i}}}{100} \right) \times D_{\mathrm{i}}, \tag{1}$$

where SMD = depth of soil water depletion (mm), $\theta_c$ = field capacity of the soil (%), $\theta_i$ = initial volumetric soil water content before the irrigation (%), $D_i$ = $i^{th}$ layer of crop root depth (mm), and $n$ = number of layers in the root zone.

Figure 3: Soil moisture measurement by using time-domain reflectometer (TDR).

Soil water storage is the amount of water, which is stored in the root zone of the crop after irrigation, which was determined based on [32].

$$\mathrm{Ds} = \sum_{i=1}^{n} \left( \frac{\theta_{\mathrm{ai}} - \theta_{\mathrm{bi}}}{100} \right) \times D_{\mathrm{i}}, \quad (2)$$

where $\theta_{ai}$ and $\theta_{bi}$ are moisture content of the i$^{th}$ soil layer after and before irrigation on an oven dry volume basis (%), respectively.

*2.3.2. Reference and Crop Evapotranspiration, and Effective Rainfall.* Based on [33], reference evapotranspiration (ETo), crop water requirement (ETc), and effective rainfalls (Pe) were evaluated from climate data through CropWat 8.0 model. Maximum irrigation consumption of scheme for actual crop pattern also evaluated by using CropWat model that was used to design main canal of irrigation scheme.

$$\mathrm{ETo} = \frac{0.408\Delta (R_{\mathrm{n}} + G) + r \frac{900}{T+273} U_2 (e_{\mathrm{s}} - e_{\mathrm{a}})}{\Delta + r(1 + 0.34U_2)}, \quad (3)$$

$$\mathrm{ETc} = \mathrm{kc} \times \mathrm{ETo}, \quad (4)$$

where kc = crop coefficients that was collected from irrigation and drainage paper (FAO 56).

$$\mathrm{Pe} = \frac{(p \times (125 - 0.2 \times 3 \times p))}{125};\ \text{if } p \leq 250/3, \quad (5)$$

$$\mathrm{Pe} = \frac{250}{3} + 0.1\mathrm{p};\ \text{if } p > 250/3. \quad (6)$$

*2.3.3. Flow Measurement.* Flow at the inlet of the plot was measured by a 3-inch RBC flume (Figure 4) and the depth of applied water to the field ($Df$) was calculated by using Equation 7.

$$Df\ (\mathrm{mm}) = \frac{Q_t}{w \times l}, \quad (7)$$

$t$, $w$, and $l$ are the duration of irrigation (s), width (m), and length (m) of the border or furrow, respectively.

Flow velocities of the canal were measured by using an electric current meter at upper, middle, and lower end of canal reach (Figure 4(b)). After measuring flow velocity, the total discharge of the canal was estimated through the mean section method as described in Equation 8.

$$Q = \sum_{n=1}^{\infty} \left( \mathrm{b1} \left( \frac{\mathrm{v1} + \mathrm{v2}}{2} \right) \times \frac{\mathrm{d1} + \mathrm{d2}}{2} \ldots. + \mathrm{bn} \left( \frac{\mathrm{vn} - 1 + \mathrm{vn}}{2} \right) \times \frac{\mathrm{dn} - 1 + \mathrm{dn}}{2} \right), \quad (8)$$

where $Q$ = discharge of canal cross-section (m$^3$/s), $b$ = width at $n$-segment of canal cross-section (m), $V$ = velocity at $n$-segment of canal cross-section (m/s), and $d$ = depth at $n$-segment of canal cross-section (m).

### *2.4. Water Management Indicators*

*2.4.1. On Farm Performance Efficiencies.* On farm irrigation performance indicators such as application efficiency, storage efficiency, percolation loss, and overall efficiency were evaluated based on [23, 32, 34].

$$\text{Application efficiency (Ea)} = 100 \times \frac{\mathrm{Ds}}{\mathrm{Df}}, \quad (9)$$

$$\text{Storage efficiency (Es)} = 100 \times \frac{\mathrm{Ds}}{\mathrm{SMD}}, \quad (10)$$

$$\text{Percolation loss (P)} = 100 \times \frac{\text{Df-Ds}}{\mathrm{Df}}, \quad (11)$$

$$\text{Overall irrigation efficiency (Eo)} = \frac{\mathrm{Ea} \times \mathrm{EC}}{100}, \quad (12)$$

where $Ds$, $Df$, and SMD stand for depth of soil water storage (mm), depth irrigation water applied to the field (mm), and soil moitsure depletion from field capacity (mm), respectively.

*2.4.2. Relative Water and Irrigation Supply and Crop Productivity.* Relative irrigation and water supply are a performance indicator was calculated based on [35], as presented in Equations 13 and 14.

$$\text{Relative water supply (RWS)} = \frac{\text{Total water supply}}{\text{Crop water requirement}}, \quad (13)$$

$$\text{Irrigation supply (RIS)} = \frac{\text{Total irrigation applied}}{\text{Net irrigation requirement}}. \quad (14)$$

Water productivity under irrigation ($I$) plus amount of rainfall water ($R$) was estimated based on [36] and land productivity also estimated based on [37].

(a)

(b)

FIGURE 4: Measurement of flow at: (a) the farm inlet and (b) along the canal.

$$\text{Water productivity } (\text{WP}_{\text{I+R}}) = \frac{\text{Yield (kg)}}{\text{Total applied water } (m^3)}, \tag{15}$$

$$\text{Land Productivity (LP)} = \frac{\text{Yield (ton)}}{\text{Irrigated land (ha)}}. \tag{16}$$

Net returns per volumetric water (EWP) gauges the economic value per unit of water in an activity, assessing water use efficiency [38] and net returns per land area (LEP) generally refers to the economic returns or profits generated per unit of land area. According to Çetin and Kara [39], the calculations for net returns per volumetric water (EWP) and net returns per land area (LEP) were derived using current prices and production costs, and all the current prices and costs were gathered under free market conditions.

$$\text{EWP}_{\text{I+R}} = \frac{\text{NR}}{\text{Total applied water } (m^3)}, \tag{17}$$

$$\text{LEP} = \frac{\text{NR}}{\text{Irrigated land (ha)}}. \tag{18}$$

NR is net return or net income ($USD) that was evaluated based on [36] as described in Equation 19.

$$\text{NR} = \text{Total production } (\$) - \text{production cost } (\$). \tag{19}$$

*2.4.3. Maintenance and Land Utilization Indicators.* Maintenance indicators such as the conveyance efficiencies, effectiveness of infrastructures [16], water surface elevation, water delivery capacity, and Manning's roughness coefficient were calculated according to Tebebal and Ayana [40].

$$\text{Conveyance efficiency (Ec)} = 100 \times \frac{\text{Discharge at outlet}}{\text{Discharge at the inlet}}, \tag{20}$$

$$\text{Effectiveness of infrastructures} = \frac{\text{Number of functional structure}}{\text{Total number of structures}} \times 100, \tag{21}$$

$$\text{Water surface elevation ratio} = \frac{\text{Actual canal depth}}{\text{Design canal depth}} \times 100, \tag{22}$$

$$\text{Water delivery capacity} = \frac{\text{Actual canal delivery capacity}}{\text{peak consumptive demand}} \times 100, \tag{23}$$

$$\text{Manning roughness coefficient } (n) = \frac{R^{\frac{2}{3}} \times S^{0.5}}{V}. \tag{24}$$

Hydraulic radius ($R$) was the ratio of cross-sectional area to wetted perimeter of existing irrigation canal. Canal longitude slope ($S$) was measured directly from the field and actual canal velocity ($V$) was measured by using current meter as discussed earlier. According to Bos et al. [41], land utilization indicators such as irrigation ratio (IR ratio) and irrigation intensity were evaluated.

$$\text{Irrigation ratio} = \frac{\text{Seasonal irrigated area}}{\text{Command area}} \times 100, \tag{25}$$

$$\text{Irrigation intensity} = \frac{\text{annual irrigated area}}{\text{Command area}} \times 100. \tag{26}$$

### *2.5. Water Management Improvement*

*2.5.1. Maintenance of Existing Irrigation Canal.* The existing earthen canal cross-section was too insufficient to carry required irrigation water requirement. Therefore, modification of existing canal cross-section was important and additional canal excavation is necessary. Site clearness up to 20 cm soil depth and excavation cost was evaluated and 30 cm working spacing in both side of canal top width. Modified main canal cross-section was design based on

Table 1: Soil physicochemical properties.

| Depth (cm) | (%) Clay | (%) Silt | (%) Sand | Texture class | BD (gm/cm$^3$) | SOM (%) | ECe (ds/m) | FC (% vol) | PWP (% vol) |
|---|---|---|---|---|---|---|---|---|---|
| 0–30 | 45 | 30 | 25 | Clay | 1.2 | 0.9 | 0.1 | 40.1 | 26.9 |
| 30–60 | 44 | 20 | 36 | Clay | 1.3 | 0.9 | 0.2 | 38.9 | 26.5 |
| 60–90 | 45 | 20 | 35 | Clay | 1.4 | 0.8 | 0.2 | 39.4 | 27.0 |
| Average | 45 | 23 | 32 | Clay | 1.3 | 0.9 | 0.2 | 39.5 | 26.8 |

Where: BD, SOM, ECe, FC, and PWP stand for bulk density, soil organic matter, extracted electric conductivity, field capacity, and permanent wilting point, respectively.

maximum duty of crop water requirement, and total length of modified earthen canal was 2,953 m.

*2.5.2. Design Optimum Furrow and Border Dimension.* Furrow and border dimension like width and length were fixed by using surface irrigation design and evaluation (SURDEV) software. Actual water delivery at farm inlet and slope was used as input and permissible velocity and manning flow resistance of soil were fixing based on soil properties. Furrow and border irrigation were designed with the best possible dimensions for the average existing application flow rate at the farm inlet.

## 3. Result and Discussion

*3.1. Soil Physiochemical Properties.* Average representative soil texture was found clay soil and average bulk densities and organic matter were 1.3 gm/cm$^3$ and 0.9%, respectively. Soil was suitable for agriculture practices to be uncompacted with bulk density ≤1.6 gm/cm$^3$ [42]. Therefore, bulk density of current study found with recommended value that means lower Kulfo catchment was too suitable for agriculture practice with normal soil compactness status. Average volumetric field capacity and permanent wilting point were 39.5% and 26.8%, respectively and average total available water evaluated was found 12.7% (Table 1). Volumetric field capacity and permanent wilting point of clay soil was found 40% and 25% [43] and 21% and 45% [44], respectively and value of current studies found between the previous finding. Field capacity of soil of the current study was used to estimate amount of soil water depletion after irrigation to refill with irrigation. The basic infiltration rate of soil was 3.6 mm/hr which lies between the basic infiltration rates of 2–5 mm/hr for clay soil textural class as suggested [7].

*3.2. Depth Soil Water Depletion and Soil Water Storage.* Depth soil water depletion and storage were evaluated for each crop up to effective root depth. Based on this parameter, soil water storage after the irrigation was not satisfied crop water requirements or soil water depletion that was due to excess runoff during the irrigation (Figure 5). In addition to this, the application rate of irrigation water to the field was greater than the basic infiltration rate of soil increasing water loss across the field.

*3.3. Water Management Indicators*

*3.3.1. On Farm Performance Efficiencies.* The application efficiency of the Arba Minch irrigation scheme ranged from 15% to 54% with the overall average application efficiency

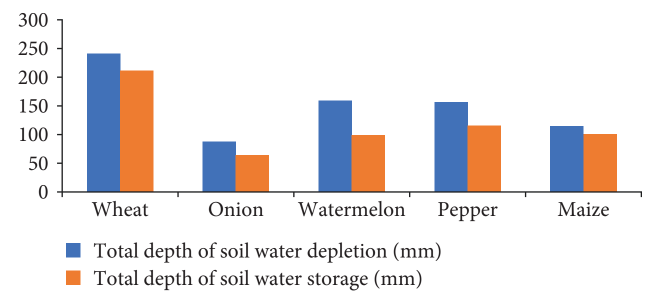


Figure 5: Depth of soil water depletion and soil water storage.

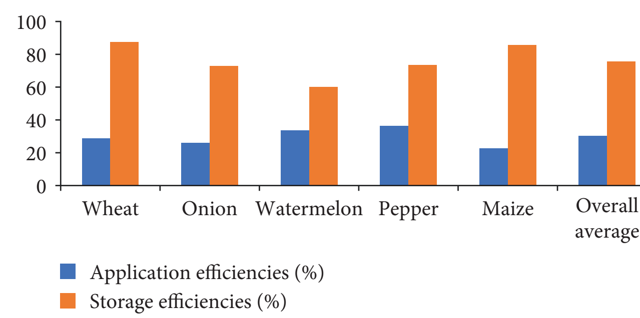


Figure 6: Average application and storage efficiencies.

of 30%, which less than recommended average application efficiency of 58% [45]. Storage efficiency was varied from 41% to 100% with an average value of 76% (Figure 6), which less than recommended storage efficiency of 93% [46]. Based on the result; the maximum storage efficiency was observed on traditional border irrigation methods, especially on wheat and maize crops. Irrigation was applied randomly without any monitoring of soil moisture depletion and irrigation interval. Adapted flooding irrigation in the scheme was decrease both application and storage efficiencies.

Percolation loss was evaluated for only watermelon and pepper crops since that was the block furrow irrigation method (Figure 7). But other crops such as wheat, maize, and onion were irrigated by using traditional flooding irrigation which challenges estimating the amount of runoff at the time of irrigation. The total number irrigation application for watermelon and pepper fruits was 11 and percolation loss assess during the time of irrigation. Average deep percolation ratio at Gemesha and Ufute irrigation schemes were 41% and 31% [47], respectively. However, the estimated average deep percolation ratio for the Arba Minch irrigation scheme was

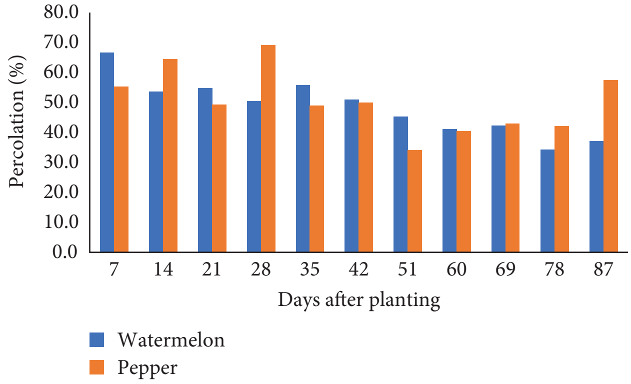


Figure 7: Percolation loss for watermelon and pepper crops.

66%. This result indicates a high amount of water was lost through deep percolation due to irregular slopes of furrow and small blocks across the furrow irrigation. This irregular furrow system happened due to a lack of scientific standard procedure to design furrow length, spacing, width, and slope. Irrigation interval and duration of irrigation were depending on the local irrigator or labors. Even if there were no professional persons to manage the irrigation system and decide the application of irrigation water is enough or not.

The average overall irrigation efficiency of the Arba Minch irrigation scheme was 25%. Overall efficiency of Cheleleka traditional flooding irrigation system was 17% as a result of poor irrigation management practices [47]. Both overall efficiencies of Arba Minch and Cheleleka traditional flooding irrigation system found under poor performances status when compared with recommended overall irrigation efficiency of 55% [19]. This low overall irrigation efficiency was observed due to a lack of scientific-based irrigation field alignment and leveling, irrigation interval and duration of irrigation, and plant density. At the launch time and night, irrigation water in Arba Minch irrigation was applied to the field without an irrigator that was the other major source of low irrigation efficiencies.

*3.3.2. Relative Water and Irrigation Supply and Crop Productivity.* The average relative water and irrigation supply in the scheme were 1.7 and 3.3, respectively (Table 2) which were greater than the average recommended relative water and irrigation of 1 [19]. The average relative water and irrigation supply in Quashine and Dodicha small scale irrigation were 5 and 6 and 3.3 and 2.9 [16], respectively. All this conducted research shows that most irrigation project in Ethiopa faced under water management problem. The total amount of irrigation water lost of Arba Minch irrigation scheme at the farm level during the irrigation season was 262 mm that could be irrigate approximately 56 ha additional area. This result also shows the application of irrigation water to the field was not based on crop water requirement or soil moisture depletion. It results water scarcity problems to downstream water users that locate in Kollashara Kebele.

The average water and land productivity of wheat, onion, pepper, watermelon, and maize were 1.1 kg/m$^3$ and 4.6 ton/ha [48], 5.4 kg/m$^3$ and 25.7 ton/ha [44], 1.6 kg/m$^3$ and 7.5 ton/ha [49], 1 kg/m$^3$and 6.2 ton/ha [50], and 1.0 kg/m$^3$ and 7.2 qun/ha [51], respectively. The mean water and land productivity of the wheat, onion, pepper, watermelon, and maize in Arba Minch irrigation were 0.1 kg/m$^3$ and 0.5 ton/ha, 0.9 kg/m$^3$ and 4.9 ton/ha, 1.5 kg/m$^3$ and 6.2 ton/ha, 0.5 kg/m$^3$ and 0.6 to/ha, and 0.9 kg/m$^3$ and 4.2 ton/ha, respectively. Both water and land productivity of wheat, onion, pepper, watermelon, and maize in the Arba Minch irrigation scheme were too low when compared with earlier study. Reduced water productivity can stem from inefficient irrigation practices, including overirrigation or underirrigation, inaccurate scheduling, uneven water distribution, and the use of inappropriate methods [52]. Poor water management exacerbates the issue, causing losses through runoff, evaporation, and deep percolation, often due to inadequate infrastructure and maintenance [53]. Suboptimal crop selection and cultivation practices, such as growing water-intensive crops in arid regions or improper land preparation, also contribute to diminished water use efficiency [54]. Climate variability and change, lack of water-saving technologies, land degradation, and soil erosion further impact productivity [55]. Inadequate water pricing, governance issues, population growth, increased demand, industrial pollution, and a lack of awareness and education on optimal water management practices collectively compound the challenges, necessitating a comprehensive approach to address these factors [56].

The net returns per volumetric water (EWP) and net returns per land area (LEP) for different crop types were analyzed based on the provided table data. Watermelon exhibited the highest net returns per hectare with $1,693, followed by onion with $1,829, pepper with $1,221, and wheat with $1,057. In terms of net returns per cubic meter of water, onion led with $0.3, followed by watermelon with $0.2, and pepper and wheat with the lowest at $0.1. These results suggest that, while watermelon and onion are more profitable in terms of total returns per hectare, onion stands out as the most economically efficient crop in terms of net returns per unit of water, emphasizing its potential sustainability in water usage. Wheat, despite its relatively lower net returns, has the advantage of a lower water consumption cost, indicating its efficiency in resource utilization but may require larger land areas to achieve comparable profitability. From the field obseravtion survey, low productivity of the scheme comes as a result of improper implementation and operation of irrigation facilities, lack of strong institutional arrangement and modern irrigation technology, and poor land and water management practice.

*3.3.3. Maintenance and Land Utilization Indicators.* The average conveyance efficiencies of Arba Minch irrigation scheme varies from 77% to 87% with 82% average value (Figure 8) and the maximum irrigation water loss was observed under main canal specifically from 0 to 1,080 m length. The total water lost along the main canal and branch canal was 334 l/s per day which potentially irrigates 214 ha with 0.4 l/s/ha irrigation duty. The values were estimated using CropWat Model by considering time factor and irrigation efficiencies of 2% and 50%, respectively. Quantification

Table 2: Relative water and irrigation supply.

| Crop | CWR (mm) | Pe (mm) | Irr req (mm) | Applied irr (mm) | RWS | RIS | Water lost (mm) | Area (ha) |
|---|---|---|---|---|---|---|---|---|
| Wheat | 453 | 372 | 126 | 704 | 2.4 | 5.6 | 578 | 266 |
| Onion | 318 | 238 | 92 | 243 | 1.5 | 2.7 | 151 | 2 |
| Pepper | 393 | 292 | 116 | 332 | 1.6 | 2.9 | 216 | 3 |
| Watermelon | 291 | 220 | 99 | 291 | 1.8 | 2.9 | 192 | 6 |
| Maize | 363 | 287 | 127 | 300 | 1.2 | 2.4 | 173 | 5 |
| Average | | | | | 1.7 | 3.3 | 262 | 56 |

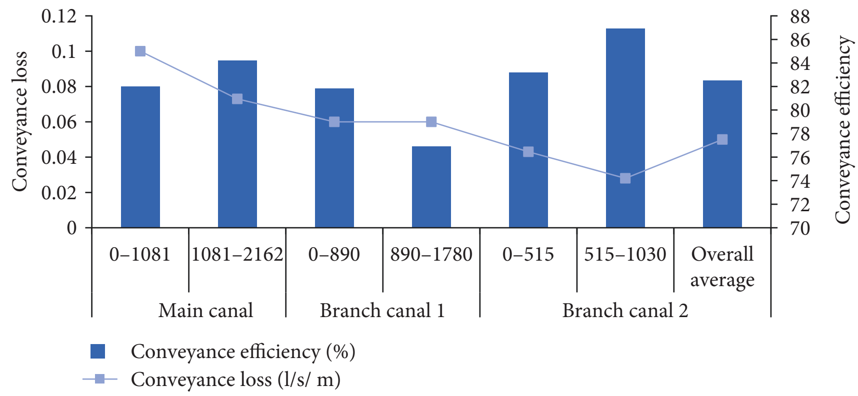


Figure 8: Canal conveyance efficiency.


Figure 9: Causes of irrigation water loss through the canal.

of the total water lost per irrigation season along the canal was difficult since variability of divert flow to each canal and temporary water diversion structure at river. Therefore, canal to be maintained to save this water lost along the canal that could have been used for additional land development.

The major cause of irrigation water losses along the canal was poor and traditional water control structure, seepage, and an overflow canal due to weeding and sedimentation (Figure 9).

The total infrastructures in the scheme such as simple intake, scape canal, and division box that construct across the main and branch canal were 10. The average value of effectiveness of infrastructure, water surface elevation ratio, and Manning coefficient were 0%, 42%, and 0.06%, respectively. The unlined canal in the system was also damaged due to weeding and siltation. Similarly, the value of effectiveness of infrastructure in Tahtay Tsalit and Hare irrigation scheme were 61% [57] and 16% [40], respectively. The mean value of water surface elevation ratio of the Hare irrigation scheme also was 90% [40]. This research shows the existing performance of infrastructure in Arba Minch irrigation scheme too low compare with schemes. Therefore, all components of the irrigation scheme starting from the diversion structure to the farm level need urgent maintenance or rehabilitation to increase system productivity. Average value of land utilization indicators irrigation ratio and intensity were 29% and 59%, respectively (Table 3) and it was showing the actual irrigated area per season and year was too low. This low coverage of the irrigated area for the given seasons shows an adaptation of improper resource management practices in the scheme. In Tahtay Tsalit irrigation scheme from the total irrigable land about 91% was irrigated per season [57] this is

Table 3: Land utilization indicators of the Arba Minch irrigation scheme under different years.

| Year | Total irrigated land (ha) | Irrigated land area per season (ha) | Irrigation ratio (%) | Crop intensity (%) |
|---|---|---|---|---|
| 2017 | 842 | 261 | 31 | 62 |
| 2018 | 842 | 235 | 28 | 56 |
| 2019 | 842 | 324 | 38 | 77 |
| 2020 | 842 | 239 | 28 | 57 |
| 2021 | 842 | 220 | 26. | 52 |
| 2022 | 842 | 201 | 24 | 48 |
| Average | | | 29 | 59 |

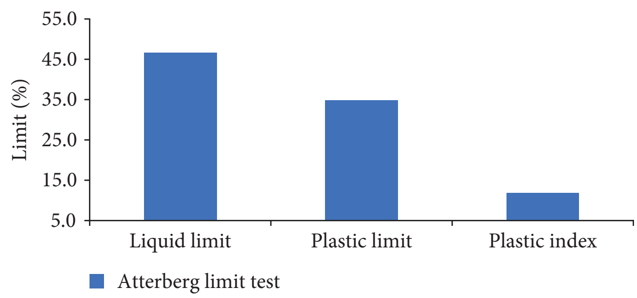


Figure 10: Atterberg limit test result.

because the scheme had effective infrastructures compare with Arba Minch irrigation scheme.

*3.4. Improving Water Conveyance and Application Techniques*

*3.4.1. Modified Existing Earthen Canal.* The possible obtain materials that used to construct unlined earthen canal with at least 35% fines, and a plasticity index (PI) >7 and low permeability characteristics [58]. Therefore, the PI of soil in the current study was 12% (Figure 10) and the component of fine (clay) was 45% that found with recommended properties to construct compacted earthen canal with trapezoidal cross-section. Utilizing compacted earth lining proves to be a highly effective approach in minimizing conveyance losses within irrigation canals, resulting in a remarkable 99.8% reduction in seepage-related water loss along the canal length [25].

The irrigated capacity of existing earthen canal was 300 ha and this result shows maintenance of existing canal was important. The cross-section of existing earthen canal was trapezoidal and its actual average depth was 0.5 m and the modified depth of irrigation canal was 1 m (Table 4). The modified design earthen trapezoidal canal was design based on maximum duty of crop that was 0.4 l/s/ha and this modified earthen canal can irrigate 842 ha. The modified earthen canal increases total annual benefit of scheme from 31,358,900 to 88,547,081 Ethiopian Birr (ETB) and total production and production cost were collected from scheme office that was used to estimate net benefit of scheme.

The annual budget of existing canal maintenance was 373,040 Ethiopian Birr that was collect from Arba Minch scheme office. The total excavation cost of additional canal depth was evaluated for site clearance and excavation work activity only and excavated depth of irrigation canal was 0.5 m. During excavation work, 0.3 m width for each side of canal top width was consider as free spacing and compaction cost was not considered and total cost of earthen canal modification was summarized in Table 5.

Table 4: Modified design earthen canal cross-section.

| Dimension | Value |
|---|---|
| Water depth (m) | 1 |
| Free board (m) | 0.2 |
| Bottom width (m) | 1 |
| Side slope | 0.5 |
| Top width | 2 |
| Canal wall thickness (m) | 0.2 |
| Full supply discharge ($m^3$/s) | 1.3 |
| Main canal length (m) | 2,953 |
| Bed slope (-) | 0.002 |
| Velocity (m/s) | 1.2 |
| Manning coefficient (-) | 0.01 |

Table 5: Cost specification of existing earthen canal modification.

| Material | Unit | Quantity | Unit price | Amount |
|---|---|---|---|---|
| Site clearance up to 20 cm | $m^2$ | 3,839 | 15 | 57,584 |
| Excavation work | $m^3$ | 4,267 | 105 | 448,044 |
| Total cost (ETB) | | | | 505,627 |
| Grand total (ETB) @15% contingency cost | | | | 581,472 |

*3.4.2. Proper Border and Furrow Design.* The average recommended land slope and flow rate for border irrigation under clay soil type were 0.3% and 3 l/s, respectively and the average border width varied from 12 to 30 m with 350 m length [43]. The average flow rate of current study at farm inlet under border irrigation was 6.5 l/s and the adapted border length and width for this flow rate were 843 and 36 m, respectively. The optimum border length and width from SURDEV software were 135, and 7 m, respectively under fixed flow condition and trapezoidal canal cross-section. This border dimension increase irrigation application efficiency from 30% to 66%. Shorter furrows and border are commonly associated with higher uniformity of application and increased potential for runoff losses [59]. The existing average furrow length and apply flow rate were 20 m and 2.5 l/s respectively. The modified dimensions of furrow length and bottom width were 595 and 0.2 m, respectively and the application efficiencies was raised from 30% to 73%. This design was evaluated for only fixed flow condition since tail water method need other economic to pump and store irrigation water for cycle purpose and cutback method also need skill man power to reduced amount of irrigation water based on reaches of advance phase.

## 4. Conclusion and Recommendation

The study highlights the historical practice of irrigated agriculture in Ethiopia and highlights the persistently poor performance of the Arba Minch irrigation scheme, largely attributed to inadequate irrigation water management practices. Through comprehensive data collection and modeling, the research reveals suboptimal efficiency indicators, including low field application efficiency and overall efficiency. Crop-specific water and land productivity variations further emphasize the scheme's inefficiencies and watermelon emerges as the most economically viable crop. Relative irrigation and water supply shown excess water was applied to the field without proper irrigation scheduling and evaluated system maintenance indicators also shown required of urgent implementation mitigation measure in the scheme. Addition to this, the existing dimension of border and furrow irrigation indicates other sources of irrigation water loss along the field compared with optimum design dimension.

To enhance the Arba Minch irrigation scheme, transition to modern water conveyance system, and recommended furrow and border dimensions to be implemented. Modify existing canals with impermeable linings to improve efficiency and reduce water loss. On farm irrigation efficiencies to be improved through advanced training in irrigation management and application techniques. Implement improved soil moisture practices to decrease percolation losses and develop a climate-responsive water management plan. Regular training for farmers and operators, continuous performance monitoring, and collaboration on innovative irrigation research are important for sustainable water management and productivity.

## Data Availability

Data availability will be based on reasonable request.

## Conflicts of Interest

The author(s) have not declared any conflict of interest.

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