ASSESSMENT OF IRRIGATION WATER UTILIZATION FOR CHAHAR ASYAB DISTRICT OF KABUL, AFGHANISTAN

A DISSERTION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

IRRIGATION WATER MANAGEMENT

by

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CANDIDATE'S DECLARATION

I hereby certify that the work being presented in the dissertation entitled "**Assessment of Irrigation Water Utilization for Chahar Asyab District of Kabul, Afghanistan"** submitted in the partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **Water Resource Development and Management Department** of the **Indian Institute of Technology, Roorkee** is an authentic record of my own work carried out during the period June 2018 to May 2019 under the supervision and guidance of **Dr. Ashish Pandey, Associate Professor, and Er. R.D. Singh, Visiting Professor, IIT Roorkee.**

Date: May, 2019

Place: Roorkee **WAHIDULLAH AMANI**

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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May, 2019
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ABSTRACT

This study has been conducted on assessment of irrigation water utilization for Chahar Asyab district, which is located in the downstream of Maidan river basin in Kabul province, Afghanistan.

Water resources of the Chahar Asyab, a semi-arid district of Kabul, Afghanistan, are extremely scarce and limited. It is highly imperative that these resources be used most carefully to ensure sustainable agriculture development and productivity. This, need to in turn, requires knowledge of irrigation water requirements (IWR) in the climatic zone(s) of the Chahar Asyab. Lack of this information often results in farmers over or under irrigating their fields with a consequent loss in yields and production. Various agencies in the country of determined IWR values for the different basin; however, for Chahar Asyab district or Maidan river basin, the water requirements of various popular crops have not been estimated.

An irrigation management model, simulated the complicated on-farm "crop, soil, and climate" phenomena, will facilitate the estimation for crop evapotranspiration, irrigation schedule, and agricultural water requirements with different cropping patterns for irrigation planning.

Although the CROPWAT model is used to estimate irrigation water requirements for many countries, it is not used for the Chahar Asyab district. The meteorological data from the Kabul airport station of Kabul province in Afghanistan were collected and analyzed, then input was prepared for the CROPWAT irrigation management model that was developed by the Food Agricultural Organization (FAO).

Based on the literature review, it is found that it is the first attempt to model existing available meteorological data for estimating the water requirement for irrigation for the most commonly grown crops (winter wheat, spring wheat, barley, maize, potato, onion, tomato, grapes, clover, and alfalfa) and comparing the results with the farmers' irrigation practices. The results of the CROPWAT model show that the annual reference evapotranspiration and effective rainfall in Chahar Asyab district 1430 mm, and 273.5 mm, respectively. Also, the irrigation requirement estimated to be (406.7, 673.2, 669.5, 734.8, 111.5, 863.5, 929.7, 339.7, 571.3, and 681.9) mm/year for winter wheat, spring wheat, barley, maize, potato, onion, tomato, grapes, clover, and alfalfa, respectively. On the other hand, results from CROPWAT model show that the total annual irrigation requirements for actual area of the cropping patterns are 5983.2 mm (27.15 MCM/year), and the peak irrigation requirements occurred during the months of June, July, and August which are about 1359, 1661, and 1274 mm respectively.

Results obtained from CROPWAT model show that the annual actual crop water use (ETc), gross irrigation (Gr. Irr.), net irrigation (Net Irr.), and actual irrigation requirement (A. Irr. Req.) are 6922, 7722, 5405, and 5872 mm, respectively. Also, the moist deficit at harvest

estimated to be 458 mm totally for all crops at a different time. On the other hand, the total flow for all crops is 78.5 l/s/ha.

Based on the results of irrigation water requirements from CROPWAT model, and available water for irrigation from observed discharge in the hydrological station, it was revealed that 40.25 m^3/sec of water was more in the Chahar Asyab district during the period (2017-2018). But according to the irrigation requirement for actual area estimated 9.55 m^3/sec, when compared with irrigation water available for 12 months, it was observed that the first 5 months (January, February, March, April, and May), and 3 months (October, November, and December) end of the year received excess water, but 4 months (June, July, August, and September) in the middle of the year were under deficient water condition.

The study shows that the irrigation management model (CROPWAT) can effectively and efficiently estimate the irrigation water requirements. Yet, it still needs further study to fit the model to the complicated situation of cropping patterns, for upgrading the ability of irrigation management of irrigation association in Afghanistan.

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LIST OF ABBREVIATIONS

MoEW	Ministry of Energy & Water
MAIL	Ministry of Agriculture, Irrigation, and Livestock
FAO	Food and Agriculture Organization of the United Nations
USGS	United States Geological Survey
SRTM	Shuttle Radar Topography Mission
GIS	Geographical Information System
RS	Remote Sensing
DEM	Digital Elevation Models
LULC	Land Use/Land Cover
USDA	United States Department of Agriculture
IDW	Inverse Distance Weighted method
PM	Penman-Monteith method
CWR	Crop Water Requirement
IR	Irrigation Requirement
E	Evaporation
T	Transpiration
ET	Evapotranspiration
ETo	Reference Evapotranspiration
ETc	Crop Evapotranspiration or Crop Water Use
ETa	Actual Evapotranspiration
Kc	Crop Coefficient
Ks	Water Stress Coefficient
RAM	Readily Available Moisture
TAM	Total Available Moisture

CHAPTER -1

INTRODUCTION

1.1. Background

1.1.1. Location of Afghanistan

Afghanistan is a dry, mountainous and landlocked country located within South Asia. Afghanistan is bordered in the south and east by Pakistan, by Iran in the west, by Turkmenistan Tajikistan and Uzbekistan in the north and by China in the far northeast. The total area covers 652000 km^2 and most of the area is covered by the high mountain range of the Hindu Kush, which experiences very cold weather with snow in the winters. The north of the country consists of fertile plains were very cold in the winter, whilst the south-west part is consisting of deserts, which is very hot in the summers.

1.1.2. Climate, Agriculture, and Irrigation of Afghanistan

Afghanistan has an arid, and semi-arid climate. Literally, it has thousands of microclimates, where frequently conditions change from one valley to another, within a fairly short distance. Afghanistan has a sloppy, high altitude hill as well as flat plains in other regions of the country. The change in altitude produce a climate with temperate and semi-tropical characteristics, wide spreading temperatures variations are usual from season to season and from day to night. Summer temperatures are high with high evaporation rate and winter is cold with the freezing condition. Afghanistan is an arid country, with more than half of the area receiving 100 to 300 mm precipitation per year, which mostly occurs in the winter season with no agricultural activities.

The total cultivable area of Afghanistan is about 8 million hectares [FAO, 2001], which is 12% of the total area. A land use survey was conducted on the 1990s and reported that about 3.2 million ha was irrigated and other lands remain bare [FAO and ICARDA 2008]. As Afghanistan is located in the arid and semi-arid region, agriculture relies heavily on irrigation. As the majority of the population is small-scale farmers, they have to irrigate their fields to produce crops. However, the irrigation allocation method has a systematic problem. Afghanistan's current method for water distribution is a traditional irrigation practice which has been set since over 300 years ago, and the amount of water is determined according to land size. Each farmer can irrigate their land in limited hours by way of a circulation schedule between the water users, but the crop types and variation of water regime are not considered. In traditional allocation system, Mirab (water master), who is selected by water users, has the responsibility to control irrigation hours according to their land size. Therefore, when Mirab releases water from the main canal to secondary canals, the upstream command area receives much water than necessary because it doesn't be considered the actual crop water requirement, In this case, enough irrigation water couldn't reach to downstream area, particularly during summer, and thus crops cannot complete their vegetation growth because of a deficit of irrigation water. Canal water decreases during summer but the amount of irrigation for the upstream area doesn't vary so much. Hence, some parts of arable lands in downstream are left without cultivation.

The available water to the irrigation system, mostly not equal to the available water for irrigation, it consists of total water requirement for all irrigation areas in addition water loss during conveyance and division of irrigation water.

When the available water for irrigation exceeds the crop water requirement, plants may get more water, which has a negative effect on their growth. Or, on the other, costly water may be wasted and not visible into the drainage system. When the available water for irrigation is less than the crop water requirement, the irrigation field may suffer from a deficit of irrigation (drought) and plant production will decline.

1.1.3. Water Resources of Afghanistan

Afghanistan is still rich in water resources mainly due to the availability of the high mountains series like Hindukush, Pamir, and Baba which are mostly covered by snow. The Hindukush mountain series at height of above 2000 m are the origin of over 80 percent of country's rivers which worked as natural storage of water form of snow during winter and thus support permanent flow in all rivers by melting snow during summer. Total annual water capacity of Afghanistan is 75 billion cubic meters.

Table 1.1: Estimated surface and ground water resources of Afghanistan (From MoEW of Afghanistan, and Wikipedia).

Type of Water Resource	Total Runoff (B. Cum)	Present Situation				
		Used (B.cum)				Un-used
		Total	Agriculture	Livestock	Water Supply	
Surface water	57	20	19.78	0.1	0.14	37
Ground water	18	3	2.78	-	0.21	15
Total	**75**	**23**	**22.57**	**0.1**	**0.35**	**52**

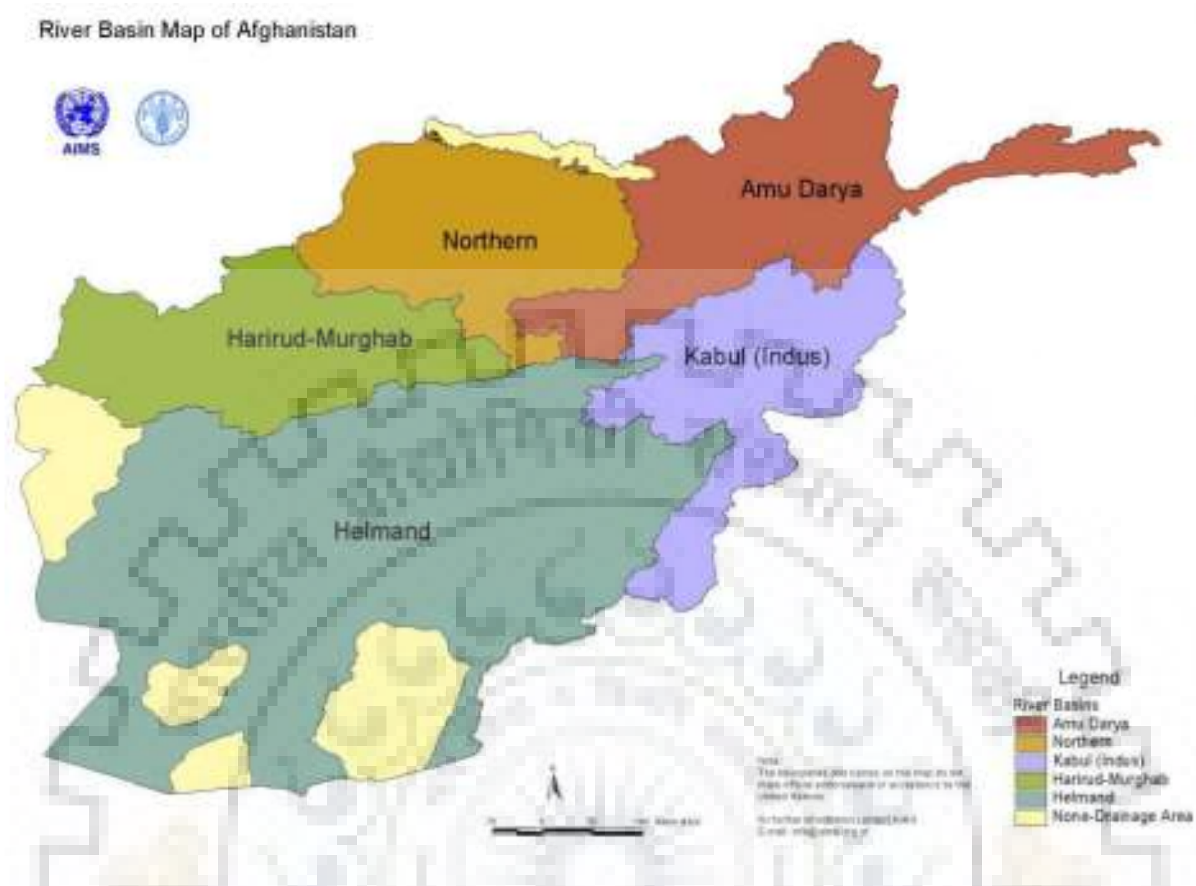


Figure 1.1: Basin and watershed of Afghanistan

Afghanistan is not independence for its water due to landlocked and shares of four out of five rivers with the neighboring countries. The four major rivers origin starts in Afghanistan by melting snow at elevation of above 2000 m, from the Hindu Kush mountain, (constitutes the volume of Afghanistan water resource and key importance to the country as a natural water storage) then flow into the neighboring countries, whilst very small portion only one third of this huge water being used in Afghanistan.

Afghanistan water flow is divided into five river basins (Figure 1.1):

(i) The Amu Darya river basin,

(ii) The Helmand river basin,

(iii) The Kabul river basin,

(iv) The Harirod river basin, and

(v) The Northern river basin.

1.1.3.1. Amu Darya River Basin

The Amu Darya river basin gets origin from High Mountain of Wakhan corridor located in the northeast of the country where that area is also called as Pamir River. It flows toward the west and forming most of the border with Union of Soviet Socialist Republics (USSR). Many large tributaries of Amu Darya enter from the north side, where Kokcha and Kunduz Rivers are major tributaries from Afghanistan. Also during monsoon season the huge flood, the Shirin Tagao, Sarepul, Balkh, and Kholem Rivers are may also add as tributaries to the flow of the Amu Darya. Finally, the Amu Darya empties into the Aral Sea.

1.1.3.2. Kabul River Basin

The Kabul River Basin flows eastward from the neighborhood of Kabul city and then goes into to Pakistan where finally enters to Indus River. The major tributary of Kabul River is: Panjshir River that enters near to Sarobi to Kabul River, from the south is Logar River. Kunar River is the major tributary which gets start from the mountains of Pakistan and enters to Kabul near Jalalabad. The last tributary is Laghman River enters in Kabul near Laghman city.

1.1.3.3. Helmand River Basin

The Helmand River Basin gets start just near Kabul city mainly from southern slopes of the Hindu Kush Mountain. It flows toward the southwest of the country until it comes to an end in the Human Sistan Basin on the Iranian border where it is lost due to evaporation. The major tributary to Helmand is the Arghandab River that drains most of the places in southeastern Afghanistan. Tirin River is from the east. Musa Qala, Kaj, and Panjao are the tributaries from the west. Most the mentioned flows originate from snow melting in the high regain of the mountain and most of the tributaries have permanent flow during the year expect Musa Qala and Kaj rivers.

1.1.3.4. Harirod River Basin

The Hari rod River Basin originates from high central Plateau and starts flows toward the west of the country forward to the Iran border where the direction of its change toward the north to form a border among Afghanistan and Iran. The only major tributary of Harirod River is Kowgon River where for long distance, it travels parallel to Hari River and finally joining near Marwa. In the north, it forms the border with Iran and at the end disappears in the desert wastes of Turkmen

1.1.3.5. Northern River Basin

The Northern River Basin is consisting of Murghab in the northwest. Its tributary is Kushka and joined the Morghab River in Turkmenistan. The Adraskand and Farah Rivers are tributaries from the west and flows parallel to each other and finally enters to Human Sistan Basin.

CHAPTER -2

LITERATURE REVIEW

This chapter concentrates on relevant literature reviewed on the estimation of crop water requirement, irrigation water requirement, irrigation scheduling, and scheme water requirement, CROPWAT along with GIS mapping model, and also assessment of irrigation water requirement based on available discharge in the river (available water for irrigation in the study area).

Inam et al. (1998) assessed the crop water requirement and irrigation water supply at Pabbi minor of Warsak gravity canal and the research study was conducted on irrigation water supply and demand at Pabbi minor of Warsak gravity canal.

Kuo et al. (2001) evaluated the crop water requirements using CROPWAT model to estimate the crop evapotranspiration, irrigation schedule, and agricultural water requirements with different cropping patterns for irrigation planning in ChiaNan irrigation association in Taiwan.

Rees et al. (2003) assessed the optimum or reasonable irrigation needs of a wide range of outdoor crops. The research under the optimum use of water for agriculture study (W6-056) provided the environment agency with a procedure. However, the procedure was limited in terms of its applicability to other agricultural sectors, including irrigated glasshouse production, ornamentals and nurseries, turf production and frost protection. The procedure was also not suitable for assessing the irrigation needs of non-agricultural abstractions, such as golf courses and racecourses.

Comejo (2003) estimated the irrigation potential of the Trasvase system in the Santa Elena Peninsula, Guayas, Ecuador. Available geographic, climatic, and soils and land use data were summarized for the Santa Elena Peninsula using a Geographic Information System. The total area that can be irrigated was calculated based on the evapotranspiration concept used by CROPWAT software from UN/FAO.

Asadi et al. (2007) studied on optimum utilization of water resource for effective irrigation management using remote sensing and GIS, to study the existing cropping patterns and water resources availability in the drought-prone area of Narsapuram watershed of Anantapur district in India. The crop water requirements (CWR) for each of the existing cropping pattern is estimated using the modified Penman method and information on existing water resources is obtained from the local government organizations. Various thematic maps, prepared from IRS-1C-LISS-III satellite imagery and SOI topo-sheet, were integrated to prepare a composite map showing the status of groundwater development and to identify sites for construction of artificial recharge structures. It is recommended that groundwater potential be improved through this artificial recharging of water to the aquifers so that it can meet the requirement of water for existing cropping patterns.

Rabanizada et al. (2008) evaluated a traditional water allocation method of Afghanistan and to find ways to optimize the use of water in the command area level, estimation of irrigation water requirement in Zohrabi Canal Command Area Khulm Watershed, Afghanistan.

Knox et al. (2008) assessed the optimum or reasonable irrigation needs of a number of additional agricultural and non-agricultural sectors dependent on direct abstraction and to provide guidelines to help the environment agency assess and set abstraction licenses for irrigation the study reviewed and combined information from desk-based research, industry surveys, water audits, and computer modeling.

Ahmad et al. (2013) studied for efficient management of irrigation networks and optimum utilization of irrigation schemes for the sustainable agriculture, the application of cutting-edge technologies such as space technology and geographical information system (GIS) are very much essential. Geospatial techniques were applied for selecting optimal multi-purpose river projects and maximizing irrigation potential for an improved method of site selection and better planning of water supply schemes.

Chowdhury et al. (2013) studied the implications of climate change on crop water requirements (CWRs) from 2011 to 2050 in Al-Jouf, Saudi Arabia. CWR were predicted for four scenarios: (i) current temperature and rainfall (S1); (ii) temperature in 2050 and current state of rainfall (S2); (iii) rainfall in 2050 and current state of temperature (S3) and (iv) temperature and rainfall in 2050 (S4).

Kumbhar et al. (2014) assessment of the irrigation and agriculture potential for Ujjani Right Bank Canal (URBC) of Bhima irrigation project using Geospatial Techniques. The study concluded that the highest agricultural potential lays in the north-central section, which is most intensively irrigated, has the lowest aridity index score, characterized by very low slope and shallow, clayey soil.

Rasooli et al. (2015) assessment of potential dam sites in the Kabul River Basin (KRB) used ArcGIS tools for KRB to present the hydrology or drainage network, irrigation, population, climate and surface pattern other necessary features of the basin in order to invest and implement infrastructure projects. He used Digital Elevation Model (DEM) and GIS tools to extracted watershed properties which involve: area, slope length, stream work density, delineating stream and watersheds, etc. while usually, this was (and still is) being done manually by using topographic/contour maps. The handling of DEM to delineate watersheds is referred to as terrain pre-processing. Meanwhile, it created the necessary thematic maps, base maps and other detailed maps for illustrating basin characteristics and features GIS based.

Nithya et al. (2016) studied the crop water requirement of Tarikere command area using CROPWAT. The crops include areca nut, coconut, and cotton, banana for two seasons, sweet pepper, onion, potato, rice, pulses, mango, and cotton, sugarcane, and millet (ragi). Crop water requirement for each crop was determined by using 30-year climatic data in CROPWAT. Reference crop evapotranspiration (ET0) was determined using the FAO Penman-Monteith method. For all the crops considered, three decades: decades I, II, and III and seven crop growth stages: nursery, nursery/land preparation, land preparation, initial stage, development stage, mid-season, and late season stage were considered.

Shams et al. (2016) studied effective utilization of irrigation water in Afghanistan. The overall objectives of this research is the shortage of water can be determined as the losses of agricultural yield via several activities, such as high on-farm distribution losses, high runoff high evapotranspiration rate, poorly land leveled, over irrigation, deep infiltration, low knowledge of farmers about crop water requirement (CWR), and lack of agrometeorological data.

2.1. Research Gaps

Based on the above review of the literature the following research gaps are found.

(i) Study based on the CROPWAT model, ArcGIS software has not been carried out for Chahar Asyab district of Kabul Afghanistan.

(ii) The general gaps are a shortage of water through water losses such as high evapotranspiration rate, high on-farm distribution losses, high run-off, over irrigation, poorly leveled land, and deep percolation, low knowledge of farmers about crop water requirement, and lack of agrometeorological data.

(iii) There is a need to develop further methods for establishing crop irrigation requirements which are accurate in order to enable the optimal use of water resources in future water planning processes.

(iv) The lack of equipment for collecting data, like climate data, in the area, required data cannot collect for assessment and analysis.

(v) Due to lack of expert, Afghanistan facing problem to improve the irrigation system, as well.

2.2. Objectives of the Study

(i) Generation of various thematic maps using ArcGIS & RS for Chahar Asyab district.

(ii) Estimation of Crop Water Requirements (CWR) and Irrigation Water Requirement (IWR) using CROPWAT 8.0 model for Chahar Asyab district.

(iii) Development of Irrigation Schedule for different management conditions and calculation of Scheme Water Requirement for varying crop patterns using CROPWAT 8.0 model for Chahar Asyab district.

(iv) Assessment of the Irrigation Water Availability for Chahar Asyab district.

CHAPTER -3

STUDY AREA

3.1. General

The study area is Chahar Asyab district with 257 km^2 one of the Kabul districts, located 34° 24' 35" N latitude and 69° 10' 00" E longitude in south part about 20 km far from Kabul city (Figure 2.1). Chahar Asyab district surrounded in the north by Kabul city, in the north-west by Paghman district, in the west by Musayi and Bagram district, in the south by Logar province.

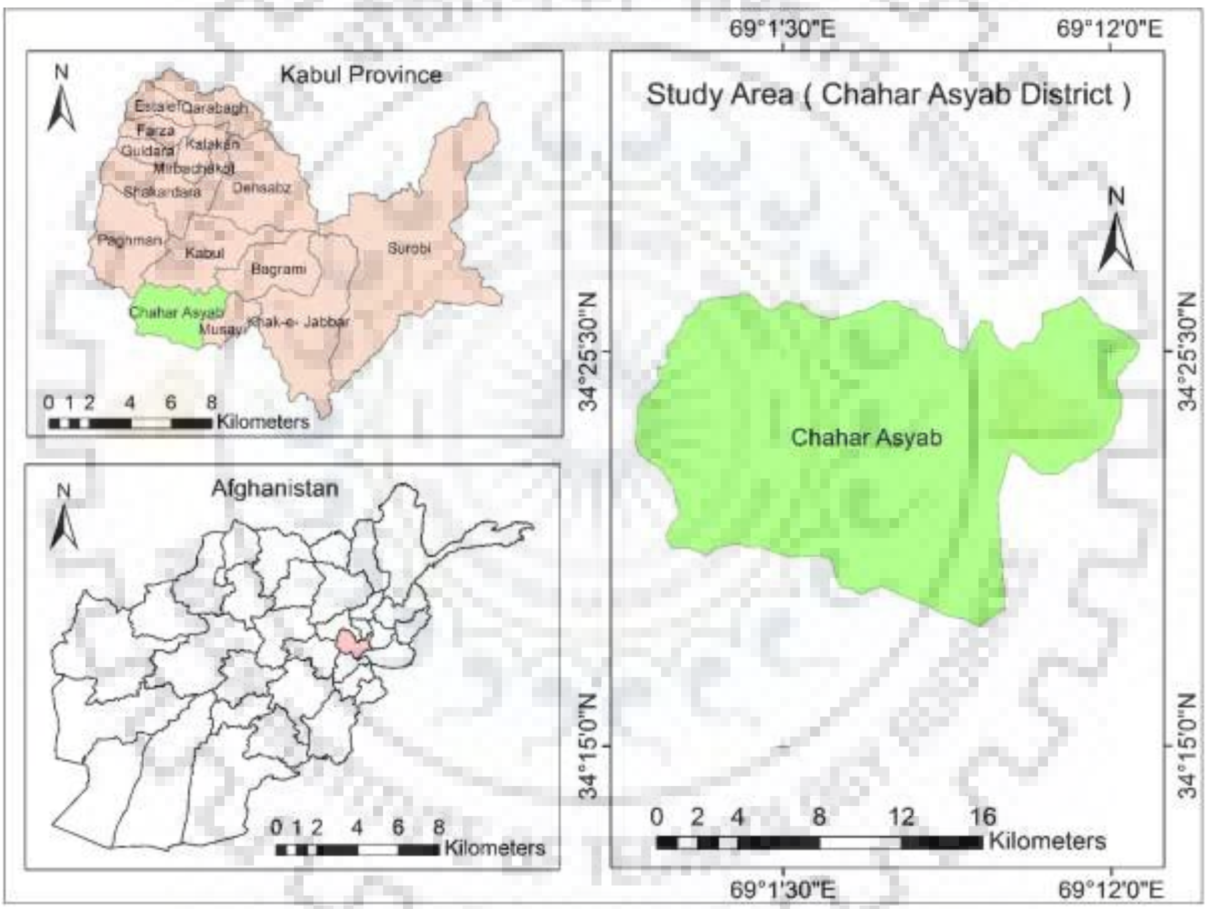


Figure 3.1: Location of the Study Area.

The district has 85 villages and around 55,000 people population. Chahar Asyab district has four seasons of the dry climate, and annual rainfall levels in the month of March and April 300 mm. In winter season the temperature is between -15 and -20 °C, while in the summer season it reaches between +15 and + 38 °C. The month of December the coldest month with an average temperature of -12 °C, and also July the warmest month of during the year, with average temperature reaching 35 °C. The spring season begins from the month of March and continues until the month of June.

Chahar Asyab district composed from 7,187 householder and all householders have agriculture and livestock occupation and also each household owns of land ranges from 2-35 jeribs (1 jerib = 1/5 hectare) and minimum one cow, a calf, chickens and sometimes a few goats or sheep. With each generation, lands are decreasing in size because it's divided up among sons. For agriculture and livestock they are using surface water, rainwater. Agriculture is the main source of income.

Table 3.1: Main crops with irrigated area from Chahar Asyab district **(**From NAIS/ASAP 2008, USAID-Afghanistan, and MAIL)

No.	Main Crops	Hectares
1	Winter Wheat	1,500
2	Spring Wheat	500
3	Barley	500
4	Maize (Corn)	550
5	Potato	750
6	Onion	500
7	Tomato	400
8	Table grapes	150
9	Clover	100
10	Alfalfa	50
Total		**5,000**

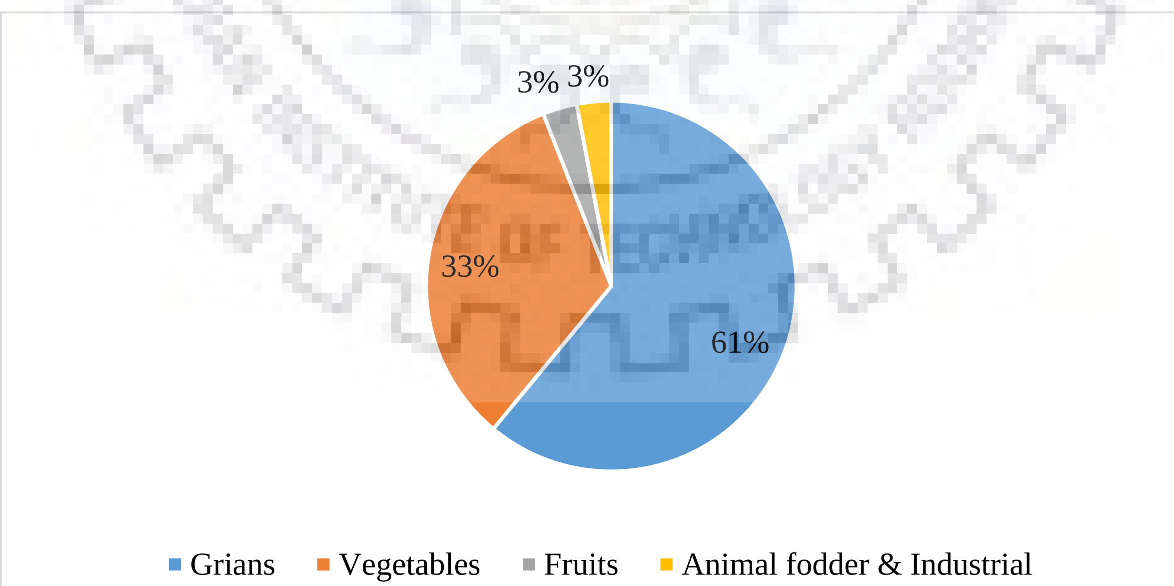


Figure 3.2: Crops percentage in Chahar Asyab district.

Figure 3.3: Views of irrigation lands in Chahar Asyab district

3.2. Available Water for Irrigation

In the arid and semi-arid regions of the world, for example, Afghanistan, with their characteristic low rainfall, where agriculture is mainly dependent on irrigation. The major source of irrigation water in these areas is rivers. These rivers have extensive catchments which contribute runoff from rainfall and/or snow-melt. If necessary, a part of the water supply for irrigation is from groundwater.

The Maidan River is one important river enters the Chahar Asyab district and have to be taken into account in the water balance. The river discharges start increasing in October. The first rain and snow only appear in November and December in the Kabul Plain. The rise in the river discharges for this period could be explained by the fact that the river may be fed by other more important rain events in upper zones of the catchment basin.

The highest water flows occur between March and May, which are also the months with the most important rainfall. It is also a possible period for the beginning of snow-melt as the monthly mean temperature rises rapidly from February. The discharges start to decrease in April or May and remain significant until June or July in the Maidan River.

The upper catchment basin of the Maidan river is a small basin with high elevated mountains (parts of the Paghman range) where the river mainly flows through narrow gorges before reaching the main part of the valley in the Darulaman Basin. This could explain the fact that if rain occurs in October it may be directly stored as snow cover that melts in spring and rapidly but continuously feeds the Maidan River whose discharge diminishes slowly until July.

Table 3.2: The possible hydrological year and values used for simulations proposed a hydrological year (From hydrology of the Kabul River basin part III: Modeling approach conceptual and numerical groundwater models).

Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Eff. rainfall occurrence												
Snowfall occurrence												
Snowmelt occurrence												
Operation-Irrigation												
High-groundwater												
Low-groundwater												

The discharge of the Maidan River is monitored at the Tangi Saidan hydrological gauging station situated before the confluence with the Paghman River. The drainage area above the station is estimated to be about 1625 km². The annual mean discharge for the period October 2008 to September 2017 varied between 2.47 to 5.67 m^3/sec. Minimum monthly mean discharges under 1 m^3/sec were observed during six months of the year in 2015, 4 months in 2016 and six months in 2017. The minimum daily discharge observed was 0.05 m^3/sec for 11 days in July 2016. In the Integrated Water Resources Management in Kabul River Basin, the river basin is divided into hydrological units based on the location of the key hydrological station.

In the present study, the hydrological unit would be utilized as a base unit to find the river discharge in upstream of the study area.

In general, the observed discharge data at the hydrological station is disturbed by human impacts such as intake and use of the water in the catchment. In this section, the characteristics of the disturbed discharge (observed discharge) are summarized.

Based on the completed monthly discharge data for 2008-2017 the average discharge in the Tangi Saidan hydrological station is calculated and shown in (Table 3.3), together with the average precipitation in the upstream catchment area, specific discharge, and runoff rate. The depth of runoff is, in general, less than 80mm in the upper Kabul river basin.

Table 3.3: Tangi Saidan hydrometric station in Kabul River basin (From ibid. (*Existing condition (2015) based on Integrated Water Resources Management in Kabul River Basin, 2015, Vol. 1, Sec. 2). (**based on WORLDCLIM data; ***Integrated Water Resources Management in Kabul River Basin, Vol.3. And from Afghanistan, emergency irrigation rehabilitation project, Technical annex, 2016. Type: A=Automatic; **** Kabul river valley development project; *****JICA study team).

Hydrological Unit or Hydrometric Station	Tangi Saidan
River	Maidan
Type	A
Longitude	69.28868330 E
Latitude	34.40897500 N
Elevation (m)	1,870
Upstream drainage area (DA) (km2)	1,625
Total population*	55,000
Average temperature (°C)	12
Average precipitation in upstream DA (mm)**	300
Monthly mean discharge in (m3/sec)	4.15
Annual Average Discharge volume (MCM)***	130.67
The depth of Run-off (mm)	77.5
Run-off rate (%)	16
Irrigation Bypass****	Yes
Capacity Bypass Channel****	Estimated average bypass (1.56 m^3/sec)
Data Available***** (Start Year - End Year)	2008 - 2017

3.2.1. Monthly Mean Water Discharge

This dataset is prepared based upon "Completed monthly discharge data for 2008 – 2017 by filling the gap of observation using correlation among the hydrological stations, which is shown in "Integrated Water Resources Management in Kabul River Basin, Vol.3".

In the present study, these completed monthly discharge data have been checked with the original data in the Hydrological Year Books and would be basically utilized for further analysis. When there are differences between the values in the Hydrological Year Books and ones prepared by "Integrated Water Resources Management in Kabul River Basin, Vol.3", the values in the Hydrological Year Books would be used.

The Tangi Saidan hydrometric station is one of the most important stations that are under study in the region. This station is at a distance of a few kilometers in the downstream of the Shatoot Dam axis. On condition that its data refers well to the natural conditions of the river.

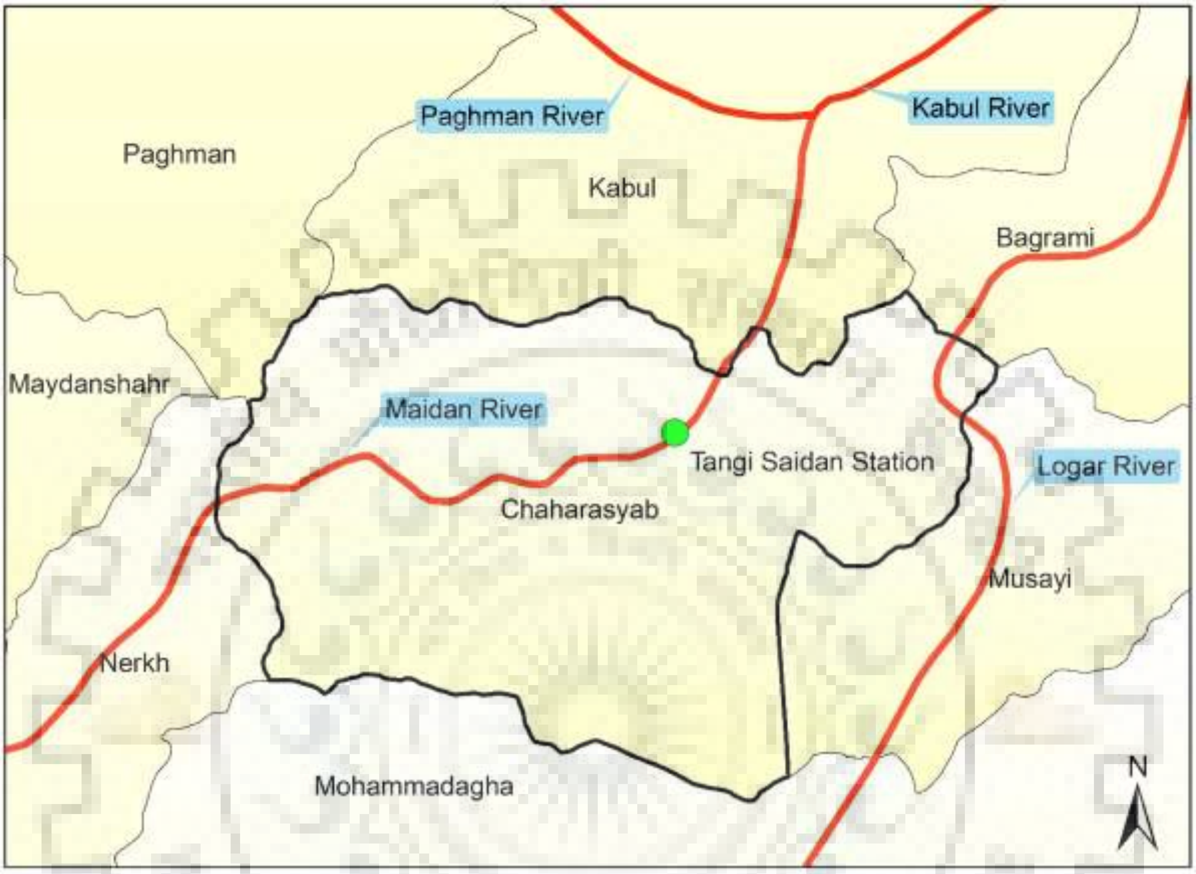


Figure 3.4: Maidan River and Tangi Saidan hydrometric station in the Study Area

Table 3.4: Monthly mean water discharge from Tangi Saidan hydrometric station in Chahar Asyab district (From MoEW).

Monthly Mean Water Discharge (m^3/sec)					
River basin	Kabul	Code	1-0.000	Water year	2008 - 2017
River	Maidan	Code	1-0.000	Elevation	1870 m MSL
Station	Tangi Saidan	Code	1-0.000-8	Drainage area	1625 Km^2
Gage	Staff/Recorder	Latitude	34.40897500 N	Longitude	69.28868330 E

Year	**Monthly Mean Water Discharge (m^3/sec)**												**Yearly summary**			
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Min**	**Mean**	**Max**	**Run-off (Mm^3)**
2008	0.00	1.26	0.77	2.60	5.14	6.32	8.25	6.01	0.46	0.00	0.00	0.00	0.00	2.57	11.46	81.3
2009	0.00	0.00	0.71	2.96	4.48	8.75	19.56	16.52	10.73	0.90	0.00	0.07	0.00	5.39	24.20	169.5
2010	0.07	1.14	3.34	2.89	3.24	5.48	23.29	5.58	0.00	0.08	3.11	0.00	0.00	4.02	56.00	126.2
2011	0.02	0.10	1.51	1.88	1.72	4.97	14.67	3.74	1.07	0.00	0.00	0.00	0.00	2.47	45.00	77.7
2012	0.02	0.31	0.27	0.55	1.22	12.01	34.36	13.60	1.65	0.00	0.00	0.00	0.00	5.33	78.00	168.1
2013	0.00	0.53	2.36	2.75	3.23	6.70	25.24	6.10	3.19	0.26	0.08	0.25	0.00	4.22	52.00	132.4
2014	0.23	2.29	2.64	2.99	2.98	4.65	15.19	13.35	6.12	0.91	0.37	0.41	0.10	4.34	55.00	136.8
2015	0.00	0.18	1.13	2.71	2.86	10.78	24.01	6.67	0.28	0.48	0.37	0.08	0.00	4.13	36.50	129.9
2016	0.42	1.79	2.70	2.50	1.87	11.89	28.60	15.25	2.12	0.05	0.55	0.46	0.00	5.68	45.70	179.5
2017	0.13	0.75	2.50	2.31	3.40	12.26	13.48	5.07	0.01	0.07	0.03	0.04	0.00	3.34	26.00	105.5
Mean	**0.09**	**0.84**	**1.79**	**2.41**	**3.01**	**8.38**	**20.67**	**9.19**	**2.56**	**0.28**	**0.45**	**0.13**	**0.00**	**4.15**	**78.0**	**130.67**

CHAPTER-4

GENERATION OF VARIOUS THEMATIC MAPS

4.1. Introduction

4.1.1. Thematic Maps (GIS and Spatial Analysis)

A thematic map is a visual representation of the features of a particular geographic location. The features shown on the map may be from a wide range of properties of interest to the researcher. These include a few geographic features such as agricultural information and water information, as well as qualitative features such as descriptive information about specific types of water resources in the region. Data for use in a subject map may be from an existing source, such as satellite imagery or official data, maybe the original data collected by the researcher or a combination of both.

Recent advancements in computer technology have offered many benefits in the field of water resources. Geographic Information Systems (GIS) is such a tool with diverse applications.

The analysis of the perspective of the development of remote sensing methods for the study of natural resources suggests that in addition to the further development of mathematical methods and the automated processing of space images, a great deal of attention is paid to the geographic information approach with the aim of spatial analysis of remote sensing data In GIS. To create the intellectual GIS, the automatic interpretation of these data can be modeled by environmental changes in the use of natural resources, the acquisition of quantitative estimates of natural resource changes and decision making using RS data as input information. In GIS, more effective organization of RS data is represented as a set of thematic maps. Hence, an immediate task is development Geographic Information Technology (GIS) provides the possibility to carry out thematic design maps using RS data.

4.1.2. Remote Sensing Techniques

Remote sensing is the attainment of information on an object or phenomenon without making physical contact with the object and thus in contrast to on-site observation, especially the Earth. Remote sensing is used in numerous fields, including geography, land surveying, and most Earth Science disciplines (for example, hydrology, ecology, meteorology, oceanography, glaciology, geology, etc); it also has military, intelligence, economic, commercial planning, and humanitarian applications.

Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites. Remote sensors collect data by detecting the energy that is reflected from Earth. These sensors can be on satellites or mounted on aircraft.

Classification of satellite image into different objects is modeled as the task of clustering based on the intensity of R-G-B values of pixels. Results obtained are presented and compared with the Survey of data Topo sheets.

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area. Special cameras collect remotely sensed images of the Earth, which help researchers "sense" things about the Earth. Some examples are:

(i) Cameras on satellites and airplanes take images of large areas on the Earth's surface, allowing us to see much more than we can stand on the ground.

(ii) Sonar systems on ships can be used to create images of the ocean floor without needing to travel to the bottom of the ocean.

(iii) Cameras on satellites can be used to make images of temperature changes in the oceans.

Some specific uses of remotely sensed images of the Earth include:

(i) Large forest fires can be mapped from space, allowing rangers to see a much larger area than from the ground.

(ii) Tracking clouds to help predict the weather or watch erupting volcanos, and help watch for dust storms.

(iii) Tracking the growth of a city and changes in farmland or forests over several years or even decades.

(iv) Mapping the ocean bottom - Discovery and mapping of the rugged topography of the ocean floor (e.g., huge mountain ranges, deep canyons, and the “magnetic striping” on the ocean floor).

4.1.3. Geographic Information Systems (GIS)

Geographic Information System (GIS) is a digital database management system designed to manage large volumes of non-spatial and especially distributed data from a variety of sources that are then geo-referenced by latitude and longitude.

Geographic information system link land cover data to topographic data and two other pieces of information concerning processes and properties related to geography location. When applied to a hydrological system, the image information may not include a description of groundwater-surface coverage groundwater conditions and the surface or below man-made systems and their characteristics. Terrain description is called terrain modeling. The downward flow of surface water contributes to the hydrological importance of terrain modeling. Although maps have always been the most common form of historical representation of terrain, the emergence of digital maps in GIS provides another way to store and retrieve this information. The amount of digital data needed to actually describe the terrain of even a small geographic area makes it a memory-intensive and computationally intensive system.

The characteristics that differentiate days from general computing mapping a drawing system is the link to the information database. Once a database is established, the association between different pieces of information can be easily checked by computer- generated overlays. For the hydrological simulation process, additional steps are usually required to generate hydrological parameters that depend on the database information. This hydrological GIS link is an important complication because it involves complex miracles or physics-based relationships. The geographic information system provides a digital representation of watershed characteristics used in hydrological modeling.

4.1.4. Advantages of using ArcGIS

It is ideal for preliminary site research because it can efficiently analyze and display information based on user-specified specifications. Once a GIS database has been developed, it can provide an efficient and cost-effective method for analyzing attributes. However, GIS may be limited due to the lack of up-to-date data available.

Secondly, GIS eliminates the tedious process of paper mapping facilities in many cases the cost of such mapping alone can justify a GIS implementation. Since the manual integration and correlation of the information related to the factors to be considered are very tedious and complex the latest computing and decision making technologies offered in the form of versatile GIS must be used. It is easy to integrate the data of various natures. Remote Sensing data products can also be used effectively in GIS. Geo-coded satellite imagery can be used directly for on-screen digitization for preparation of different climatic map as land use geology, stream network map etc.

Geographic information system helps in creating appropriate in official management of natural resources and environment. Remote sensing systems are used to observe the Earth's surface from different platforms, such as satellites and aircraft, and to collect and analyze large areas of resources and environmental information. GIS techniques have been extensively used in various areas of water resources development and management such as hydrologic modeling command area studies floodplain management waterlogging and soil salinity studies.

In early days GIS were mainly used as hydrological mapping tools. Nowadays they play a more important role in hydrological modeling studies. Their applications and a wide range of sophisticated analysis and modeling of spatial data to simple inventory are management tools. Distributed rainfall-runoff modeling requires a large number of parameters to describe local Geography soil type land use and can be substantially facilitated by the use of GIS.

GIS has announced the capacity of models in data management parameter estimation and presentation of model results but GIS cannot replace hydrologic models in solving hydrological problems. The uses of computer in the hydrologic analysis have become so widespread that it provides the preliminary source of data for decision making for the purpose of many hydrologic engineers.

4.2. Watershed Delineation

The first step in any kind of hydrological simulation is to divide the rivers and basins and obtain some basic watershed characteristics such as area, slope, flow length, river network density, and so on. The process of using DEM to divide a basin is called terrain pre-processing.

Watershed is a piece of land and all the water is discharged out in a single common exit. In hilly areas, mountain ridges separate river basins from each other. The topographic maps and digital elevation models (DEM) can use to divide the basin area.

The manual delimitation of a watershed using topographic maps is time-consuming, requires cartography knowledge and it is difficult to perform rigorous analysis on it. Whereas the use of DEM of watersheds (Figure 4.1) in Geographic Information Systems (GIS) provides better visualization and analysis capabilities to understand the context of various parameters in the basin. By dividing the watershed, it means to create a border that shows the contribution region of a specific control point/exit.

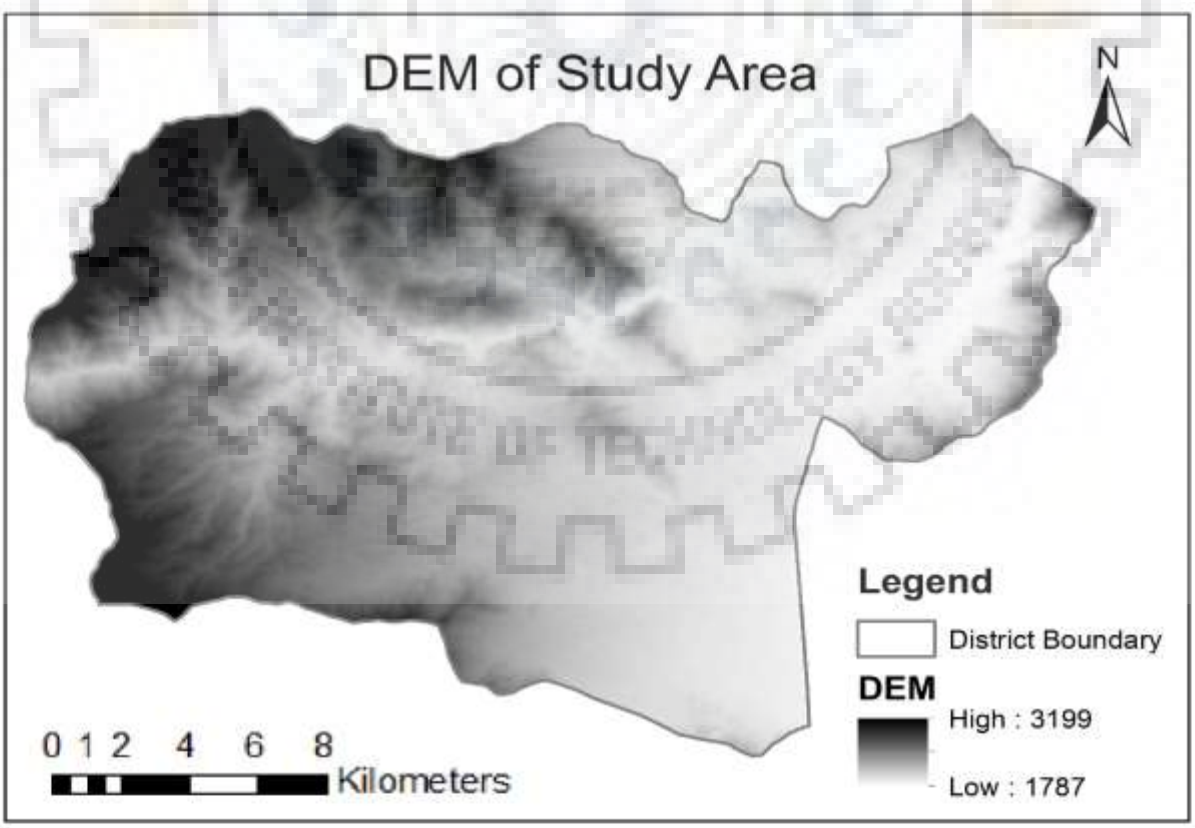


Figure 4.1: DEM map of Chahar Asyab district

4.2.1. Fill Sink

It is very important to use a DEM that has no dents or depressions because the flow direction cannot be specified for the sink. Water is trapped in the sink so it cannot flow out. The sink in the altitude data is mainly due to errors in the data and is usually caused by the sampling effect and the rounding of the altitude to an integer. As the cell size increases, the number of sinks in a dataset also increases. Therefore, to create an accurate representation of flow direction and accumulated flow, it is necessary to use DEM devoid of sinks.

4.2.2. Flow Direction Map

The flow direction of each cell must be known because it determines the final destination of the water flowing from each cell in the grid. This is done through the Flow Direction tool. The tool output shows the grid for the outflow direction of each cell. There are eight output directions associated with eight adjacent cells, and the flow can pass through these eight cells. Figure 4.2 below shows flow direction and flow accumulation map.

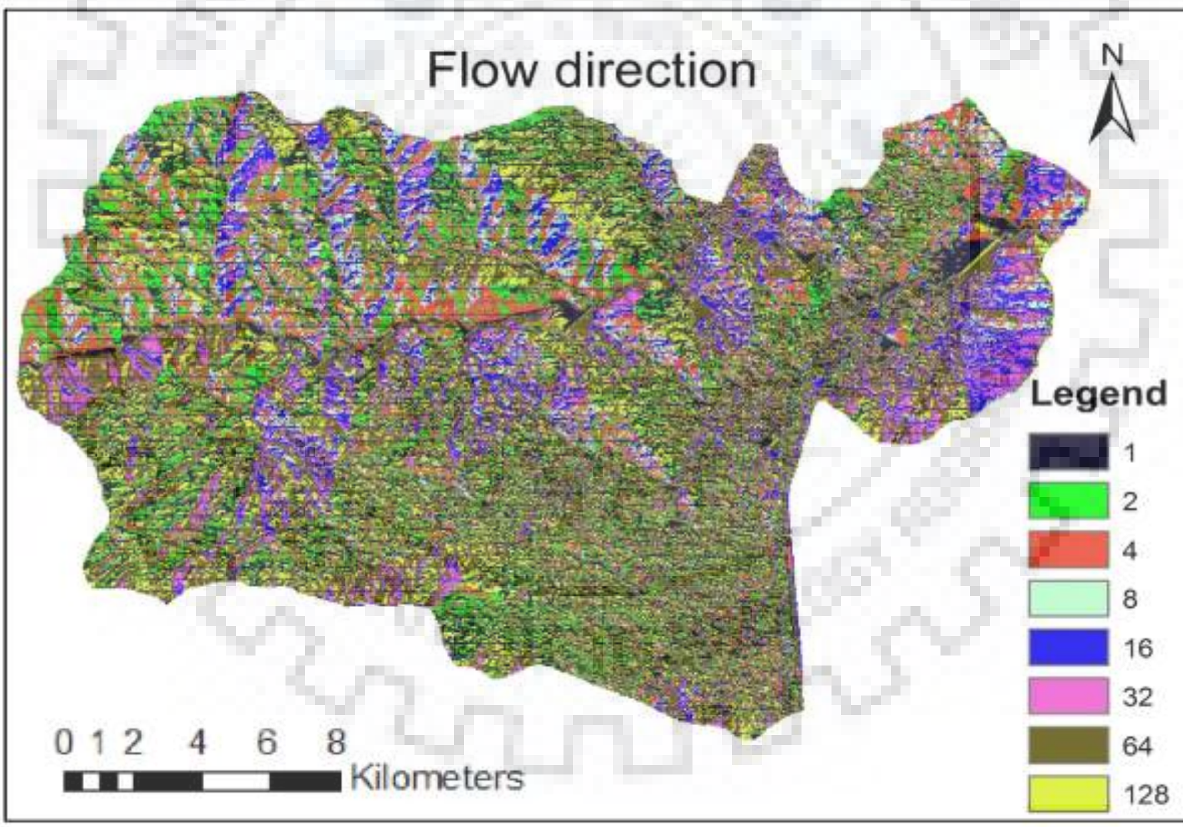


Figure 4.2: Flow direction map of Chahar Asyab district

4.2.3. Flow Accumulation Map

The tool calculates the cumulative number of upstream units of cells that flow into each lower tilt unit in the output raster. High-flow accumulations of cells are located in drains rather than on hillsides or ridges. Figure 4.3 below shows a flow accumulation map of the basin.

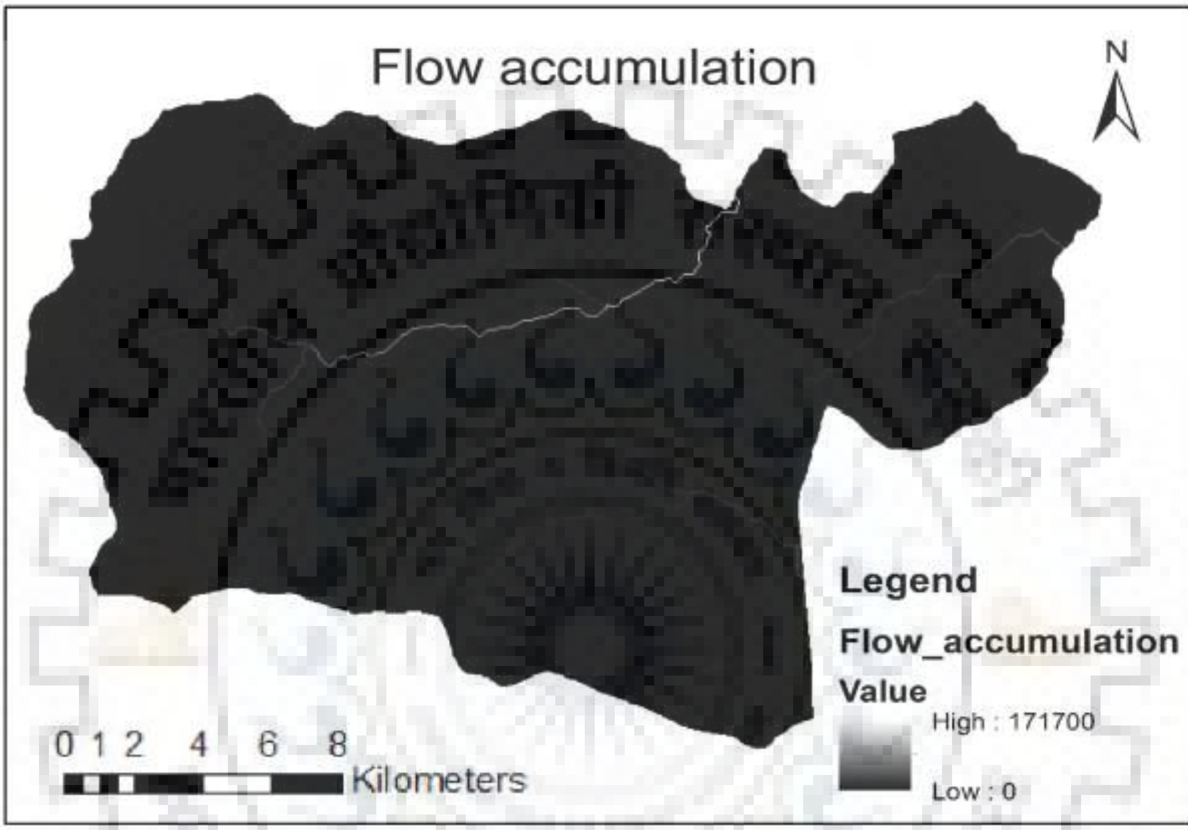


Figure 4.3: Flow accumulation map of Chahar Asyab district

4.2.4. Snap Pour Point

This tool is used to ensure that high cumulative flow points are selected when basins are used to divide the basin. It aligns the pour point with the highest flow accumulation unit within the specified distance. Figure 4.4 shows the watershed of the basin.

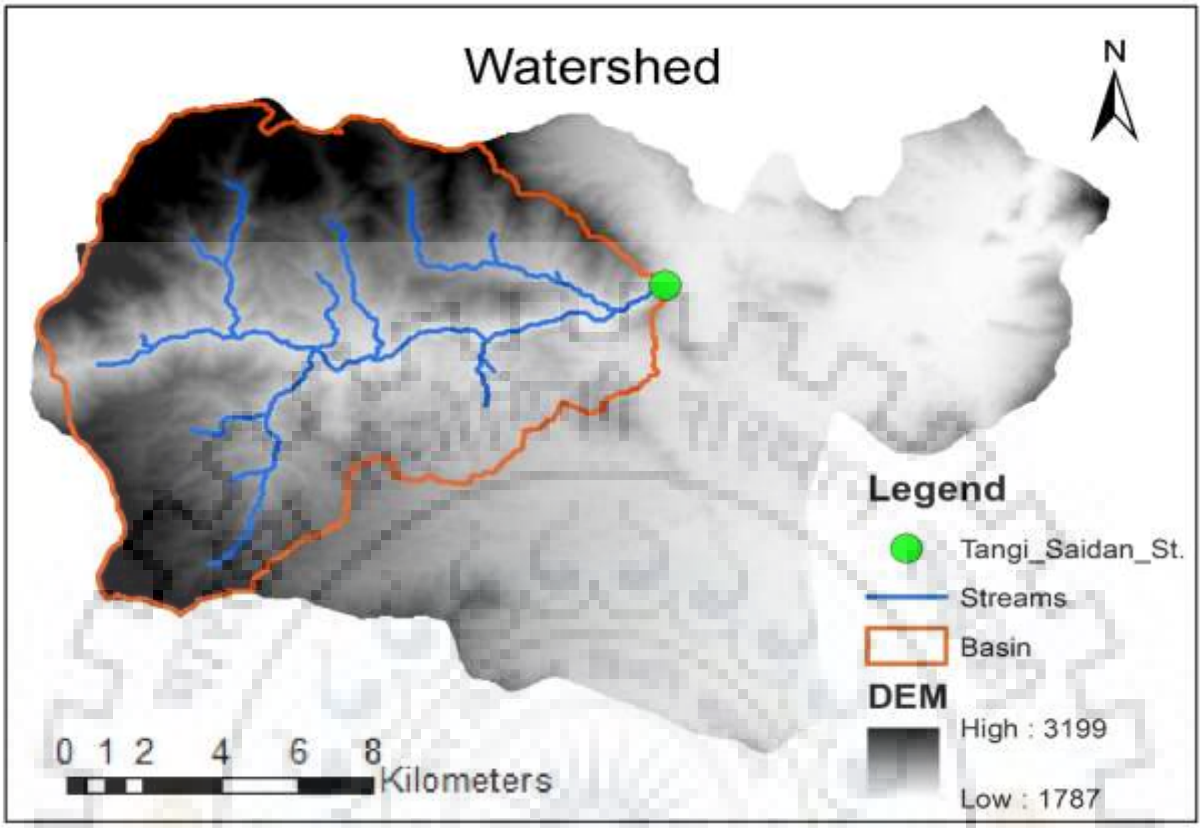


Figure 4.4: Watershed map of Chahar Asyab district

4.3. Land Use / Land Cover (LULC) Map

Land cover (LC) is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. Earth cover is the expression used by ecologist Frederick Edward Clements that has its closest modern equivalent being vegetation.

There are two primary methods for capturing information on the land cover:

(i) Field survey, and

(ii) Analysis of remotely sensed imagery.

A satellite image often contains information that can readily be analyzed visually. In most cases, it is possible to get an idea about the relative importance of urban areas, forest, agriculture, etc. just by looking at the image. Nevertheless, it is in some cases necessary to convert the satellite image to a thematic map of different land cover or land use types. This will make it possible to work quantitatively with the characteristics of the area and to analyzed and understand the distribution of different land cover types.

When converting a satellite image to a thematic map of land cover classes, it is possible to perform simple calculations like the overall area of each class. However, more detailed analyses can generate a deeper understanding of the area, i.e. by looking at the degree of fragmentation of the area or the distance from a specific class to a specific feature. With this information, it is then possible to analyze how far deforested patches in a tropical forest area are located from roads or settlements, or to analyze which agricultural crops are grown on the steepest slopes.

Classification and legend: Classification is an abstract representation of the situation in the field using well defined diagnostic criteria. A classification describes the systematic framework with the names of the classes and the criteria used to distinguish them and the relation between classes. Classification thus necessarily involves the definition of class boundaries that should be clear, precise, possibly quantitative, and based upon objective criteria.

Land use/land cover maps are prepared for the Chahar Asyab district by using ArcGIS from Landsat-8 data (2017), showing different features like water body, agricultural area, residential, and barren land (Figure 4.5).

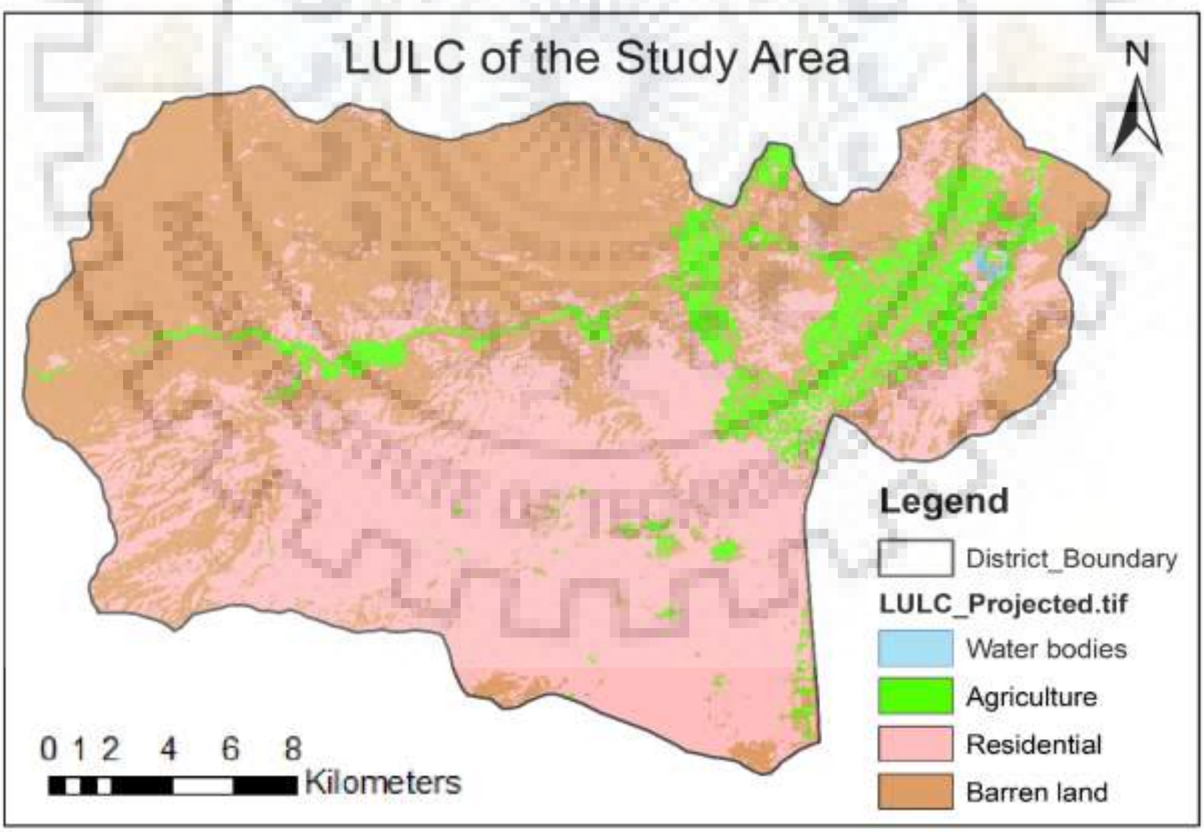


Figure 4.5: Land Use/Land Cover map of Chahar Asyab district

4.4. Soil Map

A Soil map is a geographical representation showing the diversity of soil types and/or soil properties (soil pH, textures, organic matter, depths of horizons, etc.) in the area of interest. It is typically the end result of a soil survey inventory, i.e. soil survey. Soil maps are most commonly used for land evaluation, spatial planning, agricultural extension, environmental protection, and similar projects.

Traditional soil maps typically show the only general distribution of soils, accompanied by the soil survey report. Many new soil maps are derived using digital soil mapping techniques. Such maps are typically richer in context and show higher spatial detail than traditional soil maps. Soil maps produced using (geo) statistical techniques also include an estimate of the model uncertainty.

A soil map is prepared for the study area with the help of ArcGIS 10.2 using USDA global soil data and it is classified with various type of soil (Figure 4.6).

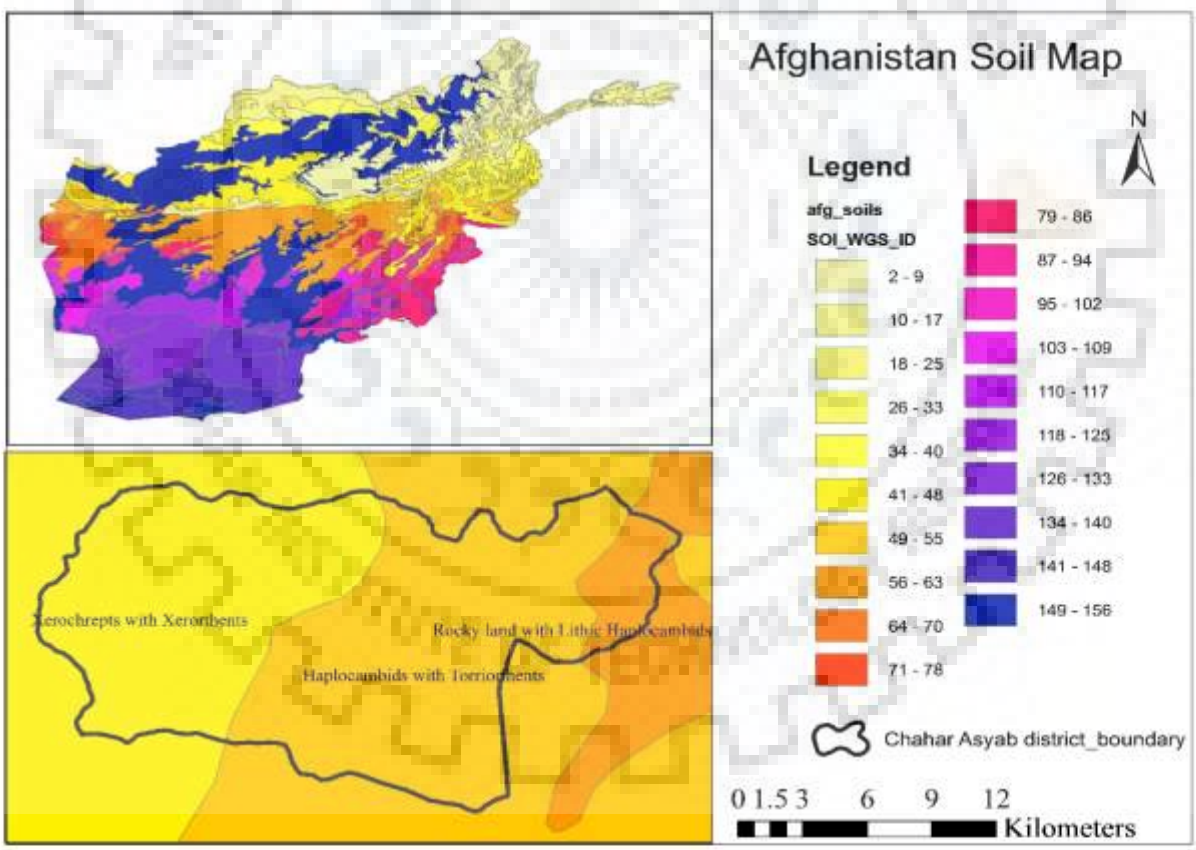


Figure 4.6: Soil map of Chahar Asyab district

4.5. Slope Map

A map indicating the topography of an area along with an analysis of topographic features as they have influenced and may continue to influence land development. In GIS mapping slope can be very important for a variety of reasons including suitability analysis, predictive modeling, and predicting potential hazards. Analyzing the terrain slope of a given location plays an important part in fields such as hydrology, site planning, conservation, and infrastructure development. The slope can be calculated from a Digital Elevation Model which form an important part of many GIS datasets; equally important are the parameters and techniques used to calculate terrain slope as well as other analyses performed with a DEM. In suitability analysis or predictive modeling, by calculating the slope within a GIS, areas can be eliminated that aren't suitable or that don't fit within the model. In predicting potential hazards, areas can be seen as dangerous due to the steepness of a slope. The slope is calculated in a GIS by comparing a certain point within a raster to that point's neighbors. Usually, a point is compared with eight of its neighbors to derive its slope, but the exact method varies depending on the specific slope analysis desired. Slope map for Chahar Asyab district is prepared with the help of ArcGIS 10.2 from SRTM data (Figure 4.7). It is clearly seen on the map that the overall slope of the area varied from 0% to more than 40% land slope and maximum area is flat in nature.

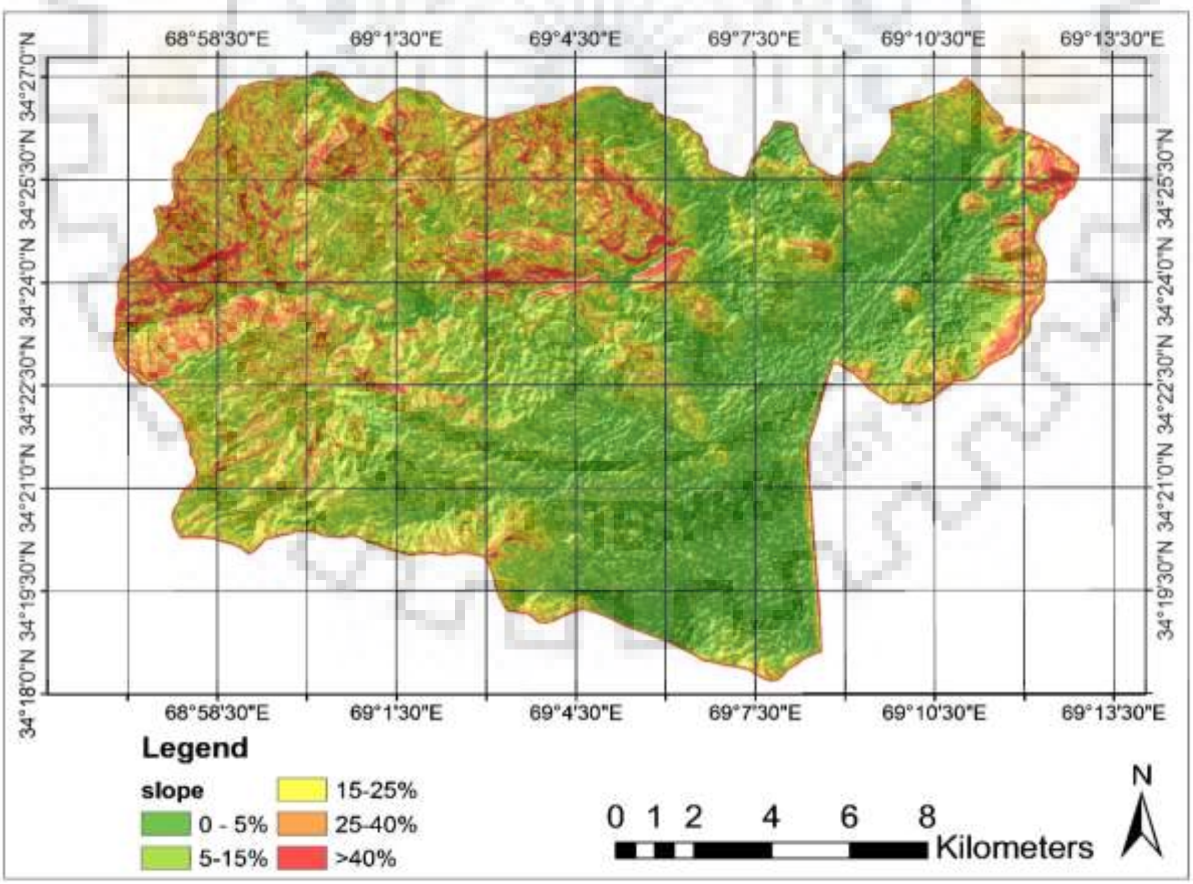


Figure 4.7: Slope map of Chahar Asyab district

4.6. Rainfall Map

In this work, a rainfall map of the study area (Figure 4.8) was prepared from the monthly rainfall data taken from the 8 stations near to the Chahar Asyab district (Table 4.1). This map shows rainfall, usually called isohyet, using Inverse Distance Weighting (IDW) method. As GIS can easily handle, store, analyze, manipulate and retrieve spatial data, map preparation can be easily implemented using the ArcGIS environment. The work was executed using ArcGIS.

Table 4.1: Statistical parameters of average precipitation in the rainfall gauging stations (mm) (From meteorological report package No. MoEW/1210/QCBS)

Station	Lon.	Lat.	Elev.	J	F	M	A	M	J	J	A	S	O	N	D	Year
Paghman	68.98	34.58	2114	61	66	81	77	33	3	9	4	5	5	24	39	407
Karizimir	69.05	34.63	1905	34	68	90	84	24	3	5	2	3	8	20	29	370
Jabul- S	69.25	35.13	1630	61	105	98	84	32	2	3	2	4	17	18	42	468
Salang-N	69.02	35.31	3366	107	128	176	191	119	14	6	10	10	22	59	93	935
Salang-S	69.07	35.30	3172	105	158	220	196	88	6	4	2	4	21	72	106	982
Kabul-A	69.02	34.55	1791	34	54	73	64	20	1	6	3	2	4	11	25	297
Gazni	68.42	33.53	2183	41	54	64	50	18	2	14	7	1	2	12	26	291
Gardiz	69.23	33.62	2350	40	61	65	44	23	4	12	7	1	4	12	31	304

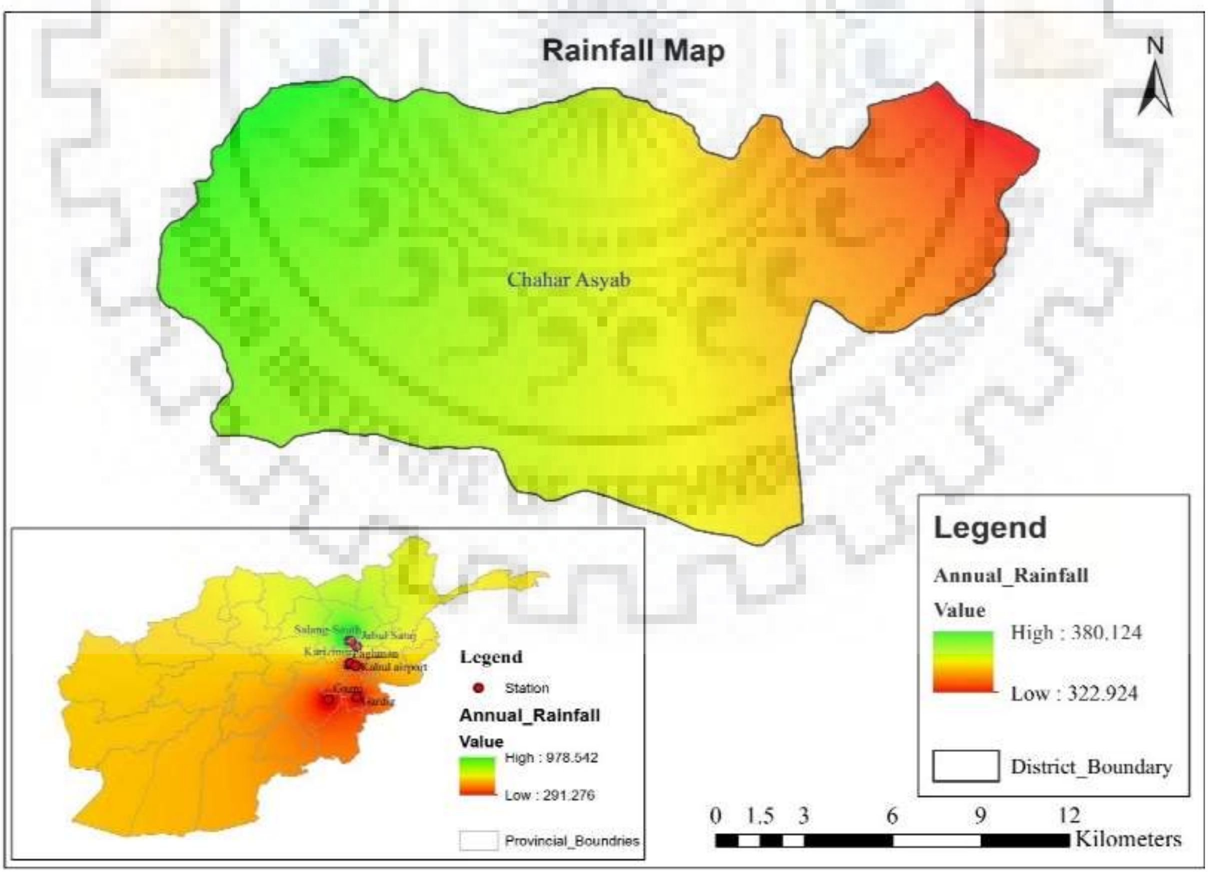


Figure 4.8: Rainfall map of Chahar Asyab district

CHAPTER-5

IRRIGATION REQUIREMENTS AND IRRIGATION SCHEDULING

5.1. Introduction

Crop water requirement is defined as the depth of water needed at the root zone of the plant to meet the water loss through evapotranspiration of crop for the physiological growth in large fields under non-restricting soils, water, and nutrient availability and achieving full production potential under the given growing environment. The success of this objective depends on matching the water availability at river source with the quantum of water required for various crops in the command area for sustainable agricultural production. Based on the past practices for planning the irrigation schemes, estimation of crop water requirements and irrigation requirements are mainly based on climatological methodology presented in FAO irrigation and Drainage papers No. 56 "Crop Water Requirements" adopting the approach of Modified Penman-Monteith formula.

Irrigation scheduling is the process of determining the time to irrigate and how much water is to be applied (irrigation depth) in each irrigation. Proper scheduling is essential for the efficient use of water and other inputs in crop production. Irrigation schedules are planned to either fully or partially provide the estimated water requirement of the crop.

5.2. Methodology

The CROPWAT model was originally developed by the FAO in 1990 for planning and management of irrigation projects. The newest version, namely CROPWAT4W under windows interface, was jointly formulated by the FAO, Southampton University of UK, and National Water Research Center (NWRC) of Egypt. Figure 5.1 shows the flowchart of the CROPWAT model.

In Figure 5.1, it can be seen that the input data cover crop, meteorology, and soil. The meteorology data include (1) maximum and minimum temperature; (2) wind speed; (3) sunshine hours; (4) relativity humidity; and (5) rainfall. The Penman-Monteith explicit equation was used to calculate the reference evapotranspiration (ETo).

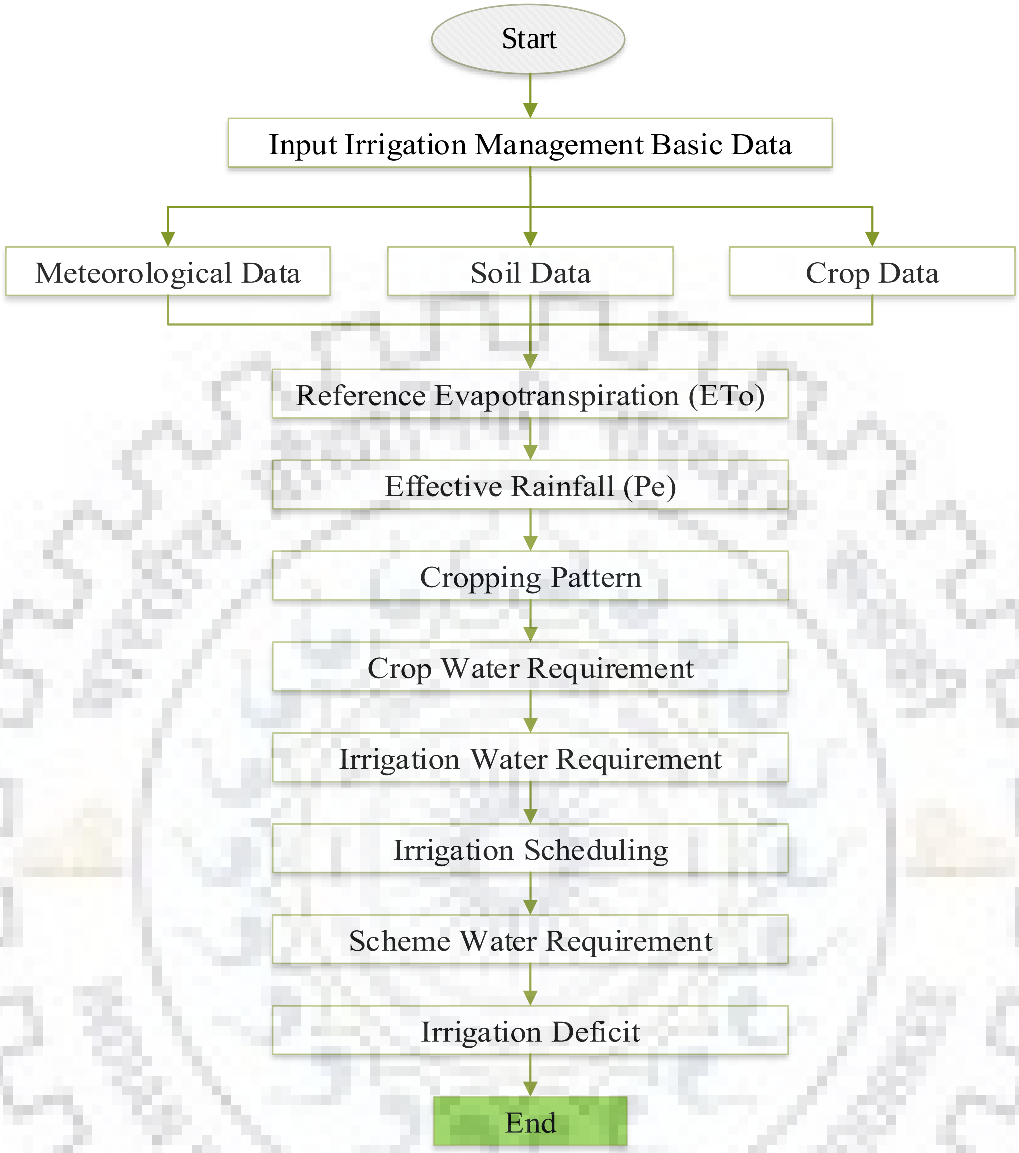


Figure 5.1. Flow chart of the methodology for CROPWAT 8.0 Model

There are four common empirical methods for calculating effective rainfalls (Smith 1991) as follows: (i) fixed percentage of rainfall; (ii) dependable rainfall; (iii) empirical formula; (iv) USDA Soil Conservation Service Method. The USDA Soil Conservation Service method was used in this study. These 4 empirical equations are abbreviated as follows (Smith 1991):

(i) Fixed Percentage of Rainfall:

$$P_e = a \times P_{tot} \quad \dots\dots\dots\dots\dots (5.1)$$

Where,

P_e: Effective rainfall,

a: Fixed percentage coefficient (specified by the model user), with a typical range of values from 0.7 to 0.9, and

P_{tot}: Measured (or generated) total daily rainfall.

(ii) Dependable rainfall: This empirical formula was developed by the FAO to estimate dependable rainfall. This method may be used for design purposes where 80% probability of exceedance is required.

$$\text{For } P_{tot} < 70 \text{ mm},\ P_e = 0.6\,P_{tot} - 10$$

$$\text{For } P_{tot} > 70 \text{ mm},\ P_e = 0.8\,P_{tot} - 24 \quad \ldots\ldots\ldots\ldots\ldots (5.2)$$

(iii) Empirical formula: This formula will determine the effective rainfalls based on analysis of local climatic records.

$$\text{For } P_{tot} < z \text{ mm},\ P_e = a\,P_{tot} + b$$

$$\text{For } P_{tot} > z \text{ mm},\ P_e = c\,P_{tot} + d \quad \ldots\ldots\ldots\ldots\ldots (5.3)$$

Where,

a, b, c, d, z: empirically derived correction coefficients.

(iv) USDA Soil Conservation Service method:

$$\text{For } P_{tot} \leq 250 \text{ mm} \qquad P_e = [P_{tot} \times (125 - 0.2 \times P_{tot})] \div 125$$

$$\text{For } P_{tot} \leq 250 \text{ mm} \qquad P_e = 125 + 0.1 \times P_{tot} \quad \ldots\ldots\ldots\ldots\ldots (5.4)$$

Where,

P_e: Effective rainfall (mm), and

P_{tot}: Total rainfall (mm).

Given the input of the required data, the CROPWAT model can be used to calculate crop-related data in each decade of a month, such as: (i) crop coefficient, (ii) crop leaf index, (iii) crop evapotranspiration, (iv) percolation, (v) effective rainfall, and (vi) crop water requirements. Also, the model can be applied to estimate the irrigation schedule for each crop with 5 different options: (i) each irrigation defined by irrigation manager, (ii) irrigation at below or above critical soil depletion (% RAM), (iii) irrigation at fixed interval per crop growth stage, (iv) deficit irrigation, and (v) no irrigation. Afterward, the CROPWAT model can simulate the on-farm crop water balance, including (i) irrigation times, dates and depths, (ii) soil moisture depletion, (iii) amount of percolation, (iv) actual crop evapotranspiration, and (v) crop yield. The on-farm water balance was based on the theory of Equation (5.5) below:

$$SMD_t = SMD_{t-1} + ET_c - P_e - I_r + R_o + D_p \dots\dots\dots\dots\dots (5.5)$$

Where,

t: Time (decade of the month),

SMD_t , SMD_{t-1}: Soil moisture depletion at t and t-1 decade (mm),

ET_c : Actual crop evapotranspiration (mm),

P_e : Effective rainfall (mm),

I_r: Irrigation depth (mm),

R_o: Runoff (mm), and

D_p: Deep percolation (mm).

The crop yield reduction in each stage was evaluated based on the degree of soil moisture depletion due to the supply of the crop evapotranspiration requirements. Eq. (5.6) calculates the crop yield reduction in each stage and the cumulative crop yield reduction represented by Eq. (5.7).

$$\left(1-\frac{Y_a}{Y_{max}}\right) = K_y\left(1-\frac{ET_a}{ET_{max}}\right) \quad \dots\dots\dots\dots\dots (5.6)$$

$$\left(1-\frac{Y_a}{Y_{max}}\right) = 1-\left(\frac{Y_a}{Y_m}\right)_1 \times \left(\frac{Y_a}{Y_m}\right)_2 \times \dots\dots\dots . \times \left(\frac{Y_a}{Y_m}\right)_i \quad \dots\dots\dots\dots\dots (5.7)$$

Where,

i: Crop growth stage,

K_y : Crop yield reduction factor,

K_a: Crop actual yield,

ET_a: Actual evapotranspiration,

Y_{max}: Maximum crop yield, and

ET_{max}: Potential or maximum evapotranspiration.

After finishing the simulation of irrigation schedule for each crop, the CROPWAT model could furthermore be used to estimate the monthly agricultural water requirements of an irrigation scheme, based on different cropping patterns as expressed in the equation below:

$$Q_{gross} = \frac{1}{e_p \times t} \times \left[0.116 \times A_s \times \sum_{i=1}^{n} (ET_c - P_e) \times \frac{A_c}{A_s}\right] \dots\dots\dots\dots\dots (5.8)$$

Where,

Q_{gross}: Monthly agricultural water requirement of irrigation scheme (l/s),

e_p : Irrigation efficiency (<=1, dimensionless),

t : Time operational factor (<=1, dimensionless),

i: Crop index of the cropping pattern for an irrigation scheme,
A_c: Crop planted area (ha),
A_s: Total area of irrigation scheme (ha),
ET_c: Crop evapotranspiration (mm/day), and
P_e: Effective rainfall (mm/day).

5.3. Meteorological Data

Crop water requirement is basically influenced by surface meteorological data including temperature, sunshine duration, wind speed, relative humidity, and rainfall. It may be worthwhile to mention here that the variation of climatological parameters such as a sunshine hour, relative humidity, maximum and minimum temperature over the area is much less than variation rainfall.

5.3.1. Collection of Meteorological Data

In this study, the meteorological data such as maximum, minimum temperatures, relative humidity, wind speed, sunshine hours have been taken from the FAO CLIMWAT 2.0 software. The CLIMWAT-database provides monthly meteorology data for CROPWAT on 144 countries (FAO, 1993). This yields the average of the time series meteorology data of meteorological station inside Afghanistan. These meteorological data are collected from the meteorological station namely Kabul airport (34.55 N, 69.21E).

Table 5.1: Monthly meteorological data for Chahar Asyab district (From Kabul airport meteorological station)

Months	Min. Temp	Max. Temp	Humidity	Wind speed	Sunshine	Radiation
	°C	°C	%	km/day	hours	MJ/m²/day
Jan	-7.1	4.5	93	86	4.7	9.1
Feb	-5.7	5.5	86	86	5.6	11.9
Mar	0.7	12.5	61	173	5.2	14
Apr	6	19.2	50	173	6.3	17.8
May	8.8	24.4	52	259	8.9	22.8
Jun	12.4	30.2	38	346	10.8	26
Jul	15.3	32.1	36	346	10.5	25.3
Aug	14.3	32	38	259	10.4	23.9
Sep	9.4	28.5	32	173	9.3	20.1
Oct	3.9	22.4	39	173	8.6	16
Nov	-1.2	15	59	173	7.3	11.9
Dec	-4.7	8.3	86	86	5.5	9.1
Average	**4.3**	**19.6**	**56**	**194**	**7.7**	**17.3**

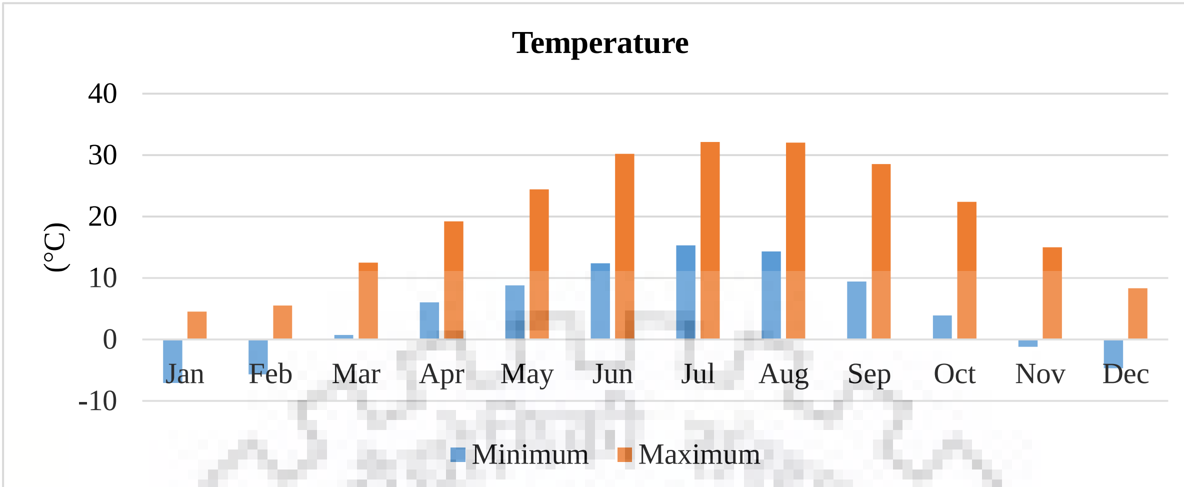


Figure 5.2: Monthly minimum and maximum temperature (°C)

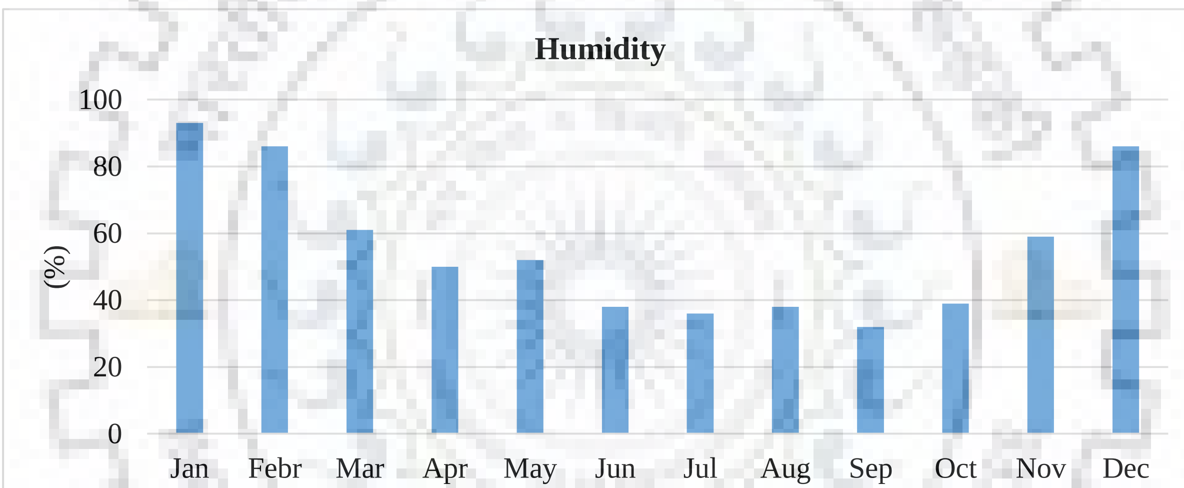


Figure 5.3: Monthly humidity in percentage (%)

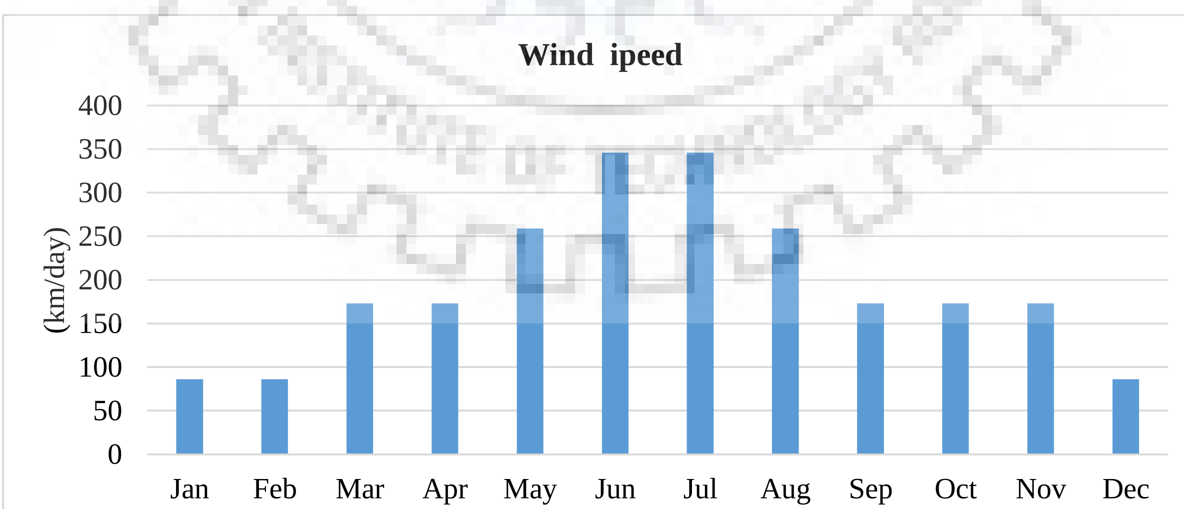


Figure 5.4: Monthly wind speed (km per day)

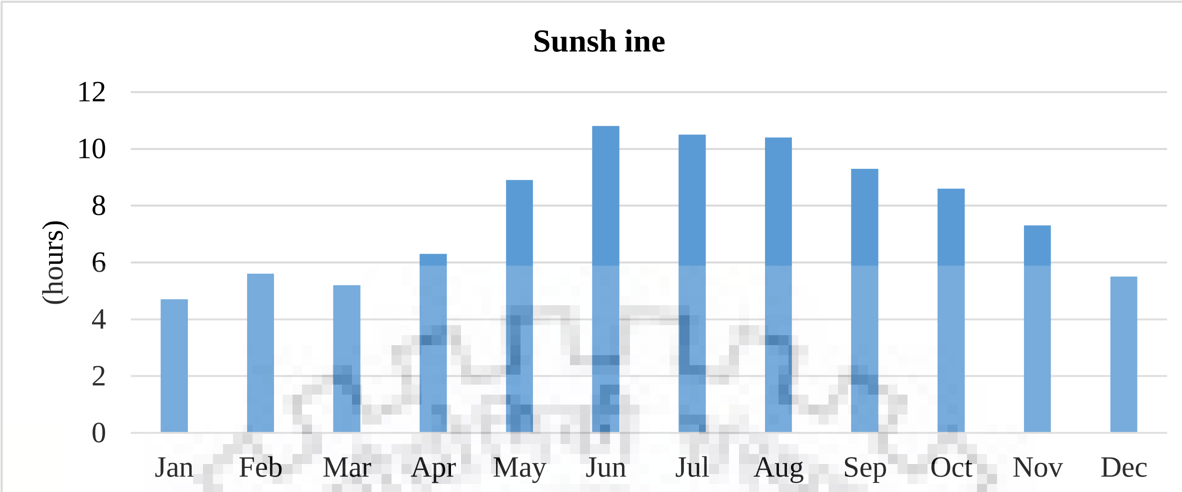


Figure 5.5: Monthly sunshine (hours)

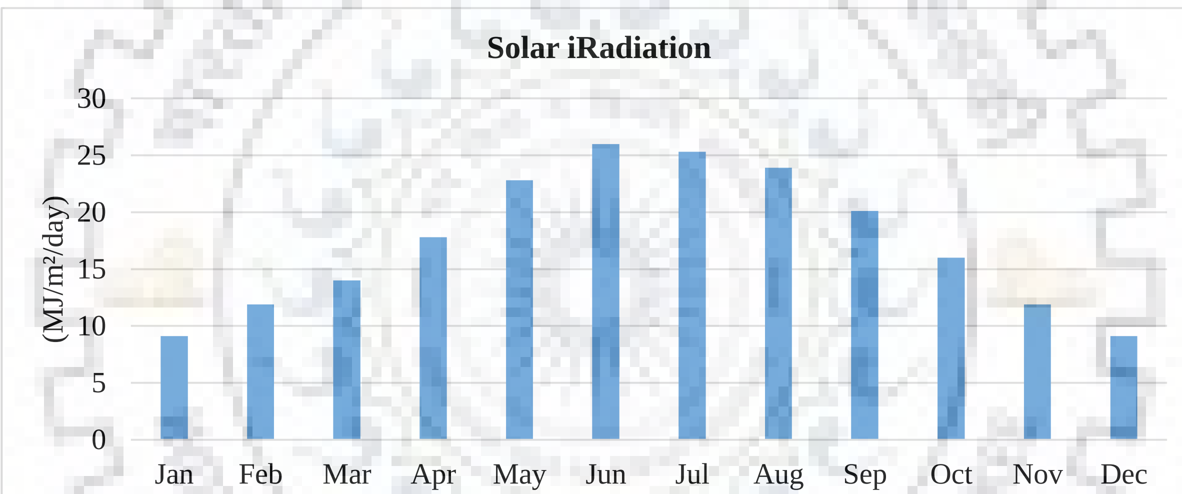


Figure 5.6: Monthly solar radiation (MJ/m²/day)

Table 5.2: Monthly rainfall (mm) data for Chahar Asyab district (From Kabul airport meteorological station)

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Rainfall	34	54	73	64	20	1	6	3	2	4	11	25	**297**

5.4. Soil Data

The soil is a granular porous medium. It is a natural body of mineral and organic constituents differentiated into horizons of variable depths. It differs from the material below in morphology, physical make-up, chemical properties, and composition as well as biological characteristics. In agricultural science, the term soil is applied only to the upper part of the weathered rock penetrated by the roots of the plants.

The soil is a storehouse of plant nutrients, a habitat for soil micro-organisms, an anchorage for plants, and a reservoir that holds the water needed for plant growth. The soil is a natural body of mineral and organic constituents. In the traditional concepts, the soil is considered as a natural medium for plant growth. The concept of soil as an independent natural body was introduced towards the end of the 19th century. Accordingly, the soil is defined as an independent natural body differentiated into horizons of layers of various depths, each with a unique morphology resulting from the combination of climate, living matter, parent rock material, relief and time.

The modern scientific definition of soil is that it is a collection of natural bodies on the earth's surface containing living matter and supporting or capable of supporting plants. The word horizon is not included in the modern concept of soil because all soils do not have distinct horizons. However, the presence or absence of the horizons is important in soil classification. The nature, kind and arrangement of soil horizons in a profile have a significant influence on soil-water-plant relationships.

5.4.1. Collection of Soil Data

Information from the soil surveys carried out in the Chahar Asyab district show following soil characteristics:

a. Soil name or soil type: Sandy Loam
b. General soil data:

Total available soil moisture (FC – WP)	160.0	mm/meter
Maximum rain infiltration rate	40	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TAM)	0	%
Initially available soil moisture	160.0	mm/meter

5.5. Cropping Pattern

Cropping pattern is a dynamic concept because it changes over space and time. It can be defined as the proportion of area under various crops at a point of time. In other words, it is a yearly sequence and spatial arrangement of sowing and fallow in a given area. In this study area, the cropping pattern is determined by climatological data and soil type.

Table 5.3: Cropping pattern or common crop in Chahar Asyab district (From NAIS/ASAP 2008 from USAID-Afghanistan for MAIL)

No.	Name of Crop	Date of Planting	Date of Harvesting	Area (%)
1	Winter Wheat	01/11	28/06	30
2	Spring Wheat	15/04	22/08	10
3	Barley	15/04	22/08	10
4	Maize (Corn)	03/06	05/10	11
5	Potato	01/01	10/05	15
6	Onion	01/04	28/08	10
7	Tomato	01/05	22/09	8
8	Table grapes	01/04	31/03	3
9	Clover	01/07	28/10	2
10	Alfalfa-perennial	01/07	30/06	1

5.6. Selection of the Crop Coefficient

The crop coefficient (Kc) is specified as the canopy coverage factor, which is influenced by the following factors:

(i) Type of crop
(ii) Growth stages of the crop
(iii) Climate, and
(iv) Surface moisture condition of the field

For the present case, the crop coefficient is considered as per the standard crops are given in (Table 5.4), and the FAO folder for standard crops in the CROPWAT 8.0 software.

5.6.1. Crop Coefficient Curve

The crop co-efficient Kc is specified as the ETc proportion of the special crop to the ETo of the reference crop. The crop co-efficient curve represents the changes in Kc during the growing season, depending on changes in vegetation and physiology. In the initial period, immediately after planting annually or before the introduction of new leaves for several years, the small amount of Kc is often less than 0.4. A simple linear approximation of Kc between critical growth points was proposed by FAO in (Doorenbos and Pruitt 1977, and Allen et al. 1998). This method is still widely used and generally provides a detailed description of the annual Kc curve for most applications. Definitions For the three Kc values, the criteria used to construct the curve and the definitions for the growth stages and relative land cover are shown in Figure 5.7.

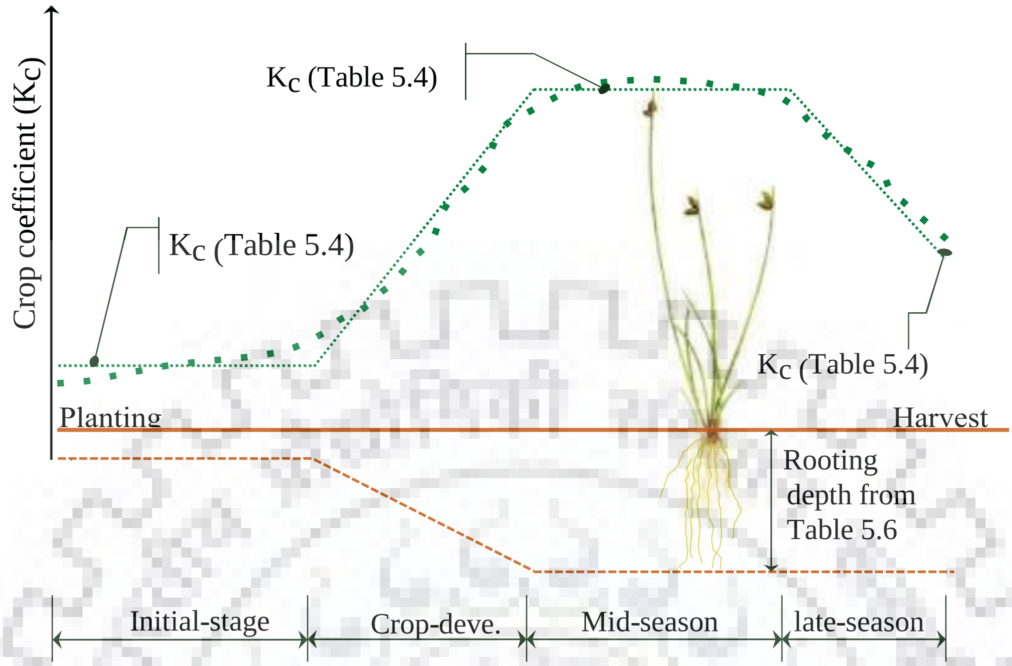


Figure 5.7: Linearized crop coefficient curve with 4 crop stages and 3 Kc values relevant to the generic ground-cover (From FAO).

The lineal Kc similarity curve is made by the following steps:

(i) Divide the growing time into 4 public growth stages explain crop canopy development and phenology for a regional special developmental crop calendar (Figure 5.7).

The 4 public growth stages are: (i) Initial time (planting/green up till around 10% ground-cover), (ii) Crop development time, from 10% ground-cover till around 70% ground-cover, (iii) Mid-Season time, from 70% ground-cover to the start of the late season time (the beginning of senility), and (iv) Late Season time (start of senility, mid-grain, fruit fill till harvest, crop-death, frost-kill, or full senility).

(ii) Determine the three Kc values commensurate with Kc initial, Kc mid, and Kc end, where Kc initial shows the mean Kc during the initial time, Kc mid shows the mean Kc during the mid-season time, and Kc end show the Kc at the end of the late season time.

(iii) Join direct line sections via each of the 4 growth stage times, with horizontal lines drawn through Kc initial during the initial time and through Kc mid during the mid-season time. Diagonal lines are drawn from Kc initial to Kc mid within the amplitude of the development time and from Kc mid to Kc end within the amplitude of the late-season time. Table 5.4 shown the lists of Kc initial, Kc mid, and Kc end for a large number of crops. The three Kc columns show typical irrigation management and precipitation periodicities.

Table 5.4: Mean crop coefficient (K_C) for well-managed crops in semi-arid climate (From based on Doorenbos and Kassam, 1997, Doorenbos and Pruitt UNFAO-1977, Allen et al., UNFAO-1988, Pruitt-1986, Wright-1981 & 1982).

Crop	$K_{C\ initial}$	$K_{C\ mid}$	$K_{C\ end}$
Onion - dry	0.70	1.05	0.75
Tomato	0.60	1.15	0.70–0.90
Potato	0.50	1.15	0.75
Barley	0.30	1.15	0.25
Spring - Wheat	0.30	1.15	0.25–0.40
Winter - Wheat – (with frozen soils)	0.40	1.15	0.25–0.40
Maize (Corn)	0.30	1.20	0.35
Alfalfa – perennial	0.40	0.95	0.90
Clover	0.40	0.90	0.85
Table - Grapes	0.27	0.58	0.48

5.6.2. Single Crop Coefficient (Kc)

In this approach, the effect of crop transpiration and soil evaporation are combined into a single coefficient (Kc). The coefficient integrates differences in the soil evaporation and crop transpiration rate between the crop and the grass reference surface. As soil evaporation fluctuates almost daily as a result of rainfall or irrigation, the single coefficient (Kc) expresses only time-averaged (multi-day) effects of crop evapotranspiration. The approach is used to compute ETc for weekly or longer periods. The time-averaged single coefficient (Kc) is valid for irrigation management, especially for surface and sprinkler irrigation methods of water application.

5.7. Growth Stages of the Crop

The growth stage of a crop profoundly influences Kc values. The crop growing period can be divided into four distinct growth stages:

(i) Initial stage (from sowing to about 10 % ground cover),

(ii) Crop development stage (from 10 % to about 70 % ground cover),

(iii) Mid-season stage (including flowering and grain setting and yield formation stage),

(iv) Late season stage (including ripening and harvest).

In general, out of the four growth stages (Figure 5.2), the mid-season stage is the most sensitive to water shortages, as it is the period of the highest crop water requirement. Water shortage during the mid-season will reduce crop yields substantially.

Table 5.5 presents the commonly observed values of the duration of different growth stages in crops at various experiment stations in different climatic/ geographic regions along with the months of planting. The data are indicative of the general conditions but variations in agro-climatic conditions will result in similar variations in Kc values. Hence, the data presented in Table 5.5 could be used only under situations when more reliable data are not available.

Table 5.5: Lengths of crop development stages for various planting periods and semi-arid regions (days) (From values are primarily from FAO-56, Allen et al. 1998, with modification to period lengths for some tree crops)

Crop	($L_{ini.}$)	($L_{dev.}$)	(L_{mid})	(L_{late})	Total	Plant date	Region
Onion, dry	15	25	70	40	150	April	Semi-Arid
Tomato	30	40	45	30	145	April	Semi-Arid
Potato	25	30	45	30	130	January	Semi-Arid
Barley	15	25	50	30	120	November	Semi-Arid
Spring - Wheat	40	30	40	20	130	April	Semi-Arid
Winter - Wheat	30	140	40	30	240	November	Semi-Arid
Maize (Corn)	30	35	40	30	125	June	Semi-Arid
Alfalfa – perenn.	150	30	150	35	365	July	Semi-Arid
Clover	10	25	50	35	120	July	Semi-Arid
Table Grapes	150	50	125	40	365	April	Semi-Arid

5.8. Rooting Depth of the Crop

If the water that goes up over the groundwater level via capillary act reaches the effective root zone of the irrigated crop, the crop may use this water. Hence, indent to calculate the capillary share of water, it require information on the effective rooting depth of the crops in the region. For this, the 4 phase (stages) of crop growth (development) are discussed as follows:

(i) In the initial growth phase (development stage), the crop only has been seeded or implanted. For all crops, we consider an initial rooting depth (0.05 m). Therefore, capillary water must be practically transported to the surface of the soil to become a water source. For this capillary water not to reason salinity, well-drained soil and adequate rainfall in the season are required.

(ii) In the crop growth phase (development stage), the upper ground biomass production grows in ratio with the root system. The depth which is the roots penetrate into the soil firstly depends on the crop. Secondly, root depth depends on the easiness of soil penetration (a type of soil and soil texture) and the depth of oxygen in the soil (most of the crop without root under the groundwater level) and the requirement for water search at a bigger depth (shallow roots with superior irrigation frequency). At the end of the growth phase (development stage), an effective root system can often be derived like a totally grown crop.

(iii) In the mid-season and late-season growth phase, for the efficient rooting depth of the crop can be used from Table 5.6.

Table 5.6: Typical crop height, ranges of maximum effective rooting depth for common crops (From FAO-56, Allen et al. 1998)

Crop	Maximum crop height (m)	Effective root depth (m)
Onion – dry	0.40	0.30–0.60
Tomato	0.60	0.70–1.50
Potato	0.60	0.40–0.60
Barley	1.00	1.00–1.50
Spring - Wheat	1.15	1.00–1.50
Winter - Wheat – (with frozen soils)	1.00	1.50–1.80
Maize (Corn)	1.25	0.80–1.20
Alfalfa – Perennial	0.7	1.0–2.0
Clover	0.6	0.6–0.9
Table - Grapes	2	1.0–2.0

The bigger amounts are for soils having no considerable layering or other specifications that can limit rooting depth. The smaller amounts for the rooting depth may be used for irrigation scheduling and the bigger amounts for modeling soil water pressure or for rain fed situation.

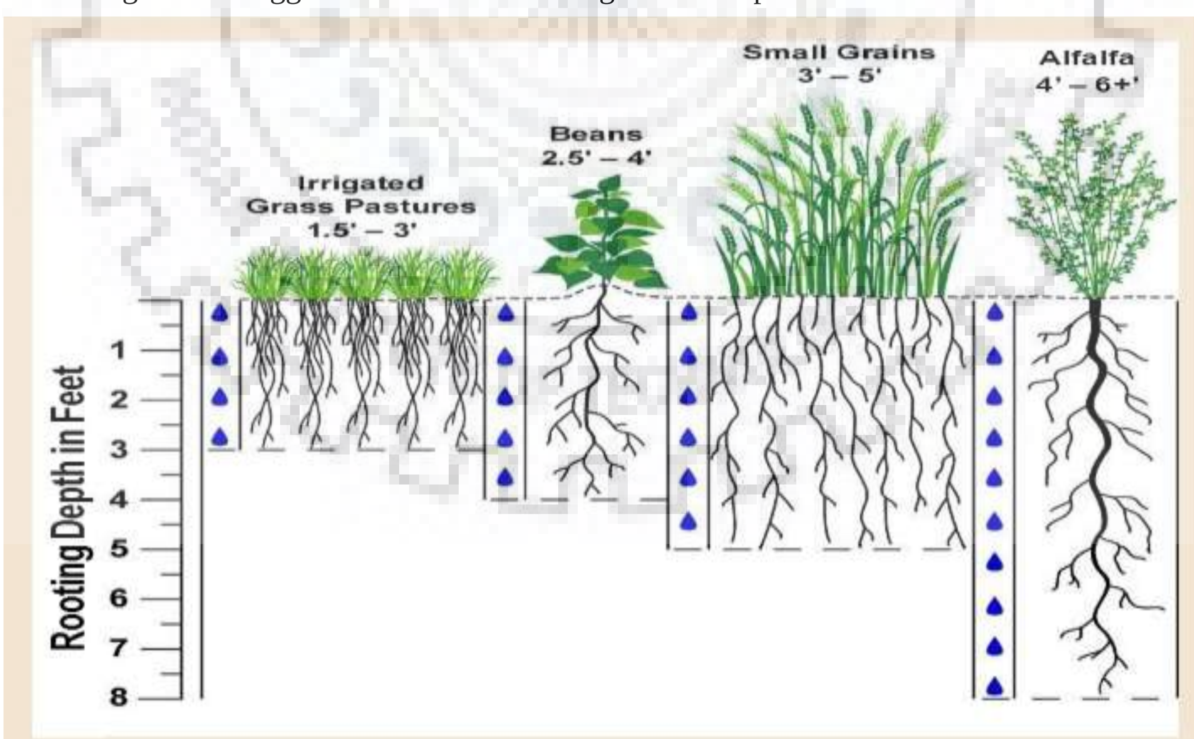


Figure 5.8: Plant rooting depths vary

5.9. Evapotranspiration (ET)

In designating water use by crops, evaporation and transpiration are combined into one term called evapotranspiration (ET), as it is difficult to separate these two losses in cropped fields. The relative amounts of direct evaporation from land and water surfaces and transpiration depend on the amount of ground covered of transpiration by crops. For most crops covering the whole soil surface only a small amount of water is lost from the ground surface.

Evaporation + Transpiration = Evapotranspiration (ET)

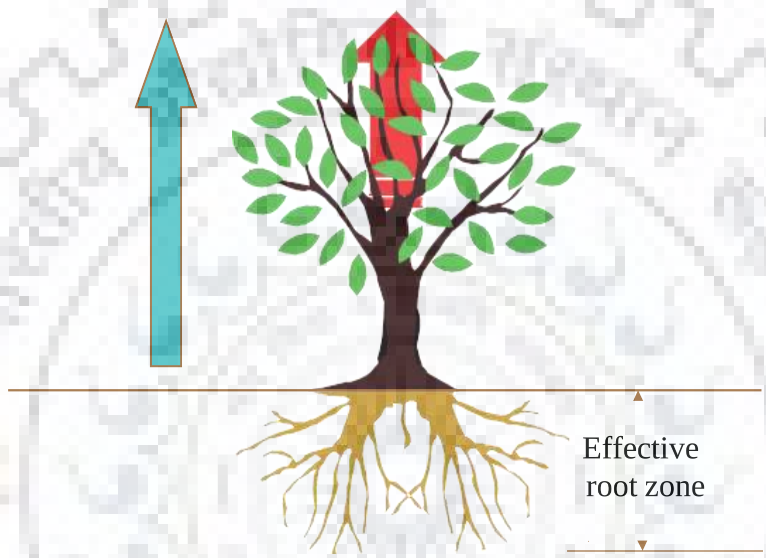


Figure 5.9: Terminology

5.9.1. Reference Evapotranspiration (ETo)

Reference evapotranspiration (ETo) is one of the important concepts in the equilibrium (balance) of water in a region. Irrigation engineers requirement to know a large amount of irrigation water consumed by the product to be consumed; only then can they calculate, or estimate, the remaining components of the water balance. Farmers, on the other hand, the requirement to know the water requirement for a particular crop so that they can get good product, and they also need to know if these water requirements are under the dominant irrigation region.

For the present study, used the Penman-Monteith Method (Combination formula) to estimate reference evapotranspiration (ETo).

The combination formula recommended by the consultation on FAO methodologies for CWR derived by combining the Eq. of aerodynamic resistance & surface resistance is stated below:

$$\mathbf{ETo} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \ldots\ldots\ldots\ldots (5.9)$$

In this Eq., ETo is reference evapotranspiration, R_n is net radiation at the crop surface, G is soil heat flux density, T is average daily temperature, Δ is the slope of the vapor pressure curve, γ is psychrometric constant, u_2 is wind speed at 2m height, e_s is saturation vapor pressure, e_a is actual vapor pressure, $e_s - e_a$ is saturation vapor pressure deficit.

Table 5.7: Calculation reference evapotranspiration for Chahar Asyab district using Penman-Monteith (PM).

Month	Min. Tem	Max. Tem	Humidity	Wind	Sun	Rad.	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
Jan	-7.1	4.5	93	86	4.7	9.1	0.74
Feb	-5.7	5.5	86	86	5.6	11.9	1.02
Mar	0.7	12.5	61	173	5.2	14	2.17
Apr	6	19.2	50	173	6.3	17.8	3.53
May	8.8	24.4	52	259	8.9	22.8	5.15
Jun	12.4	30.2	38	346	10.8	26	7.54
Jul	15.3	32.1	36	346	10.5	25.3	7.98
Aug	14.3	32	38	259	10.4	23.9	6.94
Sep	9.4	28.5	32	173	9.3	20.1	5.15
Oct	3.9	22.4	39	173	8.6	16	3.64
Nov	-1.2	15	59	173	7.3	11.9	2.07
Dec	-4.7	8.3	86	86	5.5	9.1	0.9
Av.	**4.3**	**19.6**	**56**	**194**	**7.7**	**17.3**	**3.9**

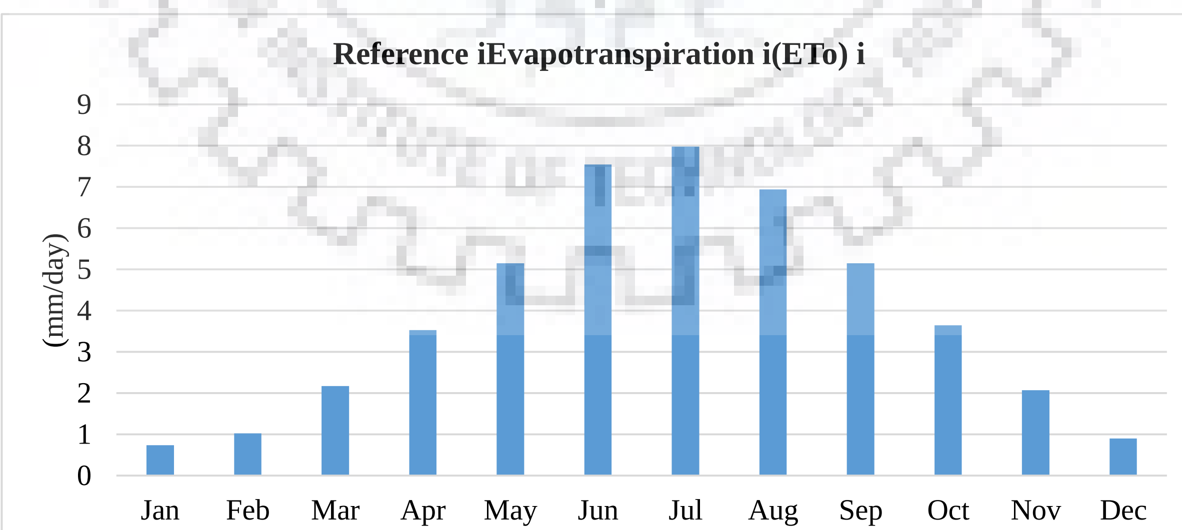


Figure 5.10: Monthly reference evapotranspiration (mm per day)

5.10. Effective Rainfall (Pe)

The entire water received from rainfall is not utilized by the growing crop; some part of it may be lost due to surface run-off, penetration, or evaporation. Only one part of the heavy and more rains can be entered and stored in the root zone. A part of stored water is utilized by the crop to meet its evapotranspiration. In the present case, "effective rainfall" has been computed using the United States Department of Agriculture Soil Conservation (USDA SC) method.

Table 5.8: Calculation effective rainfall for Chahar Asyab district using USDA S.C. Method.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall	34	54	73	64	20	1	6	3	2	4	11	25	**297**
Eff. rain	32.2	49.3	64.5	57.4	19.4	1	5.9	3	2	4	10.8	24	**273.5**

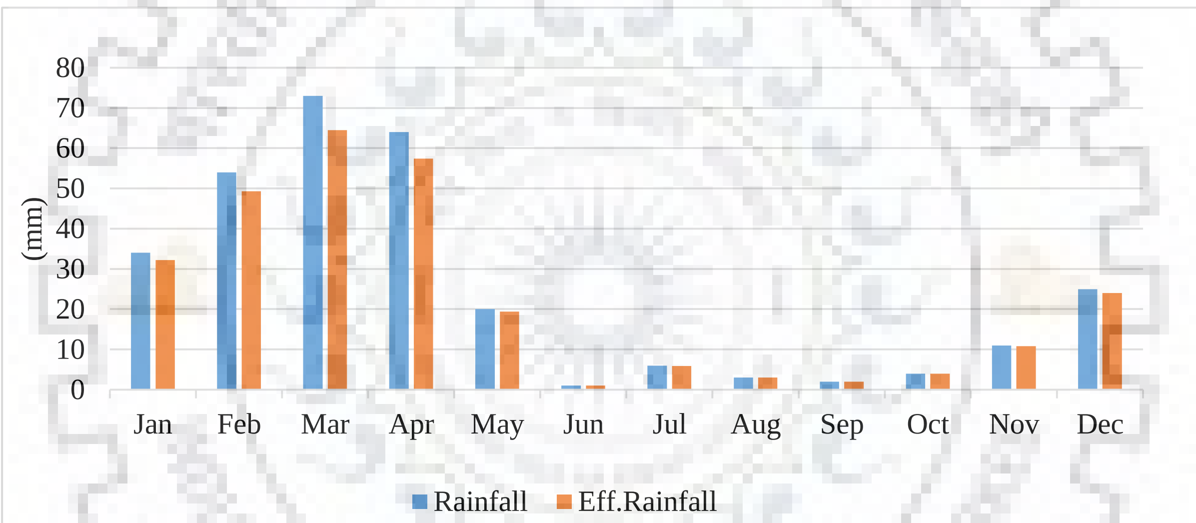


Figure 5.11: Monthly rainfall and effective rainfall (mm)

5.11. Water Requirements and Irrigation Requirement for Cropping Pattern

Water requirement of crops varies with their type and variety and stage of growth, properties of the soil and the climate. The tolerance of the crop to soil moisture stress is influenced by the genetic make-up of the crop, or the rooting characteristics and the properties of the stomata. Water management for efficient water use is profoundly influenced by the selection of suitable crops and their varieties based on the amount of water available in the area during different periods of the crop growing season.

For estimation water requirement and irrigation requirement for cropping pattern using CROPWAT 8.0 model. And also, climatological parameters have been taken from the FAO CLIMWAT 2.0 software.

5.11.1. Cereal Crops

Cereal Crops are members of the grass family grown for their edible starchy seeds. The important cereal crops produced in Chahar Asyab district are wheat, barley, maize (corn).

5.11.1.1. Wheat Crop

Wheat is most widely grown of all the cereal crops in the world. Wheat is grown in almost all temperate and most of the sub-tropical zone worldwide. It is also grown in some tropical countries at a higher elevation. Wheat varieties can be broadly grouped into winter wheat and spring wheat. Winter wheat requires a cold period during early growth. Wheat is grown under irrigation in the tropical zones or in the highlands near the equator and in the low-lands away from the equator. In the sub-tropics, with summer rainfall the crop is grown under irrigation in the winter months. In the subtropics with winter rainfall, it is grown under supplemental irrigation. The length of the total growing period of spring wheat ranges from 100 to 130 days while winter wheat needs about 180 to 250 days to mature. Day length and temperature requirements are key factors in variety selection. Winter-wheat in its early stages of development exhibits strong resistance to frost, down to - 20°C. The resistance is lost in the active growth period in spring and during head development and flowering periods, frost may lead to head sterility (infertility). Because of this sometimes more damage is done to the winter crop by spring frost than by winter frost. Figure (5.12 & 5.15) in the below depicts the stages of the crop of both the winter wheat and the spring-wheat.

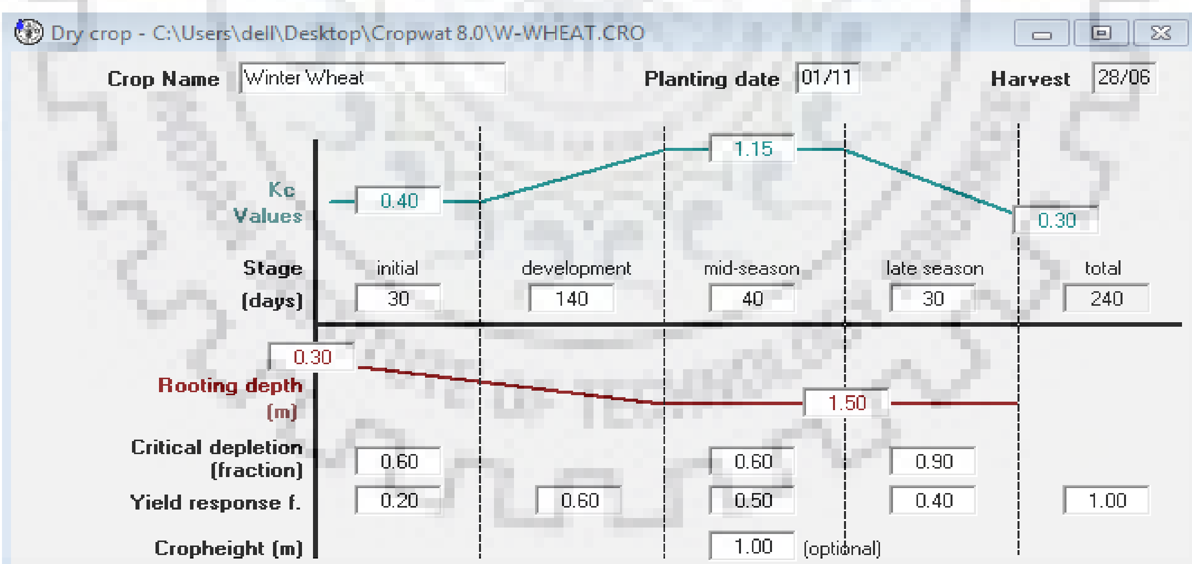


Figure 5.12: The crop coefficients of winter wheat at different growth stages.

Table 5.9: Estimation of water requirement and irrigation requirement for W-wheat crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.4	1.04	10.4	2.7	7.7
Nov	2	Init	0.4	0.83	8.3	3.4	4.9
Nov	3	Init	0.4	0.67	6.7	4.9	1.8
Dec	1	Deve	0.43	0.53	5.3	6.7	0
Dec	2	Deve	0.49	0.39	3.9	8.2	0
Dec	3	Deve	0.55	0.43	4.7	9	0
Jan	1	Deve	0.61	0.48	4.8	9.5	0
Jan	2	Deve	0.66	0.49	4.9	10.3	0
Jan	3	Deve	0.72	0.6	6.6	12.4	0
Feb	1	Deve	0.78	0.72	7.2	14.6	0
Feb	2	Deve	0.84	0.86	8.6	16.5	0
Feb	3	Deve	0.89	1.25	10	18.2	0
Mar	1	Deve	0.94	1.68	16.8	20.5	0
Mar	2	Deve	1	2.16	21.6	22.5	0
Mar	3	Deve	1.05	2.77	30.4	21.4	9
Apr	1	Deve	1.11	3.43	34.3	20.9	13.4
Apr	2	Mid	1.17	4.13	41.3	20.6	20.7
Apr	3	Mid	1.19	4.84	48.4	15.9	32.5
May	1	Mid	1.19	5.49	54.9	10.1	44.8
May	2	Mid	1.19	6.13	61.3	5.6	55.7
May	3	Late	1.18	7.03	77.3	3.8	73.5
Jun	1	Late	0.97	6.65	66.5	0.8	65.7
Jun	2	Late	0.67	5.19	51.9	0	51.9
Jun	3	Late	0.4	3.16	25.3	0.2	25
					611.3	**258.5**	**406.7**

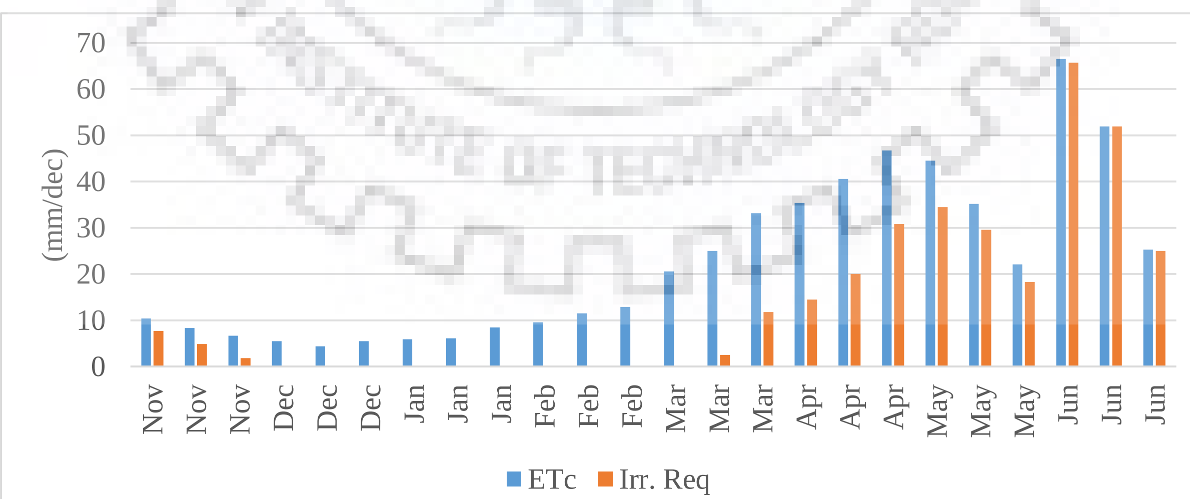


Figure 5.13: Water req. and irrigation req. for W-wheat crop (mm/dec)

Table 5.10: Irrigation schedule for winter wheat crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net. Irr.	Loss	Gr. Irr.	Flow
			mm	frac.	%	%	mm	mm	mm	l/s/ha
15-May	196	Mid	0	1	100	61	146.8	0	209.7	0.12
13-Jun	225	End	0	1	100	76	182.7	0	261	1.04
28-Jun	End	End	0	1	0	24				

Totals:

Total gross irrigation	470.7	mm	Total rainfall	282.0	mm
Total net irrigation	329.5	mm	Effective rainfall	220.4	mm
Total irrigation losses	0.0	mm	Total rain loss	61.6	mm
Actual water use by crop	608.1	mm	Moist deficit at harvest	58.2	mm
Potential water use by crop	608.1	mm	Actual irrigation req.	387.7	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	78.2	%
Deficiency irrigation schedule	0.0	%			

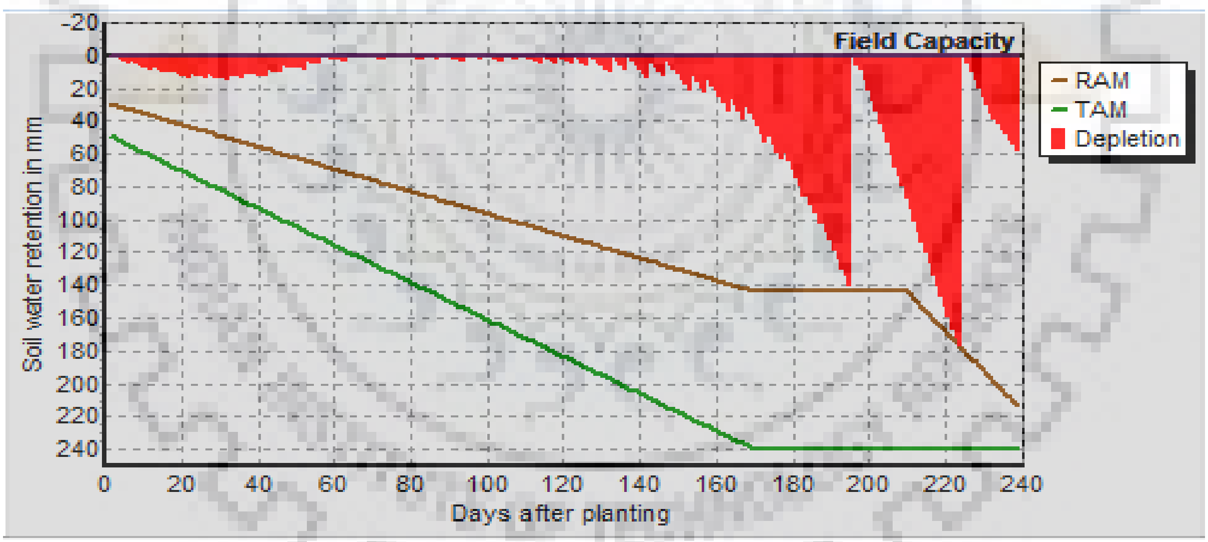


Figure 5.14: Irrigation schedule graph for W-wheat crop

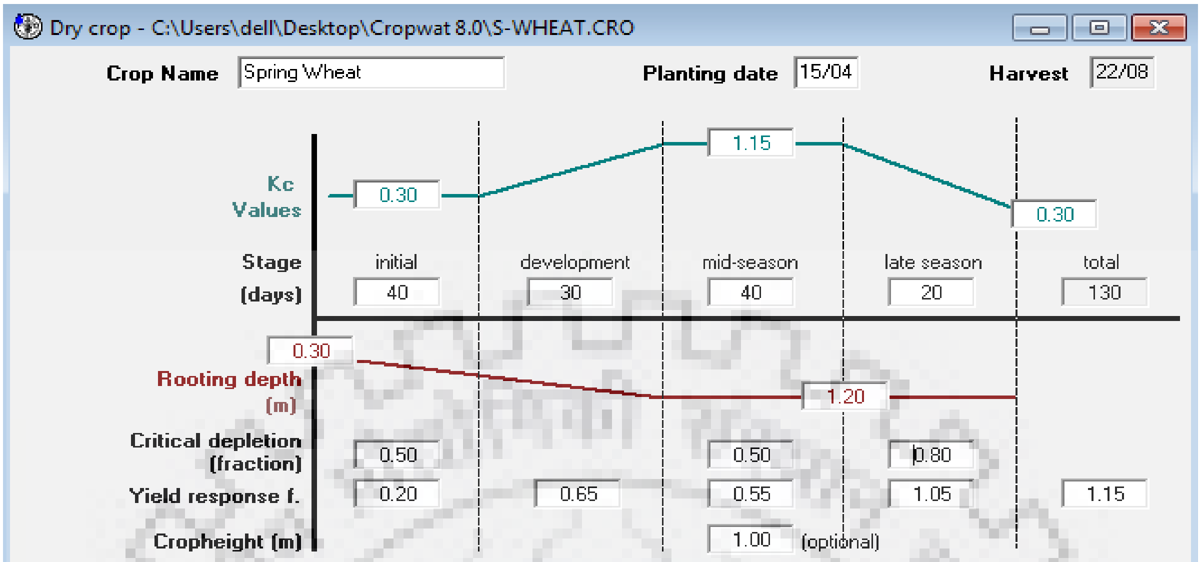


Figure 5.15: The crop coefficients of spring wheat at different growth stages

Table 5.11: Estimation of water requirement and irrigation requirement for S-wheat crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Apr	2	Init	0.3	1.06	6.4	12.4	0
Apr	3	Init	0.3	1.22	12.2	15.9	0
May	1	Init	0.3	1.38	13.8	10.1	3.7
May	2	Init	0.3	1.55	15.5	5.6	9.9
May	3	Deve	0.38	2.26	24.8	3.8	21
Jun	1	Deve	0.69	4.74	47.4	0.8	46.5
Jun	2	Deve	1	7.74	77.4	0	77.4
Jun	3	Mid	1.22	9.57	95.7	0.3	95.5
Jul	1	Mid	1.23	9.75	97.5	1.7	95.8
Jul	2	Mid	1.23	9.97	99.7	2.3	97.4
Jul	3	Mid	1.23	9.5	104.5	1.9	102.6
Aug	1	Late	1.06	7.76	77.6	1.3	76.3
Aug	2	Late	0.6	4.19	41.9	0.9	40.9
Aug	3	Late	0.32	2.05	4.1	0.2	4.1
					718.3	**57.1**	**671.1**

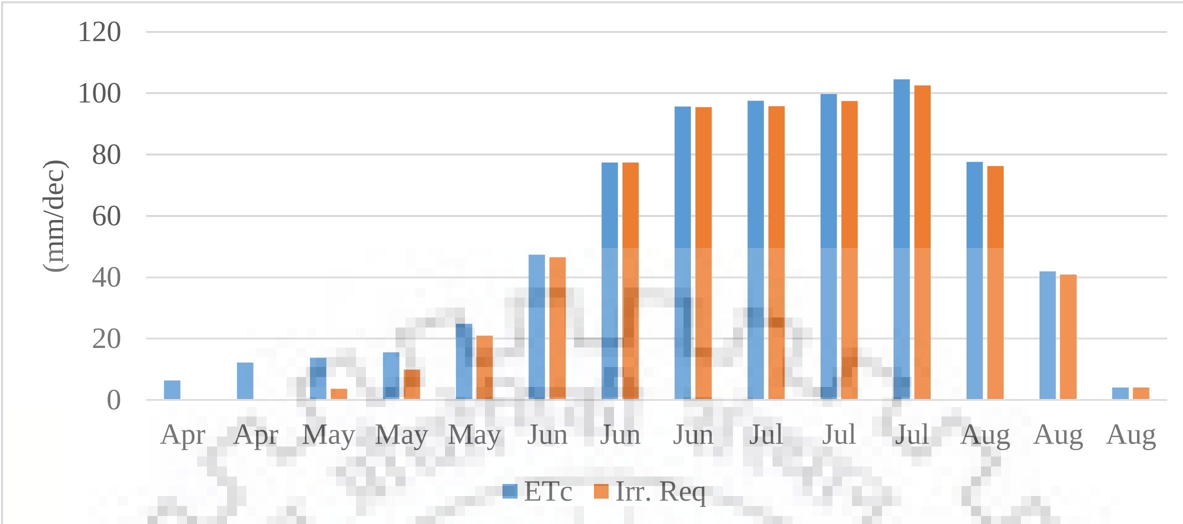


Figure 5.16: Water req. and irrigation req. for S-wheat crop (mm/dec)

Table 5.12: Irrigation schedule for spring wheat crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
10-Jun	57	Dev	0	1	100	52	85.4	0	122	0.25
22-Jun	69	Dev	0	1	100	51	96.5	0	137.9	1.33
3-Jul	80	Mid	0.8	1	100	55	104.8	0	149.8	1.58
13-Jul	90	Mid	1.2	1	100	50	96.1	0	137.3	1.59
23-Jul	100	Mid	0.9	1	100	50	96.2	0	137.4	1.59
4-Aug	112	End	0	1	100	55	105.4	0	150.6	1.45
22-Aug	End	End	0	1	0	46				

Totals:

Total gross irrigation	835.0	mm	Total rainfall	58.4	mm
Total net irrigation	584.5	mm	Effective rainfall	42.9	mm
Total irrigation losses	0.0	mm	Total rain loss	15.5	mm
Actual water use by crop	716.3	mm	Moist deficit at harvest	88.9	mm
Potential water use by crop	716.3	mm	Actual irrigation req.	673.3	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	73.5	%
Deficiency irrigation schedule	0.0	%			

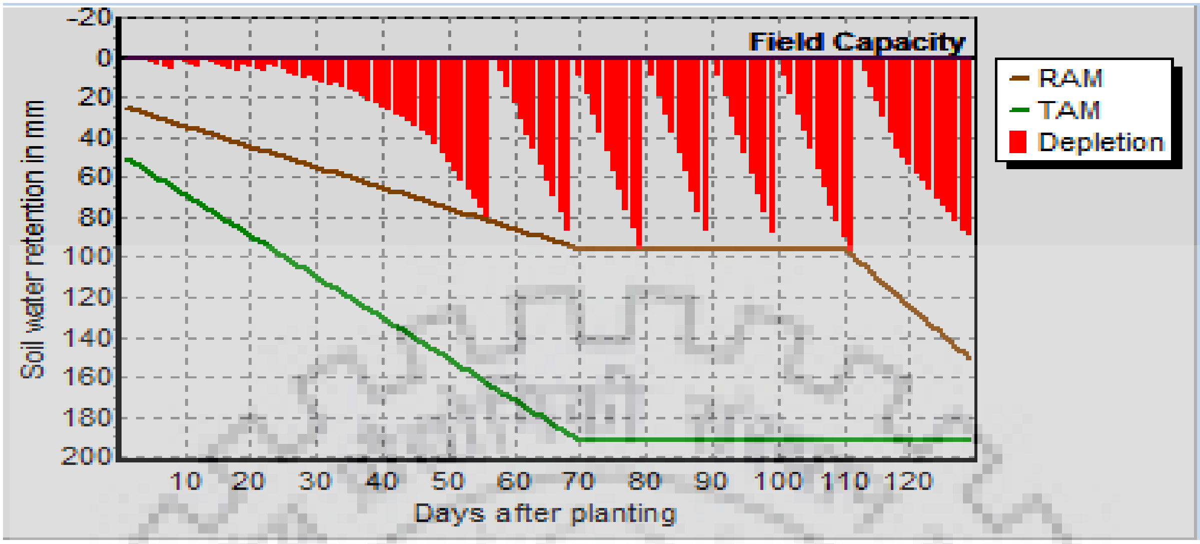


Figure 5.17: Irrigation schedule for S-wheat crop

5.11.1.2. Barley Crop

Barley needs less water than wheat for its growth. It is grown as a rain-fed crop in areas having rainfall of 200-400 mm in the growing season. Figure (5.18) in the below depicts the stages of the crop of barley.

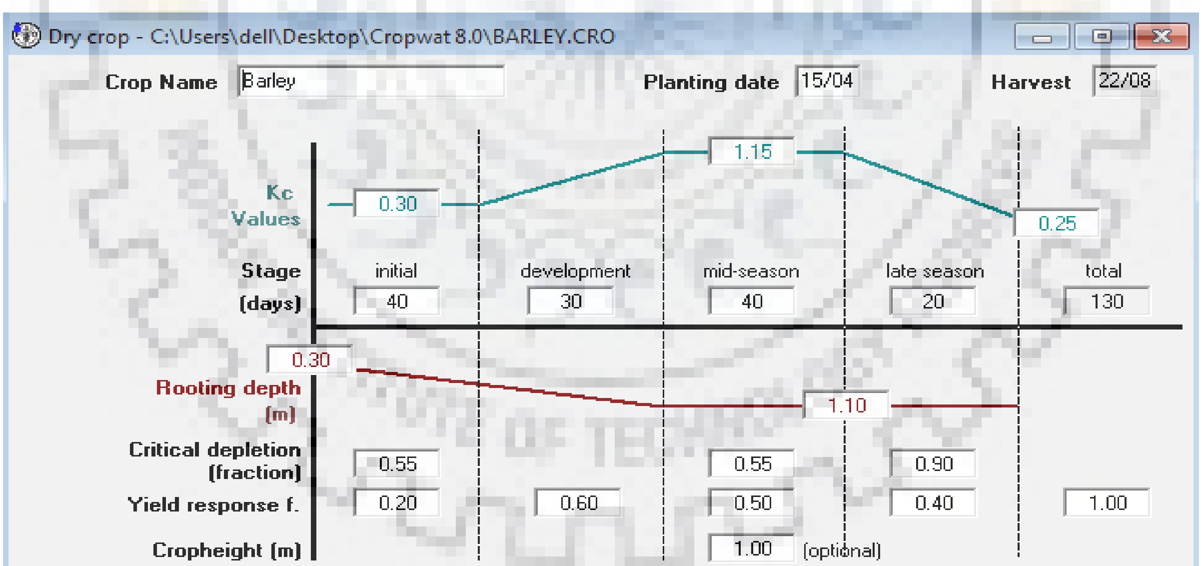


Figure 5.18: The crop coefficients of barley at different growth stages.

Table 5.13: Estimation of water requirement and irrigation requirement for barley crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Apr	2	Init	0.3	1.06	6.4	12.4	0
Apr	3	Init	0.3	1.22	12.2	15.9	0
May	1	Init	0.3	1.38	13.8	10.1	3.7
May	2	Init	0.3	1.55	15.5	5.6	9.9
May	3	Deve	0.38	2.26	24.8	3.8	21
Jun	1	Deve	0.69	4.74	47.4	0.8	46.5
Jun	2	Deve	1	7.74	77.4	0	77.4
Jun	3	Mid	1.22	9.57	95.7	0.3	95.5
Jul	1	Mid	1.23	9.75	97.5	1.7	95.8
Jul	2	Mid	1.23	9.97	99.7	2.3	97.4
Jul	3	Mid	1.23	9.5	104.5	1.9	102.6
Aug	1	Late	1.06	7.7	77	1.3	75.7
Aug	2	Late	0.57	3.95	39.5	0.9	38.6
Aug	3	Late	0.27	1.74	3.5	0.2	3.5
					714.7	**57.1**	**667.5**

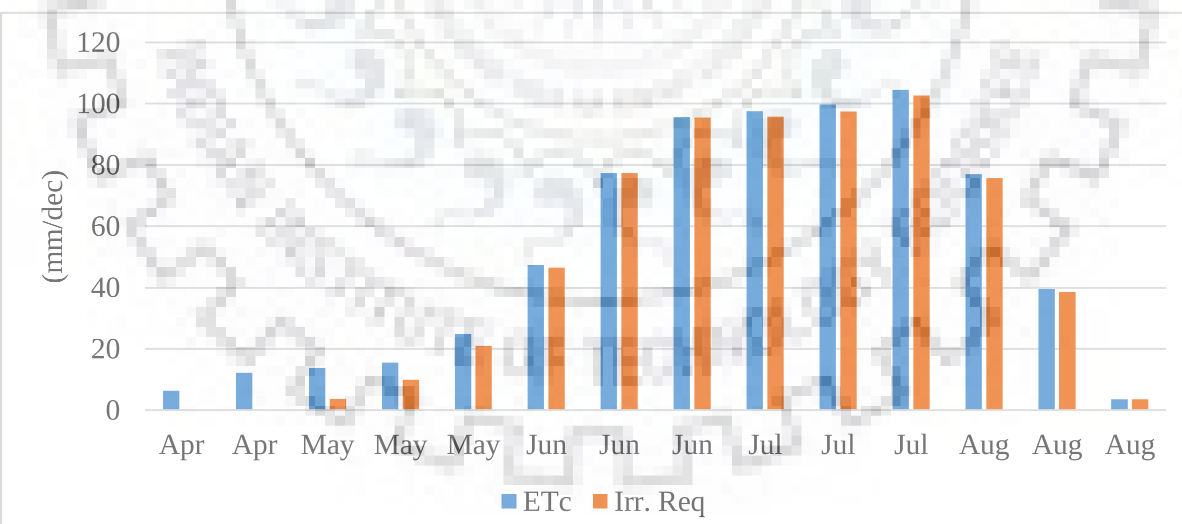


Figure 5.19: Water req. and irrigation req. for barley crop (mm/dec)

Table 5.14: Irrigation schedule for barley crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
10-Jun	57	Dev	0	1	100	56	85.4	0	122	0.25
22-Jun	69	Dev	0	1	100	55	96.5	0	137.9	1.33
3-Jul	80	Mid	0.8	1	100	60	104.8	0	149.8	1.58
14-Jul	91	Mid	0	1	100	60	106.1	0	151.5	1.59
25-Jul	102	Mid	0	1	100	60	105.2	0	150.3	1.58
8-Aug	116	End	0	1	100	66	116.3	0	166.1	1.37
22-Aug	End	End	0	1	0	32				

Totals:

Total gross irrigation	877.6	mm	Total rainfall	58.4	mm
Total net irrigation	614.3	mm	Effective rainfall	42.9	mm
Total irrigation losses	0.0	mm	Total rain loss	15.5	mm
Actual water use by crop	713.0	mm	Moist deficit at harvest	55.7	mm
Potential water use by crop	713.0	mm	Actual irrigation req.	670.0	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	73.5	%
Deficiency irrigation schedule	0.0	%			

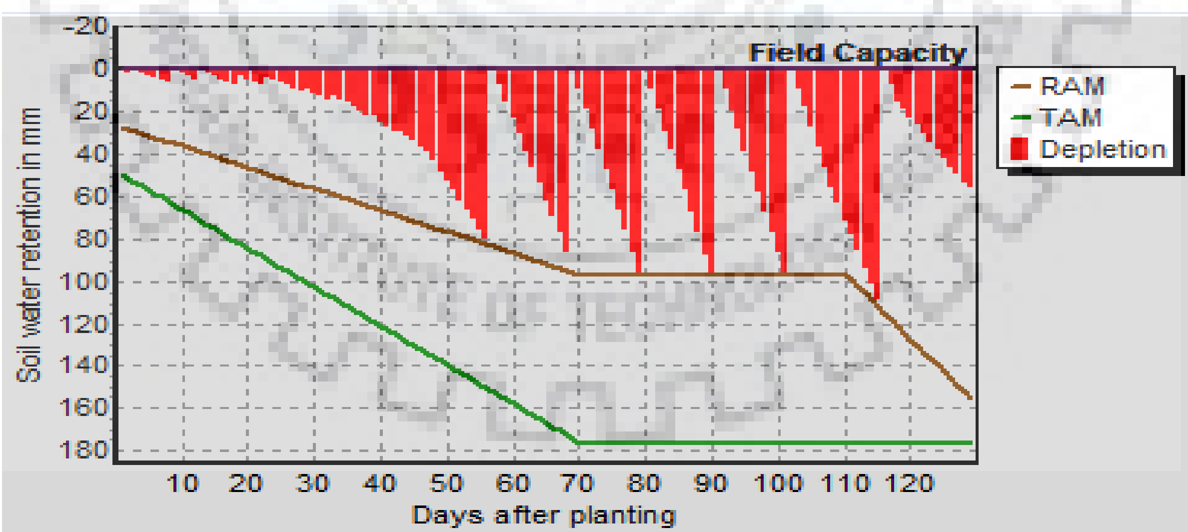


Figure 5.20: Irrigation schedule graph for barley crop

5.11.1.3. Maize (Corn) Crop

Maize also called corn, is an important cereal crop grown in climates ranging from temperate to tropical during the period when meaning daily temperatures are above 15°C and frost-free. About half of maize production in the world is from the USA. Maize is grown almost all over Afghanistan under varied soil and climate conditions. However, it is essentially a warm and humid season crop and areas of mild climate it can be grown throughout the year. In Chahar Asyab district maize is grown mostly during the months of July-October under rain-fed and irrigation conditions. Most of the improved varieties of maize require 100-130 days to mature. Figure (5.21) in the below depicts the crop stages of the maize crop.

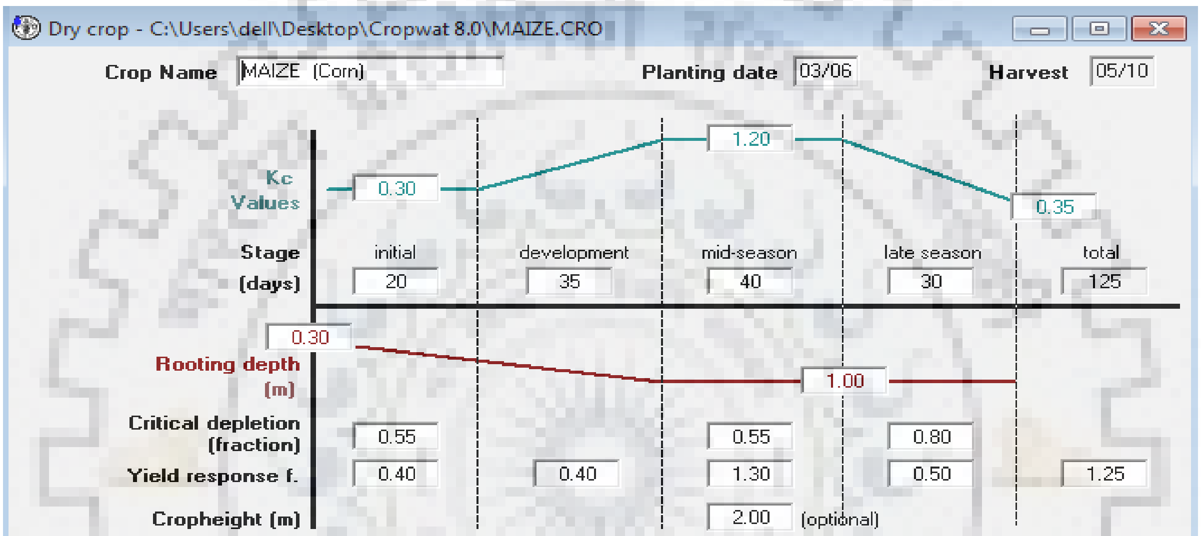


Figure 5.21: The crop coefficients of maize at different growth stages.

Table 5.15: Estimation of water requirement and irrigation requirement for maize crop.

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Init	0.3	2.06	16.5	0.7	15.7
Jun	2	Init	0.3	2.32	23.2	0	23.2
Jun	3	Deve	0.4	3.13	31.3	0.3	31
Jul	1	Deve	0.68	5.34	53.4	1.7	51.7
Jul	2	Deve	0.95	7.71	77.1	2.3	74.8
Jul	3	Mid	1.22	9.4	103.4	1.9	101.5
Aug	1	Mid	1.27	9.28	92.8	1.3	91.5
Aug	2	Mid	1.27	8.84	88.4	0.9	87.4
Aug	3	Mid	1.27	8.08	88.8	0.9	88
Sep	1	Late	1.23	7.05	70.5	0.7	69.8
Sep	2	Late	0.95	4.89	48.9	0.6	48.3
Sep	3	Late	0.64	2.98	29.8	0.8	29
Oct	1	Late	0.41	1.71	8.5	0.5	8
					732.8	**12.5**	**720.2**

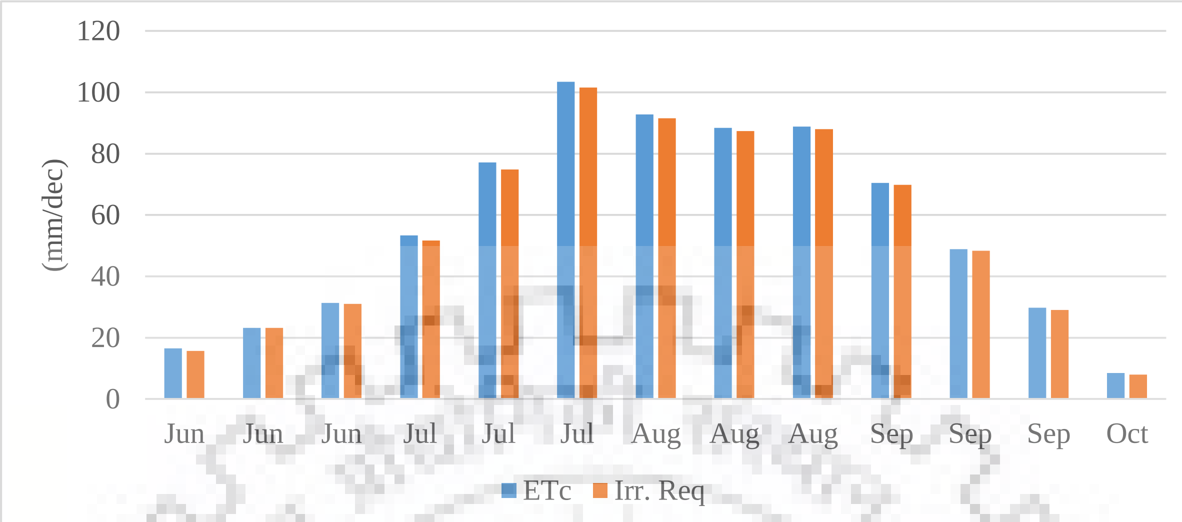


Figure 5.22: Water req. and irrigation req. for maize crop (mm/dec)

Table 5.16: Irrigation schedule for maize crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
24-Jun	22	Dev	0	1	100	56	51.7	0	73.9	0.39
10-Jul	38	Dev	0	1	100	56	70.4	0	100.5	0.73
21-Jul	49	Dev	0	1	100	57	84.2	0	120.3	1.27
31-Jul	59	Mid	0	1	100	58	92.1	0	131.6	1.52
10-Aug	69	Mid	0	1	100	57	91.5	0	130.8	1.51
21-Aug	80	Mid	0	1	100	60	95.5	0	136.4	1.44
2-Sep	92	Mid	0	1	100	59	94	0	134.3	1.3
23-Sep	113	End	0.4	1	100	71	112.9	0	161.3	0.89
5-Oct	End	End	0	1	0	17				

Totals:

Total gross irrigation	989.1	mm	Total rainfall	12.8	mm
Total net irrigation	692.3	mm	Effective rainfall	12.0	mm
Total irrigation losses	0.0	mm	Total rain loss	0.8	mm
Actual water use by crop	731.1	mm	Moist deficit at harvest	26.8	mm
Potential water use by crop	731.1	mm	Actual Irrigation req.	719.2	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	93.8	%
Deficiency irrigation schedule	0.0	%			

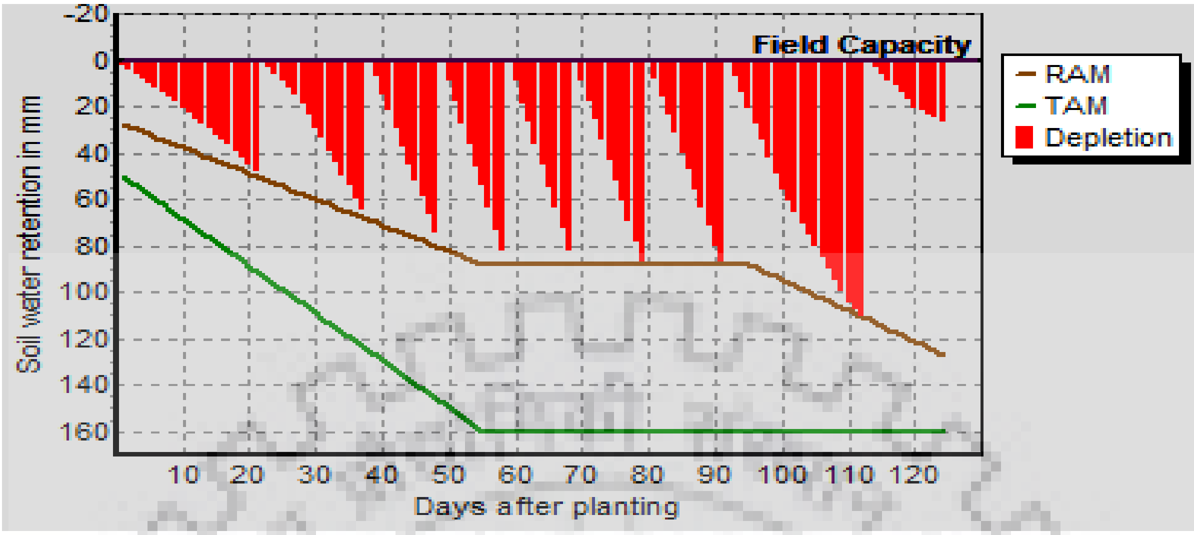


Figure 5.23: Irrigation schedule graph for maize crop

5.11.2. Vegetable Crops

Vegetables form an important component of the human diet, supplying major amounts of vitamins A and C and numerous nutrients, protein, and fat. Vegetable crops are grown over a wide variety of soils and climatic conditions. One or the other vegetable crop is grown at any time of the year, depending upon the availability of irrigation water. The important spring and summer season vegetable crops are potato, onion, and tomato in Chahar Asyab district. Most of the vegetable crops are of short duration and quick growing inhabit and need frequent irrigations for their maximum production. The irrigation requirements will vary, depending upon the duration of the crop and the season when grown. Solanaceous vegetable crops include tomatoes which are deep-rooted with high water requirements and high yields.

Adequate soil moisture availability in the root zone is of prime importance in the cultivation of vegetable crops. In arid and semi-arid climates irrigation is a basic requirement in the cultivation of vegetable crops.

The water requirement of vegetable crops and the frequency of irrigation vary with the type of crop, soil, and climatic conditions. However, as a general rule, applicable to most of the vegetable crops, the available soil moisture in the crop root zone should be replenished when 50% of it has been depleted.

5.11.2.1. Potato Crop

Potato (Solanum tuberosum) is grown in most regions throughout the world but is particularly important in the temperate climates. The optimum mean temperatures are around 15 to 20°C. Night temperatures below 15°C, are desirable for tuber initiation. Temperatures below 10°C and above 30°C adversely affect growth. Potato variety can be grouped into early (90 to 120 days), medium (120 to 150 days), and late (150 to 180 days). Early varieties are bred for temperature climates with long day lengths 15 to 17 hrs., while late varieties result in good yields under long and short day conditions. For tropical climates varieties tolerant to short days are required.

Potato is grown in 3 or more year rotations with other crops such as maize and alfalfa to maintain soil productivity, to check weed growth and prevent crop damage due to insects, pests and diseases, particularly soil-borne diseases.

Potato requires adequate soil moisture for optimum growth. The available soil moisture should not be depleted beyond 30 to 50%. Soil moisture depletion more than 50% reduces the yield of the crop. Potato has a shallow root system and about 70% of the total moisture uptake is from the top 30 cm of the root zone and nearly 100% from the top 40 to 60 cm of the root zone. Under irrigation conditions, irrigation scheduling should be based on avoiding soil moisture deficits during the periods of colonization and yield formation.

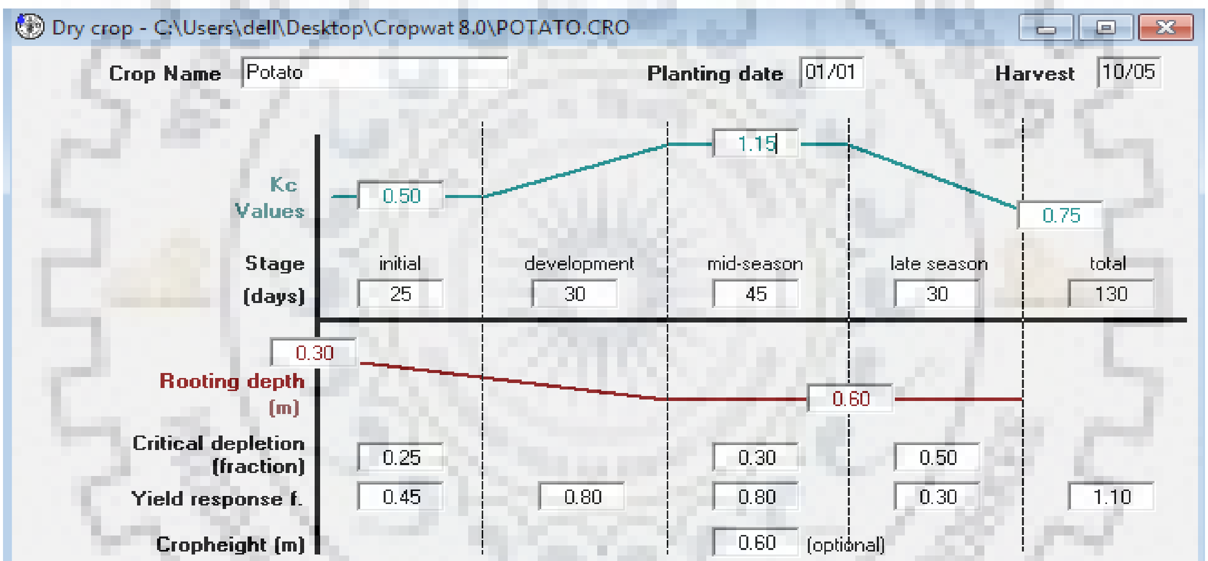


Figure 5.24: The crop coefficients of potato at different growth stages.

Table 5.17: Estimation of water requirement and irrigation requirement for potato crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.5	0.4	4	9.5	0
Jan	2	Init	0.5	0.37	3.7	10.3	0
Jan	3	Deve	0.54	0.45	4.9	12.4	0
Feb	1	Deve	0.75	0.69	6.9	14.6	0
Feb	2	Deve	0.97	0.99	9.9	16.5	0
Feb	3	Mid	1.13	1.59	12.8	18.2	0
Mar	1	Mid	1.15	2.06	20.6	20.5	0.1
Mar	2	Mid	1.15	2.5	25	22.5	2.5
Mar	3	Mid	1.15	3.02	33.2	21.4	11.8
Apr	1	Mid	1.15	3.54	35.4	20.9	14.5
Apr	2	Late	1.08	3.82	38.2	20.6	17.6
Apr	3	Late	0.95	3.88	38.8	15.9	22.9
May	1	Late	0.83	3.81	38.1	10.1	28
					271.4	**213.3**	**97.4**

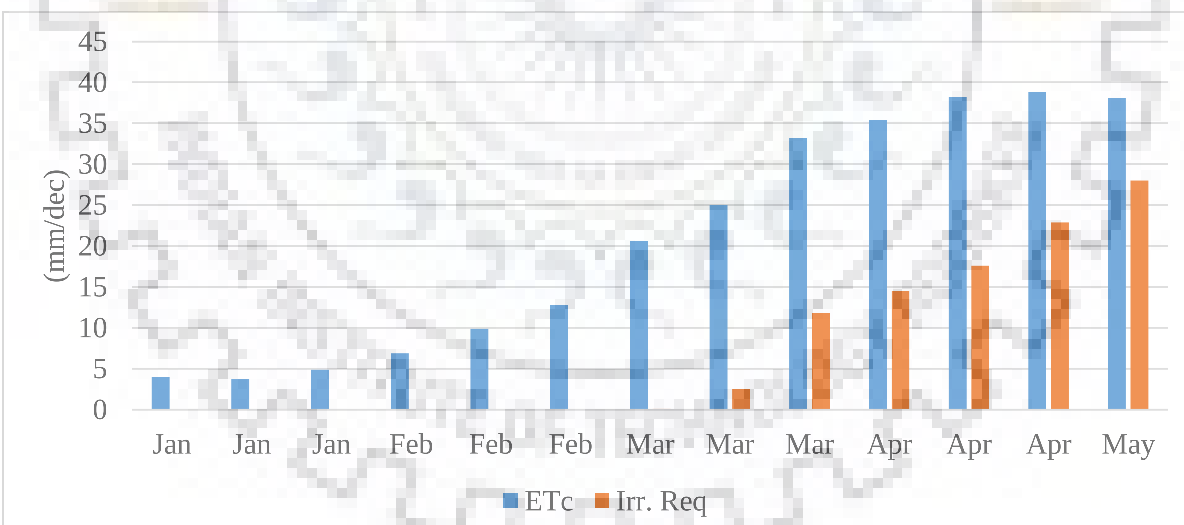


Figure 5.25: Water req. and irrigation req. for potato crop (mm/dec)

Table 5.18: Irrigation schedule for potato crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
10-Apr	100	Mid	0	1	100	32	31	0	44.2	0.05
1-May	121	End	0	1	100	46	44.1	0	63	0.35
10-May	End	End	0	1	0	22				

Totals:

Total gross irrigation	107.3	mm	Total rainfall	235.6	mm
Total net irrigation	75.1	mm	Effective rainfall	171.2	mm
Total irrigation losses	0.0	mm	Total rain loss	64.4	mm
Actual water use by crop	267.6	mm	Moist deficit at harvest	21.3	mm
Potential water use by crop	267.6	mm	Actual irrigation req.	96.4	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	72.7	%
Deficiency irrigation schedule	0.0	%			

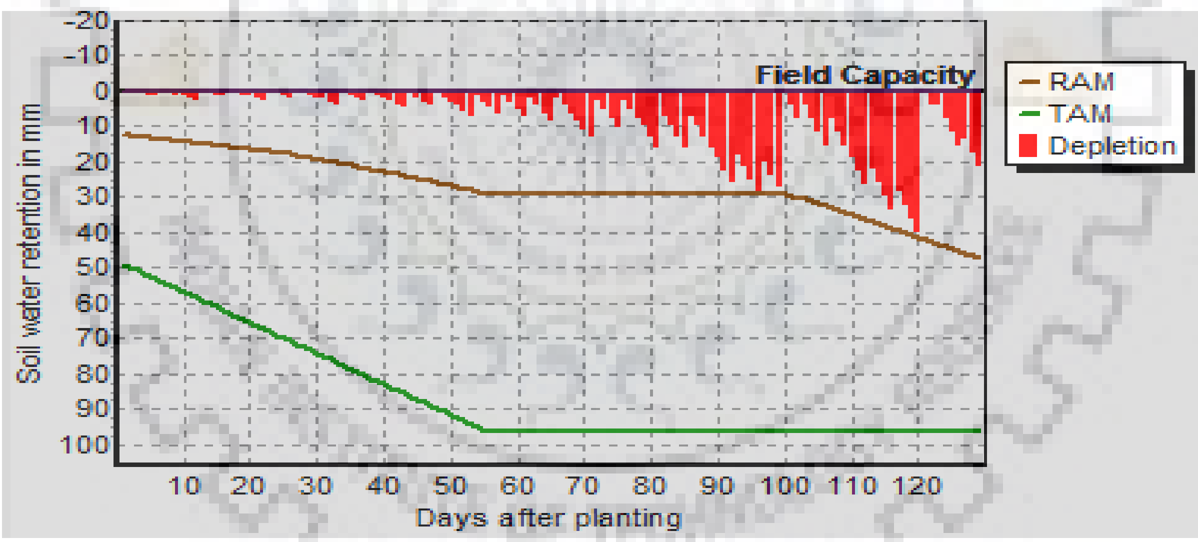


Figure 5.26: Irrigation schedule graph for potato crop

5.11.2.2. Onion Crop

Onion is the most important bulb crop grown under a variety of climates from temperature to tropical. The crop flourishes in mild climates without extremes of temperature and without excessive rainfall. During the initial growth period, cool weather and adequate soil moisture are advantageous for the proper establishment of the crop. During the crop ripening period, warm, dry weather is desirable for high yields of good quality bulbs. The mean daily temperature for the optimum growth of the crop ranges from 15 to 20°C.

The length of the growing period varies with the climate but usually ranges from 150 to 175 days, from sowing to harvest. The crop is usually grown in the nursery and transplanted after 30 to 35 days. Onion-like most other vegetable crops are sensitive to soil moisture deficits. The crop is shallow rooted with roots concentrated in the top 30 cm of the soil, requiring frequent and light irrigations. Figure (5.27) in the below depicts the crop stages of onion.

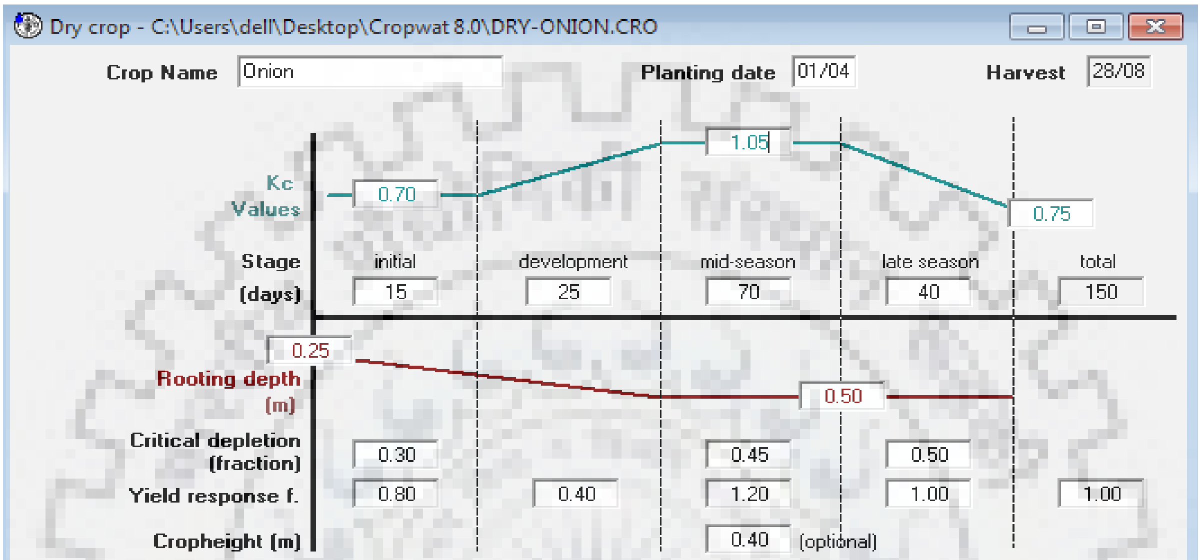


Figure 5.27: The crop coefficients of onion at different growth stages.

Table 5.19: Estimation of water requirement and irrigation requirement for onion crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.7	2.15	21.5	20.9	0.6
Apr	2	Deve	0.72	2.56	25.6	20.6	5
Apr	3	Deve	0.87	3.55	35.5	15.9	19.6
May	1	Deve	1.03	4.77	47.7	10.1	37.6
May	2	Mid	1.11	5.71	57.1	5.6	51.5
May	3	Mid	1.11	6.59	72.5	3.8	68.7
Jun	1	Mid	1.11	7.62	76.2	0.8	75.4
Jun	2	Mid	1.11	8.58	85.8	0	85.8
Jun	3	Mid	1.11	8.67	86.7	0.3	86.4
Jul	1	Mid	1.11	8.76	87.6	1.7	86
Jul	2	Late	1.11	8.96	89.6	2.3	87.2
Jul	3	Late	1.05	8.12	89.4	1.9	87.5
Aug	1	Late	0.97	7.1	71	1.3	69.7
Aug	2	Late	0.9	6.22	62.2	0.9	61.3
Aug	3	Late	0.83	5.25	42	0.6	41.1
					950.4	**86.7**	**863.4**

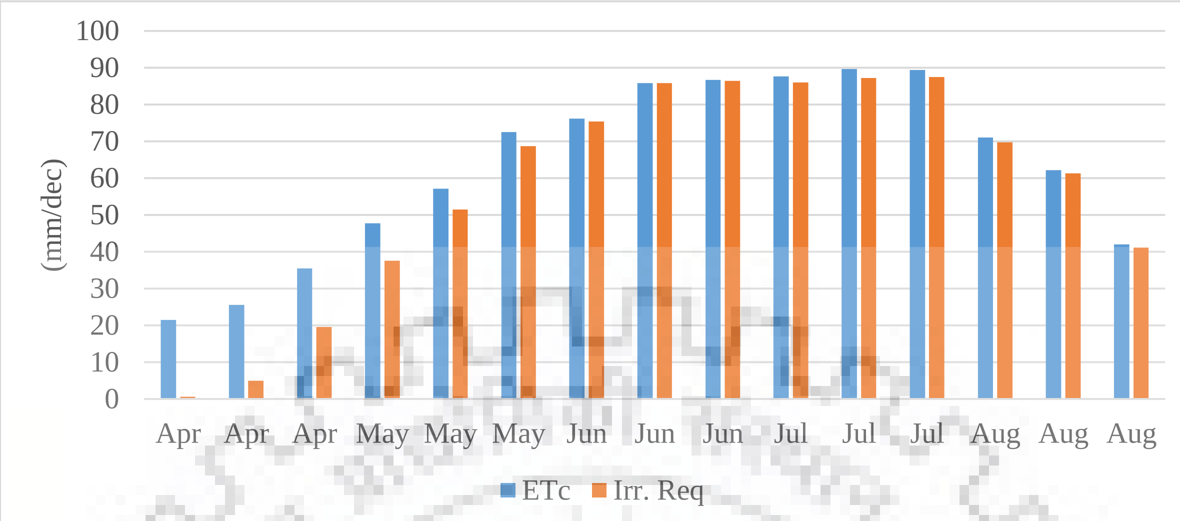


Figure 5.28: Water requirement for onion (mm/dec)

Table 5.20: Irrigation schedule for onion crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
30-Apr	30	Dev	0	1	100	42	29.1	0	41.6	0.16
10-May	40	Dev	0	1	100	46	36.9	0	52.7	0.61
18-May	48	Mid	0	1	100	50	40.1	0	57.3	0.83
25-May	55	Mid	0	1	100	53	42.5	0	60.7	1
31-May	61	Mid	0	1	100	47	37.7	0	53.8	1.04
5-Jun	66	Mid	0	1	100	47	37.7	0	53.8	1.25
10-Jun	71	Mid	0	1	100	47	37.7	0	53.8	1.25
15-Jun	76	Mid	0	1	100	54	42.9	0	61.3	1.42
20-Jun	81	Mid	0	1	100	54	42.9	0	61.3	1.42
25-Jun	86	Mid	0	1	100	54	43.2	0	61.7	1.43
30-Jun	91	Mid	0	1	100	54	43.2	0	61.7	1.43
5-Jul	96	Mid	0	1	100	54	43	0	61.4	1.42
10-Jul	101	Mid	0	1	100	54	43	0	61.4	1.42
15-Jul	106	Mid	0	1	100	55	43.6	0	62.3	1.44
20-Jul	111	End	0	1	100	55	43.6	0	62.3	1.44
25-Jul	116	End	0	1	100	50	39.7	0	56.7	1.31
30-Jul	121	End	0	1	100	50	39.7	0	56.7	1.31
5-Aug	127	End	0	1	100	54	43	0	61.4	1.18
11-Aug	133	End	0	1	100	51	41.1	0	58.6	1.13
18-Aug	140	End	0	1	100	53	42.6	0	60.9	1.01
26-Aug	148	End	0	1	100	54	43.5	0	62.1	0.9
28-Aug	End	End	0	1	0	7				

Totals:

Total gross irrigation	1223.7	mm	Total rainfall	94.2	mm
Total net irrigation	856.6	mm	Effective rainfall	83.3	mm
Total irrigation losses	0.0	mm	Total rain loss	10.9	mm
Actual water use by crop	945.1	mm	Moist deficit at harvest	5.2	mm
Potential water use by crop	945.1	mm	Actual irrigation req.	861.8	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	88.4	%
Deficiency irrigation schedule	0.0	%			

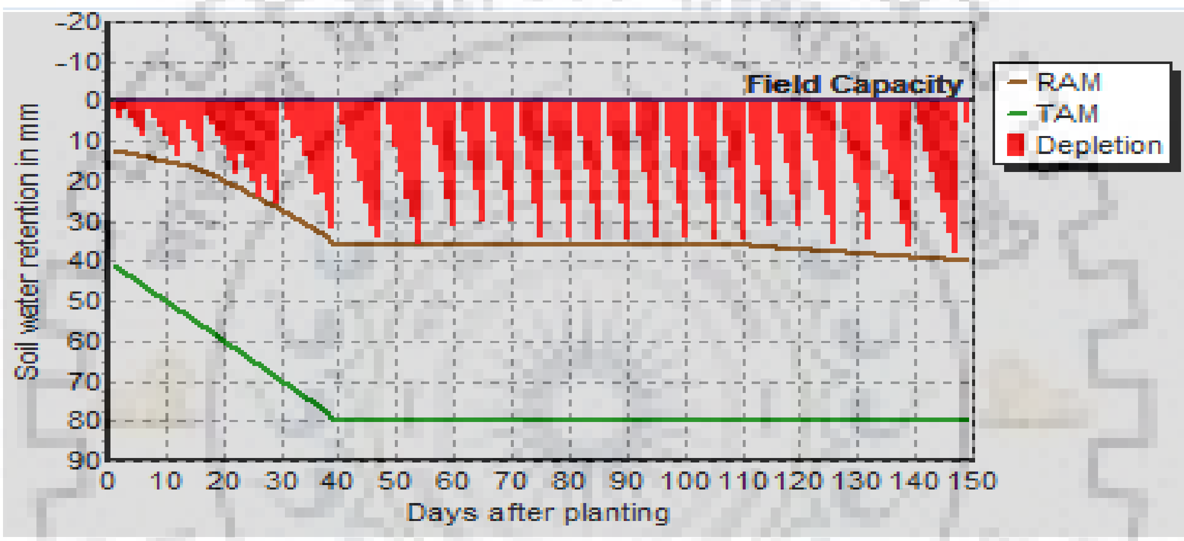


Figure 5.29: Irrigation schedule graph for onion crop

5.11.2.3. Tomato Crop

Tomato (Lycopersicon esculentum) is the second most important vegetable, next only to potato. It is a rapidly growing crop with a growing period of 90 to 150 days. The crop is natural to day length optimum mean daily temperature is in the range of 18 to 25°C with night temperature between 10 and 20°C. The growth period of tomatoes are recognized as follows: nursery stage (25 to 35 days), flowering stage (20 to 30 days), yield formation stage (20 to 30 days) and ripening stage (15 to 20 days). Tomato is most sensitive to soil moisture stress during and immediately after transplanting, during flowering and yield formation. Tomato has a fairly deep root system. In deep soils, roots may penetrate up to 1.5m. About 80% of the soil moisture uptake is from the top 50 to 60 cm of the root zone soil. For high yields of good quality, tomato needs a controlled supply of water throughout the growing period.

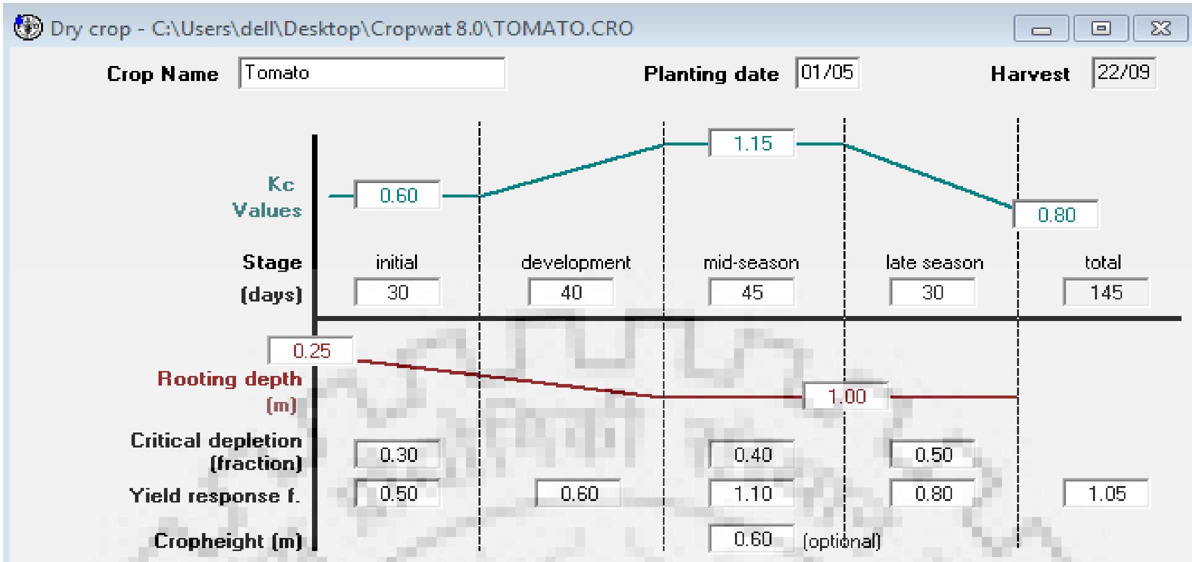


Figure 5.30: The crop coefficients of tomato at different growth stages.

Table 5.21: Estimation of water requirement and irrigation requirement for tomato crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
May	1	Init	0.6	2.77	27.7	10.1	17.6
May	2	Init	0.6	3.09	30.9	5.6	25.3
May	3	Deve	0.6	3.58	39.3	3.8	35.5
Jun	1	Deve	0.7	4.81	48.1	0.8	47.3
Jun	2	Deve	0.85	6.6	66	0	66
Jun	3	Deve	1	7.86	78.6	0.3	78.3
Jul	1	Mid	1.16	9.14	91.4	1.7	89.7
Jul	2	Mid	1.21	9.79	97.9	2.3	95.6
Jul	3	Mid	1.21	9.33	102.6	1.9	100.7
Aug	1	Mid	1.21	8.82	88.2	1.3	87
Aug	2	Mid	1.21	8.4	84	0.9	83.1
Aug	3	Late	1.17	7.42	81.6	0.9	80.8
Sep	1	Late	1.04	6	60	0.7	59.3
Sep	2	Late	0.92	4.74	47.4	0.6	46.8
Sep	3	Late	0.85	3.93	7.9	0.2	7.9
					951.6	**31**	**920.8**

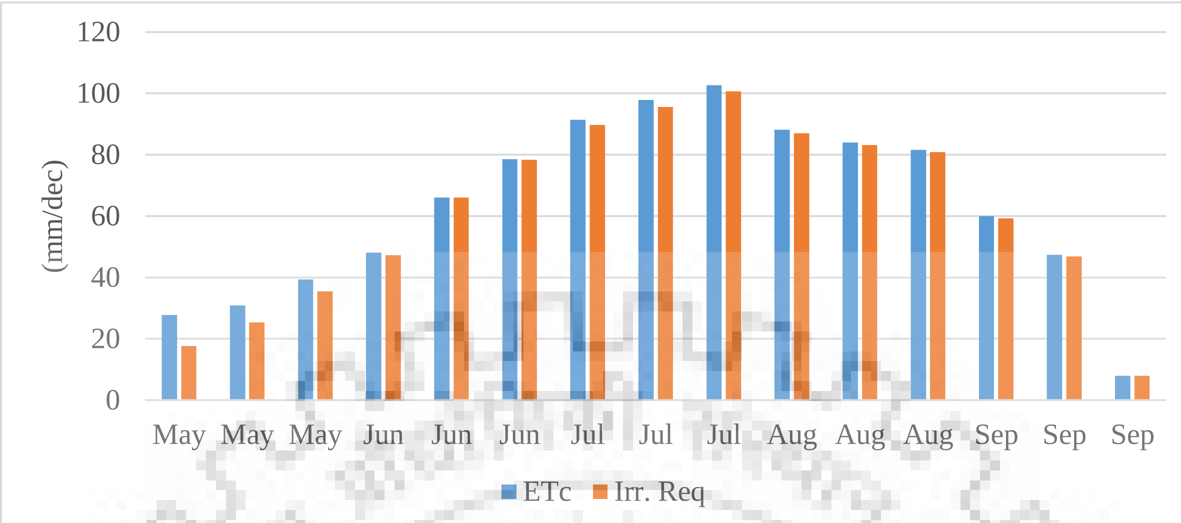


Figure 5.31: Water requirement for tomato (mm/dec)

Table 5.22: Irrigation schedule for tomato crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
11-May	11	Init	0	1	100	34	20	0	28.5	0.3
20-May	20	Init	0	1	100	30	22.3	0	31.8	0.41
29-May	29	Init	0	1	100	32	28.4	0	40.6	0.52
6-Jun	37	Dev	0	1	100	34	35.6	0	50.8	0.74
13-Jun	44	Dev	0	1	100	34	39	0	55.8	0.92
20-Jun	51	Dev	0	1	100	36	46.2	0	66	1.09
27-Jun	58	Dev	0.1	1	100	39	54.8	0	78.2	1.29
4-Jul	65	Dev	0	1	100	39	59.3	0	84.7	1.4
12-Jul	73	Mid	0	1	100	46	73.6	0	105.1	1.52
19-Jul	80	Mid	0	1	100	42	67.4	0	96.2	1.59
26-Jul	87	Mid	0	1	100	41	64.8	0	92.6	1.53
2-Aug	94	Mid	0	1	100	40	64.3	0	91.8	1.52
10-Aug	102	Mid	0	1	100	44	69.9	0	99.9	1.45
18-Aug	110	Mid	0	1	100	41	66.3	0	94.7	1.37
27-Aug	119	End	0.4	1	100	42	67.9	0	97	1.25
8-Sep	131	End	0	1	100	48	76.9	0	109.9	1.06
22-Sep	End	End	0	1	0	39				

Total:

Total gross irrigation	1223.7	mm	Total rainfall	31.5	mm
Total net irrigation	856.6	mm	Effective rainfall	28.3	mm
Total irrigation losses	0.0	mm	Total rain loss	3.2	mm
Actual water use by crop	947.7	mm	Moist deficit at harvest	62.7	mm
Potential water use by crop	947.7	mm	Actual irrigation req.	919.3	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	89.8	%
Deficiency irrigation schedule	0.0	%			

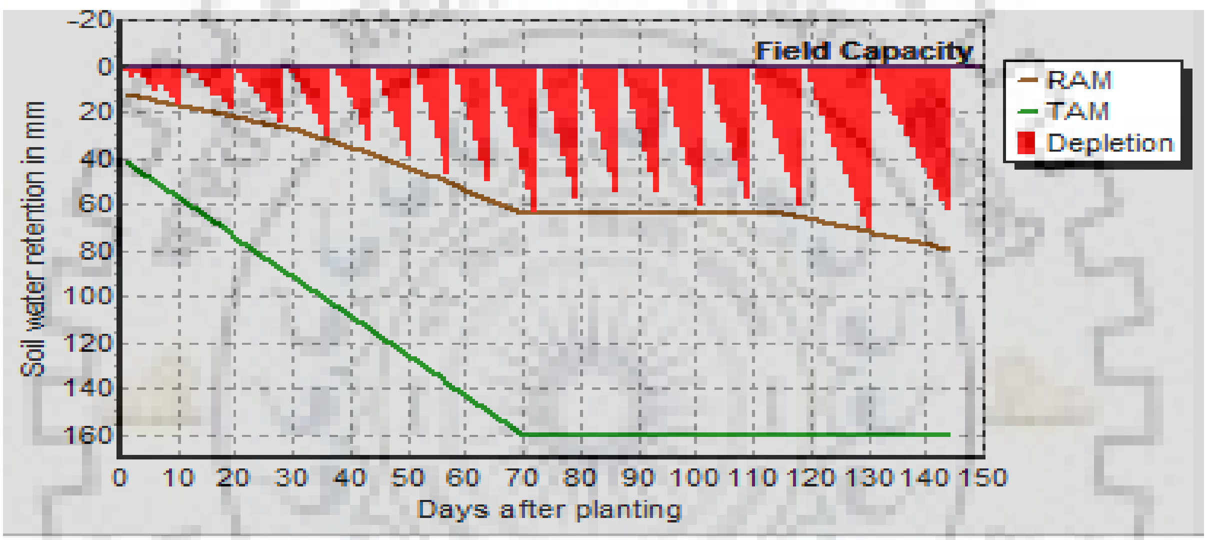


Figure 5.32: Irrigation schedule graph for tomato crop

5.11.3. Fruits Crops

Fruit crops may be of an evergreen type or deciduous type. The deciduous trees shed their leaves during winter and remain dormant for 3-4 months. A typical example is a grapevine. All fruit crops require adequate soil moisture during their establishment period of three to four years. Soil moisture should be maintained above 50% availability in the surface 1m depth of soil. At other periods and during dormancy in the case of deciduous trees, irrigations may be applied when the soil moisture depletion reaches below 30% of the available soil moisture in the root zone.

5.11.3.1. Grapes Crop

Grapes are an important fruit crop requiring a long, warm, dry summer and cool winter. Grapes are adapted to a wide range of well-drained soils. Largest vines and high yields are obtained in deep, fertile soil. Most grape varieties are propagated by cuttings grown in nurseries to produce roots.

Grape vines are deep-rooted with roots penetrating to a depth of 2 to 3 m. grapes can adjust moderately to limit water supply.

Prior to and during flowering adequate soil moisture is essential for flower development. During the vegetative period, flowering and early yield formation stage soil moisture depletion should not exceed 0.35 to 0.45 when the ETc is 5 to 6 mm/day. Later in the growth period, moisture depletion can be at a higher level, while towards and after harvest a high level of soil moisture depletion is required.

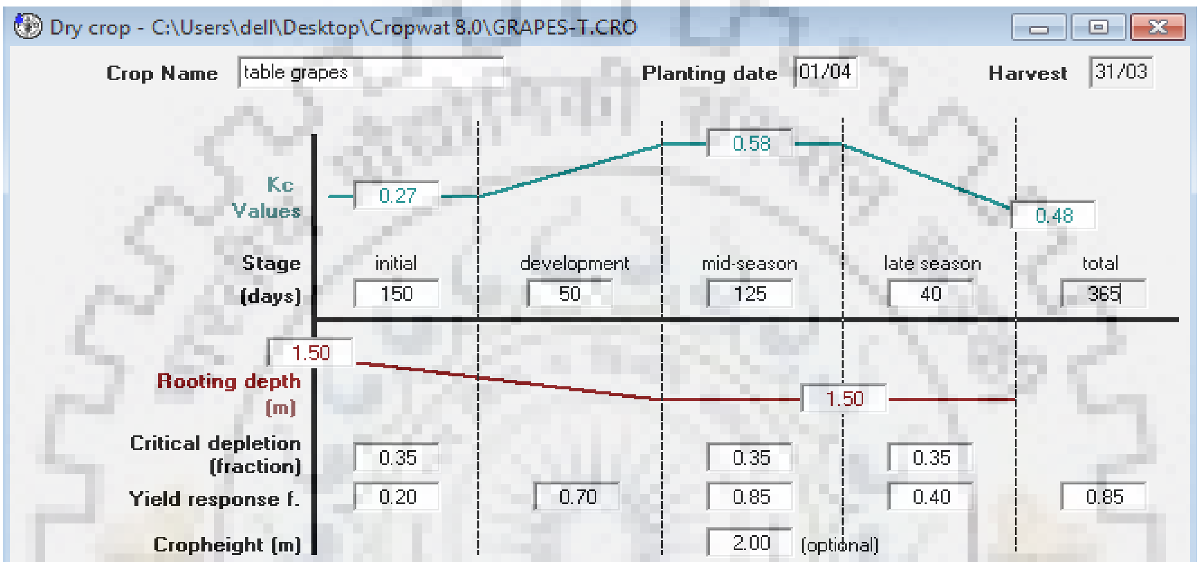


Figure 5.33: The crop coefficients of grape at different growth stages.

Table 5.23: Estimation of water requirement and irrigation requirement for grapes crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.27	0.83	8.3	20.9	0
Apr	2	Init	0.27	0.95	9.5	20.6	0
Apr	3	Init	0.27	1.1	11	15.9	0
May	1	Init	0.27	1.24	12.4	10.1	2.4
May	2	Init	0.27	1.39	13.9	5.6	8.4
May	3	Init	0.27	1.61	17.7	3.8	13.9
Jun	1	Init	0.27	1.86	18.6	0.8	17.7
Jun	2	Init	0.27	2.09	20.9	0	20.9
Jun	3	Init	0.27	2.11	21.1	0.3	20.9
Jul	1	Init	0.27	2.13	21.3	1.7	19.7
Jul	2	Init	0.27	2.18	21.8	2.3	19.5
Jul	3	Init	0.27	2.08	22.9	1.9	21
Aug	1	Init	0.27	1.97	19.7	1.3	18.4
Aug	2	Init	0.27	1.87	18.7	0.9	17.8

Table 5.23: Conteniou

Aug	3	Deve	0.27	1.73	19.1	0.9	18.2
Sep	1	Deve	0.32	1.85	18.5	0.7	17.8
Sep	2	Deve	0.39	1.98	19.8	0.6	19.2
Sep	3	Deve	0.45	2.08	20.8	0.8	20
Oct	1	Deve	0.51	2.11	21.1	1	20.1
Oct	2	Mid	0.57	2.07	20.7	1.1	19.6
Oct	3	Mid	0.58	1.81	19.9	2	18
Nov	1	Mid	0.58	1.51	15.1	2.7	12.4
Nov	2	Mid	0.58	1.2	12	3.4	8.7
Nov	3	Mid	0.58	0.98	9.8	4.9	4.9
Dec	1	Mid	0.58	0.71	7.1	6.7	0.4
Dec	2	Mid	0.58	0.47	4.7	8.2	0
Dec	3	Mid	0.58	0.45	5	9	0
Jan	1	Mid	0.58	0.46	4.6	9.5	0
Jan	2	Mid	0.58	0.43	4.3	10.3	0
Jan	3	Mid	0.58	0.48	5.3	12.4	0
Feb	1	Mid	0.58	0.54	5.4	14.6	0
Feb	2	Late	0.58	0.59	5.9	16.5	0
Feb	3	Late	0.57	0.8	6.4	18.2	0
Mar	1	Late	0.54	0.97	9.7	20.5	0
Mar	2	Late	0.52	1.12	11.2	22.5	0
Mar	3	Late	0.49	1.28	14.1	21.4	0
					498.3	**273.7**	**339.8**

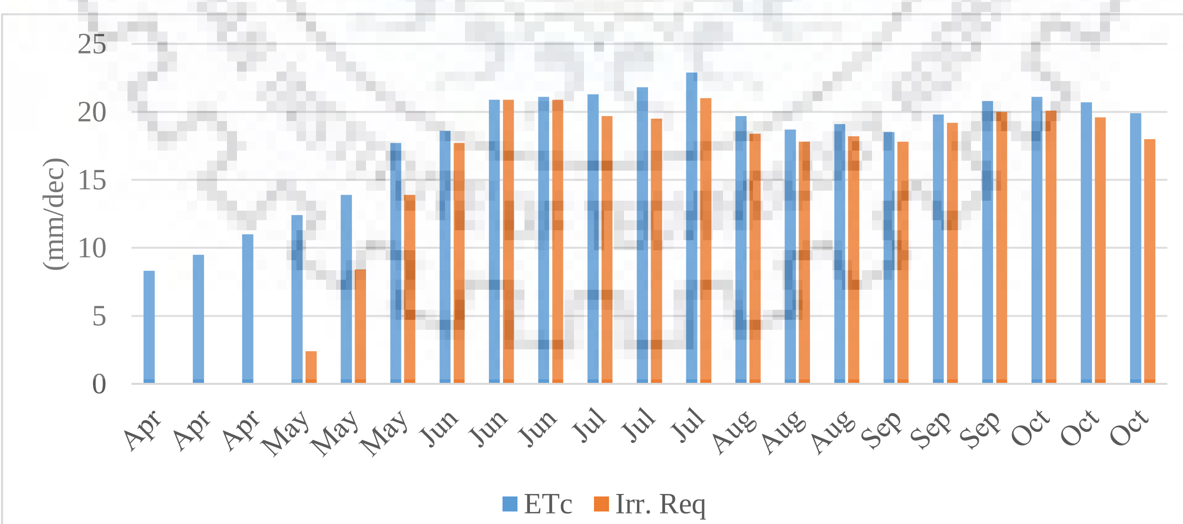


Figure 5.34: Water req. and irrigation req. for the grapes crop (mm/dec)

Table 5.24: Irrigation schedule for grapes crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
29-Jun	90	Init	0	1	100	36	85.7	0	122.4	0.16
12-Aug	134	Init	0	1	100	35	84.4	0	120.5	0.32
28-Sep	181	Dev	0	1	100	36	85.6	0	122.3	0.3
22-Nov	236	Mid	0	1	100	35	84.8	0	121.1	0.25
31-Mar	End	End	0	1	0	2				

Totals:

Total gross irrigation	486.4	mm	Total rainfall	297.3	mm
Total net irrigation	340.5	mm	Effective rainfall	151.5	mm
Total irrigation losses	0.0	mm	Total rain loss	145.8	mm
Actual water use by crop	497.1	mm	Moist deficit at harvest	5.1	mm
Potential water use by crop	497.1	mm	Actual irrigation req.	345.6	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	51.0	%
Deficiency irrigation schedule	0.0	%			

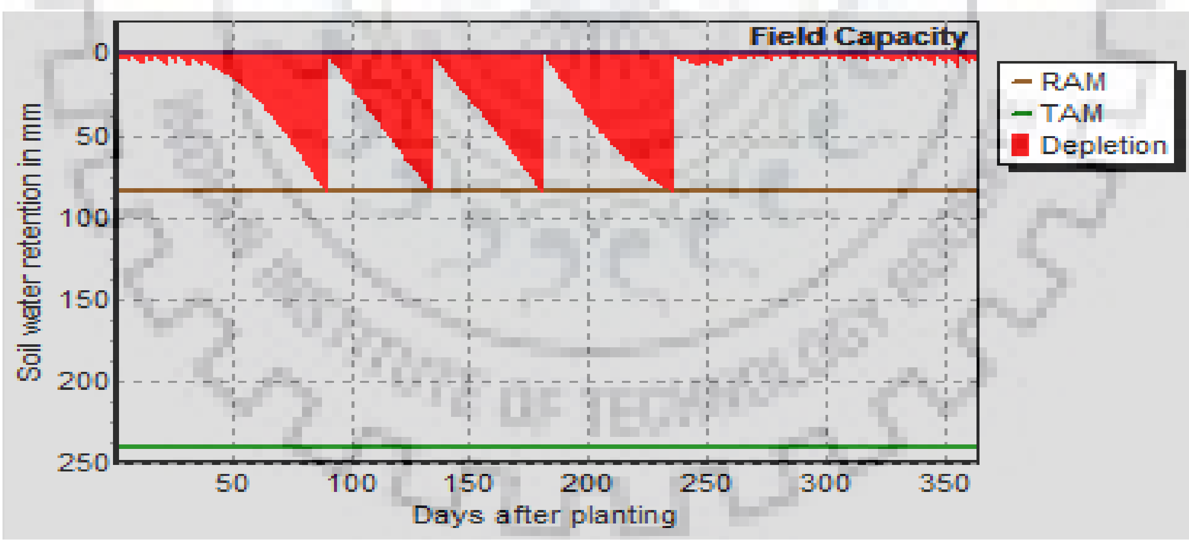


Figure 5.35: Irrigation schedule graph for grapes

5.11.4. Fodder Crops

The important summer season fodders are clover and alfalfa. Some fodder crop like alfalfa grown as a perennial crop. The objective in the irrigation of fodder crops generally is optimum vegetative growth of a certain quality. Since seed production is not generally the objective, the timing of irrigation with respect to grain yields does not apply. For example, in maize grain yield is not appreciably affected by early season stress (prior to bloom) if there is on severe wilting. Such stress will have a marked effect on vegetative growth and fodder yield.

Alfalfa under moisture stress. As a general rule, optimum forage production is possible only with a continuous high moisture level. A safe rule to follow is to irrigate so as to keep the available soil moisture level above 50 percent at all times.

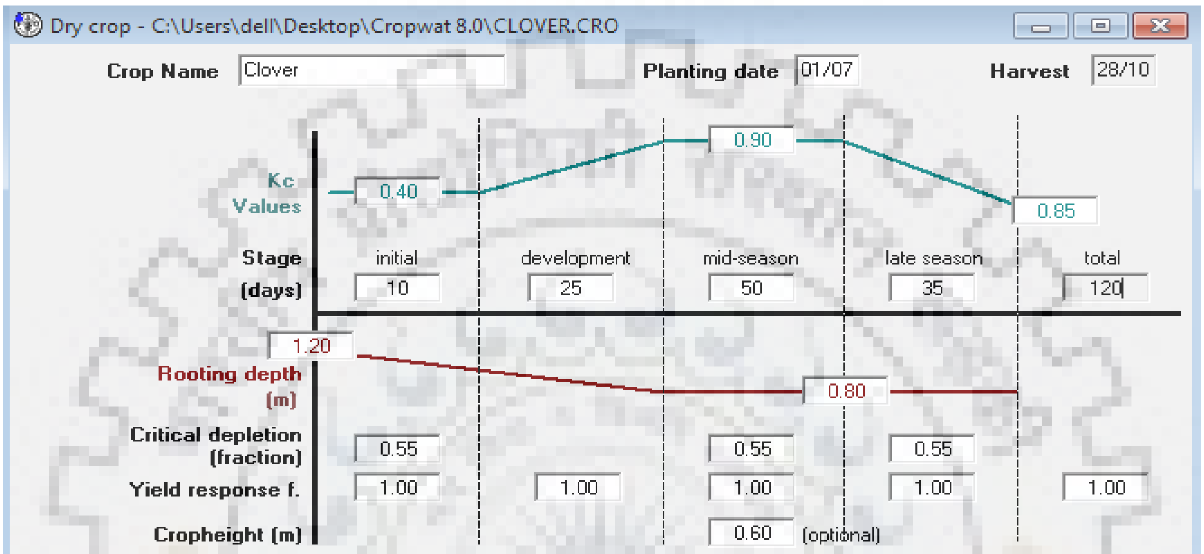


Figure 5.36: The crop coefficients of clover at different growth stages.

Table 5.25: Estimation of water requirement and irrigation requirement for clover crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	0.4	3.16	31.6	1.7	30
Jul	2	Deve	0.52	4.2	42	2.3	39.7
Jul	3	Deve	0.75	5.77	63.4	1.9	61.5
Aug	1	Mid	0.93	6.79	67.9	1.3	66.6
Aug	2	Mid	0.94	6.55	65.5	0.9	64.6
Aug	3	Mid	0.94	5.99	65.9	0.9	65
Sep	1	Mid	0.94	5.42	54.2	0.7	53.5
Sep	2	Mid	0.94	4.86	48.6	0.6	48
Sep	3	Late	0.94	4.37	43.7	0.8	42.8
Oct	1	Late	0.92	3.83	38.3	1	37.3
Oct	2	Late	0.91	3.31	33.1	1.1	32
Oct	3	Late	0.89	2.79	22.3	1.4	20.3
					576.5	**14.6**	**561.4**

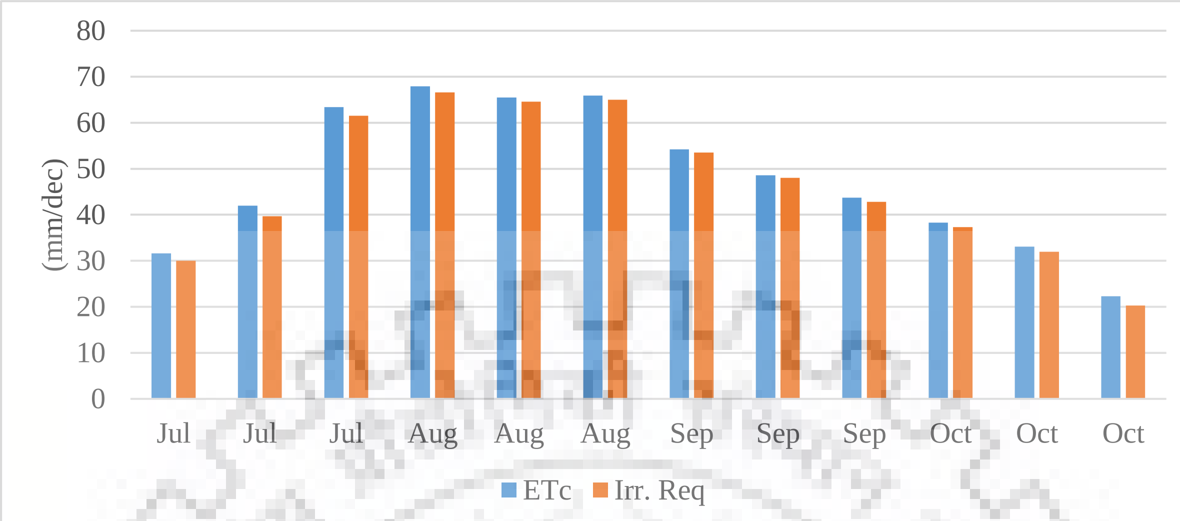


Figure 5.37: Water req. and irrigation req. for clover crop (mm/dec)

Table 5.26: Irrigation schedule for clover crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
23-Jul	23	Dev	0.9	1	100	57	86	0	122.8	0.62
4-Aug	35	Dev	0	1	100	56	71.7	0	102.4	0.99
15-Aug	46	Mid	0	1	100	57	72.4	0	103.4	1.09
27-Aug	58	Mid	0.4	1	100	57	73.4	0	104.8	1.01
9-Sep	71	Mid	0	1	100	56	72.1	0	102.9	0.92
24-Sep	86	End	0	1	100	55	70.5	0	100.7	0.78
13-Oct	105	End	0.6	1	100	57	72.5	0	103.5	0.63
28-Oct	End	End	0	1	0	31				

Total:

Total gross irrigation	740.5	mm	Total rainfall	15.2	mm
Total net irrigation	518.4	mm	Effective rainfall	14.6	mm
Total irrigation losses	0.0	mm	Total rain loss	0.6	mm
Actual water use by crop	573.7	mm	Moist deficit at harvest	40.6	mm
Potential water use by crop	573.7	mm	Actual irrigation req.	559.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	100.0	%
Deficiency irrigation schedule	0.0	%			

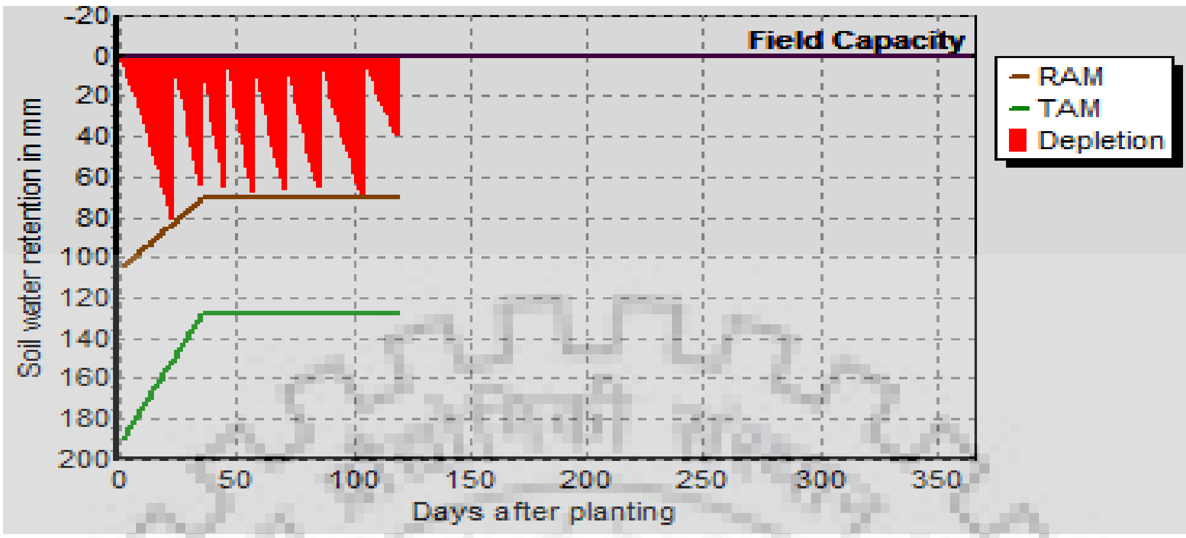


Figure 5.38: Irrigation schedule graph for clover crop

5.11.4.2. Alfalfa (Lucerne) Crop

Alfalfa is an important fodder crop of high nutritive value, and also important fodder crop of the spring season. It is a perennial crop planted from seed and reaches its maturity in the first year. The highest yields are obtained in the second year of growth. It is a legume which grows well on a variety of well-drained soils with pH values above 7. Alfalfa is moderately sensitive to soil salinity. When properly inoculated it develops nitrogen-fixing bacteria in the root nodes. It is a dense crop grown in closely spaced rows. It is cut for fodder several times during each growing season and may remain productive for 3 to 7 years or more. Alfalfa is also grown as a short season annual crop. An important feature of the crop from the point of view of irrigation is the well-developed tap root system. The taproot penetrates up to 4m in deep soils.

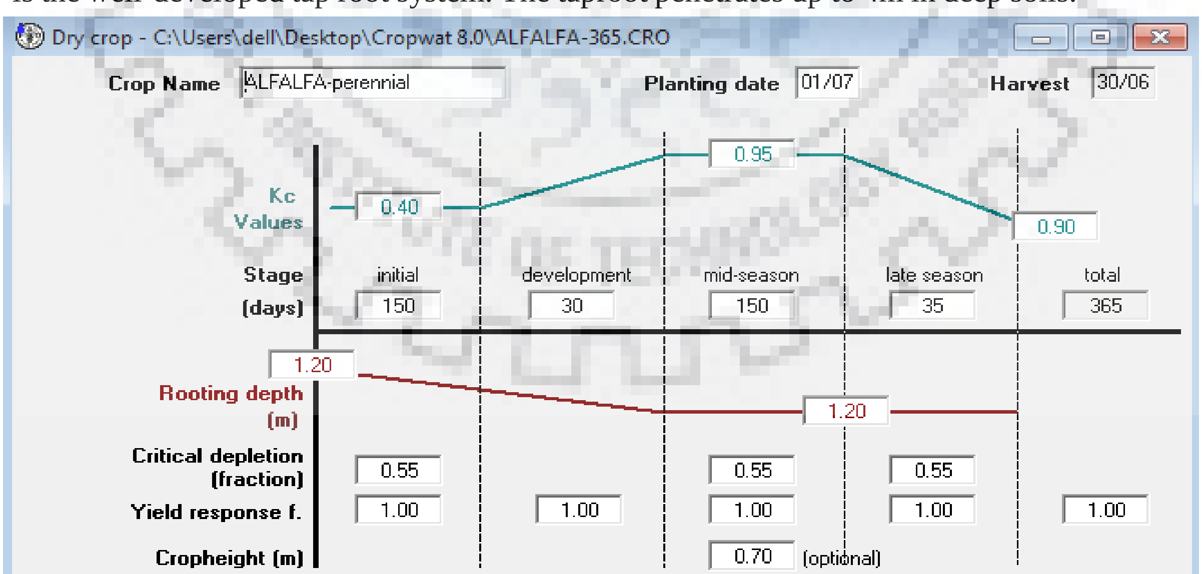


Figure 5.39: The crop coefficients of alfalfa at different growth stages.

To promote growth, irrigation is and normally applied just after each cutting. Adequate soil moisture is maintained in the root zone throughout the growing period by irrigation when the rainfall is inadequate. However, excess irrigation may cause reduced soil aeration which is harmful to the crop. Figure (5.39) in the above depicts the crop stages of alfalfa.

Table 5.27: Estimation of water requirement and irrigation requirement for alfalfa crop

Month	Decade	Stage	Kc	ETc	ETc	Eff. rain	Irr. Req.
			Co-eff.	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	0.4	3.16	31.6	1.7	30
Jul	2	Init	0.4	3.23	32.3	2.3	30
Jul	3	Init	0.4	3.08	33.9	1.9	32
Aug	1	Init	0.4	2.92	29.2	1.3	27.9
Aug	2	Init	0.4	2.78	27.8	0.9	26.8
Aug	3	Init	0.4	2.54	27.9	0.9	27.1
Sep	1	Init	0.4	2.3	23	0.7	22.3
Sep	2	Init	0.4	2.06	20.6	0.6	20
Sep	3	Init	0.4	1.86	18.6	0.8	17.8
Oct	1	Init	0.4	1.66	16.6	1	15.6
Oct	2	Init	0.4	1.46	14.6	1.1	13.5
Oct	3	Init	0.4	1.25	13.7	2	11.8
Nov	1	Init	0.4	1.04	10.4	2.7	7.7
Nov	2	Init	0.4	0.83	8.3	3.4	4.9
Nov	3	Deve	0.41	0.69	6.9	4.9	2
Dec	1	Deve	0.56	0.68	6.8	6.7	0.1
Dec	2	Deve	0.74	0.59	5.9	8.2	0
Dec	3	Mid	0.92	0.71	7.9	9	0
Jan	1	Mid	0.95	0.75	7.5	9.5	0
Jan	2	Mid	0.95	0.7	7	10.3	0
Jan	3	Mid	0.95	0.79	8.7	12.4	0
Feb	1	Mid	0.95	0.88	8.8	14.6	0
Feb	2	Mid	0.95	0.97	9.7	16.5	0
Feb	3	Mid	0.95	1.34	10.7	18.2	0
Mar	1	Mid	0.95	1.7	17	20.5	0
Mar	2	Mid	0.95	2.06	20.6	22.5	0
Mar	3	Mid	0.95	2.5	27.4	21.4	6.1
Apr	1	Mid	0.95	2.93	29.3	20.9	8.4
Apr	2	Mid	0.95	3.36	33.6	20.6	13
Apr	3	Mid	0.95	3.87	38.7	15.9	22.8
May	1	Mid	0.95	4.38	43.8	10.1	33.8
May	2	Mid	0.95	4.9	49	5.6	43.4
May	3	Late	0.96	5.73	63	3.8	59.2
Jun	1	Late	0.98	6.72	67.2	0.8	66.3
Jun	2	Late	0.98	7.56	75.6	0	75.6
Jun	3	Late	0.98	7.64	76.4	0.3	76.1
					930	**274**	**694.2**

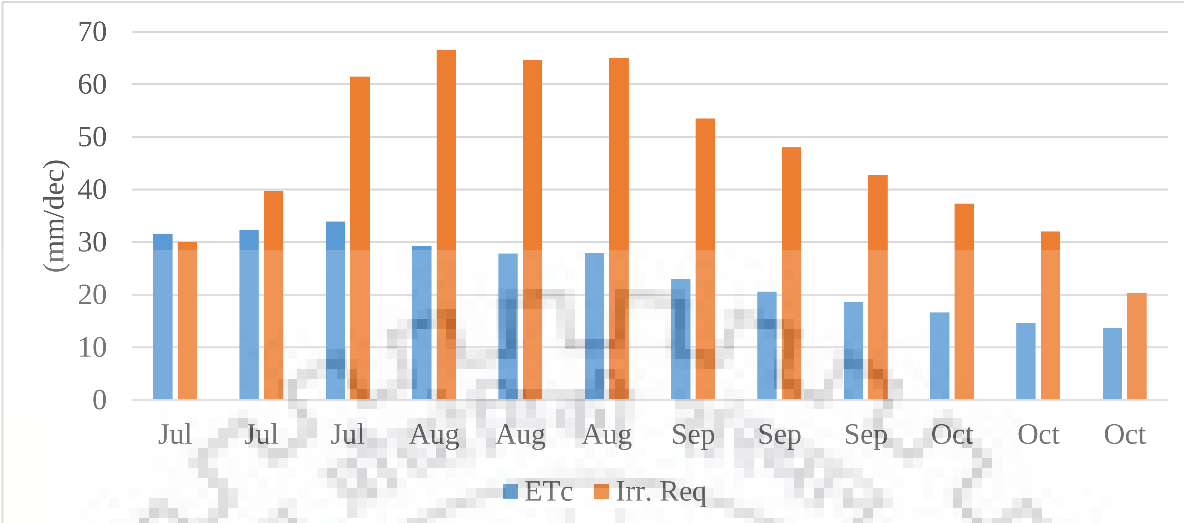


Figure 5.40: Water req. and irrigation req. for alfalfa crop (mm/dec)

Table 5.28: Irrigation schedule for alfalfa crop

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr.	Loss	Gr. Irr.	Flow
			mm	fract.	%	%	mm	mm	mm	l/s/ha
5-Aug	36	Init	0	1	100	55	105.9	0	151.3	0.49
18-Sep	80	Init	0	1	100	55	105.9	0	151.4	0.4
12-May	316	Mid	0	1	100	57	110	0	157.1	0.08
2-Jun	337	End	0	1	100	57	109.1	0	155.8	0.86
17-Jun	352	End	0	1	100	55	106.2	0	151.8	1.17
30-Jun	End	End	0	1	0	47				

Totals:

Total gross irrigation	767.2	mm	Total rainfall	297.3	mm
Total net irrigation	537.1	mm	Effective rainfall	294.1	mm
Total irrigation losses	0.0	mm	Total rain loss	3.2	mm
Actual water use by crop	922.3	mm	Moist deficit at harvest	91.2	mm
Potential water use by crop	922.3	mm	Actual irrigation req.	628.2	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	98.9	%
Deficiency irrigation schedule	0.0	%			

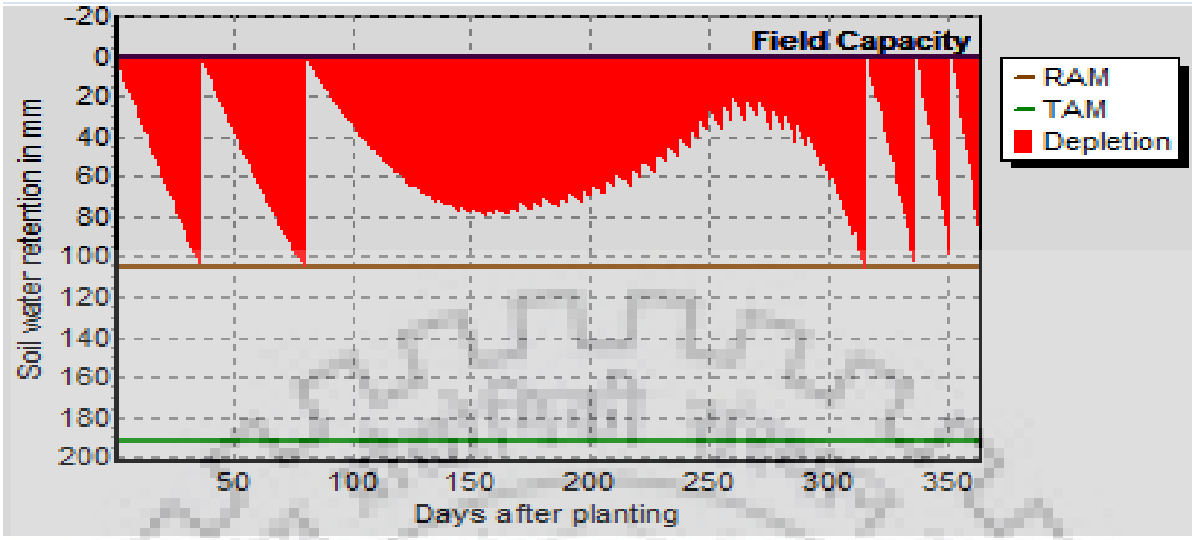


Figure 5.41: Irrigation schedule graph for alfalfa crop

5.12. Scheme Water Requirements

The irrigation supply to any irrigation scheme or canal command area can be calculated by adding up the requirements of each cropped area. Any changes in cropping pattern can be conveniently calculated by modifying the area size of the different crops. Similarly, the irrigation supply for each canal unit can be determined through CROPWAT 8.0.

5.12.1. Input and Output Data for Scheme Water Requirements

Data on climate/ ETo, rainfall, soil, and cropping pattern are required. The scheme module includes calculations, producing:

(i) Irrigation requirement for each crop of the scheme

(ii) The net scheme irrigation requirement

(iii) Irrigated area as a percentage of the total area

(iv) Irrigation requirement for the actual area.

Table 5.29: Estimation of monthly irrigation requirements of an irrigation scheme with deferent cropping patterns.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Winter Wheat	0	0	9.1	67	174.6	143	0	0	0	0	14.4	0
2. Spring Wheat	0	0	0	0	34.7	220.1	296.7	121.7	0	0	0	0
3. Barley	0	0	0	0	34.7	220.1	296.7	118	0	0	0	0
4. Maize (Corn)	0	0	0	0	0	70.2	233	273.3	150.2	8.1	0	0
5. Potato	0	0	19.3	61.9	30.3	0	0	0	0	0	0	0
6. Onion	0	0	0	25.2	157.8	247.7	260.7	172.1	0	0	0	0
7. Tomato	0	0	0	0	78.5	192.8	289.2	253.6	115.6	0	0	0
8. Table grapes	0	0	0	0	24.6	59.5	60.2	54.4	57	57.7	25.9	0.4
9. Clover	0	0	0	0	0	0	132.4	199.6	146.9	92.4	0	0
10. Alfalfa	0	0	6.2	44.6	136.1	205.7	92	81.7	60	40.8	14.6	0.2
Net scheme Irr. req.												
in mm/day	0	0	0.2	1.1	2.8	4.6	4.5	3.2	1	0.2	0.2	0
in mm/month	0	0	5.7	32.3	88	138.7	139.5	98	31	4.9	5.3	0
in l/s/h	0	0	0.02	0.12	0.33	0.53	0.52	0.37	0.12	0.02	0.02	0
Irrigated area	0	0	46	56	87	83	55	55	25	17	34	4
(% of total area)												
Irr. req. for actual area	0	0	0.05	0.22	0.38	0.64	0.95	0.67	0.48	0.11	0.06	0
(l/s/h)												

RESULTS

I. Generation of Various Thematic Maps

All maps are generated for Chahar Asyab district (study area) with the help of ArcGIS and RS techniques.

For generating the Land use/land cover map, the Landsat-8 image was used to show different features like water bodies, an agricultural area, residential area, and barren land.

For generating the soil map, data used from USDA global soil data and it is classified with various type of soil. This map shows three types of soil for Chahar Asyab district.

For generating the slope map, the SRTM image used, it is clearly seen on the map that the overall slope of the area varied from 0% to more than 40% land slope and maximum area is flat in nature.

For generating the rainfall map, the annual average rainfall data used form 8 stations, it is clearly observed that the rainfall is varied from 380.12 to 322.92 mm.

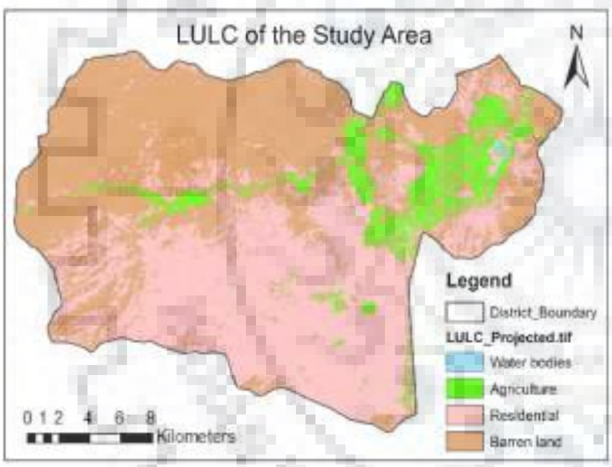


Figure i: LULC Map of the study area

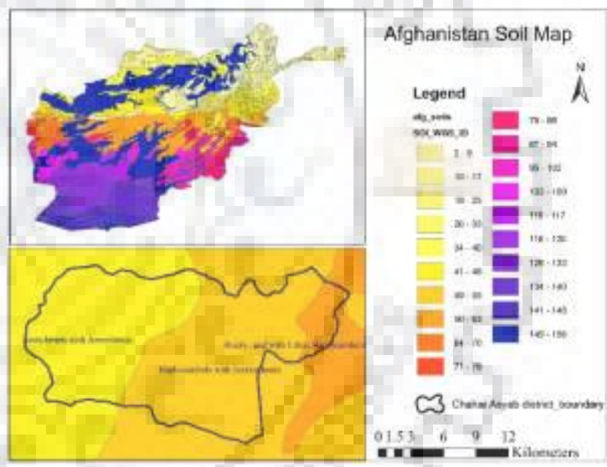


Figure ii: Soil Map of the study area

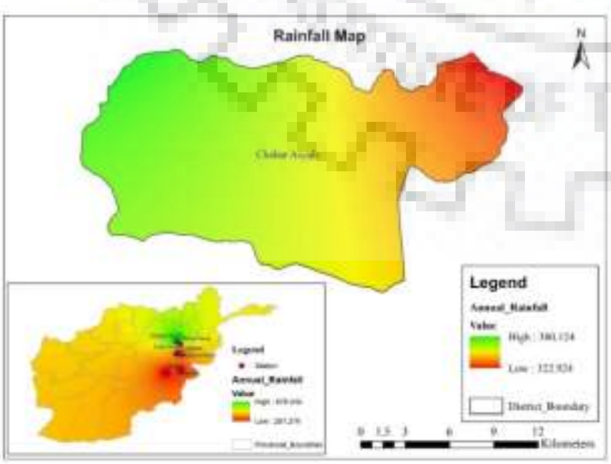


Figure iii: Rainfall Map of the study area

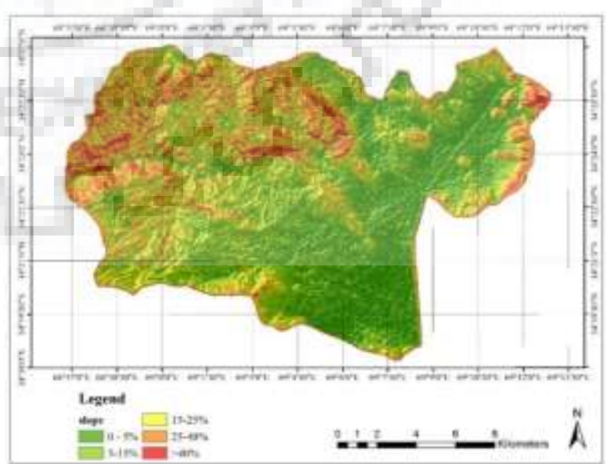


Figure iv: Slope Map of the study area

Generating the flow accumulation map to calculates the cumulative number of upstream units of cells that flow into each lower tilt unit in the output raster. High-flow accumulations of cells are located in drains rather than on hillsides or ridges.

For generating the watershed map, the topographic maps and digital elevation models (DEM) used to divide the basin area. And show water common exit point in the study area to find out the water discharged for a selected area.

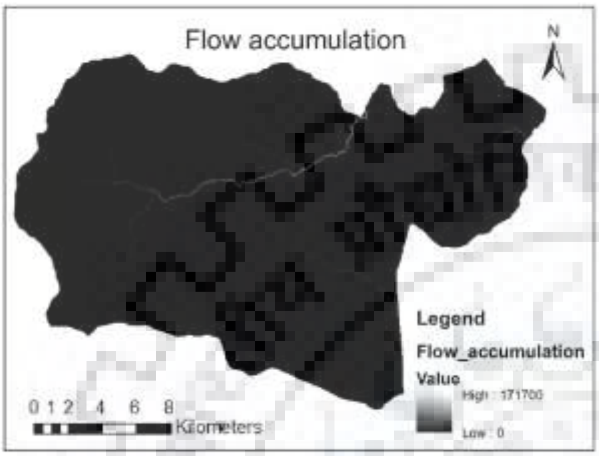


Figure v: Flow Accu. Map of the study area

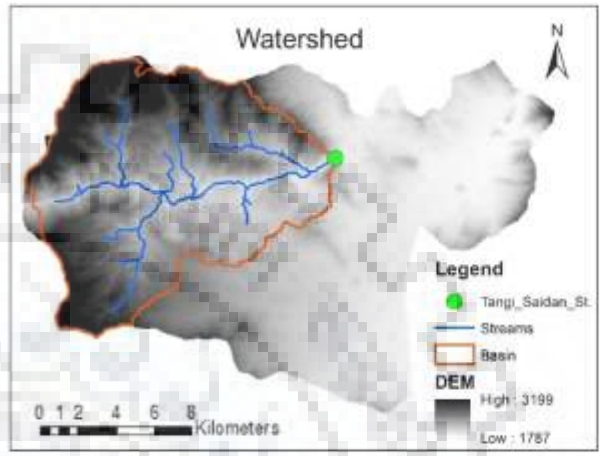


Figure vi: Watershed Map of the study area

II. Reference Evapotranspiration (ETo)

The reference evapotranspiration of the Chahar Asyab district is calculated by using the Penman-Monteith method and it is shown in the figure vii.

Monthly ETo Penman-Monteith - C:\Users\dell\Desktop\Evapotranspiration.pem

Country: Afghanistan   Station: KABUL-AIRPORT

Altitude: 1791 m.   Latitude: 34.55 °N   Longitude: 69.21 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	-7.1	4.5	93	86	4.7	9.0	0.73
February	-5.7	5.5	86	86	5.6	11.9	1.02
March	0.7	12.5	61	173	5.2	14.0	2.17
April	6.0	19.2	50	173	6.3	17.8	3.53
May	8.8	24.4	52	259	8.9	22.9	5.15
June	12.4	30.2	38	346	10.8	26.1	7.54
July	15.3	32.1	36	346	10.5	25.3	7.99
August	14.3	32.0	38	259	10.4	23.9	6.94
September	9.4	28.5	32	173	9.3	20.0	5.15
October	3.9	22.4	39	173	8.6	16.0	3.64
November	-1.2	15.0	59	173	7.3	11.9	2.07
December	-4.7	8.3	86	86	5.5	9.1	0.90
Average	**4.3**	**19.6**	**56**	**194**	**7.8**	**17.3**	**3.90**

Figure vii: ETo of the Chahar Asyab district

It is observed that from the above figure vii, the reference evapotranspiration (ETo) was high in the month of July 7.99 mm/day and which is due to high temperature (average high temperature for the month July is 32.1°C) and minimum humidity (36% of the average for the month of July). And also the minimum ETo was in the month of November 0.73 mm/day. The annual average reference evapotranspiration (ETo) is 3.90 mm/day.

III. Effective Rainfall (Pe)

The effective rainfall is the rainfall ultimately used to determine the crop irrigation requirements and to determine the effective rainfall used the average rainfall data from 2008 to 2017. In this case, "effective rainfall" has been computed using the United States Department of Agriculture Soil Conservation (USDA SC) method with the help of CROPWAT 8.0 model. It is observed that from the flowing figure the effective rainfall was high in the month of March 64.5mm and which is due to high rainfall. And also the minimum effective rainfall was in the month of June 1mm. The annual effective rainfall is 273.5mm.

Monthly rain - C:\Users\dell\Desktop\Eff. rainfall.crm

Station KABUL-AIRPORT Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	34.0	32.2
February	54.0	49.3
March	73.0	64.5
April	64.0	57.4
May	20.0	19.4
June	1.0	1.0
July	6.0	5.9
August	3.0	3.0
September	2.0	2.0
October	4.0	4.0
November	11.0	10.8
December	25.0	24.0
Total	297.0	273.5

Figure ix: Effective rainfall in the Chahar Asyab district

IV. Irrigation Water Requirement (IWR)

It is defined as the amount of irrigation water that is required to meet the evapotranspiration needs of a crop during its full growth. However, if during the growth period of a crop, rain occurs, a part of it will be retained by the soil in the root zone and then some will be available to meet a part of the evapotranspiration requirements of the crop and hence the quantity of irrigation water required to be applied will be correspondingly reduced. Thus, if ETc (ETc= ETo x Kc) is the actual evapotranspiration or consumptive use of water for a crop and Pe is the effective rainfall during the growth period of the crop then, **IWR =ETc- Pe**

Crop Water Requirements

ETo station: KABUL-AIRPORT | Crop: Winter Wheat
Rain station: KABUL-AIRPORT | Planting date: 01/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.40	1.04	10.4	2.7	7.7
Nov	2	Init	0.40	0.83	8.3	3.4	4.9
Nov	3	Init	0.40	0.67	6.7	4.9	1.8
Dec	1	Deve	0.43	0.53	5.3	6.7	0.0
Dec	2	Deve	0.49	0.39	3.9	8.2	0.0
Dec	3	Deve	0.55	0.43	4.7	9.0	0.0
Jan	1	Deve	0.61	0.48	4.8	9.5	0.0
Jan	2	Deve	0.66	0.49	4.9	10.3	0.0
Jan	3	Deve	0.72	0.60	6.6	12.4	0.0
Feb	1	Deve	0.78	0.72	7.2	14.6	0.0
Feb	2	Deve	0.84	0.86	8.6	16.5	0.0
Feb	3	Deve	0.89	1.25	10.0	18.2	0.0
Mar	1	Deve	0.94	1.68	16.8	20.5	0.0
Mar	2	Deve	1.00	2.16	21.6	22.5	0.0
Mar	3	Deve	1.05	2.77	30.4	21.4	9.0
Apr	1	Deve	1.11	3.43	34.3	20.9	13.4
Apr	2	Mid	1.17	4.13	41.3	20.6	20.7
Apr	3	Mid	1.19	4.84	48.4	15.9	32.5
May	1	Mid	1.19	5.49	54.9	10.1	44.8
May	2	Mid	1.19	6.13	61.3	5.6	55.7
May	3	Late	1.18	7.03	77.3	3.8	73.5
Jun	1	Late	0.97	6.65	66.5	0.8	65.7
Jun	2	Late	0.67	5.19	51.9	0.0	51.9
Jun	3	Late	0.40	3.16	25.3	0.2	25.0
					611.3	258.5	406.7

Figure x: CWR and IWR for Winter Wheat

Table i: Estimation of irrigation water requirements for all cropping pattern

Crop	Monthly IWR (mm/month)												Total IWR
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(mm/year)
W-Wheat	0	0	9.1	67	175	143	0	0	0	0	14.4	0	406.7
S-Wheat	0	0	0	0	34.7	220	297	122	0	0	0	0	673.2
Barley	0	0	0	0	34.7	220	297	118	0	0	0	0	669.5
Maize	0	0	0	0	0	70.2	233	273	150	8.1	0	0	734.8
Potato	0	0	19.3	61.9	30.3	0	0	0	0	0	0	0	111.5
Onion	0	0	0	25.2	158	248	261	172	0	0	0	0	863.5
Tomato	0	0	0	0	78.5	193	289	254	116	0	0	0	929.7
Grape	0	0	0	0	24.6	59.5	60.2	54.4	57	57.7	25.9	0.4	339.7
Clover	0	0	0	0	0	0	132	200	147	92.4	0	0	571.3
Alfalfa	0	0	6.2	44.6	136	206	92	81.7	60	40.8	14.6	0.2	681.9
Total	**0**	**0**	**34.6**	**199**	**671**	**1359**	**1661**	**1274**	**530**	**199**	**54.9**	**0.6**	**5983.2**

From the (Table i), it can observe that the monthly IWR for different crops are shown and the maximum irrigation was required in the months of June and July (1359 mm and 1661 mm of water) for all crops grown and which is minimum in the months of January, February, and December because the is only a few crops were irrigated like winter-wheat, potato, grapes, and alfalfa- perennial.

Figure i, showing the result of total IWR from the plating to harvesting and also showing that tomato was the highest water-consuming crop with 929.7 mm, and potato is the lowest water-consuming crop with 111.5 mm in the study area.

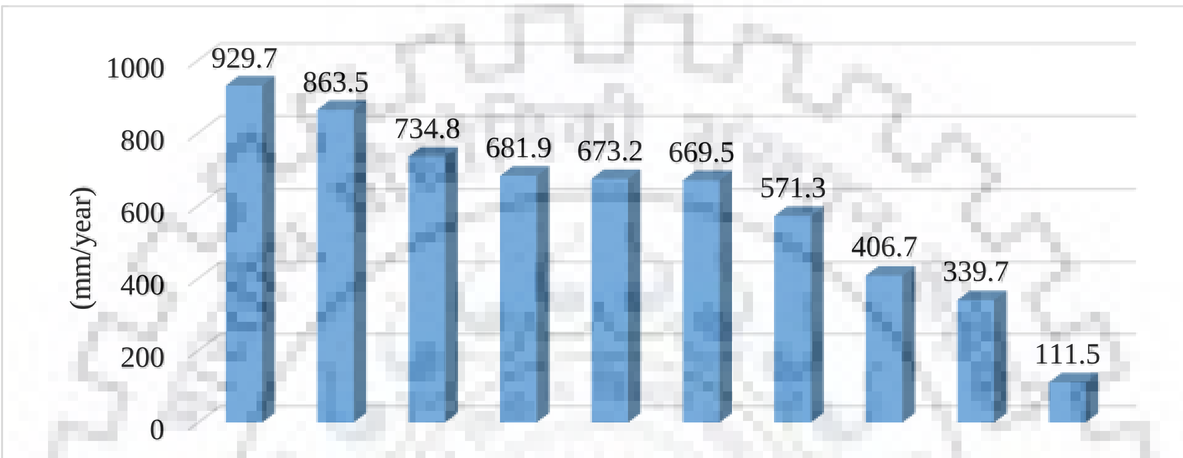


Figure vi: Irrigation water requirement in Chahar Asyab district.

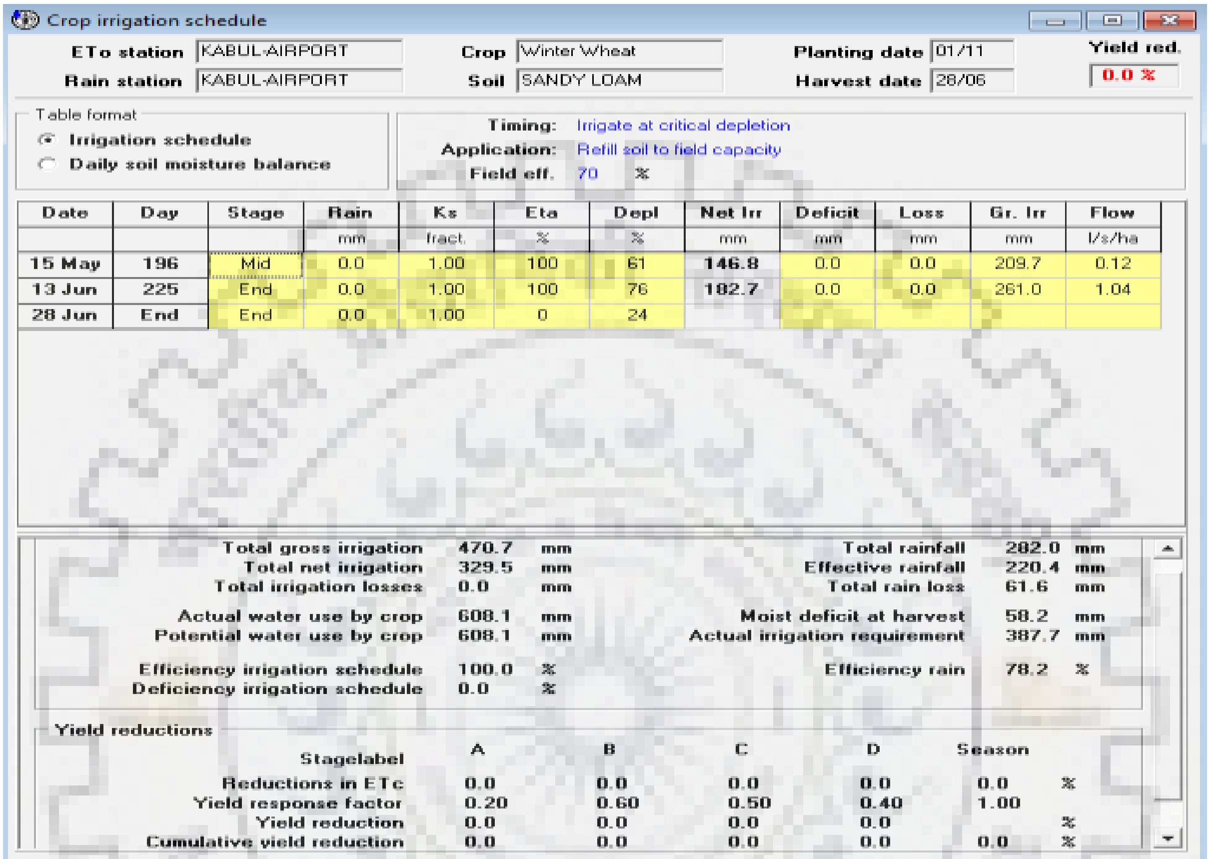
Table ii: Estimation of irrigation water requirements for all crops in the Chahar Asyab district.

No.	Crop	Irrigated Area (Ha)	IWR (mm/year)	IWR for Actual Area (MCM/year)
1	W-Wheat	1,500	406.7	6.10
2	S-Wheat	500	673.2	3.37
3	Barley	500	669.5	3.35
4	Maize	550	734.8	4.04
5	Potato	750	111.5	0.84
6	Onion	500	863.5	4.32
7	Tomato	400	929.7	3.72
8	Grapes	150	339.7	0.51
9	Clover	100	571.3	0.57
10	Alfalfa	50	681.9	0.34
Total		**5,000**	**5983.2**	**27.15**

The above table showing the IWR for actual area with ten major crops during the study period (2017) was estimated as 27.15 MCM/year (0.86 m^3/sec).

V. Irrigation Scheduling

A calculation of irrigation scheduling with the help of CROPWAT 8.0 model on the basis of input data from the study area (Climatic data, rainfall, crops, and soil data).


Crop irrigation schedule

ETo station KABUL-AIRPORT | Crop Winter Wheat | Planting date 01/11 | Yield red.
Rain station KABUL-AIRPORT | Soil SANDY LOAM | Harvest date 28/06 | 0.0 %

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
15 May	196	Mid	0.0	1.00	100	61	146.8	0.0	0.0	209.7	0.12
13 Jun	225	End	0.0	1.00	100	76	182.7	0.0	0.0	261.0	1.04
28 Jun	End	End	0.0	1.00	0	24					

Total gross irrigation	470.7	mm	Total rainfall	282.0	mm
Total net irrigation	329.5	mm	Effective rainfall	220.4	mm
Total irrigation losses	0.0	mm	Total rain loss	61.6	mm
Actual water use by crop	608.1	mm	Moist deficit at harvest	58.2	mm
Potential water use by crop	608.1	mm	Actual irrigation requirement	387.7	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	78.2	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.20	0.60	0.50	0.40	1.00	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

Figure xii: Irrigation Schedule for Winter Wheat

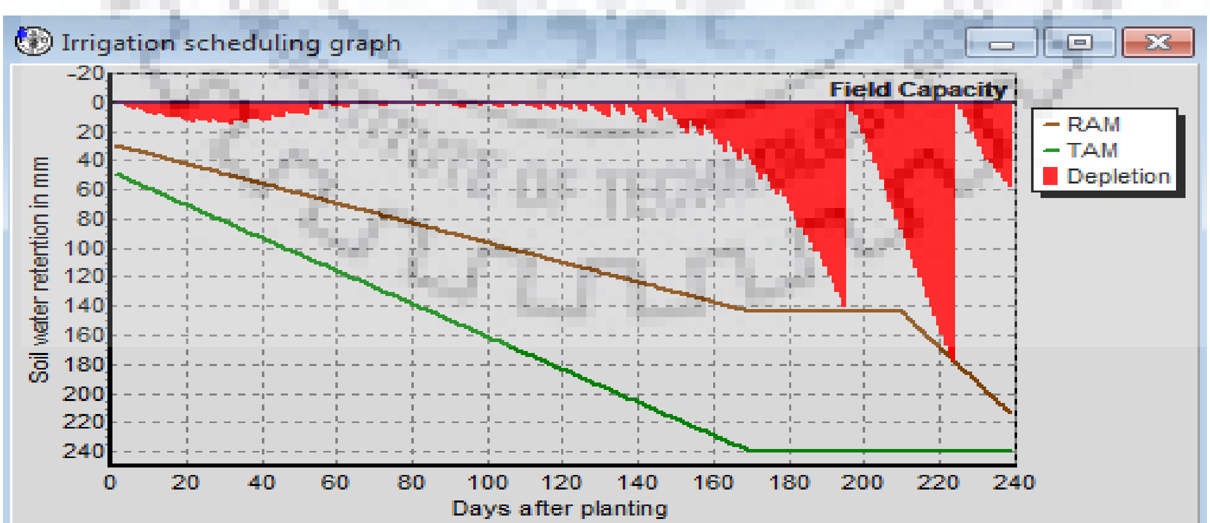


Figure xiii: Irrigation scheduling graph for Winter Wheat

The irrigation scheduling is done by taking the net irrigation water requirement for all crops with irrigation scheduling graph in sandy loam soil from the study area. CROPWAT takes field irrigation efficiency 70% as its default value to calculate gross irrigation water. Which this percentage also matches with the study area.

Table iii: Development of irrigation scheduling for cropping pattern in Chahar Asyab district.

Crop	ETc	Rain	Rain Loss	Eff. Rain	Gr. Irr.	Irr. Eff.	Net Irr.	MDH	A. Irr. Req.	Flow
	(mm)	(mm)	(mm)	(mm)	(mm)	(%)	(mm)	(mm)	(mm)	(l/s/h)
W-Wheat	608.1	282.0	61.6	220.4	470.7	70	329.5	58.2	387.7	1.2
S-Wheat	716.3	58.4	15.5	42.9	835.0	70	584.5	88.9	673.4	7.8
Barley	713.0	58.4	15.5	42.9	877.6	70	614.3	55.7	670.1	7.7
Maize	731.1	12.8	12.0	0.8	989.1	70	692.4	26.8	730.3	9.1
Potato	267.6	235.6	64.4	171.2	107.3	70	75.1	21.3	96.4	0.4
Onion	945.1	94.2	10.9	83.3	1224	70	856.6	5.2	861.8	24.4
Tomato	947.7	31.5	3.2	28.3	1224	70	856.6	62.7	919.4	18.0
Grapes	497.1	297.3	145.8	151.5	486.4	70	340.5	5.1	345.6	1.0
Clover	573.7	15.2	0.6	14.6	740.5	70	518.4	40.6	559.1	6.0
Alfalfa	922.3	297.3	3.2	294.1	767.2	70	537.0	91.2	628.2	3.0
Total	**6922**	**1383**	**333**	**1050**	**7722**		**5405**	**456**	**5872**	**78.5**

Note: ETc (Actual water use by crop), Eff. (Effective), Gr. Irr. (Gross irrigation), Net Irr. (Net irrigation), M.D.H. (Moist deficit at harvest), A. Irr. Req. (Actual irrigation requirement).

From the above table, it can observe that the annual actual crop water use (ETc), gross irrigation (Gr. Irr.), net irrigation (Net Irr.), and actual irrigation requirement (A. Irr. Req.) are 6922, 7722, 5405, and 5872 mm, respectively. Also, the moist deficit at harvest estimated to be 58.2, 88.9, 55.7, 26.8, 21.3, 5.2, 62.7, 5.1, 40.6, and 91.2 mm for winter wheat, spring wheat, barley, maize, potato, onion, tomato, grapes, clover, and alfalfa, respectively. On the other hand, the total flow for all crops is 78.5 l/s/ha.

VI. Scheme Water Requirement

Irrigation requirements of irrigation scheme to estimate the monthly irrigation requirements of an irrigation scheme with different cropping patterns with the help of CROPWAT 8.0 model. Scheme water supply for different crops in the Chahar Asyab district are shown in (Table iv).

Table iv: Scheme water requirements for all crops (l/s/h).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net scheme Irr. req.	0	0	0.02	0.12	0.33	0.53	0.52	0.37	0.12	0.02	0.02	0
Irrigated area (%)	0	0	46	56	87	83	55	55	25	17	34	4
Irr. req. for actual area	0	0	0.05	0.22	0.38	0.64	0.95	0.67	0.48	0.11	0.06	0

From the above table, it can observe that the irrigation requirement for actual area shown and the maximum irrigation requirement for actual area was required in the months of June and July (0.64 l/s/h and 0.95 l/s/h) and which is minimum in the months of January, February, and December because the is only a few crops were irrigated like winter-wheat, potato, grape and alfalfa- perennial and also these months include to winter season in Chahar Asyab district.

VII. Available Water for Irrigation

The district has one flowing river, by the name of Maidan River beginning in the western hilly region and draining within Chahar Asyab district. This river jointly with one of the Kabul river tributary by the name of Paghman River in the center of Kabul city after exit from Chahar Asyab district. Total water potential (available and utilizable) of Maidan River is pooled (Table v) for Chahar Asyab district as a whole. Utilizable water resources in Chahar Asyab district are 49.80 m^3/sec. The average monthly river water discharge in (2008-2017), was estimated 49.80 m^3/sec.

Table v: Average monthly river water discharge (m^3/sec).

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2008	0.00	1.26	0.77	2.60	5.14	6.32	8.25	6.01	0.46	0.00	0.00	0.00
2009	0.00	0.00	0.71	2.96	4.48	8.75	19.56	16.52	10.73	0.90	0.00	0.07
2010	0.07	1.14	3.34	2.89	3.24	5.48	23.29	5.58	0.00	0.08	3.11	0.00
2011	0.02	0.10	1.51	1.88	1.72	4.97	14.67	3.74	1.07	0.00	0.00	0.00
2012	0.02	0.31	0.27	0.55	1.22	12.01	34.36	13.60	1.65	0.00	0.00	0.00
2013	0.00	0.53	2.36	2.75	3.23	6.70	25.24	6.10	3.19	0.26	0.08	0.25
2014	0.23	2.29	2.64	2.99	2.98	4.65	15.19	13.35	6.12	0.91	0.37	0.41
2015	0.00	0.18	1.13	2.71	2.86	10.78	24.01	6.67	0.28	0.48	0.37	0.08
2016	0.42	1.79	2.70	2.50	1.87	11.89	28.60	15.25	2.12	0.05	0.55	0.46
2017	0.13	0.75	2.50	2.31	3.40	12.26	13.48	5.07	0.01	0.07	0.03	0.04
Mean	**0.09**	**0.84**	**1.79**	**2.41**	**3.01**	**8.38**	**20.67**	**9.19**	**2.56**	**0.28**	**0.45**	**0.13**

VIII. Assessment of the Irrigation Water Availability for Chahar Asyab District

The results of the scheme water requirements for the given cropping pattern can now be compared with the available water for irrigation from the diversion at the river.

Average monthly discharge of the Maidan River (average over the 2008-2017 period) is shown in the (Table vi) and compared with the estimated irrigation requirement for actual area based on our schematic cropping pattern, and taking into account a 70% efficiency.

Table vi: Irrigation deficit between available water for irrigation and irrigation requirement for the actual area in Chahar Asyab district.

Month	Net Irr. Req.	Gr. Irr. Req.	Irrigated Area	Irr. Req. for Actual Area	Available Water for Irrigation	Irrigation Deficit
	(mm/day)	(mm/day)	(Ha)	(m^3/sec)	(m^3/sec)	(m^3/sec)
Jan	0.00	0.00	0.00	0.00	2.41	2.41
Feb	0.00	0.00	0.00	0.00	3.01	3.01
Mar	0.20	0.29	2300	0.08	8.38	8.30
Apr	1.10	1.57	2800	0.51	20.67	20.16
May	2.80	4.00	4350	2.01	9.19	7.18
Jun	4.60	6.57	4150	3.16	2.56	-0.60
Jul	4.50	6.43	2750	2.05	0.28	-1.77
Aug	3.20	4.57	2750	1.46	0.45	-1.01
Sep	1.00	1.43	1250	0.21	0.13	-0.08
Oct	0.20	0.29	850	0.03	0.09	0.06
Nov	0.20	0.29	1700	0.06	0.84	0.78
Dec	0.00	0.00	200	0.00	1.79	1.79
Total				**9.55**	**49.80**	**40.25**

From these analyses, it is revealed that 40.25 m^3/sec of water is more in the Chahar Asyab district during that period. But according to the irrigation requirement for actual area estimated, when compared with irrigation water available for 12 months, it is observed that the first 5 months (January, February, March, April, and May), and 3 months (October, November, and December) end of the year received excess water, but 4 months (June, July, August, and September) in the middle of the year were under deficient water condition.

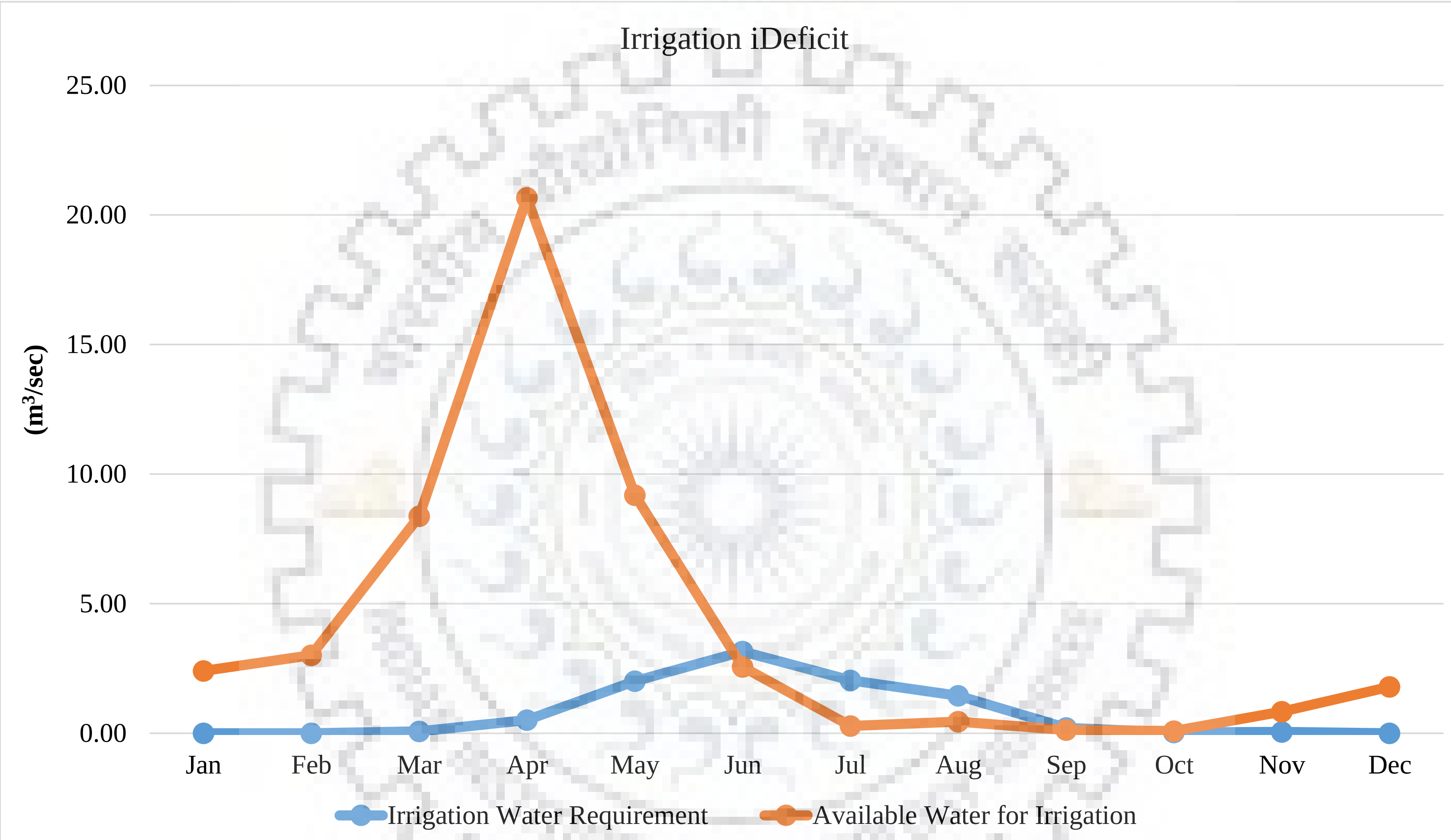


Figure ix: Irrigation deficit between available water for irrigation and irrigation water requirements in Chahar Asyab district.

CONCLUSIONS AND RECOMMENDATIONS

The study provides a summary of the assessment of irrigation water utilization for Chahar Asyab district of Kabul, Afghanistan based on available agriculture and irrigation data. Due to incomplete coverage and data quality issues, the primary focus of the assessment is based on collected data from 2008-2017.

Generation of various thematic maps of the study area namely, watershed, land use/land cover, soil, slope and rainfall were prepared using remote sensing and GIS techniques. All the required input datasets of SRTM and satellite imageries were obtained from USGS site. Also some addition meteorological data used in the study was taken from a station near to the study area.

All the thematic maps and scheme water requirements are integrated for the generation of an action plan, which is optimally suitable to the terrain and to the development of local resources so that the level of production is sustained without decline over time. Various water resources development and management techniques, soil and water conservation measures and optimal cropping patterns are suggested for the overall sustainable economic development of the watershed.

Based on the integration of all the thematic maps, an action plan map for water resources development showing suitable sites for construction of recharge and storage structures like check dams is generated. This provides augmented recharge and storage for water supply during the deficit of water at the irrigation season.

In this study, the climatic data such as maximum, minimum temperatures, relative humidity, wind speed, sunshine hours have been taken from the FAO CLIMWAT 2.0 model. These climatic data are collected from the meteorological station namely Kabul airport (34.55 N, 69.21E), and amount of water available for irrigation has been taken from the Ministry of Energy and Water (MoEW). It was collected from Tangi Saidan hydrological station.

The CROPWAT 8.0 model was used to calculate the annual reference evapotranspiration (ETo) and effective rainfall (Pe) in Chahar Asyab district, which are 1430 mm, and 273.5 mm, respectively. On the other hand, results from CROPWAT model show that the total annual irrigation requirements for actual area of the cropping patterns are 5983.2 mm (27.15 MCM/year), and the peak irrigation requirements occurred during the months of June, July, and August which are 1359, 1661, and 1274 mm respectively.

It can be observed from CROPWAT model that the annual actual crop water use (ETc), gross irrigation (Gr. Irr.), net irrigation (Net Irr.), and actual irrigation requirement (A. Irr. Req.) are 6922, 7722, 5405, and 5872 mm, respectively. Also, the moist deficit at harvest estimated to be

458 mm totally for all crops at different times. On the other hand, the total flow for all crops is 78.5 l/s/ha.

Based on the results of irrigation water requirements from CROPWAT model, and available water for irrigation from observed discharge in the hydrological station, it is revealed that 40.25 m^3/sec of water is more in the Chahar Asyab district during that period. But according to the irrigation requirement for actual area estimated 9.55 m^3/sec, when compared with irrigation water available at 12 months, it is observed that the first 5 months (January, February, March, April, and May), and 3 months (October, November, and December) end of the year received excess water, but 4 months (June, July, August, and September) in the middle of the year were under deficient water condition.

REFERENCES

Ahmad, S. R., Ahmad, U. & Masood, A. (2013). "Geo-Spatial techniques in the selection of potential dam site", Pakistan Journal of Science Volume. 65 No. 1.

Asadi, S. S., Vuppala, P., & Reddy, M. A. (2007) "Optimum utilization of water resource for effective irrigation management using remote sensing and GIS – A case study", vol. 6, no. 4, pp. 573–582.

Ashraf, M., & Majeed, A. (2006). "Water Requirements of Major Crops for Different Agro-Climatic Zones of Balochistan", Water Conservation Union (IUCN), Water Program, Balochistan Program Office.

Bithel, S. L., & Smith, S. H. (2011). "The method for estimating crop irrigation volumes for the Tindall Limestone Aquifer, Katherine, water allocation plan", Northern Territory Gov. Australia.

Bos, M. G., Kselik, R. A., Allen, R. G., & Molden, D. (2009). "Water requirements for irrigation and the environment", Springer Science & Business Madia, vol. 9781402089.

Chowdhury, S., Al-Zahrani, M., & Abbas, A. (2016). "Implications of climate change on crop water requirements in arid region: an example of Al-Jouf, Saudi Arabia", Journal of King Saud University-Engineering Sciences 28.1, 21-31.

Comejo, C. (2003) "Use of an evapotranspiration model and a Geographic Information System (GIS) to estimate the irrigation potential of the Trasvase System in the Santa Elena Peninsula, Guayas, Ecuador", PhD. Dissertation, University of Florida.

Gassman, P. W., Reyes, M. R., Green, C., H., & Arnold, J. G. (2007). "The soil and water assessment tool, historical development, applications, and future research directions", Transaction, ASABE, vol. 50, no. 4, pp. 1211–1250.

IIT, Kharagpur, "Lesson-3 Estimating Irrigation Demand", Module-3, Irrigation Engineering Principles, Version 2 CE IITK.

Inam, A. P. P. D. E., Khan, U. P. P. D. H., & Khan, L. S. A. (1998). "An assessment of the crop water demand and irrigation water supply at Pabbi minor of Warsak gravity canal".

Jimenez, G., Paroush, Z. E., & Ish-Horowicz, D. (1997). "Chapter 5: Crop calendar adjustment of irrigation dry crop", Genes and Development, vol. 11, no. 22, pp. 3072–3082.

Knox, J. W., Weatherhead, E. K., & Rodriguez-Disz. J. A. (2008). "Assessing optimum irrigation water use : additional agricultural and non-agricultural sectors". enivormintal agency seince report-SC040008/SR1.

Kumbhar, V., Choudhury, S., Sen A., & Singh, T. P. (2014). "Assessment of irrigation and agriculture potential using Geospatial Techniques : A case study of ' Bhima - Ujjani ' Project", Procedia – Social & Behaviora. Sciences., vol. 157, pp. 277–284.

Kuo, S. F., Lin B. J., & Shieh, H. J. (2001). "CROPWAT model to evaluate crop water requirements in Taiwan", international commission on Irrigation and drainage.

MAIL, 8 July (2012). "Agriculture Prospects Report", Stat. Mark. Inf. Off., pp. 1–32.

Nithya, K. B., & Shivapur, A.V. (2016). "Study on water requirement of selected crops under Tarikere command area using CROPWAT", Irrig. Drain. Syst. Eng. 5, 153, 2.

Qureshi, A. S. (2002). "Water resources management in Afghanistan", the issues and options. Vol. 49. Iwmi.

Rabanizada, E., & Hiroaki, S. (2008) "Estimation of irrigation water requirement in Zohrabi canal command area Khulm watershed, Afghanistan".

Rasooli, A., Kang, D. (2015). "Assessment of potential dam sites in the Kabul river basin using GIS", Int. J. Adv. Comput. Sci. Appl., vol. 6, no. 2, pp. 83–89.

Rees, B., Cessford, F., Connelly, R., Cowan, J., Bowell, R., Weatherhead, E.K., Knox, J.W., Twite, C.L., & Morris, J. (2003). "Optimum use of water for industry and agriculture : Phase 3", R & D Technical Report W6-056/TR2.

Rout, B. (2008). "How the water flows: A typology of irrigation systems in Kabul Afghanistan", Afghanistan research and evaluation unit.

Sarmiento, C. J. S., Ayson, R. J. V., Gonzalez, R. M., & Castro P. P. M. (2010). "Remote sensing and GIS in inflow estimation: the Magat reservoir, Philippines experience", Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch., vol. 38, pp. 227–232.

Shams, H. K. (2016)."Study on effective utilization of irrigation water in Afghanistan study on effective utilization of irrigation water in Afghanistan".

T. U. States and G. Considerations, "Chapter 4: Water Quantity Requirements", Water, no. 11.

United States, Department of Agriculture (1993). "Chapter 2.2-1: Irrigation water requirements", Part 623, National engineering handbook, Agriculture Soil Conservation Service.

USAID, Afghan. (2008). “Kabul Provence Agricultural Profile”, ASAP.

USDA, May (2010). “Afghanistan : Crop Progress Report”, Foreign Agricultural Service.

Yevalla, G. M. S., Seidou, D. N., Ngoc, B. V., Hoi, T. V., & Tabod, T. C. (2018). “Hydrological studies for the Assessment of run-of-river hydropower potential and generation over the Wouri-Nkam river using GIS and Remote Sensing Techniques”, Aquademia: Water, Environment and Technology, vol. 2, no. 1, pp. 1–7.