



## Afghan International Journal of Science (AIJS)

Publisher: Afghan International Islamic University

Website: <https://aijs.aiiu.edu.af>

e-ISSN: 3134-5859

### Modeling Irrigation Practices for Major Crops in the Tajiki Canal Command Area of Afghanistan

Ebadullah Pagoon<sup>1</sup> and Mohammad Haroon Sarwary<sup>2</sup>

*Afghan International Islamic University, Department of Industrial Engineering, Faculty of Engineering, Kabul,  
Afghanistan*

#### Abstract

A research study was conducted in the service area of the Tajiki Canal in Kabul, Afghanistan, to assess water management practices, including water supply, crop water requirements, cropping patterns, crop water productivity, and irrigation scheduling. Irrigation supply was measured using a rectangular weir installed at the canal intake. The site was surveyed, and reference marks were placed 1.2 m upstream of the weir to record daily water levels, which were converted into discharge values. We mapped cropping patterns using a Global Positioning System (GPS), and estimated crop water requirements using the CROPWAT model. We evaluated irrigation scheduling through CROPWAT simulations and field data collected using a structured proforma. We measured the irrigation depth applied to individual fields using a cut-throat flume. The results showed that grape was the dominant crop, occupying 16% of the cultivable command area, followed by wheat (15%), tomato (6%), and apple (5%). Crop water requirements for all crops, except wheat, increased progressively and peaked in July. The maximum water requirements for grape, wheat, tomato, and apple were 7.04, 6.31, 10.29, and 10.19 mm/day, respectively. Irrigation supply was generally lower than crop demand, exceeding it only in July and August, while relative water supply ranged from 0.3 to 1.16. The average crop water productivity of tomato ranged from 5.13 to 5.59 kg/m<sup>3</sup>, whereas grape productivity declined from 1.99 kg/m<sup>3</sup> at the head to 1.82 kg/m<sup>3</sup> at the tail. Traditional irrigation scheduling largely matched CROPWAT estimates, although local practices applied 153 mm of water to grapes compared to 106 mm estimated by the model.

**Keywords:** CROPWAT; Crop water productivity; Crop water requirements; Irrigation scheduling; Water supply.

#### Article History

**Published:** September 30, 2026

**Accepted:** July 29, 2026

**Revised:** July 11, 2026

**Received:** May 6, 2026

**Cite as:** Pagoon, E. & Sarwary, M. H. (2026). Modeling Irrigation Practices for Major Crops in the Tajiki Canal Command Area of Afghanistan. *Afghan International Journal of Science*, 2(3), 310-334. DOI: <https://doi.org/10.66546/aijs.v2i3.77>

## Introduction

Improved access to irrigation water can provide several advantages, including increased agricultural production, food security, and more employment opportunities. Water is crucial not only to people's livelihoods but also to Afghanistan's economy. Agriculture remains a cornerstone of the national economy, contributing approximately 35% of the country's gross

\*Email: [eng.ebadkhan@gamil.com](mailto:eng.ebadkhan@gamil.com) (corresponding author)

Link to this article: <https://aijs.aiiu.edu.af/index.php/aijs/article/view/77>

domestic product (GDP) and employing about 45% of the workforce, with a particularly high share in rural areas (World Bank, 2023). Arable land in Afghanistan is estimated at around 7.85 million hectares, representing roughly 12% of the total land area (World Bank, 2023; FAO, 2023). The proportion of irrigated agricultural land remains low, with only about 6% of total agricultural land equipped for irrigation, underscoring the reliance on rain-fed cultivation and the need for improved water management (World Bank, 2024). Although limited, this irrigated area contributes disproportionately to agricultural production and food security nationwide.

As an agrarian country, Afghanistan relies heavily on irrigation, mainly during summer when precipitation is very rare. Irrigated agriculture has a long history in Afghanistan dating back to approximately 4,500 years (Azami et al., 2020). Rainfed agriculture remains limited in most parts of the country because rainfall is low and highly variable, particularly outside the northern highlands, where moisture availability is marginal and unpredictable (Taraky et al., 2024). Afghanistan has a complex irrigation landscape, with many irrigation systems, most of which are traditional schemes that rely primarily on surface water sources such as rivers and streams, and, to a lesser extent, on groundwater sources including springs, karezes, and wells (Ado and Abubakar, 2024). Traditional surface irrigation systems remain widespread, accounting for approximately 80–90% of the country's irrigated land, ranging from small mountain systems to large plains canals, while formal modern irrigation systems cover a much smaller share of the total irrigated area (Rahmani and Azizi, 2024). Both traditional and modern systems depend heavily on surface water, with springs and karezes contributing a smaller share of irrigated area (Hussainzada and Lee, 2022).

Local customs and community practices strongly influence water distribution and allocation in the country's traditional irrigation systems, where farmers integrate maintenance and water sharing into seasonal calendars and communal agreements rather than formal administrative schedules. Traditional water rights and allocation often prioritize landownership and upstream access, resulting in inequitable distribution favoring upstream farmers over downstream users (Sharma et al., 2023). In these systems, the mirab (a locally selected water master) plays a central role in managing and regulating water deliveries to agricultural areas, organizing labor for canal maintenance, and resolving disputes among users (Hussainzada and Lee, 2022).

Inadequate irrigation water supply remains a major constraint on agricultural expansion in Afghanistan, especially in arid and semi-arid regions where water shortages directly affect crop productivity and rural livelihoods (Rahmani and Abid, 2024). Decades of conflict severely damaged irrigation infrastructure, creating obstacles to efficient water distribution and use, and reinforcing the need to rehabilitate canals and water conveyance systems to improve agricultural productivity (World Bank, 2021). Increasing agricultural water productivity is vital for enhancing food security and economic resilience among rural populations. Improving irrigation infrastructure, adopting appropriate water management practices, and building human and institutional capacity are among the most effective strategies to achieve this goal. Effective irrigation scheduling plays a critical role in meeting crop water requirements, as irrigation frequency and depth depend on crop type, growth stage, soil conditions, and climatic variability (Pereira et al., 2020).

Several government and non-government organizations, including the On-Farm Water Management (OFWM) Project in Kabul, are rehabilitating and developing irrigation systems to improve water-use efficiency and increase agricultural productivity per unit area. Prior research in Afghanistan has demonstrated that optimizing irrigation scheduling and water allocation can significantly increase crop water productivity and yield under water-scarce conditions (Pereira et al., 2020).

Despite the critical importance of irrigation for agricultural productivity in Afghanistan, few empirical studies have evaluated on-farm water management practices at the canal command level, particularly in the service area of the Tajiki Canal in Kabul. Existing studies primarily focus on national-scale assessments or infrastructure rehabilitation, with insufficient attention to field-level irrigation scheduling, water supply–demand relationships, and crop water productivity. Moreover, comparative analysis between model-based irrigation scheduling (e.g., CROPWAT) and traditional farmer practices is lacking. This study addresses these gaps by systematically evaluating irrigation performance and water management efficiency within the Tajiki Canal command area.

This research aims to evaluate on-farm water management practices across different reaches of the canal system, with particular emphasis on analyzing irrigation water supply in relation to crop water demand. The study was designed to address the following research questions:

1. How does the current irrigation water supply compare to the water requirements of major crops in different canal sections of the command area?
2. How do the irrigation scheduling parameters (including irrigation depth and irrigation interval) predicted by the simulation model differ from those of traditional farmer irrigation methods?
3. What are the crop water productivity levels of major crops such as wheat, tomatoes, and grapes grown in different canal sections of the command area?
4. How efficient are existing irrigation and water resource management measures in meeting crop water requirements and improving water productivity?

## **Methods and Materials**

### **Study Area**

A field investigation was conducted in District Shakardara, approximately 30 km north of Kabul (34.41° N, 69.01° E). The study focused on the command area of the Tajiki Canal in Danishmand village Figure 1. The village has nearly 200 households, and agriculture is the main livelihood for most residents. The total cultivated area is estimated at 526 hectares, most of which is irrigated through the Tajiki Canal, which extends 14.02 km.

In addition to canal irrigation, certain sections of the village use groundwater extraction through tube wells, particularly in downstream or tail-end areas where canal water supply is insufficient. Farmers primarily use this supplemental irrigation to sustain vegetable production and maintain crop productivity under limited surface water availability. Overall, the irrigation

system in the study area combines canal and groundwater resources, highlighting the adaptive strategies farmers use to cope with water scarcity.

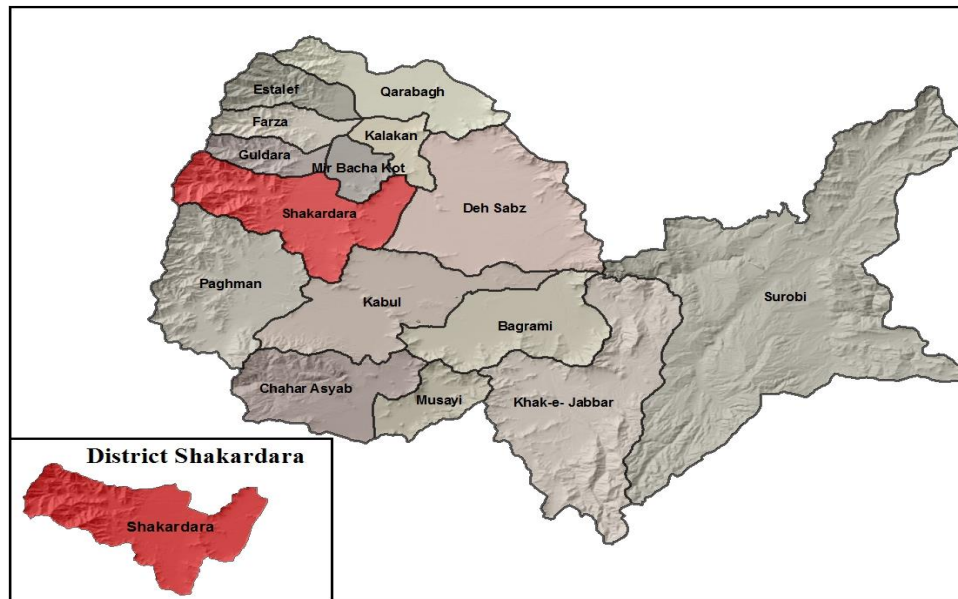


**Figure 1.** District map of Kabul province highlighting the study area

A layout map of the canal command area was developed using a Global Positioning System (GPS) Figure 2. A GARMIN GPSMAP 76Cx device was used to record waypoints at regular intervals and at key locations, including canal outlets and the boundaries of the command area, through field surveys. The collected data were subsequently transferred to a computer using MapSource software to generate the final layout map of the canal command area.

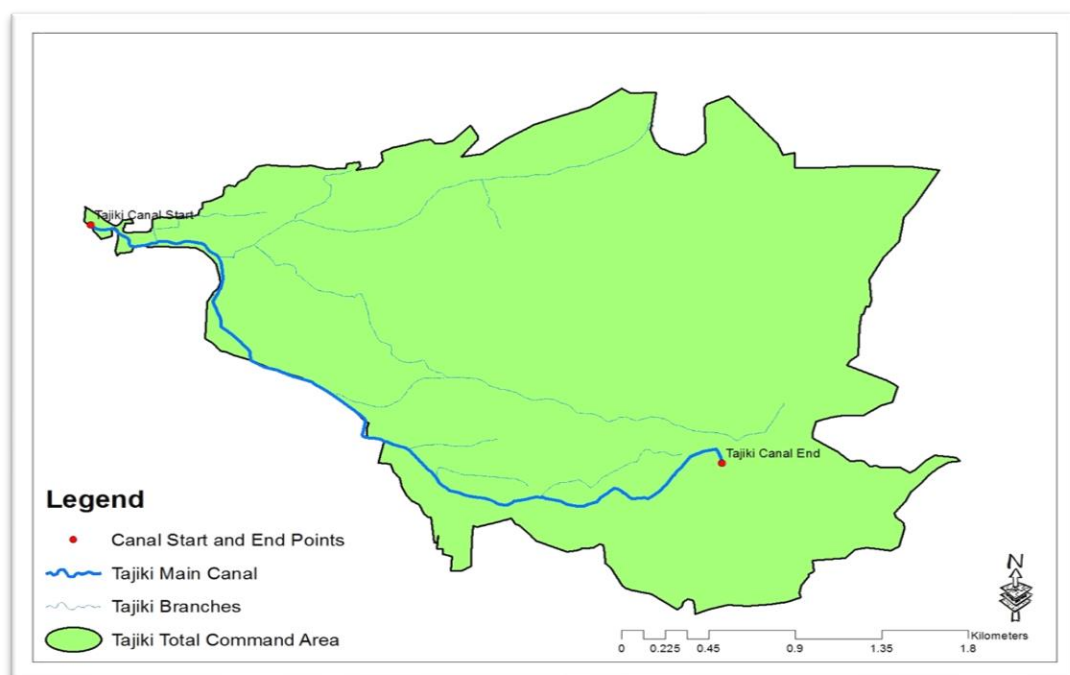


**Figure 2.** Layout map of the study area

## Irrigation Supply and Crop Water Demand

The irrigation water supplied to the command area was measured using a sharp-crested rectangular weir installed at the Tajiki Canal intake. The intake section was surveyed, and reference marks (white marks) were established 1.2 meters upstream of the weir. Daily observations of these reference points relative to the canal crest were recorded in a structured format to determine the water depth (head) over the weir crest. The measured head was subsequently converted into discharge using the standard rectangular weir equation:

$$Q = C \times L \times H^{3/2} \dots\dots\dots (1)$$

Where Q is the discharge over the weir ( $\text{m}^3 \text{s}^{-1}$ ), C is the discharge coefficient, L is the effective length of the weir crest (m), and H is the head of water above the weir crest (m).

Accurate estimation of crop water demand is essential for farm-level crop planning and irrigation project design. Crop water requirement is defined as the quantity of water needed to compensate for losses due to evapotranspiration from the crop field (Jovanovic et al., 2021). This requirement varies depending on crop type, growth stage, canopy characteristics, rooting depth, and root density. We estimated crop water demand using the following procedure.

## Cropping Pattern and Reference Crop Evapotranspiration ( $ET_0$ )

We determined the cropping pattern within the command area using a Global Positioning System (GPS) device (Garmin). Initially, the boundaries of the command area were mapped to estimate its total extent. Subsequently, individual field plots were surveyed, and the area under each crop was recorded and stored in the GPS with specific identifiers. In addition, farmers located at the head, middle, and tail sections of the command area were interviewed to collect detailed information on water management practices and agronomic activities.

Similarly, reference crop evapotranspiration was estimated using the computer software CROPWAT (version 8.0), developed by the Land and Water Development Division of the Food and Agriculture Organization (FAO). The software uses the Penman–Monteith equation. The analysis required two categories of input data: general data, including the station's latitude, longitude, and altitude, and climatic data, including temperature, relative humidity, sunshine duration, and wind speed. All required data were obtained from the meteorological station in Kabul.

## Crop Coefficient ( $K_c$ ) and Crop Water Requirements ( $ET_c$ )

The crop coefficient ( $K_c$ ) varies by crop type and growth stage. The  $K_c$  values used to estimate crop water requirements were adopted from the FAO Irrigation and Drainage Paper No. 33, *Yield Response to Water* (Doorenbos and Kassam, 1979).

Crop water requirement (CWR) represents the total amount of water required to compensate for water losses through crop transpiration and soil evaporation during the growing period. Under standard growing conditions, where soil moisture is not limiting, the crop water requirement is assumed to be equal to the crop evapotranspiration ( $ET_c$ ). Climatic conditions, crop characteristics, soil properties, groundwater conditions, land slope, irrigation practices, tillage methods, and water application techniques primarily influence crop water requirements.

In this study, we estimated crop water requirements using the CROPWAT (Version 8.0) model. The crop water requirement was calculated as:

$$CWR = ET_c = K_c \times ET_o \dots\dots\dots (2)$$

where  $ET_c$  is the crop evapotranspiration ( $\text{mm day}^{-1}$ ),  $ET_o$  is the reference evapotranspiration ( $\text{mm day}^{-1}$ ), and  $K_c$  is the crop coefficient, which varies with crop type and growth stage.

### Effective Rainfall and Net Irrigation Requirement

Effective rainfall ( $P_{eff}$ ) was estimated using the FAO dependable rainfall method implemented in CROPWAT 8.0. Monthly meteorological data were obtained from the Meteorological Station of the Ministry of Agriculture, Irrigation, and Livestock, Kabul. The effective rainfall was calculated using the following equations:

$$P_{eff} = 0.6P - 10/3 \text{ for monthly precipitation } (P) \leq 70/3 \text{ mm} \dots\dots\dots (3)$$

$$P_{eff} = 0.8P - 24/3 \text{ for monthly precipitation } (P) > 70/3 \text{ mm} \dots\dots\dots (4)$$

Where ( $P_{eff}$ ) is the effective rainfall (mm), and ( $P$ ) is the monthly precipitation (mm). The Net Irrigation Requirement (NIR) was subsequently determined using CROPWAT (version 8.0), based on the following Equation:

$$NIR = ET_c - P_{eff} \dots\dots\dots (5)$$

where NIR represents the net irrigation requirement ( $\text{mm day}^{-1}$ ),  $ET_c$  is the crop evapotranspiration ( $\text{mm day}^{-1}$ ).

### Irrigation Scheduling and Traditional Practices

We estimated irrigation scheduling using the CROPWAT model and compared it with traditional irrigation practices. CROPWAT uses a soil water balance approach and considers inputs such as crop characteristics, soil properties, rainfall, and crop evapotranspiration. Key crop parameters included crop type, rooting depth, and allowable depletion, while soil data comprised soil type, initial moisture, and total available water. The optimal irrigation schedule used the "critical depletion" option for timing and "refill to field capacity" for application, with an assumed irrigation efficiency of 70%.

In contrast, traditional irrigation in the study area was managed through the Mirab system, which involves a water master (Mirab), community elders, and water users. Water distribution was based on a customary unit known as Qulba, where one Qulba (equivalent to 12 hours of irrigation) typically covers 20–30 hectares. Because water is limited and land is fragmented, irrigation supply is often insufficient, leaving some areas uncultivated. Farmers receive water according to predefined schedules and entitlements, with the community managing the system and resolving conflicts. We obtained information on traditional practices through farmer interviews.

### Crop Water Productivity

Crop water productivity (CWP) refers to the relationship between crop yield and the total volume of water used during the growing season. It is commonly defined as the amount of crop produced per unit volume of water consumed and is expressed in kilograms per cubic meter

(kg m<sup>-3</sup>) (Mahmoud et al., 2024). Crop water productivity was calculated using the following Equation:

$$CWP = \frac{Y}{W_a} \dots\dots\dots (6)$$

where CWP is the crop water productivity (kg m<sup>-3</sup>), Y is the seasonal crop yield (kg ha<sup>-1</sup>); and W<sub>a</sub> represents the total seasonal water applied (m<sup>3</sup> ha<sup>-1</sup>), including irrigation water and effective rainfall.

We used an 8-inch cut-throat flume to measure the discharge of irrigation water applied to the field. We installed the flume in a straight, vegetation-free section of the irrigation channel and sealed its sides with soil to prevent leakage from the sides and bottom. After the flow reached steady-state conditions, we recorded three to four discharge readings and measured the total irrigation time. We determined the field area using both a measuring tape and a Global Positioning System (GPS).

The depth of irrigation water applied during each irrigation event was calculated using Equation (7):

$$d = \frac{Q \times T}{A} \dots\dots\dots (7)$$

where d represents the depth of water applied (m), T is the irrigation time (S), Q is the discharge measured with the cut-throat flume (m<sup>3</sup> s<sup>-1</sup>), and A is the irrigated field area (m<sup>2</sup>).

The seasonal irrigation depth was estimated by multiplying the depth of water applied per irrigation event by the total number of irrigation events during the crop growing season.

Tomato yield was determined by weighing the harvested produce using a container of known weight. For grapes, yield was estimated by calculating the average yield from three to four representative vines in each field and multiplying it by the total number of vines in that field.

## Findings

This section presents results on water supply and demand, relative water supply, and crop water productivity within the command area of the Tajiki Canal, Kabul, Afghanistan. It also compares irrigation scheduling from the CROPWAT model with existing traditional irrigation practices. The analysis aims to assess the efficiency of current water management strategies and identify potential improvements to optimize water use and enhance agricultural productivity in the study area.

### Water Supply and Demand

The water supply and demand section outline the findings on cropping patterns, crop water requirements, net irrigation requirements, and the overall relationship between water availability and demand. The analysis focuses on understanding how different crops cultivated in the study area influence water demand under prevailing climatic conditions and irrigation practices. Crop water requirements were estimated to evaluate the seasonal water needs of major crops, while net irrigation requirements were determined by accounting for effective rainfall and other contributing factors. The study also examined the relationship between

available water supply and actual crop water demand to assess the adequacy and efficiency of existing irrigation systems.

### Cropping Pattern

Figure 3 shows the distribution of major crops cultivated within the command area, along with their respective percentage shares.

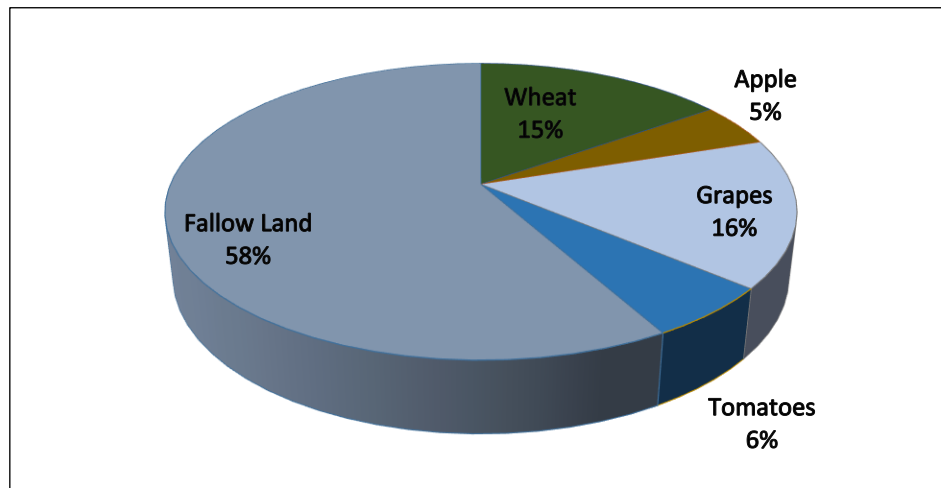


**Figure 3:** Overall cropping pattern in the command area of Tajiki Canal

Among these, grape emerged as the most dominant crop, occupying approximately 16% of the total cultivable area. Wheat was the second most widely grown crop, covering about 15% of the area. Tomato cultivation accounted for nearly 6% of the command area, whereas apple was the least cultivated crop, occupying only 5% of the total cultivable land.

Despite these crops, a significant proportion of cultivable land remained unused. More than half of the total command area was left fallow, mainly because of insufficient irrigation water. This indicates that water scarcity is a major limiting factor affecting agricultural productivity in the region. The underutilization of land resources highlights the need for improved water management practices and efficient irrigation strategies to enhance crop cultivation and optimize land use within the command area.

### Reference Crop Evapotranspiration ( $ET_0$ )

Reference crop evapotranspiration was very low at the beginning of the year, mainly because cold, near-freezing temperatures limit atmospheric moisture demand. In January, the evapotranspiration rate was about  $0.74 \text{ mm day}^{-1}$ . As the season progressed and temperatures increased, evapotranspiration gradually increased, eventually peaking at about  $8 \text{ mm day}^{-1}$  in July (Figure 4 below). After this peak, evapotranspiration declined steadily toward the end of the year, falling to around  $0.9 \text{ mm day}^{-1}$ .

This seasonal pattern is consistent with findings reported in recent studies (Gocic and Trajkovic, 2014; Jayashree et al., 2023), which indicate that evapotranspiration rates tend to decrease during the later stages of the growing season and crop maturity periods. The reduced evapotranspiration observed at both the beginning and end of the year is mainly due to lower

temperatures, reduced solar radiation, and shorter daylight hours in the region, all of which limit atmospheric evaporative demand.

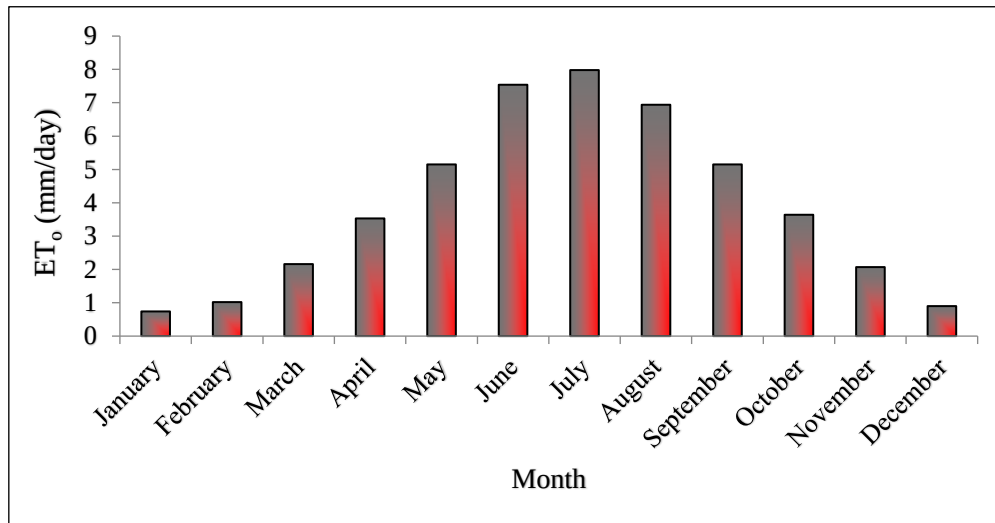


**Figure 4:** Monthly reference crop evapotranspiration ( $ET_0$ ) of the study area

### Crop Coefficient ( $K_c$ ) and Crop Water Requirements

The crop coefficient ( $K_c$ ) values corresponding to different growth stages of the selected crops are presented in Table 1. These values were adopted from FAO Irrigation and Drainage Paper No. 33 and used to estimate crop water requirements under varying climatic conditions. The crop coefficient is an essential parameter that reflects variation in crop evapotranspiration across developmental stages, including the initial, development, mid-season, and late-season phases.

**Table 1:** Crop coefficient ( $K_c$ ) values for major crops at different growth stages

| Crop   | Initial stage | Devel. Stage | Mid-season | Late season |
|--------|---------------|--------------|------------|-------------|
| Tomato | 0.45          | 0.75         | 1.15       | 0.88        |
| Grape  | 0.45          | 0.70         | 0.80       | 0.70        |
| Wheat  | 0.35          | 0.75         | 1.13       | 0.70        |
| Apple  | 0.45          | 0.58         | 1.15       | 0.90        |

In the initial stage, crops generally have lower  $K_c$  values because of limited canopy cover and reduced transpiration. As the crops progress into the development and mid-season stages, the  $K_c$  values increase, reaching their maximum during peak growth when water demand is highest. In the late season, the values decline as crops approach maturity and water requirements decrease. These stage-wise variations in crop coefficients are critical for accurately estimating irrigation needs and managing water resources effectively.

Crop water requirements for most crops in the command area showed a consistent upward trend beginning in June and peaking during the second ten-day period (decade) of July (Table 2 below). Wheat was an exception, peaking earlier during the first decade of June, followed by a gradual decline in subsequent periods.

**Table 2:** Daily crop water requirement ( $\text{mm day}^{-1}$ ) of selected crops in the area

| Month | Decades | Grape | Wheat | Tomato | Apple |
|-------|---------|-------|-------|--------|-------|
| June  | 1       | 3.76  | 6.31  | 6.72   | 5.88  |
| June  | 2       | 5.08  | 4.52  | 9.24   | 8.41  |
| June  | 3       | 6.00  | 2.35  | 9.95   | 9.80  |
| July  | 1       | 6.80  | --    | 10.05  | 9.96  |
| July  | 2       | 7.04  | --    | 10.29  | 10.19 |
| July  | 3       | 6.71  | --    | 9.76   | 9.67  |
| Aug   | 1       | 6.35  | --    | 8.23   | 8.61  |
| Aug   | 2       | 6.04  | --    | 6.52   | 7.55  |
| Aug   | 3       | 5.39  | --    | 4.88   | 6.40  |

For grape cultivation, the crop water requirement was recorded at  $3.76 \text{ mm day}^{-1}$  during the first decade of June. This demand increased steadily, reaching a maximum of  $7.04 \text{ mm day}^{-1}$  in the second decade of July, after which it gradually decreased toward the later part of the growing season. Tomato followed a similar temporal pattern, with water demand rising sharply during the early and mid-growth stages and peaking at  $10.29 \text{ mm day}^{-1}$  in July. Thereafter, the requirement declined during the maturation and late growth stages. This trend is consistent with previously reported findings on crop evapotranspiration and stage-specific water requirements (Aydın, 2022). For apple, the crop water requirement was initially  $5.88 \text{ mm day}^{-1}$  in June. It increased progressively over the following weeks, reaching a maximum value of  $10.19 \text{ mm day}^{-1}$  in mid-July, before declining gradually toward the end of the study period. Overall, the highest recorded crop water requirements for grape, wheat, tomato, and apple were  $7.04$ ,  $6.31$ ,  $10.29$ , and  $10.19 \text{ mm day}^{-1}$ , respectively. Across all crops and time periods, daily crop water requirement ranged from  $2.35$  to  $10.29 \text{ mm day}^{-1}$ , indicating substantial variability by crop type and growth stage.

### Effective Rainfall

Table 3 shows the rainfall recorded during the study period, along with the corresponding effective rainfall values.

**Table 3:** Rainfall and effective rainfall (mm) for the study area in 2025

| Months | Rainfall (mm) | Effective rainfall (mm) |
|--------|---------------|-------------------------|
| Jan    | 25.50         | 5.30                    |
| Feb    | 408.50        | 302.80                  |
| Mar    | 197.30        | 133.80                  |
| April  | 44.90         | 16.90                   |
| May    | 69.50         | 31.70                   |
| Jun    | 4.50          | 0.00                    |
| July   | 0.00          | 0.00                    |

|       |        |        |
|-------|--------|--------|
| Aug   | 14.50  | 0.00   |
| Sep   | 0.00   | 0.00   |
| Oct   | 0.00   | 0.00   |
| Nov   | 0.00   | 0.00   |
| Dec   | 5.00   | 0.00   |
| Total | 769.70 | 490.60 |

The results showed that most precipitation occurred during winter and early spring, particularly from January to April. Among these months, February and March received the highest rainfall amounts, contributing significantly to the annual total. In contrast, June to December saw very low to negligible rainfall, with several months showing no recorded precipitation. Effective rainfall, which represents the portion of total rainfall that is available for crop use, was estimated using the FAO dependable rainfall method. The results showed that not all recorded rainfall contributed to soil moisture availability, as losses from runoff, evaporation, and deep percolation reduced the usable fraction. Total annual rainfall for 2025 was 769.70 mm, while effective rainfall was 490.60 mm.

A detailed monthly analysis showed that February had the highest effective rainfall (302.80 mm), followed by March (133.80 mm), reflecting these months' substantial contribution to agricultural water availability. In contrast, despite receiving small amounts of rainfall, months such as June, July, August, and the later part of the year contributed little to no effective rainfall, indicating inefficient utilization due to climatic conditions.

### Crop Irrigation Demand

The irrigation requirements of different crops, as presented in Table 4, exhibited a clear seasonal pattern.

**Table 4:** Irrigation demand ( $L\ s^{-1}\ ha^{-1}$ ) of various crops in the command area

| Month    | Decade | Grape | Tomato | Wheat | Apple |
|----------|--------|-------|--------|-------|-------|
| Jun-I    | 1      | 0.43  | 0.77   | 0.27  | 0.68  |
| Jun-II   | 2      | 0.59  | 1.07   | 0.37  | 0.97  |
| Jun-III  | 3      | 0.69  | 1.15   | 0.40  | 1.13  |
| July-I   | 1      | 0.79  | 1.15   | 0.00  | 1.15  |
| July-II  | 2      | 0.82  | 1.16   | 0.00  | 1.18  |
| July-III | 3      | 0.85  | 1.22   | 0.00  | 1.23  |
| Aug-I    | 1      | 0.74  | 0.94   | --    | 1.00  |
| Aug-II   | 2      | 0.70  | 0.74   | --    | 0.87  |
| Aug-III  | 3      | 0.69  | 0.44   | --    | 0.52  |

Water demand increased progressively from June to July, then gradually declined toward the end of August. This trend reflects peak crop water needs during mid-season growth stages.

At the beginning of June, the irrigation demand for grapes was estimated at  $0.43 \text{ L s}^{-1} \text{ ha}^{-1}$ , which increased significantly to  $0.85 \text{ L s}^{-1} \text{ ha}^{-1}$  in July. Afterward, demand declined steadily over the following months. A similar pattern was observed for tomato, where the irrigation requirement rose from  $0.77 \text{ L s}^{-1} \text{ ha}^{-1}$  in early June to a peak value of  $1.22 \text{ L s}^{-1} \text{ ha}^{-1}$  in July, indicating maximum water consumption during this period. Apple followed a similar trend, with the highest irrigation demand in July, after which it gradually decreased to its lowest level by the end of the cropping season. This behavior is consistent with recent studies on evapotranspiration and crop water requirements (Sun et al., 2024), which report comparable trends in irrigation demand under varying climatic conditions.

Overall, the irrigation demand of crops such as grape, apple, wheat, and tomato ranged from  $0.27$  to  $1.23 \text{ L s}^{-1} \text{ ha}^{-1}$  throughout the growing period. Among these, apple exhibited the highest water requirement ( $1.23 \text{ L s}^{-1} \text{ ha}^{-1}$ ), while grape showed the lowest demand ( $0.27 \text{ L s}^{-1} \text{ ha}^{-1}$ ). These variations highlight the importance of crop-specific irrigation planning to ensure efficient water use in the command.

### Crop Seasonal Irrigation Requirements

The seasonal irrigation requirements for tomato, wheat, grape, and apple were estimated at 802 mm, 321 mm, 586 mm, and 1033 mm, respectively (Figure 5).

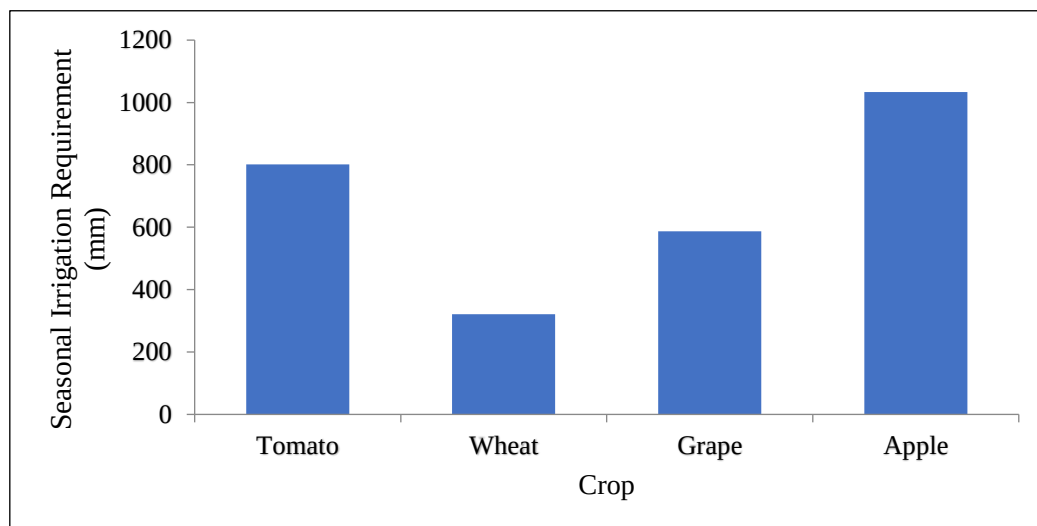


**Figure 5:** Seasonal irrigation requirements of crops grown in the command area

The results clearly indicated significant variation in water demand among the selected crops. Wheat exhibited the lowest seasonal irrigation requirement, reflecting its relatively lower water consumption under the studied conditions. In contrast, apple showed the highest irrigation demand, followed by tomato and grape.

This trend is consistent with the values and crop water requirement patterns reported in FAO Irrigation and Drainage Paper 66. The differences in irrigation requirements can be attributed to variations in crop physiology, growth duration, rooting depth, and evapotranspiration rates.

### Comparison of Irrigation Supply and Crop Water Demand

Figure 6 shows significant variation between irrigation water supply and crop water demand during June and July. At the beginning of June, the available water supply was considerably

low, recorded at approximately 43 l/s. However, it gradually increased over time due to seasonal changes, particularly the onset of snowmelt, which enhanced river discharge.

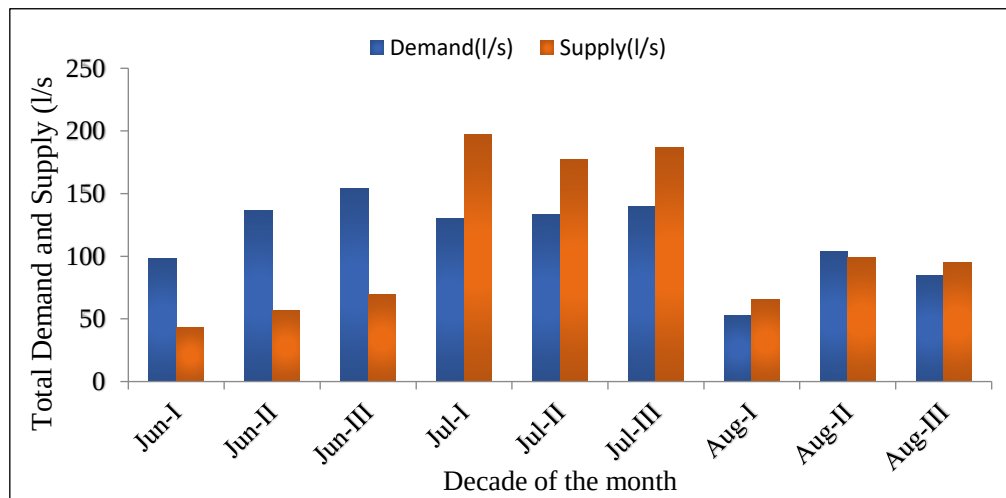


**Figure 6:** Comparison of irrigation supply and crop water demand

In contrast, crop water demand rose steadily during this period, increasing from about 130 l/s to 140 l/s by July. Despite this growing demand, irrigation supply eventually exceeded the required amount, peaking at approximately 197 l/s in July. This surplus can be attributed to increased upstream water availability resulting from melting snow and improved flow conditions.

The analysis also indicated that a balance between irrigation supply and crop water demand was nearly achieved only in August. During the earlier months, particularly June, there was a clear deficit, whereas July experienced a noticeable surplus. These fluctuations underscore the temporal mismatch between water availability and crop requirements, emphasizing the need for improved water management strategies to ensure efficient irrigation scheduling.

### Relative Water Supply

Irrigation supply in the command area depends primarily on snowmelt (Figure 7 below). A severe water shortage persisted throughout most of the year, except in July, when snowmelt increased river discharge and the relative water supply exceeded unity. The relative water supply was approximately 0.3 during the first decade of June. It then increased gradually, reaching 1.16 in the first decade of July, before declining to 0.44 in the first decade of August. It then increased from 0.44 to 0.90 by the end of August. These findings align with recent studies (Khiavi et al., 2024) reporting significant seasonal mismatches between irrigation supply and crop water requirements.

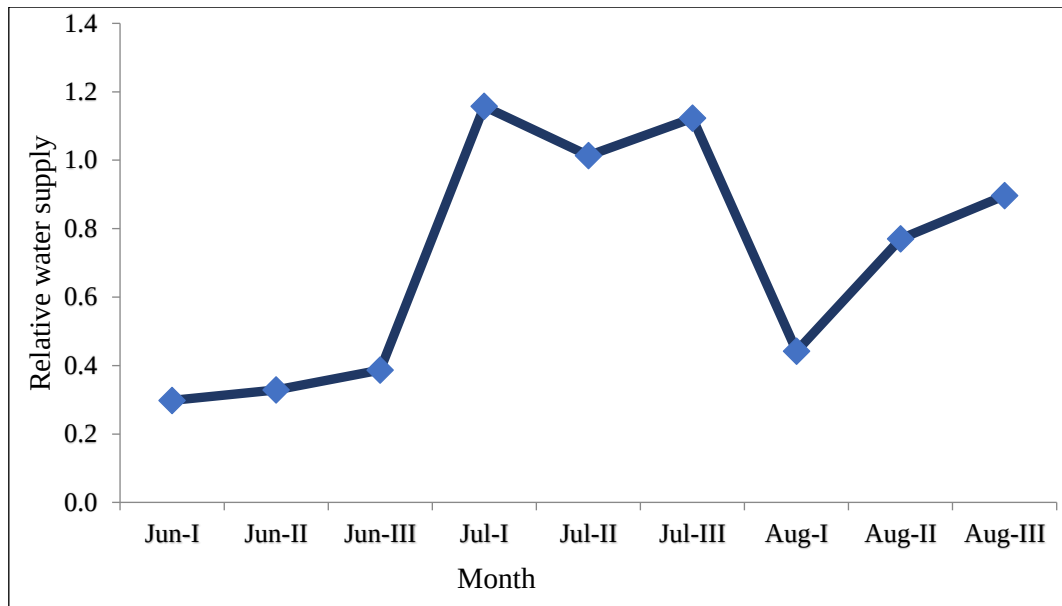


**Figure 7:** Relative water supply in the command area

Relative irrigation supply (RIS), defined as the ratio between water delivered and crop water requirements, is widely used as a key indicator of irrigation system performance (Benavides et al., 2021). Values close to unity indicate a balance between supply and demand and require careful water management to avoid deficits or inefficiencies. In contrast, values significantly greater than one reflect excess water supply, which may reduce water use efficiency and lead to losses through runoff or deep percolation.

### Crop Water Productivity

Crop water productivity (CWP) of grape and tomato ranged from 1.82 to 1.99 kg m<sup>-3</sup> and 5.13 to 5.59 kg m<sup>-3</sup>, respectively Table 5.

**Table 5:** Crop water productivity of major crops at head, middle and tail reaches

| Location | Crops  | Average depth Applied (mm) | No of Irrigation | Crop Production (kg ha <sup>-1</sup> ) | Average Volume of Water Applied (m <sup>3</sup> ha <sup>-1</sup> ) | Crop Water Productivity (kg m <sup>-3</sup> ) |
|----------|--------|----------------------------|------------------|----------------------------------------|--------------------------------------------------------------------|-----------------------------------------------|
| Head     | Grape  | 162                        | 5                | 16100                                  | 8078                                                               | 1.99                                          |
|          | Tomato | 31                         | 26               | 17111                                  | 3212                                                               | 5.33                                          |
| Middle   | Grape  | 161                        | 4                | 9800                                   | 5140                                                               | 1.91                                          |
|          | Tomato | 35                         | 27               | 52500                                  | 9390                                                               | 5.59                                          |
| Tail     | Grape  | 144                        | 4                | 4200                                   | 2308                                                               | 1.82                                          |
|          | Tomato | 41                         | 25               | 31500                                  | 6134                                                               | 5.13                                          |

The average crop water productivity of grape was 1.90 kg m<sup>-3</sup>, which showed a decreasing trend from the head to the tail reaches of the command area due to water shortages. This observation is consistent with more recent findings reported by Murtaza et al. (2020), who highlighted that uneven water distribution within irrigation systems significantly reduces crop water productivity, particularly in tail-end regions.

For tomato, crop water productivity increased from the head to the middle reaches, ranging from 5.33 to 5.59 kg m<sup>-3</sup>, then declined toward the tail to 5.13 kg m<sup>-3</sup>. Iqbal et al. (2019) reported similar spatial variations in tomato water productivity under different irrigation conditions, emphasizing the influence of irrigation uniformity and water availability on yield efficiency.

The depth of irrigation water applied to grapes varied across different reaches of the command area. The applied depths at the head, middle, and tail reaches were 162 mm, 161 mm, and 144 mm, respectively, while the number of irrigations was 5, 4, and 4. In contrast, both the depth of water applied and the number of irrigations for tomato remained nearly uniform across the head, middle, and tail reaches. This consistency is attributed to tube well irrigation, which ensured relatively stable discharge and uniform water application throughout the command area.

### Irrigation Scheduling Predicted through CROPWAT

Table 6 presents the irrigation scheduling parameters, including irrigation depth, irrigation interval, and the total number of irrigations required for wheat, tomato, and grape. The results clearly indicate considerable variation among the selected crops in irrigation requirements and application patterns.

**Table 6:** Irrigation scheduling predicted by CROPWAT

| Crops  | Ave. No. of Irrigations | Irrigation Interval (days) |      |      | Depth Applied (mm) |      |      |
|--------|-------------------------|----------------------------|------|------|--------------------|------|------|
|        |                         | Min.                       | Max. | Ave. | Min.               | Max. | Ave. |
| Tomato | 37                      | 2                          | 7    | 4.5  | 28                 | 41   | 31   |
| Grape  | 8                       | 11                         | 15   | 13   | 103                | 109  | 106  |
| Wheat  | 3                       | 17                         | 18   | 17.5 | 107                | 126  | 120  |

Among the crops studied, tomato exhibited the highest irrigation demand, receiving a total of 37 irrigations throughout its growing period. In contrast, grape required a moderate number of irrigations (8), while wheat showed the lowest irrigation requirement, with only 3 irrigations applied. This variation reflects differences in crop water requirements, growth duration, and sensitivity to soil moisture conditions.

Furthermore, tomato required more frequent irrigation at shorter intervals (2- 7 days), along with relatively lower application depths. In contrast, wheat had longer irrigation intervals (17–18 days) and higher irrigation depths, indicating its ability to use larger amounts of water over longer periods. Grape showed intermediate behavior, with moderate irrigation intervals (11–15 days) and relatively high irrigation depths.

### Farmers' Irrigation Practices

Information on irrigation intervals and the number of irrigations was collected through farmer interviews using a structured questionnaire Table 7 below. The depth of irrigation water applied was estimated following the methodology described in the previous sections.

**Table 7:** Farmers' irrigation practices in the command area

| Crops  | No. of Irrigations |      |      | Irrigation interval (days) |      |      | Depth Applied (mm) |       |       |
|--------|--------------------|------|------|----------------------------|------|------|--------------------|-------|-------|
|        | Min.               | Max. | Ave. | Min.                       | Max. | Ave. | Min.               | Max.  | Ave.  |
| Tomato | 24.0               | 30.0 | 27.0 | 1.0                        | 6.0  | 3.5  | 31.0               | 41.0  | 36.0  |
| Grape  | 4.0                | 7.0  | 5.5  | 14.0                       | 16.0 | 15.0 | 144.0              | 162.0 | 153.0 |
| Wheat  | 3.0                | 4.0  | 3.5  | 14.0                       | 18.0 | 16.0 | 87.0               | 110.0 | 99.0  |

The data show notable variation in irrigation practices across crops. On average, tomato received the most irrigations (27), followed by grape (5.5) and wheat (3.5). Tomato cultivation required frequent irrigation with relatively small application depths, reflecting its higher water demand and sensitivity to soil moisture fluctuations. In contrast, grape cultivation involved fewer irrigation events at longer intervals, but with significantly greater water depths per irrigation. Wheat showed moderate irrigation frequency and depth, consistent with its seasonal water requirements and growth stages.

### Comparison of Irrigation Scheduling through CROPWAT and Traditional Practices

A comparison between irrigation scheduling based on traditional farming practices and estimates generated by the CROPWAT model revealed generally similar trends Figure 8.

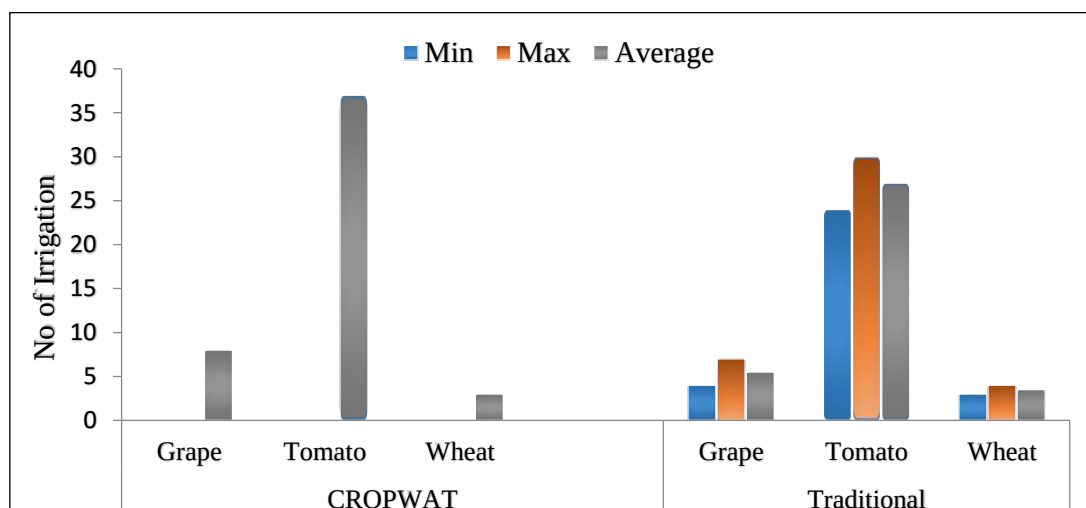


**Figure 8:** Comparison of number of irrigation applied traditionally and predicted by CROPWAT

However, some variations were observed depending on the crop type and local management practices. For grape cultivation, the CROPWAT model estimated about eight irrigation events, whereas farmers typically applied around six irrigations during the growing season. For tomato, the difference was more pronounced: farmers applied about 27 irrigations compared to the 37 suggested by the model, indicating a potential underestimation of water requirements under conventional practices. For wheat, the difference between the two approaches was minimal, with CROPWAT recommending three irrigations and farmers applying four, demonstrating close agreement. Overall, these results suggest that while traditional irrigation practices generally align with model-based estimates, discrepancies may arise because of local climate conditions, soil characteristics, and farmer experience.

These findings align with previous research indicating that the FAO-CROPWAT model is a reliable tool for estimating crop water requirements and optimizing irrigation scheduling. Although minor differences may occur, the model often produces results that closely correspond to field practices, supporting its applicability for improving water management in agricultural systems (El-Shafei and Mattar, 2022).

The comparison between irrigation intervals estimated using CROPWAT and those practiced by local farmers revealed only minor differences. Both approaches showed similar trends, with the shortest irrigation interval for tomato and the longest for wheat (Figure 9s).

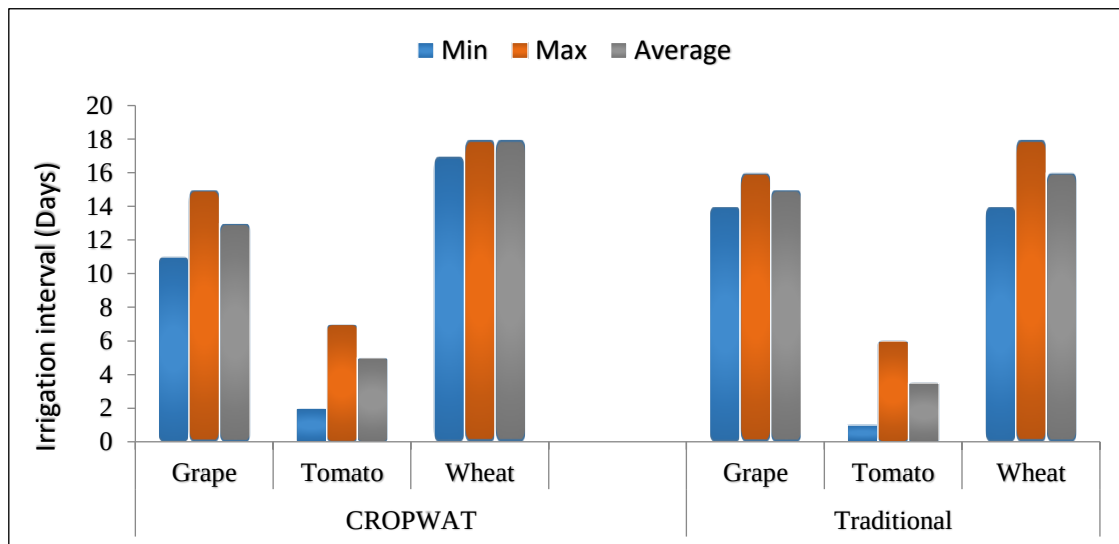


**Figure 9:** Comparison of irrigation interval predicted by CROPWAT and practiced traditionally

According to CROPWAT simulations, tomato requires irrigation at an average interval of approximately five days, whereas farmers typically apply water every four days. For wheat, CROPWAT suggested an irrigation interval of about 18 days, while farmers commonly irrigate at slightly shorter intervals of around 16 days. For grape cultivation, CROPWAT predicted irrigation once every 13 days; however, farmers irrigated less frequently, maintaining an interval of about 15 days between applications.

CROPWAT and local estimates differ slightly in applied depth. Tomato is the only crop receiving the minimum depth as predicted by CROPWAT and applied traditionally. Minor differences also exist in the amount of water applied to grapes. It receives 153 mm of water traditionally, while CROPWAT calculated 106 mm (Figure 10 below). Similarly, farmers applied nearly 100 mm of water to wheat, while CROPWAT predicted an average depth of 120 mm. Moreover, the lowest and highest depths applied traditionally were 36 and 153 mm for tomato and grape, respectively. CROPWAT estimated the lowest depth for tomato and the highest for wheat.

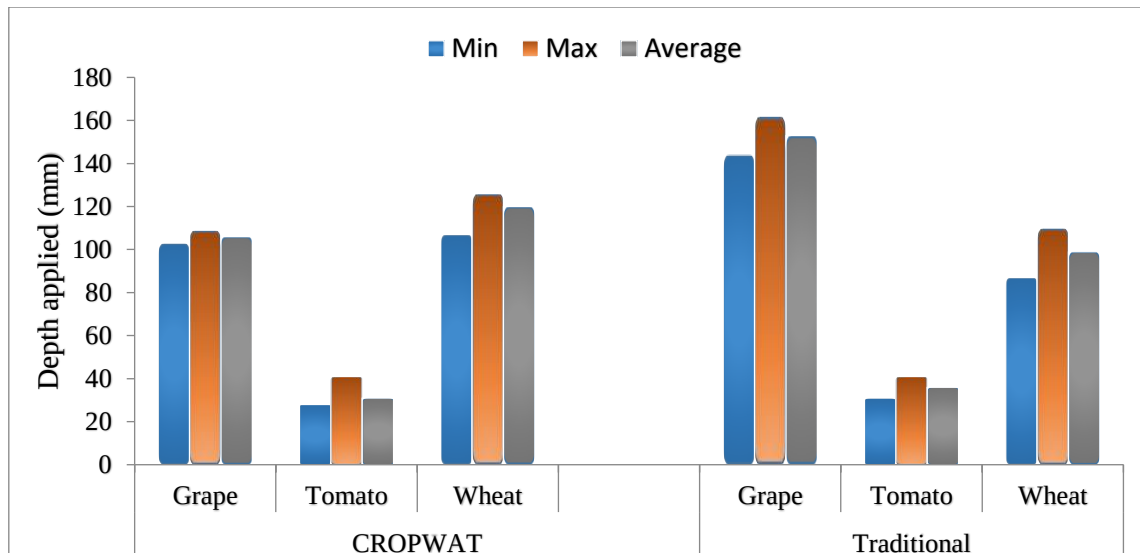


**Figure 10:** Comparison of depth predicted through CROPWAT and applied traditionally

## Discussions

Soil, water, and plants are fundamental natural resources that are essential for the survival of human beings and animals (Shah et al., 2022). Recent climate projections indicate a rising trend in crop water requirements (CWR), primarily driven by rising temperatures and increased evapotranspiration rates (Gabr, 2023; N'guessan et al., 2023). Under such changing climatic conditions, irrigation scheduling has become an essential management tool for determining when and how much water to deliver to crops. Since each crop passes through distinct growth stages, including initial, developmental, mid-season, and late-season, the irrigation requirement varies substantially across these stages, underscoring the need for stage-specific irrigation planning to optimize water use efficiency (Solangi et al., 2022).

This study used the CROPWAT 8.0 model to assess the relationship between irrigation supply and crop water demand. The estimated seasonal irrigation requirements were approximately 600–900 mm for tomato, 300–650 mm for wheat, 500–1200 mm for grape, and 900–1100 mm for apple, which are in agreement with values reported in previous studies (Abdelraouf et al., 2024; Er-Raki et al., 2010; Atroosh et al., 2013; Rallo et al., 2017). A clear seasonal trend was observed, with water demand increasing from June to July, corresponding to peak crop growth stages, and declining towards the end of August. Recent studies have also reported similar mid-season peaks in water requirements for crops such as grape, tomato, and apple (An et al., 2022). This pattern is consistent with previous findings that agricultural water demand tends to increase during the hottest and driest periods of the year, when high temperatures, low relative humidity, and limited rainfall accelerate evapotranspiration and reduce soil moisture availability, thereby increasing irrigation demand (Zhong et al., 2014).

The CROPWAT model has been widely applied in water-scarce regions to estimate irrigation requirements and support agricultural planning (Surendran et al., 2015; Ewaid et al., 2019; Selmy et al., 2024). It has also been used effectively for various crop types, including field crops, fruit crops, and perennial systems, to improve irrigation scheduling and maximize yield (Knežević et al., 2013; Laouisset and Dellal, 2016; Al-Najar, 2011). Crops with longer growing

periods generally require more irrigation because of their prolonged water demand over multiple seasons, whereas crops with shorter growing seasons tend to have comparatively lower irrigation requirements (Solangi et al., 2022). Although the crops assessed in the present study differ in growth duration and physiological characteristics, the observed variation in irrigation demand confirms the importance of crop-specific irrigation scheduling for efficient water allocation in canal command areas. Additionally, numerous studies have explored the implications of climate change on crop water requirements, highlighting the increasing pressure on water resources and the need for adaptive management strategies (Gilanipour and Gholizadeh, 2016; Rohila et al., 2024).

Our wheat findings are consistent with earlier studies by Khan et al. (2019) and Khan et al. (2021), supporting the reliability of the present estimates. Similarly, the overall irrigation requirements determined in this study are comparable with results reported by Solangi et al. (2022) for major crops under similar climatic conditions. Similar consistency has also been reported in regional assessments conducted in West Bengal (Konar and Dey, 2015), Ahmednagar district in Maharashtra (Bhausahed et al., 2021), and Haryana state (Shaloo et al., 2021), where irrigation water requirement estimates for wheat and other staple crops fell within comparable ranges. Such consistency across diverse agro-climatic regions strengthens confidence in the reliability of the present estimates and supports the applicability of CROPWAT-based irrigation assessments for agricultural water resource planning.

Daily crop water requirements in this study ranged from 2.35 to 10.29 mm/day, indicating substantial variation among crops by growth stage and environmental conditions. This range aligns with FAO guidelines, which suggest that crop evapotranspiration typically varies between 1 and 10 mm/day depending on climate, crop type, and development stage (FAO, 1998). Previous studies have also reported similar crop water requirement ranges for major crops across different climatic zones (Konar and Dey, 2015; Bhausahed et al., 2021; Shaloo et al., 2021), further supporting the present study's findings.

Climate change is expected to significantly influence agricultural water availability through shifts in temperature and precipitation patterns (Zhang et al., 2019; Masia et al., 2021). These changes are forcing farmers to adopt climate-resilient crop varieties and improved irrigation practices to cope with periodic water shortages. In perennial crops such as apple, water stress can have severe impacts, particularly during early growth stages, where imbalances may occur between root and shoot development (Ucar et al., 2023). Furthermore, inadequate water supply can reduce flowering, fruit set, and overall productivity. Therefore, selecting suitable crop varieties and implementing precise irrigation scheduling based on crop growth stages are essential for maintaining productivity under changing climatic conditions (Ertek, 2011).

## Conclusion

This study assessed water management practices in the Tajiki Canal command area of Kabul, Afghanistan, by evaluating irrigation supply, crop water requirements, cropping patterns, crop water productivity, and irrigation scheduling using field measurements and the CROPWAT model. The findings confirmed that grape was the dominant crop, occupying 16% of the cultivable command area, followed by wheat (15%), tomato (6%), and apple (5%). The analysis of crop water requirements showed that water demand for all crops except wheat increased

progressively and peaked in July, with maximum requirements of 7.04 mm/day for grape, 6.31 mm/day for wheat, 10.29 mm/day for tomato, and 10.19 mm/day for apple.

The study also showed that irrigation supply was generally lower than crop water demand throughout most of the year, exceeding demand only in July and August. Relative water supply varied from 0.30 to 1.16, indicating substantial temporal variability in water availability. Crop water productivity analysis revealed that tomato had comparatively higher productivity, ranging from 5.13 to 5.59 kg/m<sup>3</sup>. In comparison, grape productivity declined from 1.99 kg/m<sup>3</sup> at the head reaches to 1.82 kg/m<sup>3</sup> at the tail reaches of the canal, reflecting inequities in water distribution and utilization.

Comparison of traditional irrigation practices with CROPWAT-based scheduling showed that local practices were broadly consistent with model estimates; however, farmers generally applied greater irrigation depths to grape (153 mm) than the model recommended (106 mm). Differences in irrigation intervals and the number of irrigation events for grape, wheat, and tomato suggest opportunities to improve irrigation efficiency through science-based scheduling. The results further indicated that inadequate and uneven water supply, combined with deviations from optimal irrigation scheduling, contributes to reduced water productivity and underutilization of agricultural land, including a large proportion of fallow area. Therefore, improving water management through efficient allocation of canal water, better use of snowmelt and runoff resources, farmer training on scientific irrigation scheduling, and adoption of improved irrigation technologies and agronomic practices is essential to enhance crop water productivity and achieve sustainable agricultural development in the Tajiki Canal command area.

## References

- Abdelraouf, R. E., Abdou, M. A., Bakr, A., Hamza, A. E., Rashad, Y. M., Abd-ElGawad, A. M., Hafez, M., & Ragab, R. (2024). Enhancing tomato production by using non-conventional water resources within integrated sprinkler irrigation systems in arid regions. *Atmosphere*, 15(6), 722. <https://doi.org/10.3390/atmos15060722>
- Ado, S. G., & Abubakar, A. S. (2024). Towards self-sufficient agriculture in Afghanistan: A review of enhancements and challenges. *Journal of Natural Science Review*, 2(Special. Issue), 316-331. <https://doi.org/10.62810/jnsr.v2iSpecial.Issue.135>
- Al-Najar, H. (2011). The integration of FAO-CropWat model and GIS techniques for estimating irrigation water requirement and its application in the Gaza Strip. *Natural Resources*, 2(3), 146. <http://www.scirp.org/journal/nr>
- An, S., Yang, F., Yang, Y., Huang, Y., Zhangzhong, L., Wei, X., & Yu, J. (2022). Water Demand Pattern and Irrigation Decision-Making Support Model for Drip-Irrigated Tomato Crop in a Solar Greenhouse. *Agronomy*, 12(7), 1668. <https://doi.org/10.3390/agronomy12071668>
- Atroosh, K. B., Mukred, A. W. O., & Moustafa, A. T. (2013). Water requirement of grape (*Vitis vinifera*) in the northern highlands of Yemen. *Journal of Agricultural Science*, 5(4), 136. <http://dx.doi.org/10.5539/jas.v5n4p136>

- Aydın, Y. (2022). Quantification of water requirement of some major crops under semi-arid climate in Turkey. *PeerJ*, 10, e13696. <https://doi.org/10.7717/peerj.13696>
- Azami, A., Sagin, J., Sadat, S. H., & Hejran, H. (2020). Sustainable irrigation: Karez system in Afghanistan. *Central Asian Journal of Water Research*, 6(2), 65-86. 10.29258/CAJWR/2020-R1.v6-2/1-18.eng
- Benavides, J., Hernández-Plaza, E., Mateos, L., & Fereres, E. (2021). A global analysis of irrigation scheme water supplies in relation to requirements. *Agricultural Water Management*, 243, 106457. <https://doi.org/10.1016/j.agwat.2020.106457>
- Bhausahab, D. K., Balasaheb, K. S., & Vishwanath, M. M. (2021). Study of crop water requirement and irrigation scheduling of major crops grown in Ahmednagar district. *Multilogic Sci*, 10(36), 1710-1716.
- Doorenbos, J., Kassam, A. H., & Bentvelsen, C. (1979). Yield response to water, irrigation and drainage. Rome: FAO.
- El-Shafei, A. A., & Mattar, M. A. (2022). Irrigation scheduling and production of wheat with different water quantities in surface and drip irrigation: field experiments and modelling using CROPWAT and SALTMED. *Agronomy*, 12(7), 1488. <https://doi.org/10.3390/agronomy12071488>
- Er-Raki, S., Chehbouni, A., & Duchemin, B. (2010). Combining satellite remote sensing data with the FAO-56 dual approach for water use mapping in irrigated wheat fields of a semi-arid region. *Remote Sensing*, 2(1), 375-387. <https://doi.org/10.3390/rs2010375>
- Ertek, A. (2011). Importance of pan evaporation for irrigation scheduling and proper use of crop-pan coefficient (Kcp), crop coefficient (Kc) and pan coefficient (Kp). *African Journal of Agricultural Research*, 6(32), 6706-6718.
- Ewaid, S. H., Abed, S. A., & Al-Ansari, N. (2019). Crop water requirements and irrigation schedules for some major crops in Southern Iraq. *Water*, 11(4), 756. <https://doi.org/10.3390/w11040756>
- Food and Agriculture Organization (FAO). (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements (FAO Irrigation and Drainage Paper No. 56)*. Rome: FAO.
- Food and Agriculture Organization (FAO). (2023). *FAOSTAT database: Arable land area of Afghanistan*. Rome, Italy: FAO.
- Frenken, K. (2013). Irrigation in Central Asia in figures: AQUASTAT Survey-2012. <https://openknowledge.fao.org/handle/20.500.14283/i3289e>
- Gabr, M. E. (2023). Impact of climatic changes on future irrigation water requirement in the Middle East and North Africa's region: a case study of upper Egypt. *Applied Water Science*, 13(7), 158. <https://doi.org/10.1007/s13201-023-01961-y>
- Gilanipour, J., & Gholizadeh, B. (2016). Prediction of rice water requirement using FAO-CROPWAT model in North Iran under future climate change. <https://dx.doi.org/10.20944/preprints201610.0134.v1>

- Gocic, M., & Trajkovic, S. (2014). Analysis of trends in reference evapotranspiration data in a humid climate. *Hydrological Sciences Journal*, 59(1), 165-180. <https://doi.org/10.1080/02626667.2013.798659>
- Hussainzada, W., & Lee, H. S. (2022). Effect of an improved agricultural irrigation scheme with a hydraulic structure for crop cultivation in arid northern Afghanistan using the Soil and Water Assessment Tool (SWAT). *Scientific reports*, 12(1), 5186. <https://doi.org/10.1038/s41598-022-09318-2>
- Iqbal, R., Raza, M. A. S., Rashid, M. A., Toleikiene, M., Ayaz, M., Mustafa, F., Ahmed, M. Z., Hyder, S., Rahman, M. H. U., Ahmad, S., & Aslam, M. U. (2021). Partial root zone drying irrigation improves water use efficiency but compromise the yield and quality of cotton crop. *Communications in Soil Science and Plant Analysis*, 52(13), 1558-1573. <https://doi.org/10.1080/00103624.2021.1892720>
- Jovanovic, N., Pereira, L. S., & Paredes, P. (2021). Updates and advances to the FAO56 crop water requirements method. <http://hdl.handle.net/10566/6104>
- Khan, M. J., Malik, A., Rahman, M., Afzaal, M., & Mulk, S. (2019). Assessment of crop water requirement for various crops in Peshawar, Pakistan using CROPWAT model. *Irrig. Drain. Syst*, 10(9).
- Khan, Z. A., Imran, M., Umer, J., Ahmed, S., Diemuodeke, O. E., & Abdelatif, A. O. (2021). Assessing Crop Water Requirements and a Case for Renewable-Energy-Powered Pumping System for Wheat, Cotton, and Sorghum Crops in Sudan. *Energies*, 14(23), 8133. <https://doi.org/10.3390/en14238133>
- Khiavi, A. N., Vafakhah, M., & Sadeghi, S. H. (2024). Application of strategic planning and multi-objective decision-making models in integrated watershed management: A case study in the Cheshmeh-Kileh Watershed, Iran. *Journal of hydrology*, 631, 130690. <https://doi.org/10.1016/j.jhydrol.2024.130690>
- Knežević, M., Perović, N., Zivotic, L., Ivanov, M., & Topalović, A. (2013). Simulation of winter wheat water balance with CROPWAT and ISAREG models. *Agriculture & Forestry*, 59(1), 41-53.
- Konar, A., & Dey, G. (2015). A study on growth of irrigated area under groundwater in some districts of West Bengal in India. *International Journal of Ecosystem*, 5(5). DOI: 10.5923/c.ije.201501.18
- Laouisset, M. B., & Dellal, A. (2016). Estimation of barley (*Hordeum vulgare* L.) crop water requirements using CROPWAT software in Ksar-Chellala Region, Algeria. *Agris on-line Papers in Economics and Informatics*, 8(3), 91-102. <https://doi.org/10.22004/ag.econ.245887>
- Mahmoud, S. H., Ati, A. S., & Majeed, S. S. (2024). Calculating water productivity using the portal WaPOR. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1371, No. 8, p. 082039). <https://doi.org/10.1088/1755-1315/1371/8/082039>

- Masia, S., Trabucco, A., Spano, D., Snyder, R. L., Sušnik, J., & Marras, S. (2021). A modelling platform for climate change impact on local and regional crop water requirements. *Agricultural Water Management*, 255, 107005. <https://doi.org/10.1016/j.agwat.2021.107005>
- Murtaza, G., Saqib, M., Zia-ur-Rehman, M., Naveed, M., & Ghafoor, A. (2020). Mitigation of Climate Change Impacts Through Treatment and Management of Low Quality Water for Irrigation in Pakistan. In *Environmental and Agricultural Informatics: Concepts, Methodologies, Tools, and Applications* (pp. 1181-1198). IGI Global. DOI: 10.4018/978-1-5225-9621-9.ch053
- N'guessan, K. J. Y., Adahi, B., Konan-Waidhet, A. B., Masayoshi, S., & Assidjo, N. E. (2023). Assessment of climate change impact on water requirement and rice productivity. *Rice Science*, 30(4), 276-293. <https://doi.org/10.1016/j.rsci.2023.03.010>
- Pereira, L. S., Paredes, P., Melton, F., Johnson, L., Wang, T., López-Urrea, R., ... & Allen, R. G. (2020). Prediction of crop coefficients from fraction of ground cover and height. Background and validation using ground and remote sensing data. *Agricultural Water Management*, 241, 106197. <https://doi.org/10.1016/j.agwat.2020.106197>
- Rahmani, H., & Abid, M. O. (2024). Agriculture Water Management is an Important Approach for Mitigating the Effects of Climate Change in Afghanistan. *Nangarhar University International Journal of Biosciences*, 528-531. <https://doi.org/10.70436/nuijb.v3i02.290>
- Rahmani, H., & Azizi, N. M. (2024). Innovative Approaches for Afghanistan's Agricultural Water Management. *Journal of Natural Science Review*, 2(Special. Issue), 64-71. <https://doi.org/10.62810/jnsr.v2iSpecial.Issue.116>
- Rallo, G., González-Altozano, P., Manzano-Juárez, J., & Provenzano, G. (2017). Using field measurements and FAO-56 model to assess the eco-physiological response of citrus orchards under regulated deficit irrigation. *Agricultural water management*, 180, 136-147. <https://doi.org/10.1016/j.agwat.2016.11.011>
- Rohila, J. S., Gealy, D. R., Jackson, A. K., & Ziska, L. H. (2024). Assessment of outcrossing potential between cultivated and weedy rice under alternate wetting and drying irrigation management. *Agronomy Journal*, 116(4), 1903-1916. <https://doi.org/10.1002/agj2.21594>
- Selmy, S. A., Jimenez-Ballesta, R., Kucher, D. E., Sayed, A. S., García-Navarro, F. J., Yang, Y., & Yousif, I. A. (2024). Land suitability assessment and crop water requirements for twenty selected crops in an arid land environment. *Agronomy*, 14(11), 2601. <https://doi.org/10.3390/agronomy14112601>
- Shah, S. A., Jehanzaib, M., Yoo, J., Hong, S., & Kim, T. W. (2022). Investigation of the effects of climate variability, anthropogenic activities, and climate change on streamflow using multi-model ensembles. *Water*, 14(4), 512. <https://doi.org/10.3390/w14040512>

- Shaloo, B. H., Sarangi, A., Prajapati, V. K., Mishra, A. K., & Singh, M. (2021). Water Requirement and its Trend for Rice and Wheat Crops in Haryana State, India. *Int. J. Curr. Microbiol. App. Sci*, 10(02), 203-209.
- Sharma, U. C., Datta, M., & Sharma, V. (2023). Land use and management. In *Soils in the Hindu Kush Himalayas: Management for agricultural land use* (pp. 295-462). Cham: Springer International Publishing. [https://doi.org/10.1007/978-3-031-11458-8\\_7](https://doi.org/10.1007/978-3-031-11458-8_7)
- Solangi, G. S., Shah, S. A., Alharbi, R. S., Panhwar, S., Keerio, H. A., Kim, T. W., Memon, J. A., & Bughio, A. D. (2022). Investigation of irrigation water requirements for major crops using CROPWAT model based on climate data. *Water*, 14(16), 2578. <https://doi.org/10.3390/w14162578>
- Sun, X., Zhang, B., Dai, M., Gao, R., Jing, C., Ma, K., Gu, S., Gu, L., Zhen, W., & Gu, X. (2024). Research on methods for estimating reference crop evapotranspiration under incomplete meteorological indicators. *Frontiers in Plant Science*, 15, 1354913. <https://doi.org/10.3389/fpls.2024.1354913>
- Surendran, U., Sushanth, C. M., Mammen, G., & Joseph, E. J. (2015). Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India. *Aquatic Procedia*, 4, 1211-1219. <https://doi.org/10.1016/j.aqpro.2015.02.154>
- Taraky, Y. M., McBean, E., Binns, A., & Gharabaghi, B. (2024). Advancing water security and agricultural productivity: A case study of transboundary cooperation opportunities in the Kabul river basin. *Environments*, 11(11), 253. <https://doi.org/10.3390/environments11110253>
- TR, J., Reddy, N. S., & Acharya, U. D. (2023). Modeling daily reference evapotranspiration from climate variables: assessment of bagging and boosting regression approaches. *Water resources management*, 37(3), 1013-1032. <https://doi.org/10.1007/s11269-022-03399-4>
- Ucar, Y., Kocięcka, J., Liberacki, D., & Rolbiecki, R. (2023). Analysis of crop water requirements for apple using dependable rainfall. *Atmosphere*, 14(1), 99. <https://doi.org/10.3390/atmos14010099>
- World Bank. (2021). *Reliable irrigation boosts crop yields and diversity in Kabul Province*. World Bank Feature Story.
- World Bank. (2023). *Agriculture value added (% of GDP) and Employment in agriculture (% of total employment) – Afghanistan*. World Bank Development Indicators.
- World Bank. (2023). *Arable land (hectares) – Afghanistan*. World Bank Development Indicators.
- World Bank. (2024). *Arable land (hectares) – Afghanistan*. World Development Indicators. <https://data.worldbank.org/indicator/AG.LND.ARBL.HA?locations=AF>

- Zhang, Y., Wang, Y., & Niu, H. (2019). Effects of temperature, precipitation and carbon dioxide concentrations on the requirements for crop irrigation water in China under future climate scenarios. *Science of the Total Environment*, 656, 373-387.  
<https://doi.org/10.1016/j.scitotenv.2018.11.362>
- Zhong ShouQin, Z. S., Zhang WeiHua, Z. W., Lv JiaKe, L. J., & Wei ChaoFu, W. C. (2014). Temporal variation of soil water and its influencing factors in hilly area of Chongqing, China. <http://www.ijabe.org/>