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GIS and RS-Based Irrigation Performance Assessments of Sarkita Irrigation Scheme, near Burie Town, Amhara Region)

Walelgn Dilnesa Cherie

Hydraulic and Water Resources Engineering Department Debre Markos University

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Abstract

Irrigation performance assessment is paramount for comprehensively understanding irrigation schemes, their health, and their operation. This study will evaluate the Sarkita irrigation scheme using GIS and remote sensing tools alongside physical performance evaluation mechanisms. The SEBAL approach was used to calculate the actual evapotranspiration potential of the irrigation field. Additionally, the Penman-Monteith method was used to calculate the potential evapotranspiration of the irrigation project. Without a comprehensive performance assessment program, field officers rely on their experience and skills to control water distribution, which hardly leads to any performance improvements. ETact data from low-cost satellite data and canal flows from regular field measurements were used to carry out GIS operations and satellite remote sensing for estimating ETact through the SEBAL approach. This approach helped quantify related parameters of the selected performance indicators using image processing, GIS techniques, and performance evaluation data processing. The calculated crop water requirements using the SEBAL model and satellite data were not consistent with the applied water. The physical performance measure in this study indicated that the overall efficiency of the scale irrigation scheme was 35%. This result is relatively poor, falling below the 40-50% range. The findings from this study also showed that irrigation system performance indicator parameters were limited due to excessive water applied to the field. The study revealed an acceptable range of RET (0.8, 0.9); however, the irrigation system's reliability was poor according to field observations at each stage of the crop season. This was due to the field receiving an excessive amount of water. Generally, the Sarkita irrigation scheme operated in a lower range.

Key words ; Sarkita, SABEL, Landsat, RET

1. Introduction

Irrigation performance assessment is an important management tool for implementing, monitoring, and evaluating water delivery services. Murray-Rust and Snellen (1993) and Molden et al. (2001) describe several ways in which irrigation performance tools can be applied. These include operational performance assessments, which describe the functioning of management processes, and strategic performance assessments, which provide information on whether an organization is using resources efficiently.

Irrigation Practice in Ethiopia: Irrigation practice is a crucial factor in the development of many countries. In Ethiopia, the majority of the population relies on rain-fed agricultural production for their livelihood. However, crop production through rain-fed agriculture is insufficient to meet the country’s food requirements. Increased irrigation development, through the construction and functioning of irrigation schemes, boosts agricultural output. Despite this, the performance of irrigation in developing countries, including Ethiopia, remains below the expected standard. Awulachew and Ayana (2009) found that most small-scale irrigation schemes in Ethiopia have low productivity.

Importance of Performance Evaluation: Performance evaluation is a practical tool to assess the success of irrigation management in meeting the growing demand for food. Irrigation performance indicators measure performance and simplify the complex factors affecting the performance of irrigated agricultural systems. These indicators range from water distribution to agricultural, economic, social, and environmental aspects (Bos et al., 1994).

Remote Sensing and GIS: Though remote sensing was identified as a tool for assessing performance over a decade ago (Abernethy and Pearce, 1987), its application has been infrequent. Improved irrigation management and informed decision-making require new tools such as satellite remote sensing and GIS to provide the necessary spatial and temporal information (Thiruvengadachari, 1996).

Challenges in Ethiopia: Irrigation performance assessment is rarely conducted in Ethiopia due to a lack of field-level data. Some attempts have been made to assess the scheme-level performance of some irrigation schemes (Belete, 2006; Habib, 2004; Mekonen and Awulachew, 2009; Yusuf and Tena, 2006). There is a need to develop aggregate indicators to provide insight into the performance of irrigation development under limited data availability. Yercan et al. (2004) employed physical performance indicators in Turkey, showing the extent to which developed schemes meet their objectives. Such indicators are useful in Ethiopia, where measured data are scarce.

Sustainable Management: Satellite remote sensing and GIS offer great promise for natural resources management, predicting different levels of crop response in a spatial and temporal dimension. These technologies aid in efficient resource management to enhance crop productivity sustainably. Sustainable production increases in irrigated agriculture can be achieved by developing new irrigation projects or improving existing schemes' performance. Recently, improving irrigation systems' performance has become preferable to developing new irrigation areas.

Performance Indicators: A large number of performance indicators quantify irrigation performance (Bos et al., 2005). They link socio-economic, institutional, financial, and technical aspects of irrigation management to the physical processes of water distribution, consumption, and crop production. These indicators should have a scientific basis, be easy to use, quantifiable, unbiased, and cost-effective (Bos, 1997). Inputs required to assess physical irrigation performance include measurements of water balance terms such as discharge, evapotranspiration, effective precipitation, crop yields, irrigated area estimates, and cropping intensities.

1.2. Statement of the problem

The Irrigation Department assesses the strategic performance to understand how irrigation schemes utilize available resources. Performance assessment from the operational level of the scheme up to the national level is of prime importance. It is necessary to evaluate whether the current performance assessment program can effectively measure the performance of the schemes and the irrigated agriculture sector.

Performance Gap: The performance gap, or the deviation of actual performance from the target level, determines low performance. Before taking corrective measures, it is essential to diagnose the cause of low performance. By incorporating other indicators related to potential causes, the root causes can be identified through a diagnostic approach. The rationale behind performance assessment is to diagnose any performance gap in the goal-achieving process and rectify the situation. Therefore, managers at different levels should identify the performance gap, find the cause, and take corrective measures to address below-target performance.

Performance in Ethiopia: In Ethiopia, scheme performance is estimated to be an average of 36% below design capacity. Small-scale irrigation schemes account for 90% of this irrigation performance gap (Awulachew et al., 2010a; 2010b). The Amhara region, with its vast potential for irrigation development, faces challenges due to the erratic nature of rainfall and a growing population. Yakob and Melaku (2006) reported that the performance of many irrigation schemes in the Amhara region is far below their potential, mainly due to inefficient irrigation water management and poor repair or rehabilitation.

Irrigation is crucial for agricultural production, food security, enhancing the income of rural people, and public investment for rural development. However, there is widespread dissatisfaction with the performance of irrigation projects in developing countries (Behailu et al., 2004). Objective data on actual field performance is needed to assess performance, but unavoidable time delays in acquiring and processing field data cause delays in decision-making. Satellite remote sensing can provide near-real-time data in an objective and unbiased manner. The irrigation performance for many rivers in West Gojjam has not been investigated or assessed in detail under different irrigation systems. Therefore, this study examines the surface water irrigation performance of the Sarkita River to generate a database for future irrigation expansion or development. The assessment of irrigation performance can also be included in the irrigation development agenda of the West Gojjam Zone, Amhara region, and at the national level.

1.3 Objectives

The main objective of the study **is** GIS and RS-based irrigation performance assessments of the Sarkita irrigation scheme

1.3.1 The Specific Objectives

1. To assess the status of irrigation schemes using performance indicators.
2. To Evaluate the Performance of water requirement and the Relative Water Supply of the study area.
3. To determine actual evapotranspiration using SEBAL and Penman-Monteith Method

2. Materials and Methods

2.1. Description of the Study Area

The Sarkita Small Scale Irrigation Project is located in the Amhara National Regional State, West Gojjam Zone, Bure Woreda, in Wangedam Kebele. The diversion site is geographically positioned at 292318E and 1185897N, with an altitude of 2101m a.s.l. The watershed spans Burie Zuria Woreda and Burie Town administrative kebeles Weynma, Ambaye, and Wangedam.

The site is accessible by driving 4 km on the main asphalt road from Burie-Finote Selam-Addis Ababa, then 2 km on a dry weather road up to the small village called Ambaye, and around 2 km on foot to the diversion site, 105 km from Debre Markos. The scheme includes a diversion weir with a catchment area of about 137.36 km^2 and an annual average rainfall of 87.92 mm.

The project comprises one main canal, the left main canal, and three secondary canals. It irrigates 53 hectares of command area, benefiting 116 farmers. Water is diverted from a weir constructed across the Serkita River into a rectangular masonry canal that runs for 2.2 km from the diversion point to the end of the scheme (Design Document).

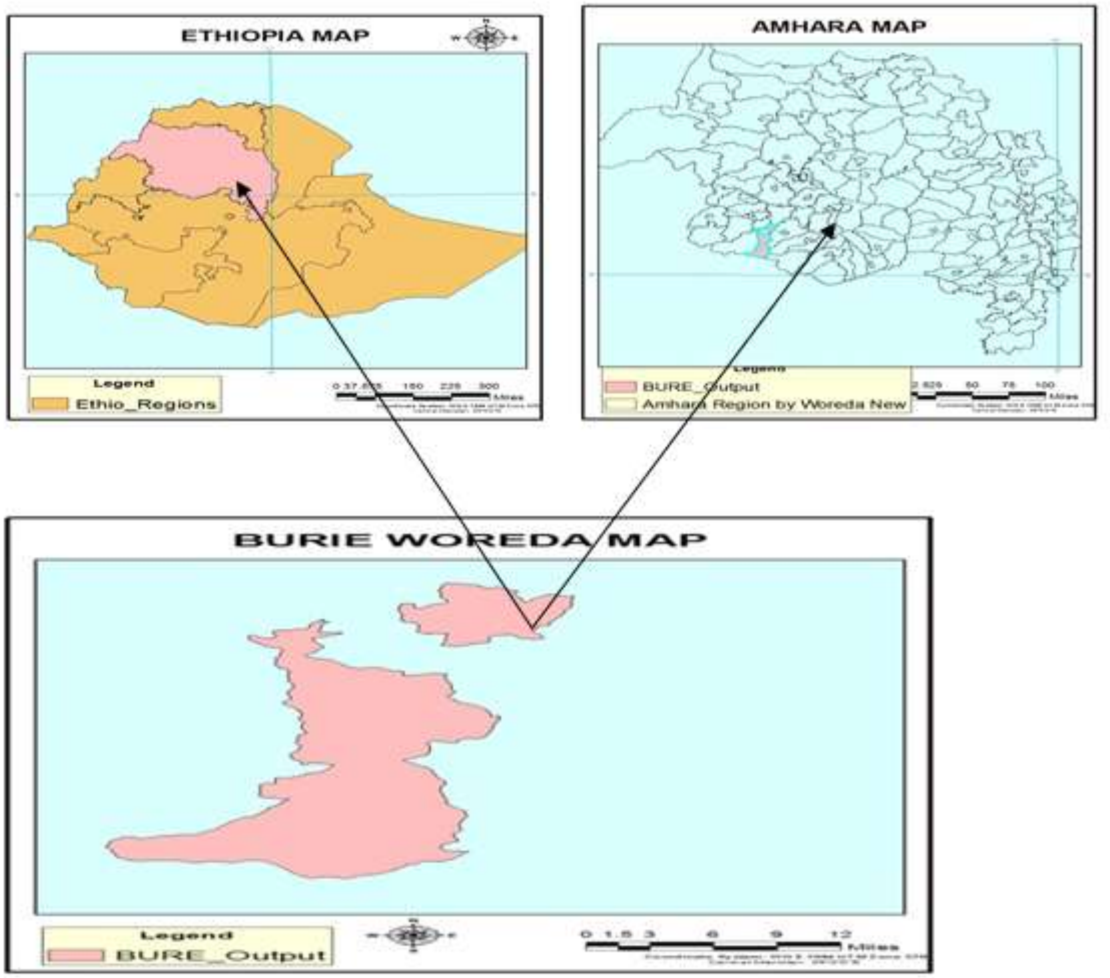


Figure 1 Map of the study area

2.2 Data Collection and Analysis

The methodology applied in this study includes several stages: (1) generating digital data layers; (2) fieldwork; (3) generating crop pattern maps; (4) calculating evapotranspiration; and (5) performance assessment. ArcGIS 10.8 geographic information systems (GIS) software and remote sensing software were used to create the digital database.

Data were collected from both primary and secondary sources. Primary data were gathered from Woreda Agricultural Office experts, consultations with some farmers regarding the general condition of the irrigation scheme, and field measurements/observations. Secondary data were collected through a literature review and formal and informal communication with respective organizations, as well as interviews aided by questionnaires. Climate data, including monthly average temperatures, wind speed, sunshine hours, and minimum relative humidity, were obtained from the Ethiopian Meteorological Agency (EMA). GPS readings were also taken from the study area.

The remote sensing inputs used for this study include Landsat ETM+ data with a spatial resolution of 30m for visible and near-infrared bands (b1 to b5 and b7) and 60m resolution for the thermal band (b61 and b62) at satellite nadir.

2.3 Primary data

The primary data were collected directly from the field and laboratory. This included activities such as dis charge measurements, questionnaires, number of beneficiary farmers/households, field observations, and l aboratory results.

2.4 Secondary Data

In addition to primary data, secondary data were collected from various necessary sources. The secondary data included documents, studies, and other useful written materials needed for the study. These sources provided information on the documented layout of the scheme, irrigated area, area irrigated per crop per season/year, crop types, cropping patterns, and the role of the irrigation water user's association. Based on interviews developed from Woreda Agricultural Office experts' and farmers' questionnaires, key constraints of scheme performance were identified.

2.5 Materials Required

In this study, the surface water irrigation performance assessment of the Sarkita irrigation scheme was conducted by implementing a digital elevation model (DEM) on GIS. In addition to estimating the irrigation water demand and supply command area of the scheme, the following materials were used:

- Climate/Meteorological data
- Stream flow of rivers in the catchment
- Software: ArcGIS 10.1, DEM, remote sensing (RS), and Cropwat 8.0 computer model
- GPS (Geographical Positioning System)
- Google Earth
- ERDAS Imagine
- Current meter
- Measuring tape
- Camera

2.6 Methods

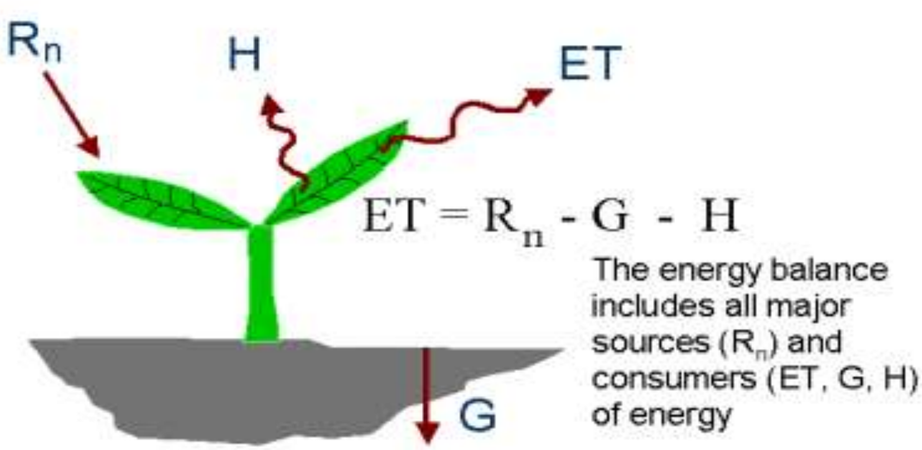


Figure 2 Energy Balance

Where ET is the latent heat flux (W/m²), Rn is the net radiation flux at the surface (W/m²), G is the soil heat flux (W/m²), and H is the sensible heat flux to the air (W/m²). The data needed for this study were collected in an agricultural field across four different stages of irrigation water supply. These stages included:

1. Early Stage (ES)
2. Planting Stage (PS)

3. Middle Stage (MS)
4. Harvesting Stage (HS)

To measure the quantity of water diverted to the field and soil moisture, data was collected from these stages. Additionally, three reaches of the canal section were selected to assess soil moisture and measure the amount of water diverted to the field. The canal length was used to measure the amount of water using a partial flume, and soil moisture was assessed before and after irrigation using an auger.

The experimental plot was situated in a single path and row overlap zone (120 and 30). Actual and potential evapotranspiration were evaluated using satellite images acquired by the Enhanced Thematic Mapper (ETM) sourced from the United States Geological Survey (USGS) portal. The images were analyzed and evaluated using the ARC GIS image analysis section.

Table 1 image source and acuried year

Image type	**Path/Row**	**Year**
LC08_L1TP	169/052	2020
LC08_L2SP	169/052	2021
LC08_L2SP	169/052	2022
LE07_L2SP_	169/052	2023

2.6.1 SEBAL Procedure

The first step in the SEBAL procedure involves computing the net surface radiation flux (Rn) using the surface radiation balance equation. This is done through a series of steps using the ERDAS Model Maker tool to compute the terms in the following equation. Below is a flow chart of the process:

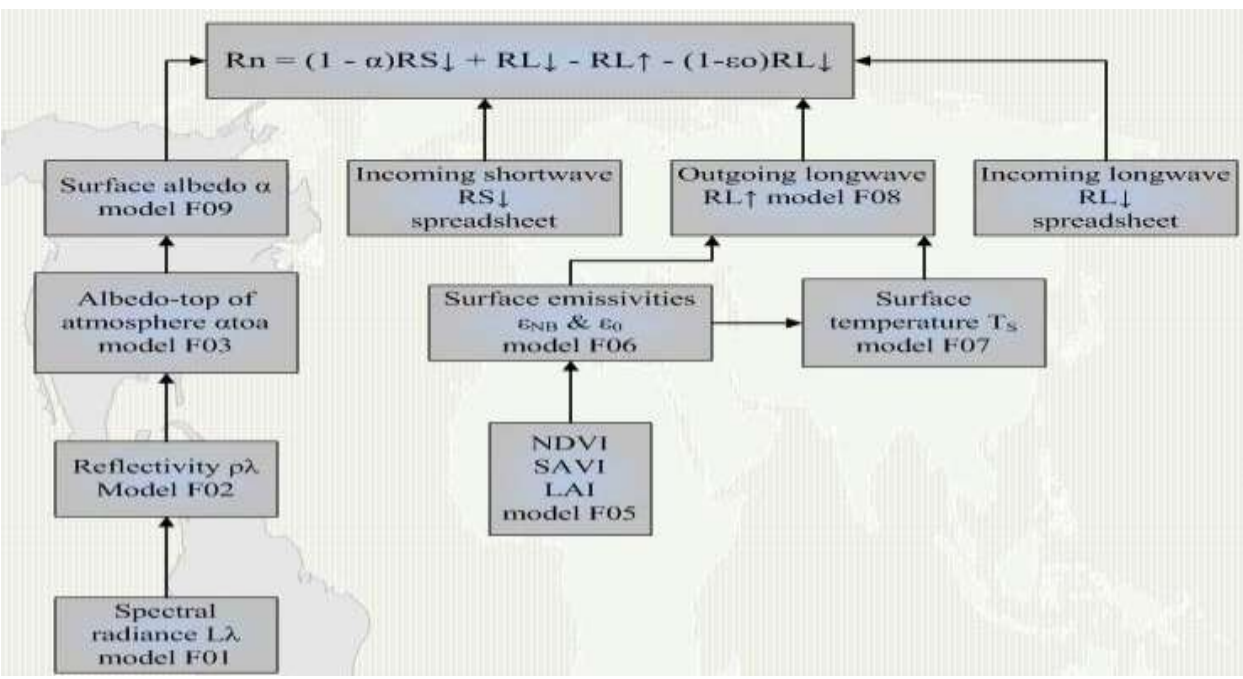


Figure 4 Flow Chart of the Net Surface Radiation Computation(source Bastiaanssen, 2002)

The computer model number used for each computation is provided along with the variable name. The computation steps begin at the bottom of the figure with model F01 and continue upward to model F09 for the computation of Rn. The two terms RS↓ and R are computed with a spreadsheet or a calculator rather than the Model Maker tool.

In summary, SEBAL is applied following these steps:

a) Calculation of Rn for each pixel from Eq. 2 b) Calculation of G for each pixel from Eq. 3 c) Definition of the dT function (Eq. 6) using dT and Ts obtained from the two "anchor" pixels d) Calculation of dT for each pixel from the pixel surface temperature, using Eq. 6 e) Calculation of H for each pixel from Eq. 5 f) Calculation of LE (ET) from Eq. 1

All energy balance fluxes (Rn, G, H, and LE) represent instantaneous fluxes corresponding to the moment when the satellite image was taken.

2.6.2. Irrigation Performance Indicators

A large number of performance indicators are used to quantify irrigation performance (Bos et al., 2005). These indicators link technical, socioeconomic, environmental, institutional, and financial aspects of irrigation management to the physical processes of water distribution. The indicators can be applied at various scales, from plot level to irrigation system level, and require different input data depending on the scale and complexity. Moreover, indicators should have a scientific basis, be easy to use, quantifiable, unbiased, and cost-effective.

Performance Indicators for Serkita SSI Command Area: The main output considered is crop production, with the major inputs being water and land. The performance indicators computed include irrigation intensity, water utilization index, depth of water applied, overall consumption rate, relative water supply, output per unit cropped area, and water productivity. These were based on cropped area, command area, potential evapotranspiration, water diverted from the main canal, rainfall, and crop production.

Based on the potential irrigation performance indicators that can be quantified using remote sensing and available ground data, five performance indicators were evaluated in our study:

1. Relative Evapotranspiration (ETrel)
2. Depleted Fraction (DF)
3. Overall Consumed Ratio (ep)
4. Crop Water Deficit (CWD)
5. Relative Water Supply

2.7 Relative Water Supply (RWS)

The two most crucial factors in irrigation planning, design, and operation are the available water supply a nd water demand. Relative Water Supply (RWS) is defined by Levine (1982) as the ratio of water supply to water demand, expressed as follows:

RWS=Water SupplyWater Demand

$$RWS = \frac{\text{Amount of water diverted to the scheme}}{\text{Water demand of the scheme}} = \frac{\text{Total Water supply}}{\text{Water demand}} \qquad (3.2)$$

Demand may be based solely on technical criteria, such as evapotranspiration, soil water requirements such as those used for estimating land preparation water requirements, and it may include water lost through natural seepage and percolation. Water supply may include irrigation and effective rainfall waters.

2.7.1 Overall Consumed Ratio (ep)

The Overall consumed ratio (efficiency) quantifies the degree to which the crop irrigation requirements are met by irrigation water in the irrigated area (Bos and _ Vugteren,1990). The ratio is expressed as follows:

$$\text{Overall Consumed Ratio} = \frac{\text{Crop Irrigation Water Requirement}}{\text{Total Inflow into Canal System}} \quad (3.3)$$

$$eP = \frac{ETp-Pe}{Vc}$$

Where, ETp = Potential evapo-transpiration (mm) and Pe = Effective rainfall (mm).

Vc is the volume of irrigation water diverted from source)If the Supply is sufficient eP value around 1.0 if it is greater than one it indicates under irrigation whereas value < 1.0 indicates over irrigation.

2.7.2 Depleted Fraction

Irrigation provides water necessary for crop development and can positively affect crop yields. Maximum crop yield is achievable if the required water quantity is applied at the right time. However, excessive irri gation can decrease crop yield and pollute groundwater and the environment due to nutrient loss through l eaching and runoff.

To analyze water depletion in irrigation systems and at the watershed level, components such as actual ev apotranspiration (ETa), precipitation, and irrigation water (excluding the drainage component) are used in the depleted fraction estimation. This can be calculated using the following equation:

Depleted Fraction=ETa+Precipitation+Irrigation WaterTotal Water Supplied

(Bos and Bastiaanssen, 2003):

$$\text{Depleted fraction*} = \frac{\textit{ET act} \text{ from the gross Command Area}}{\text{Surface Water and precipitation on gross com. area}}$$

$$DF = \frac{ETa}{P+Vc} \quad (3.4)$$

Where ETa is the actual evapotranspiration, VC is the river diversion, and P is the precipitation.

The acceptable range of DF value is considered 0.6-1.1 (Bastiaanssen, 2001).

2.7.3 Crop Water Deficit

Crop water deficit over a period is defined as the difference between the potential and actual evapotranspiration of the cropping pattern within an area, as determined by the water manager. A common period for this measurement is one month.

Thus:

Crop water deficit = ETp-ETa (in mm/month) (3.5)

If an average crop water deficit of 1 mm/day, or 30 mm/month, is accepted, then only a few of the lateral units are within the proper range. The availability of data for each pixel allows for the computation of the average and standard deviation of the indicator. Additionally, the percentage of pixels outside the accepta ble range of the performance indicator can be calculated. Thus, remote sensing data are suitable for obtain ing spatio-temporal information on irrigation performance.

2.7.4 Actual Crop Evapotranspiration

The Penman-Monteith method is used to calculate reference evapotranspiration (ETo). Crop water requirement (ETc) was calculated by the formula (ETc =ETo x Kc). Net irrigation (In) was also calculated as In = ETc-Re and approximate net irrigation depth per irrigation application could be taken by assuming the root depth of each vegetable crop and soil type of the study area. Some irrigation applications can be calculated from: the irrigation water needs over the growing season / net depth of each irrigation application (FAO, 1995). The amount of water that is lost through the evapotranspiration process from the disease-free and well-fertilized crop fields is known as potential crop evapotranspiration (ETc).

2.7.5 Crop Water Requirement

Crop water requirements (CWR) are calculated based on monthly effective rainfall (Peff) and reference evapotranspiration (ET), the first being calculated from average rainfall following the Penman-Monteith approach (FAO-56, 2006). The CROPWAT model - a computer program for crop water requirement calculations developed by FAO (FAO, 1995a) – was used to compute net irrigation water requirements.

2.8 Geographical Information Systems Methods

GIS will be used for mapping contours, soils, and ground data for land use classification and the display of geo-referenced data.

2.8.1 GPS Application

Satellitebased GPS provides accurate georeferenced positional locations (in terms of latitude and longitude) and boundaries. This technology is also used for land use and land cover classification, which is essential for accurately assessing evapotranspiration across different land uses.
The flow chart of the methods followed is shown in Figure 4 below

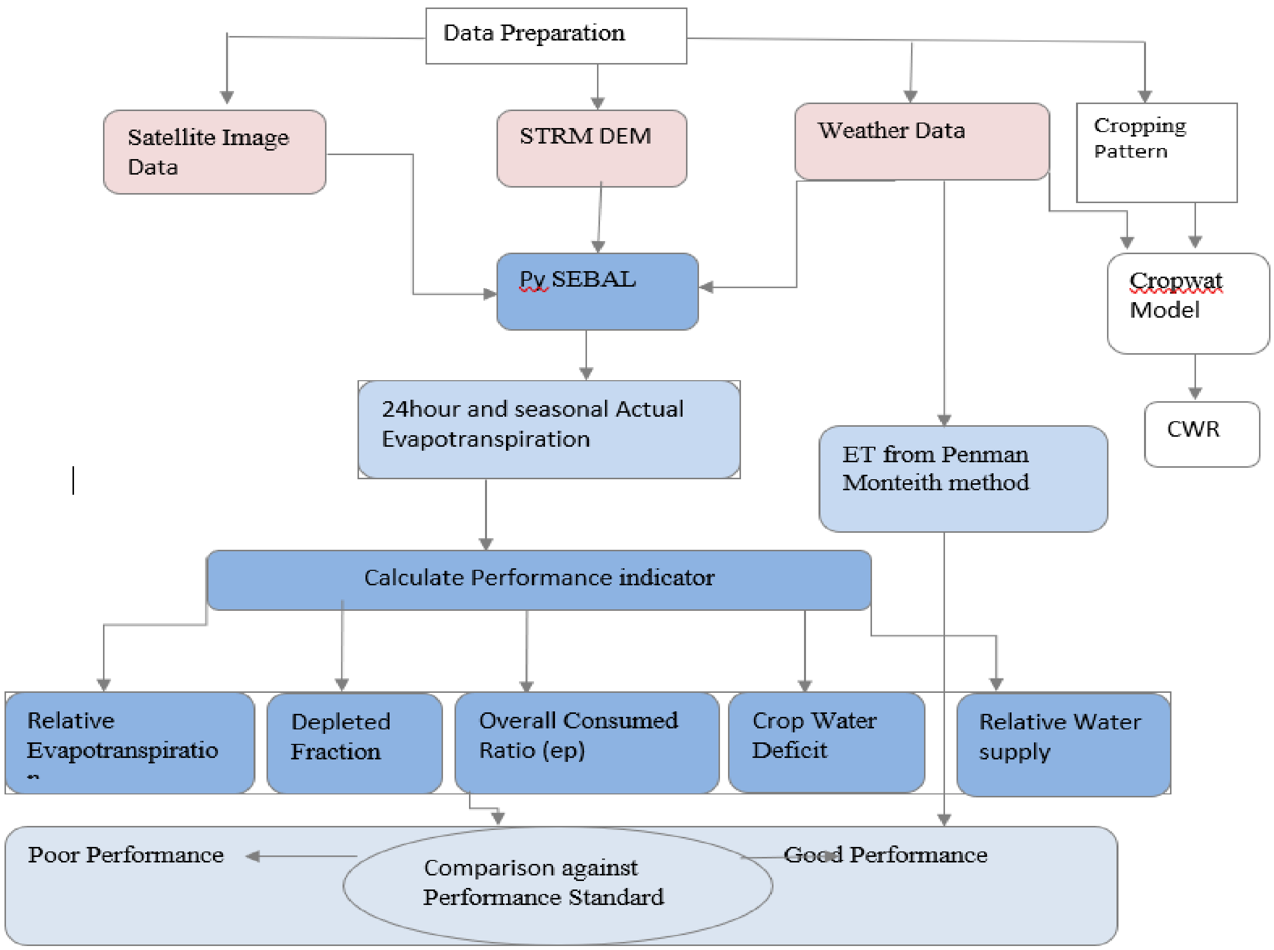


Figure 3 the flow chart of the method for assessing irrigation Performance in the Serkita irrigation scheme

For this study, performance assessment for surface irrigation systems will be identified using a GIS-based Multi-Criteria Evaluation (MCE) and remote sensing techniques. The irrigation water demand will be determined from the water requirements of different combinations of commonly grown crops in the study area. To perform these tasks, the following datasets will be collected or determined:

a. Climate Data
b. Soil Data

c. Land Use Data
d. Crop Data

2.8.2 Indicators Selected for Irrigation Performance BY SEBAL Method

Cropping Intensity: Derived from a long-term normalized difference vegetation index (NDVI) time series (Dec 2010-March 2022). Water Productivity (WP): Defined as the estimated crop yield divided by water consumption from evapotranspiration. Uniformity: The coefficient of variation (cv) of water consumption by evapotranspiration to evaluate the uniformity of water consumption. Head-Tail Performance Indicator: Assesses the spatial pattern of water consumption, crop yields, and water productivity among irrigators in head and tail reaches. The methodology involves spatially assessing biomass production and water consumption using actual evapotranspiration data based on satellite images and the SEBAL algorithm.

2.8.3 Evapotranspiration and Crop Yield

The Sarkita irrigation project field practice assumes that the root-zone soil moisture content is always adequate for evapotranspiration. Therefore, crop researchers in the country have not established any specific relationship between evapotranspiration rate and grain yield, even for academic interest. When considering production/water use relationships, one should consider the water use by the crop only, i.e., transpiration. Photosynthesis and dry matter production are directly related to transpiration through the processes of diffusion of carbon dioxide and water vapor through the stomata of the leaves.

Hence, water use efficiency of plants can be defined as dry matter yield (Y) in kg/ha per unit of transpiration (T) in mm (kg/ha mm). When plotting Y versus T, water use efficiency represents the slope 'a' of the Y-T line. Often, transpiration (T) cannot be directly determined, but evapotranspiration (ET) can be measured. In linear Y-ET relationships: $Y = a \cdot ET - b$ where the intersection of the line with the horizontal ET-axis is interpreted as the total amount of evaporation from the soil, with 'a' and 'b' being the regression constants.

Stewart et al. (1977) showed field results of maize grown under different irrigation regimes and water quality, where 97% of the variation in dry matter production could be explained by changes in evapotranspiration. The Gilat maize data of Hillel and Guron (1973) showed Y-ET relationships different from the Davis data of Stewart et al. (1977), indicating that the Y-ET relationship may vary by region and year.

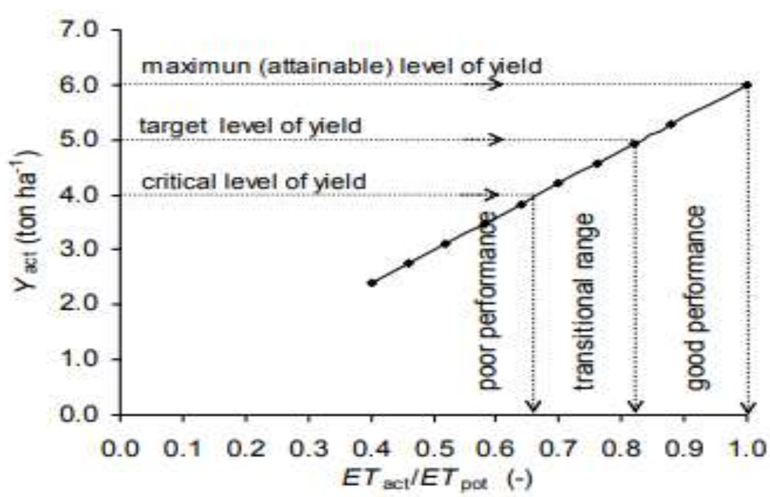


Figure 4 The linear relationship between actual grain yield Yact and the relative evapotranspiration

2.8.4 Flow Measurement Fieldwork

The true carrying capacity of the irrigation canal was determined using a current meter, with measurements taken once a week for three months at various locations along the canals to document temporal and geographical variations in irrigation water flows. Canal discharges were measured at 200-m intervals through secondary canals, starting at the system's intake, with 12 replications of measurements at each location.

The discharge at each location was computed using the area–velocity methodology and the mid-section method of discharge computation, ensuring accuracy through multiple replications. Canal diameters were first measured with a tape meter, and cross-sectional areas were calculated, with multiple replications taken to reduce measurement errors.

In the research areas, the waterways are clay canals with irregular shapes, so multiple replications of measurements were taken to account for variations in shape and size. The velocity of flow through the canal was measured using a current meter. Flow velocity was calculated using the propeller rotation speed (n) obtained by the control unit at three segments of the canal flow width. The mean flow velocity was calculated using the average rotation speeds. Flow depth was measured at specific canal locations, and flow rotations were recorded using a current meter and stopwatch.

Following that, the actual discharge of each segment was calculated by multiplying the segment's average area by the flow velocity. Finally, the average real carrying capacity of the canal was calculated by aggregating the average discharge for each segment.

3. Results and Discussion

3.1 Rainfall Data Analysis

The rainfall conditions at the Sarkita irrigation project are abundant and sufficient for summer agricultural activities for the nearby farmers. The rainfall conditions and the average effective rainfall pattern were analyzed, and the average values for those watersheds were satisfactory. Rainfall and runoff are also determinant factors in evaluating irrigation performance indicators and the rise and fall of irrigation capacity in the Sarkita irrigation project. Below is a schematic view of the rainfall-runoff pattern.

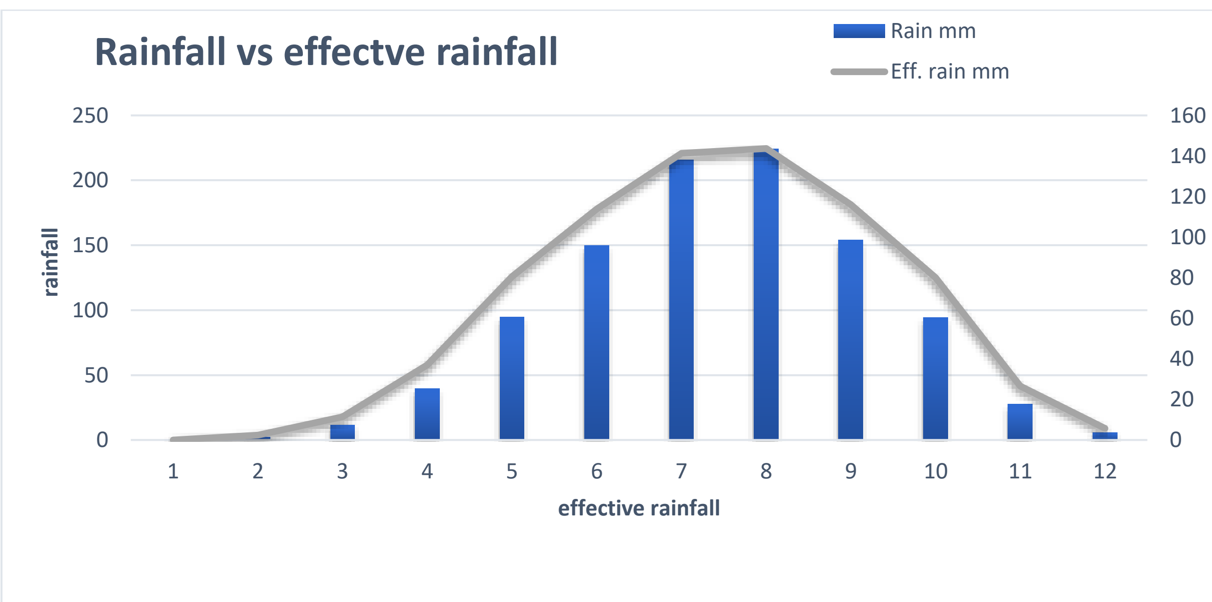


Figure 5 Rainfall analysis

Table 2 Evaluation of metrological analysis

Month	Min Temp °C	Max Temp °C	Humidity	Wind	Sunshine	Radiation	ETo
			%	km/day	hours	MJ/m²/day	mm/day
January	11.3	25.6	53	88	9.8	22.7	4.66
February	13.2	27.7	55	79	9.8	23.7	4.51
March	11.8	26.4	46	69	6.9	26.4	3.77
April	14.6	27.4	51	90	9.7	20.7	4.23
May	14.5	28.8	67	85	8.6	17.6	3.17
June	12.5	28.4	83	67	5.5	19.9	3.56
July	12	24.5	80	74	4.9	15.9	3.71
August	11	25.9	76	49	5.7	17.3	4.89
September	12.3	22.3	81	65	6.5	19.8	3.63
October	14.3	28.4	77	63	5.7	16.8	4.62
November	14	22.5	69	61	8.8	23.4	4.63
December	12.1	28.5	69	75	9.3	22.6	3.89
Average	**12.8**	**26.4**	**67.3**	**72.1**	**7.6**	**21**	**4.10**

3.2 Data used in the Calculation of Irrigation Performance Indicators

Table 4 shows the monthly and seasonal values of the Vc, Pg, and Pe parameters required to calculate the selected irrigation performance indicators for the 2022-2023 irrigation season. The amount of water released to the field within the two seasons was recorded using a staff gauge for selected months over one year. The amount of discharge, calculated in m^3/s, was converted to millimetres (mm). Tables 7 and 8 show the monthly and seasonal values of the ETa and ETp parameters required to calculate irrigation performance indicators for the 20222023 irrigation seasons. Wheat and onion were the most dominant crops on the Sarkita irrigation development project site. Table 5 shows the crop areas for the 2022-2023 irrigation seasons at each upper, middle, and lower canal reach. The total area in the surface irrigation system was evaluated concerning the wheat and onion plantation and harvest stages. ETa and ETp values vary among pixels in Tables 5 and 7 due to crop pattern variation, vegetative growth, and poor irrigation water operation. Table 5 also shows the results of irrigation system performance indicator parameters.

3.2.1 Overall Consumed Ratio(ep)

Because the total water supply was the first measurement in an irrigation system, ep would be the first available indicator in each experimental area. Table 3 shows the monthly values of the ep indicator for evaluating irrigation performance. The following ep indicator values were obtained:

- ES: (0.6, 0.6, 0.5, 0.6) for October, January, April, and July
- PS: (0.6, 0.7, 0.3, 0.6) for October, January, April, and July
- MS: (0.6, 0.6, 0.4, 1) for October, January, April, and July
- HS: (0.5, 0.6, 0.8, 0.6) for October, January, April, and July

Some sites yielded extremely high results, while others yielded negative results, indicating that ETP was less effective than effective precipitation. This condition developed as a result of excessive water delivered from the source to the irrigation field. The highest ep values for all selected months, except HS in July, were observed during the study period. Except for HS in July, these values were less than the expected value. This result demonstrates that in all stages of the plant growing season, monthly irrigation water application necessitates the use of some irrigation management techniques.

Table 3 shows the seasonal values and temporal variation of the ep indicator. The overall stages of the average seasonal ep indicator were less than the target value of 1. This is a clear indication that the water application technique was ineffective for all stages. The results show that all stages indirectly raised the groundwater table the most and had the poorest performance with the lowest ep value. This could be influenced by the fact that there was unscheduled irrigation application and poor operational performance of the systems.

Due to the relatively balanced approach, there is a spatial variation in the irrigation system's efficiency in the July MS experimental field. This was supported by the crop's relatively good efficient performance value, which limited some extra water percolation to the root zone. This entire treatment (ES, PS, MS, HS) must use scheduled irrigation application, thus inducing some water flow to the field. The Sarkita irrigation project was unable to harvest crops on time due to drainable surplus water, which generally indicates that there was proper irrigation application but ineffective water use in the irrigation schemes. As a result, the irrigation performance in this regard is not good.

Table 3 Overall consumed ratio (EP)

Stages	Oct	June	April	July
ES	0.6	0.6	0.6	0.6
PS	0.6	0.7	0.3	0.6
MS	0.6	0.6	4	1
HS	0.5	0.6	0.8	0.6
total	2.3	2.5	2.1	2.8

From an economic development standpoint, the system was inefficient. As a result, irrigation agronomists must avoid irrigating crops, particularly in April close to harvest time, to keep the water content in the dominantly grown cereal crops as low as possible. During periods with low ratios, indicating that the overall consumed fraction of water was shown in all experimental stages, extra water added to the field that was not consumed by the crop caused the groundwater table to rise. When the ratio is close to 0.6, groundwater must be pumped out from the irrigation field, and irrigation water management techniques must be used to solve the drainage problem.

The ep indicators vary from month to month due to variations in monthly water requirements, effective precipitation, and water volume obtained. As a result, all stages in the study experienced increased irrigation problems during the 2022-2023 irrigation seasons. However, the average ep values for all of the project areas were experiencing excess water supply, which induced surface drainage problems.

Reported results from another study showed the seasonal averages of the ep for the Geray, Chemoga, Gedeb, and Taba water use associations in the upper Blue Nile Basin were 0.66, 0.09, 0.78, and 0.79, respectively, for the 2022 irrigation season. These values are comparable to the monthly results obtained in this study for all stages of the crop sown season.

Table 4 Amount of the water diverted from source (Vc), total precipitation (Pg)

Stages	Oct	June	April	July	Sum
ES	298	258	256	102	915
PS	274	285	220	170	950
MS	300	281	114	114	810
HS	313	270	213	64	860
pg(mm)	0	27.3	48.3	285	361
pe(mm)	0	26.1	45	155	225

Table 5 Values of monthly and seasonal actual evapotranspiration (ETa) during 2022-2023

Stages	Oct	June	April	July	Sum
ES	168	177	172	168	685
PS	150	170	169	174	663
MS	156	172	172	180	680
HS	156	177	168	171	672
Average(MM)	158	174	170	173	675

3.2.2 Depleted Fraction (DF)

A critical value of DF (0.6) indicates that if ETa is less than about 0.6 (Pg + Vc), a portion of the water applied to the field raises the groundwater table, causing agricultural field drainage problems. In contrast, crop water requirements increase if ETa is greater than 0.6 (Pg + Vc).

Table 6 shows the monthly values of the DF indicator for evaluating irrigation performance. As shown in Table 6, there are no values of the DF indicator for all stages (planting, early, middle, and harvesting: ES, PS, MS, HS) that exhibit good performance. Some unnecessary water was added to the field, which must be safely avoided.

Except for one case, the averages of DF values for all stages in the Sarkita irrigation project area had ETa values less than the critical value (0.6 (Pg+Vc)). In this study, MS in July had a relatively safe water dose in the study area. Still, results from other sites show that the unused portion of water delivered from the source in these remaining months may feed the groundwater. A large amount of extra water was delivered from a nearby source, but the plants consumed nearly as much water while the excess had to be removed from the site.

The researcher observed the field using an auger at different root depths in all stages until one meter. There was soil moisture, indicating that extra water was supplied. The DF results of all stages were especially low in MS in July, indicating excessive water application. This value may be influenced by a poor irrigation system, which could cause the groundwater table to rise.

The monthly DF values for all stages were far below the critical value, indicating that a significant portion of the water delivered from the source during these months (except for MS in July) could not have been consumed by the plants. This observation could explain the inadequacy of the irrigation system and the experience of low water conditions in the irrigation field.

According to literature and different scholars, adequacy is defined as a value close to both the upper and lower parts of the number (0.6(vc+pg)) to ETa. If 0.6(vc+pg) is less than ETa, a drainage problem has occurred, and irrigation water management is required. If 0.6(vc+pg) is greater than ETa, the crop is under water stress and requires additional water application. Adequacy relates to crop water requirements, and anything above or below these requirements indicates inadequacy in irrigation performance.

Except for MS in July, the performance of all stages was within acceptable limits. As determined by the other performance indicators in Table 6, this result can be attributed to poor irrigation water application and management. Values for diverted water were quite high for all treatments, and DF values fluctuated erratically, indicating neither good operation nor good water application had been achieved. The seasonal value for this water use association was found to be 0.6 in this study, consistent with findings from other studies. Seasonal averages of DF for the same basin's Geray, Gedeb, and Taba were found to be 0.55, 0.57, and 0.88, respectively. These values are nearly identical to the monthly values identified in this study

Table 6 Depleted fraction (DF), (2022-2023)

	Oct	**June**	**April**	**July**
ES	0.58	0.57	0.45	0.54
PS	0.57	0.59	0.37	0.56
MS	0.58	0.57	0.4	0.96
HS	0.57	0.53	0.5	0.59
Total	2.3	2.26	1.72	2.64

Table 7: Values of monthly and seasonal potential evapotranspiration (ETp) during the 2022-2023 irrigation season

ETP	Oct	June	April	July	Sum
ES	187	215	220	210	830
PS	193	211	213	187	803
MS	211	144	144	130	628
HS	192	210	223	198	822
Average(mm)	196	200	200	181	770

3.2.3 Relative Evapotranspiration (RET)

Table 8 shows the monthly values of the Relative Evapotranspiration (RET) indicator. All stages of the crop season had the highest RET values in January and July due to minimal variation in the monthly sensible heat flux. Between January and July, most crop leaves were covered in moisture, resulting in the highest sensible heat flux. In this study, all stages of RET values were greater than the critical limit. RET, the ratio of actual to potential evapotranspiration, had values as follows: ES (0.9, 0.8, 0.8, 0.8) in October, January, April, and July, respectively. Other stages, such as PS, MS, and HS, had values similar to those of ES. These results align with the recommended values for the study area's irrigated agricultural land (Table 8). According to Bastiaanssen, the operational range for RET is 0.8 to 1, and the acceptable range is 0.7 to 1. The findings from the current study are within this range, indicating reliable irrigation system performance in the study area. The monthly RET performance for all stages of crop growth in all irrigation schemes was suitable. The values from the study area also show the temporal variation of the RET indicator. The average RET values in the Nilo Coelho irrigation system in Brazil, determined using remote sensing, were 0.7, 0.76, and 0.8. Even though the RET averages for the stages in the study area were greater than 0.75, indicating system reliability under water stress conditions, it was not applicable under water excess conditions.

As stated previously, three indicator results show extra water in the irrigation field, implying a greater problem with water supply. These findings are similar to the monthly averages obtained in the current study but generally worse than those of most Ts.

Table 8 Table Relative evapotranspiration (RET)

	Oct	June	April	July
ES	0.9	0.8	0.8	0.8
PS	0.9	0.8	0.8	0.8
MS	0.9	0.8	0.8	0.8
HS	0.9	0.8	0.8	0.8
Total	3.6	3.2	3.4	3.8

3.2.4 Evaporative fraction

Table 9 displays the monthly values of the ʌ indicators. Every stage in every monthly value exceeded the critical limit evaporative fraction. However, if the total crop water requirements (ETp) in Table 9 were evaluated alongside total monthly values of potential evapotranspiration (ETp), it can be stated for all months that some water not consumed by the crop was percolated to the groundwater.

A lack of month-to month consistency in the ʌ indicator can also be seen in the values (Table 9). However, it exhibited the same homogeneity variation across three performance indicators. A study on the Geray development irrigation system in Ethiopia showed ʌ values in the range of 0.7-0.9. According to Bastiaanssen, this was a direct result of keeping the topsoil moist through irrigation and having a nearly complete crop cover.

These findings led to the conclusion that the evaporative fraction in this study, above the critical value (0.8), indicated that the crop was not under water stress, and numerical variation within the same stage indicates that water distribution varied. In general, during surface irrigation methods, equity was under requirement or simply not achievable from a crop development perspective. There is no equity if you add more water than the crop requires or less water than the crop requires.While all months, except for October, showed water distribution within acceptable limits, there was no equal or uniform distribution of water to meet crop water requirements. According to the findings of this study, the monthly ʌ indicators for all stages were within critical limits. Another study found that the monthly value of ʌ during an earlier mango energy balance study in 1998 was 0.73 in August, 0.86 in September, 0.78 in October, and 0.80 in November, although these values are comparable to the monthly values obtained in this study.

Lotufo stated that an evaporative fraction (ʌ) value of around 0.83 corresponded to a 67 percent degree of soil moisture saturation in the root zone, which is consistent with our arguments.

Table 9 Evaporative fraction

Stages	Oct	June	April	July
ES	0.91	0.85	0.85	0.84
PS	0.9	0.84	0.84	0.81
MS	0.91	0.84	0.84	0.82
HS	0.9	0.85	0.85	0.82
Total	3.62	3.38	3.37	3.3

3.2.5 Water Supply Ratio

The total annual water delivery per command area, total annual water delivery per irrigated area and annual relative water supply ratio investigated to determine the water delivery performance. To determine the total area,land belongs to both the government and the individual farmers in the region in general and in the project area in particular area areincluded. The discharges of water released in to the Zengini irrigation area were 150, 245, 320, 350 and 450 l/s in respective years. The total annual water delivery per hectare and its water delivery in the command area are shown below. As can be seen from the table, the irrigation capacity has been increasing every year since the project began to provide irrigation services until now. It means that the irrigation capacity is increasing. Similarly, irrigation water inflow increased from 78840 m^3 to 236 520 from 2019 to 2023. Irrigation ratio also increased from 16.97% to 22.03%. The annual water supply rate also increased from 549, 847, 1106, 1210 and 1556 in m^3/ha for the respective year. The total annual water delivery per irrigation area was larger coverage in 2023 while, its minimum values in m3/ha were observed in 2019 its value was 3055.8.

Table 10 Water supply evaluation of the irrigation scheme

Years	Annual volume of irrigation water inflow (m^3)	Irrigated Area (ha)	Command Area (ha)	Irrigation Ratio (%)	Total annual water delivery per Irrigated area (m^3/ha)	Total annual water delivery per Command area (m^3/ha)
2019	77 840	53.3	116	16.97	1460.4	671
2020	123840	55.8	116	18.55	2219.4	1067
2021	133 192	57.9	116	19.47	2300.3	1148
2022	153 960	58.1	116	21.25	2649.9	1327
2023	173 520	58.8	116	22.03	2951.0	1495
Total						

Table 11 Relative water supply ratio

Years	Total annual volume of irrigation water inflow (m^3)	The total volume of water required by the crop (m^3)	Relative water supply
2019	78 840	79, 950	0.98
2020	128 772	110,220	1.16
2021	168 192	156,780	1.07
2022	183 960	145,450	1.26
2023	236 520	115,000	2.0

3.2.6 Conveyance efficiency

Table 12 Convieance efficiency of (Upper, Middle and Lower) Reach

Cross Section	Depth (m)	Width (m)	Area (m^2)	Velocity(m/s)	Q (m3/s	Conv.Efficiency (%)	Remark
Upper canal	0.18	0.5	0.054	0.05	0.0027	77.7	Upper
Lower canal	0.15	0.5	0.03	0.70	0.0021		
Upper canal	0.18	0.5	0.09	0.019	0.00171	82.5	Middle
Lower canal	0.13	0.5	0.065	0.063	0.00141		
Upper canal	0.14	0.5	0. 07	0.089	0.0063	41.2	lower
Lower canal	0.11	0.5	0.055	0.046	0.0026		
Upper canal	0.09	0.4	0.036	0.047	0.001692	41.13	Upper &middle
Lower canal	0.12	0.4	0.048	0.0145	0.000696		
Upper canal	0.16	0.4	0.064	0.030	0.00192	56.25	

Lower canal	0.18	0.4	0.064	0.015	0.00108		Middle &lower

3.2.7 Application Efficiency

Table 13 Application efficiency of irrigation efficiency

Field	Code	Applied Depth	Average depth	Application efficiency, Ea %
Upper	P1	20.2	15.5	76.7
	P2	23.6	17.5	74.1
Middle	P1	20.1	14.7	73.1
	P2	22.6	18.2	80.5
Lower	P1	21.3	15.8	74.1
	P2	24.0	14.8	67.2

3.2.8 Distribution Uniformity

Distribution Uniformity (DU%) measures whether all plants receive the same amount of water, expressed as a percentage (%). The higher the distribution uniformity, the better the irrigation system works. The computed distribution uniformities (DUs) showed strong similarity across the irrigation field, with all DU values greater than 50%. Performance in the upper, middle, and lower regions had DU values of 95%, 86%, and 60%, respectively.

Nevertheless, these values were generally lower than expected for pressure-compensated irrigation systems. Comparing these values with the standard DU for irrigation of 85% indicates that all ranges were performing at an acceptable level, though still underperforming.

3.3 Overall Scheme Efficiency

The overall scheme efficiency is the ratio of the water made available to the crop to the amount released at the headwork. In other words, it is the product of conveyance efficiency and application efficiency. In the present study, the overall efficiency of the scale irrigation scheme, evaluated using equation (3.7), is 35.268%. This result indicates relatively poor performance, as it falls below the expected range of 40%-50%.

3.4 Satellite remote sensing approach to determine crop parameters

Actual evapotranspiration (ETact) is one of the water balance components used to assess the performance of irrigated crops. For the Sarkita irrigation scheme, field measurements of ETact are not available. To evaluate the actual evapotranspiration condition, the Surface Energy Balance Algorithm for Land (SEBAL) approach was used to compute ETact over the cropped area using MODIS images. The images were downloaded from the USGS (United States Geological Survey) portal with a 30 by 30-meter resolution.

The SEBAL approach requires a limited number of weather data, which are available from the National Meteorological Agency of Ethiopia, with the nearest gauging station located in Burie Woreda. For accurate computations, potential evapotranspiration (ETpot) was estimated using the Penman-Monteith approach. Additionally, above canopy net-radiation derived from remote sensing measurements was also incorporated. A remote sensing model applying reflectance data was used to estimate the seasonal grain yield prior to harvesting.

3.5 Accuracy Assessment

The actual evapotranspiration (ETact) error due to the spatial scale of the MODIS images was described as the deviation of ETact with respect to those derived from the Landsat data. The input parameters of the MODIS and Landsat data represent two distinctive pixel sizes of 1000 m and 30 m, respectively. Hence, the smaller pixels of Landsat were transformed into the size of the larger pixel of MODIS by incorporating neighboring pixels through a linear aggregation of 33 × 33 pixels. Some of the model functions of the SEBAL approach (e.g., Normalized Difference Vegetation Index - NDVI) were formulated by non-linear relationships among input variables. Therefore, linear aggregation of pixels was followed by the SEBAL approach. Spectral properties over the ground may vary due to the heterogeneity of vegetation cover. Hence, a normal distribution of spectral measurement values cannot be assumed for each sample of 30 × 30 sets of pixels.

For comparison, the computation of ETact was carried out by taking the mean value, the median value, and the mode value of the sample aggregation. The results indicate that ETact values computed by taking mean values have the highest correlation with the corresponding ETact values derived from the MODIS data.

Under water-stressed situations, the ETact derived from the 1000 m × 1000 m MODIS data deviated 10% from those derived from the 30 m × 30 m Landsat data. However, under normal situations (i.e., ETact being close to ETpot), this deviation was reduced to only 6% and below.

The error component of ETact when ground cover area increases could be described as follows:

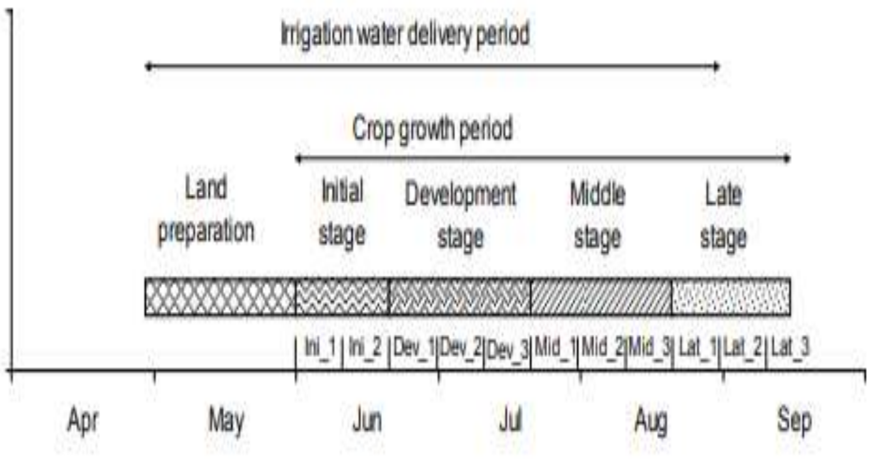
1. When the area concerned was too small compared with the low resolution of the MODIS measurements, the impact of boundary pixels on the final output value would be significant.
2. When the area concerned was too large compared with the heterogeneity of the land cover (i.e., site-specific condition), the effect due to the variations of the pixel values would dominate the final output.

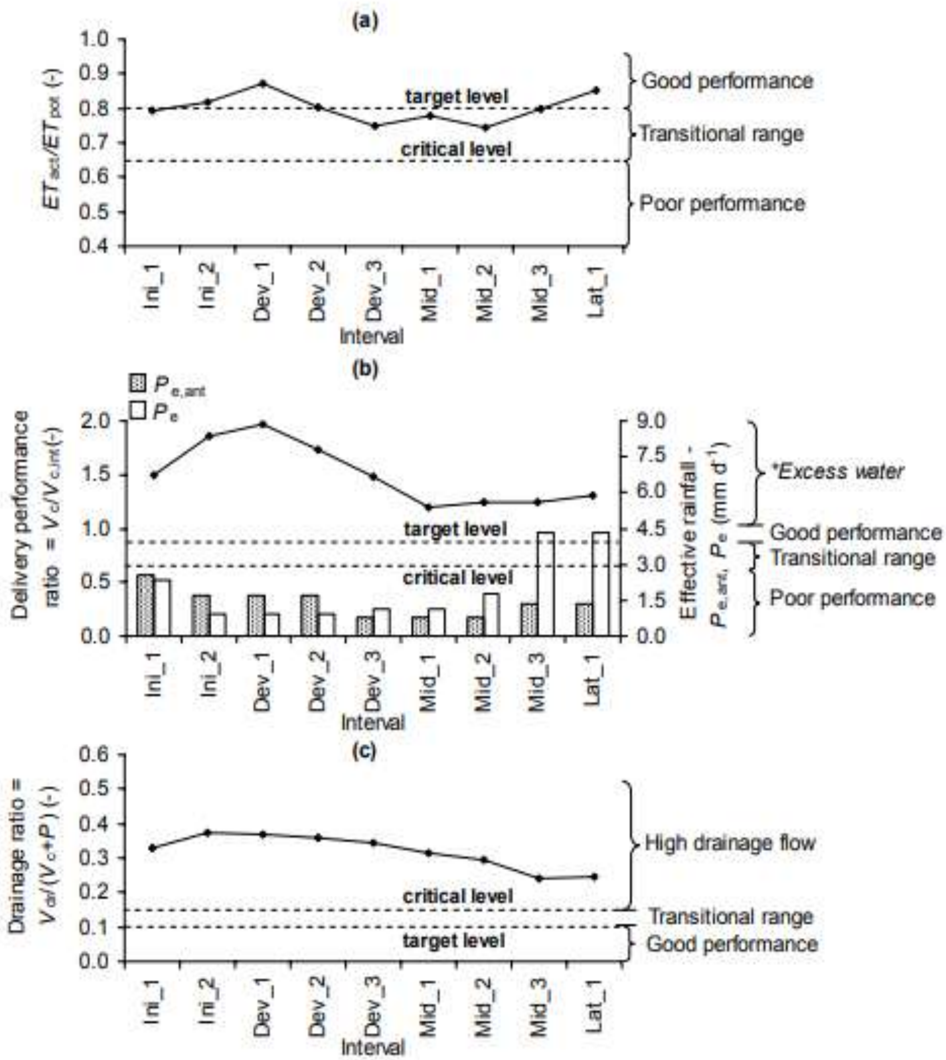
Firstly, the error component of ETact was estimated for a sample of 4 × 4 pixels in a MODIS output map of SEBAL. To make an unbiased representation, a large extent of the cloud-free area was selected, with the population represented by 320 samples. Linear regression analysis was applied for error estimation. Using the same SEBAL output map of ETact, the sample size was increased from 4 × 4 pixels to 12 × 12 pixels by discrete intervals within the same population.

Secondly, the same process was repeated within a cultivation season for three data sets representing the initial, development, and middle growth stages.

3.5.1 Performance assessment for the wet season

The wet season of 2022-2023 saw the start of cultivation in December, continuing the ongoing national wheat production program. Based on the graphical illustration of each performance indicator shown in the figure, the operational performance of the scheme was assessed. The variation of ETact/ETpot versus the depleted fraction ETact/(Vc + P) for each interval is shown in the water use matrix for irrigated crops. The performance assessment began with relative evapotranspiration since it describes crop water stress against the potential water need. Throughout the season, ETact/ETpot fluctuated around its target value. The reasons for the observed performance levels can be diagnosed by assessing the water deliveries from the main source.


Irrigation water delivery period
Crop growth period
Land preparation
Initial stage
Development stage
Middle stage
Late stage
Ini_1 Ini_2 Dev_1 Dev_2 Dev_3 Mid_1 Mid_2 Mid_3 Lat_1 Lat_2 Lat_3
Apr
May
Jun
Jul
Aug
Sep


(a)
ET_{act}/ET_{pot} (-)
target level
critical level
Good performance
Transitional range
Poor performance
Interval
(b)
$P_{e,ant}$
P_e
Delivery performance ratio = $V_c/V_{c,int}$(-)
Effective rainfall - $P_{e,ant}$, P_e (mm d^{-1})
target level
critical level
*Excess water
Good performance
Transitional range
Poor performance
Interval
(c)
Drainage ratio = $V_{dr}/(V_c+P)$ (-)
critical level
target level
High drainage flow
Transitional range
Good performance
Interval

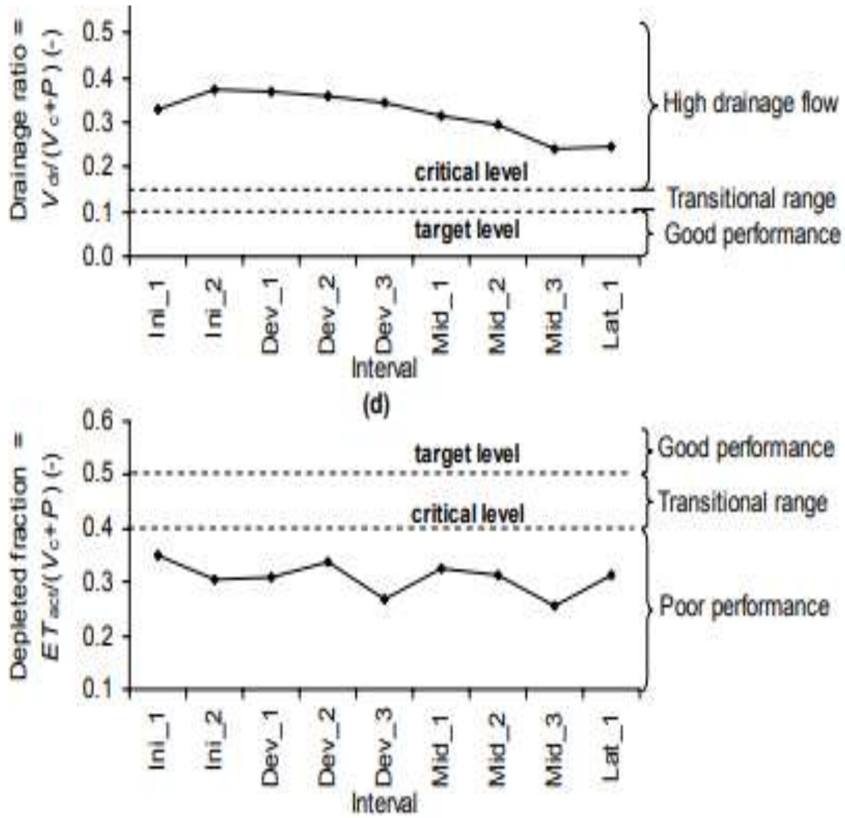


Figure 6 performance indicators during the wet season 2022-2023

The delivery performance ratio (Vc /Vc,int) remained in the region of excess water (i.e., Vc /Vc,int = 1.5) and thereafter showed a decreasing trend. The command area experienced less rainfall than anticipated. Throughout the season, the delivery performance ratio (Vc /Vc,int) was above its target level. This situation reveals that a short supply of irrigation water from the river diversion no longer exists.

There can be two possible reasons for the fluctuation of ETact /ETpot:

1. A portion of delivered water drained out from the canal system during the water deliveries.
2. A portion of water retained in the cropped area discharged to the drains.

During the initial stage and the beginning of the development stage, both the delivery performance ratio (Vc /Vc,int) and ETact /ETpot were kept above their target levels, i.e., the manager delivered more water from the reservoir than required, and the cropped area received sufficient water. Thus, the increasing trend of the drainage ratio (Vdr /(Vc + P)) during the initial stage indicates that excess water is drained from the cropped area.

In the field, when increased drainage flow is observed, the irrigation manager starts to reduce the water deliveries from the main source. Subsequently, the field staff also starts to reduce flow in the distributary system. Throughout the season, rainfall varied completely from its anticipated levels. Thus, for the field staff, manual operations of the canal system with frequent variations of rainfall would be rather complicated. Without real-time information on rainfall, they perform canal operations based on their experience, leading to shortcomings in field water distribution.

To retain water for a few days (i.e., 2-3 days) in the paddy fields, small bunds are formed at suitable intervals during land preparation. Before the water level rises to the top of the field bunds, farmers divert excess water to the drainage canals. If the project area experiences regular rains when sufficient water is in the paddy fields, farmers do not attempt to retain water in their paddy fields. Ultimately, the available water for the crop would decrease. Additionally, because of the moderately high permeability of the soil layers, it is impractical to retain water in the paddy fields for more than three days.

Under these circumstances, ETact/ETpot has fluctuated. The decreasing trend of evapotranspiration during the latter part of the season would seriously affect grain yield more than it did in the initial stages.

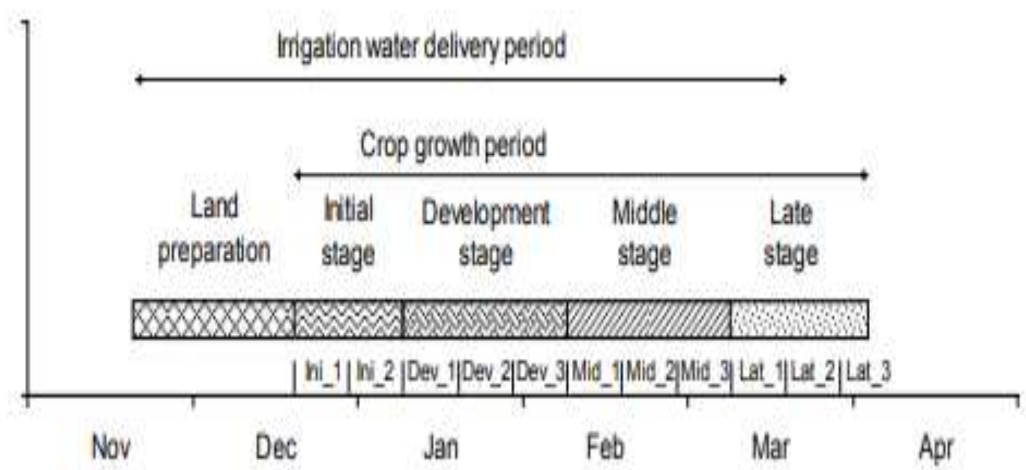
3.5.2 Performance Assessment for the Dry Season

The dry season of 2023 started with land preparation and cultivation in November. Based on the graphical illustration of each performance indicator shown in the figure, the operational performance of the scheme was assessed. ETact, estimated by remote sensing, is shown in the figure. The variation of ETact/ETpot versus the depleted fraction ETact/(Vc + P) for each interval is presented in the water use matrix for irrigated crops.

In this dry season, both ETact/ETpot and the delivery performance ratio (Vc/Vc,int) were close to their target levels, with a few intermittent fluctuations. Until the latter part of the development stage, ETact/ETpot remained below its target level, indicating that the cropped area did not receive adequate water. This situation can be diagnosed by observing the other indicators.

At the beginning of the season, the delivery performance ratio (Vc/Vc,int) remained closely above its target level. The Sarkita irrigation project area received the anticipated rainfall, suggesting no water shortage from the supply side. Hence, it was necessary to assess the performance of water distribution. The drainage ratio (Vdr/(Vc + P)) increased above its critical level, indicating that a portion of the irrigation water accumulated in the drainage canals. Justifying this situation, the depleted fraction (ETact/(Vc + P)) moved below its critical level. This reveals that a substantial portion of the delivered water flowed directly into the drainage system.

Since the water supply was on target, water did not accumulate in the cropped area. Therefore, either incorrect flow operations or physical damages to the canal system may have caused the increase in drain discharge. When it rains, a substantial amount of rainfall runoff from the surrounding highlands accumulates in the drainage canals.



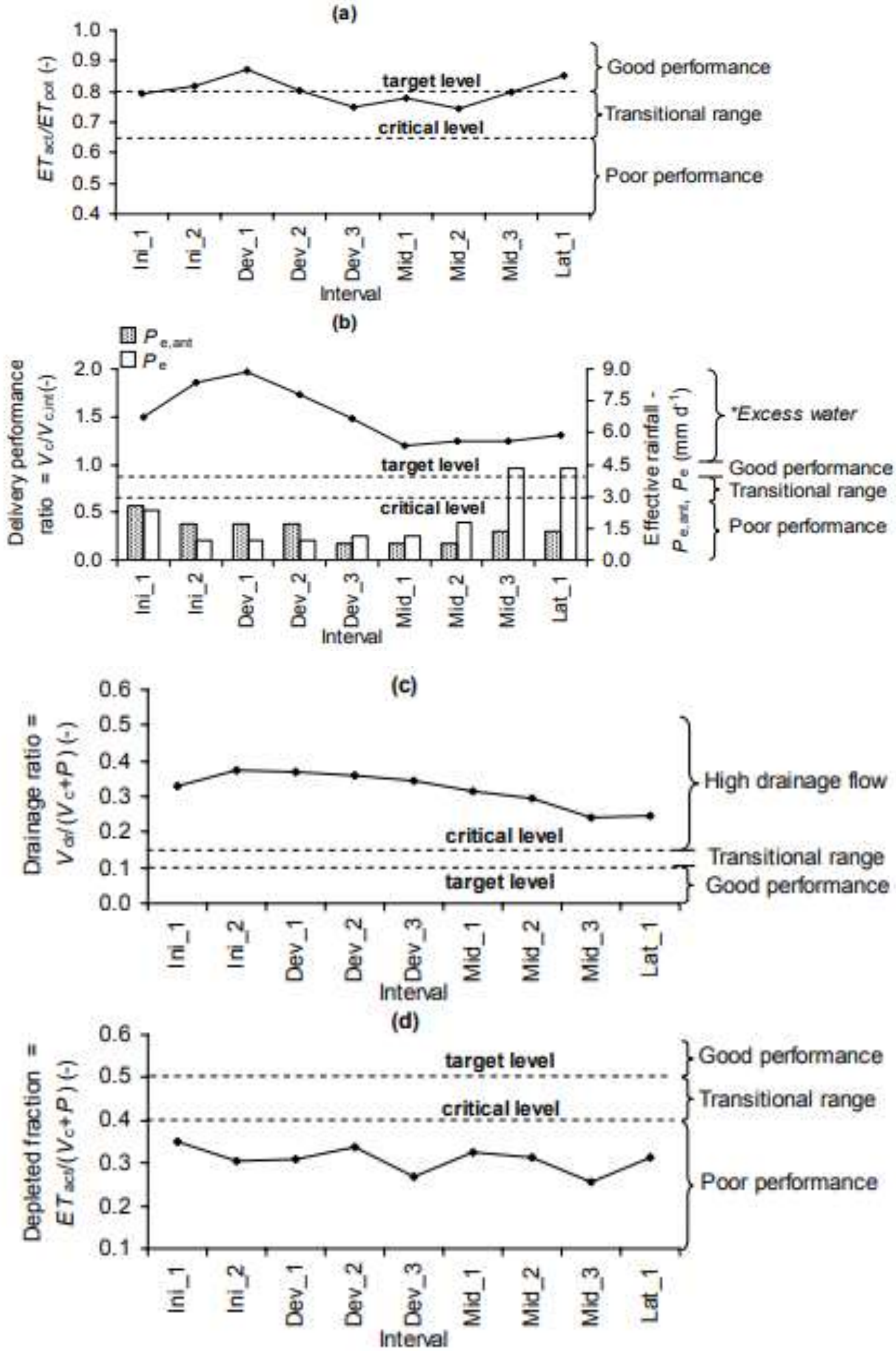


Figure 7 Performance indicators during the wet season

4. Conclusion and Recommendation

Effective integration of GIS with satellite remote sensing techniques enhances performance evaluation and diagnostic analysis capabilities. The study indicates that enhanced operational use of such techniques calls for further development work on optimum crop classification algorithms, yield prediction models, more appropriate vegetation indices, and satellite data normalization procedures.

Evidence from the majority of case studies suggests that irrigation systems are not managed in response to performance. Where operational or maintenance rules are indicated in case studies, they are most often routinized rather than made in response to actual field conditions. Virtually none of the case studies indicate the actual objectives of operating the system, thereby removing a major component of the performance assessment process. There is strong evidence that actual conditions do not coincide with the stated targets in most case studies. However, given the data available, it is hard to distinguish between cases where the mismatch between desired and actual conditions is deliberate, in response to legitimate changes at the field level and those where it is the result of poor control.

Priority was given to satellite data to recover new performance pillars rather than physical performance measures. Satellite measures, such as the overall consumed ratio (ep), depleted fraction (DF), evaporative fraction, and relative evapotranspiration, were employed. Each pillar has its own set of irrigation system performance indicator parameters (efficiency, adequacy, reliability, and equity).

Irrigation system performance for all stages, whether taken monthly or seasonally, was typically poor. The variability of monthly performance indicator values showed that supplied water values to the field were generally very high, indicating non-uniform irrigation across the months. This result was attributed to the fact that effective precipitation was not accounted for by the workers irrigating the crop. To manage Sarkita irrigation system performance, irrigation scheduling based on crop water requirements was successfully carried out. Each month in the irrigation site had slightly different performance indicators calculated using the four pillars.

The primary cause of poor performance is unscheduled crop water requirements. Because irrigation agronomists did not normally account for resident soil moisture during irrigation, the workers did not know the accurate water dose to apply to the crop. The irrigation system was inefficient, as evidenced by the low overall consumed ratio, due to an excess of water supplied to the field. Similarly, the depleted fraction result showed some excess water-induced percolation to the groundwater. These results suggest that the irrigation system was inadequate, and hence any additional water should be drained from the field to sustain the project.

Gorantiwa states that evaporative fraction values of ≤ 0.8 indicate no stress, while those of ≥ 0.8 indicate an increase in moisture stress. These findings, however, contradict the preceding argument. The moisture condition of the field soil before and after irrigation, as well as crop root depth, was measured. When a soil auger was used in each experimental site, there was no indication of soil moisture stress. On the other hand, the results in Table 7 show that the evaporative fraction value was ≥ 0.8, indicating no moisture stress even though the irrigation system had plenty of water.

Recommendations

The natural resources of the valley are pivotal for improving the lives of the people. The pressurized irrigation project under implementation is one of the key development projects aimed at enhancing the quality of life. However, surface water resources are limited. The discharge of Golina and Hormat rivers is rather low during the dry seasons, and most of the remaining rivers in the valley are intermittent or have very low flows during these periods. Therefore, the land that can be irrigated using surface water sources is limited, necessitating a greater emphasis on pressurized irrigation systems.

Based on the above discussion, the writer of this research recommends the following points:

1. **Carry out GIS operations and satellite remote sensing**: Use these tools for estimating ETa t hrough the SEBAL approach and quantifying related parameters of the selected performance i ndicators.
2. **Cooperate with farmer organizations**: Work closely with farmer organizations to achieve the objectives of the performance assessment program.

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