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Crop Water Requirements and Irrigation Scheduling for Major Crops in Kankai Irrigation System in Eastern Nepal

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Abstract

There is a growing demand of food and fiber in the world due to the increase in population and urbanization. United Nations Sustainable Development Goal 2 also aims to double the agricultural productivity to feed the growing population by 2030. Agriculture is the highest consumer of fresh water resources so there is a need to decrease the consumption, improve irrigation management techniques and determine the water requirement of major crops. In this research paper, Food and Agriculture organization (FAO)CROPWAT 8.0 simulation software is used to find the crop water requirements (CWRs) and Irrigation Schedules for some major crops which are cultivated in the study area. The study area is Kankai Irrigation System (KIS), a major irrigation project in the eastern terai (plain) of Nepal located between the latitudes of 26 to 27 degree North and longitude of 87 to 88 degree East in the district of Jhapa of State Number 1. This research study reveals that crop water requirement and irrigation schedules are specific to the local study area owing to the seasonal and ecological features of the area. It enhances our understanding of the water requirement of some major crops in KIS, which will ultimately help to improve the management of water resources and productivity. Water resource planners can use the result of the study for proper planning and management of water resources in the country.

Key words: Crop Water Requirement, Irrigation Scheduling, command area, crop yield, Kankai Irrigation System

1. Introduction

Agriculture is the largest consumer of the earth's available freshwater and consumes over 70 percent of the global freshwater withdrawals [1]. The sustainability of water resources largely depends on the proper management and efficient utilization of agricultural water [2]. Irrigation is vital in achieving food security and its share in world food production will rise even in the future. However, due to availability of limited fresh water in many parts of the world, the increasing agricultural land will face water scarcity for irrigation [3].

Agriculture is the main sector of water consumer in Nepal and the irrigation system requires modernization and sound management by evaluating the prerequisites of water system accurately [4]. It is important to know the crop water requirement and irrigation scheduling to take care of water demand of crops.

Cropwat 8.0 is a significant software modeling program for the assessment of crop evapotranspiration, CWR and irrigation scheduling. Food and Agriculture organization (FAO) has developed such software as tools to assist irrigation engineer and agronomists to calculate for water irrigation studies in the management and design of irrigation schemes [5]. In the present study, irrigation water requirements and irrigation scheduling of five major crops grown in the command area of KIS were studied using the CROPWAT model.

2. Materials and Methods

2.1 *Area of Study*

The study is conducted for the command area of the Kankai Irrigation System (KIS) situated in the Jhapa district of eastern Nepal, between the latitudes of 26° to 27 ° north and longitude of 87 ° to 88 ° east. The elevation of the system varies from 120 m in North to 75 m in the South. The mean temperature shows a wide range of fluctuation throughout the year with a maximum of 40 °C during summer (June) and a minimum temperature of 5 °C. Relative humidity ranges between 35 to 45% in winter and between 75 to 85% in summer and monsoon season. The command area of the system is surrounded by India in the South, Kankai River in the east, Krishna River in the west, and Main canal in the north and covers a GCA of 7,000 ha and CCA of 6,609 ha [6]

Kankai Irrigation System

catchment area: 1190 KM^2	Command Area: 7000 ha
Designed Discharge: 10.15 cumec	Main Canal Length : 36 km
Secondary Canals : 74km (22nos)	Minor Canals : 130km (354nos) [7]

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Figure 1. Kankai Irrigation System and its location in Nepal

2.2 *Description of CROPWAT Model 8.0*

Cropwat 8.0 is a decision support program developed by FAO to calculate reference evapotranspiration, crop water requirement, irrigation scheduling and irrigation water requirement using hydro-meteorological, agronomy and soil data [8]. This program includes general data for various types of crops, local climate conditions and soil properties and helps to improve irrigation schedules and calculate the water supply scheme for different crop patterns under irrigated and rain-fed conditions [8].

2.3 *Data requirement*

CROPWAT software requires four different types of data. They are rainfall data, climatic data, crop data and soil data [9]. Climatic data for 15 years (2004-2018) were gathered from nearby Chandragadhi Meteorological station (Table 2), obtained from the CLIMWAT 2.0 which is a climatic database to be used in association with the CROPWAT program to calculate the irrigation requirements for different crops [8].

CLIMWAT contains seven monthly climatic parameters including location coordinates and altitudes. They are: minimum and maximum atmospheric temperature (°C), mean relative humidity (%), wind speed (km/hr), amount of rainfall (mm) and sunshine hours (h) [10]. Five major crops grown in the command area of KIS are selected as monsoon rice (summer crop), wheat, maize, potato and vegetables (winter crops) and spring rice (spring crop). The above crop data have been added to the CROPWAT system including rooting depth, crop coefficient, depletion point, yield response factor and plant growth stage duration [10]. Planting dates were taken as per the cropping calendar of KIS [11]

Various soil data obtained from FAO CROPWAT 8.0 model include detailed information about the soil proximity to the meteorological station. The data included are total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion level and initial available soil moisture. In this study, The United States Department of Agriculture (USDA) soil conservation (S C) method is used to find the effective rainfall of the study area. The field soil test in the Kankai area shows that the soil belongs to silty loam type having infiltration capacity of 16mm/hr.

2.4 *Reference Evapotranspiration (RT0)*

The combined effect of removal of water due to the process of evaporation and transpiration from a soil mass is known as Evapotranspiration (ET). Similarly, reference evapotranspiration is the rate of ET from a reference crop with a crop height of 12cm, albedo (0.23) and fixed canopy resistance (70s/m) Penman-Monteith equation was used in the CROPWAT model for the calculation of ET0 [12].

The Penman-Monteith equation is:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \qquad (1)$$

where R_n is the net solar radiation, G is the soil heat flux, $(e_s - e_a)$ is the vapor pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ is the slope of the saturation vapor pressure with temperature, γ is the psychometric constant, and r_s and r_a are the surface and aerodynamic resistances respectively (13).

When the theoretical characteristics of crop and standard height of wind speed (2m) are applied to the above equation, equation (1) is simplified as follows

$$ET_0 = \frac{0.408\Delta\,(R_n - G) + \gamma\frac{900}{T+273}u_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2)$$

where

ET_0 is the reference evapotranspiration in mm/day, T is the mean air temperature in a day in ◦C at a height of 2m, u_2 is the wind speed at a height of 2m in m/sec and e_s and e_a are the saturation and actual vapour pressure in kpa respectively [8].

2.5 *Crop Water Requirement (CWR)*

CWR is defined as the amount of water that is required to meet the evapotranspiration need of the crops for its proper growth. Once ET_0 is known, the water requirement of the crops can be calculated. CWR is derived from crop evapotranspiration (ET_c) which is given by the following equation [14]

$$ET_c = K_c \times ET_0 \qquad (3)$$

where k_c is the crop coefficient which is the ratio of ET observed for the crop considered to that of the referenced crop under the same condition. K_c depends on type of crop, stage of crop growth and plant health (15).

2.6 *Irrigation Water Requirement (IR)*

Irrigation Water Requirement is the amount of water that is to be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the only source of water supply for the crop, the irrigation water requirement will always be greater than the crop water requirement due to the inefficiencies caused by irrigation system. However, If the crop receives some amount of water from other sources (rainfall), then the irrigation water requirement will be less than the crop water requirement.

The CROPWAT Model can compute the water balance of the root zoon on daily basis by the following equation [16].

$D_{r,I} = D_{r,i-1} - (P_i - RO_i) - I_i - CR_i + ET_{ci} + DP_i$ where

$D_{r,I}$ = Root zone depletion at the days end i (mm)

$D_{r,i-1}$ = water content in the root zoon at the previous day's end i (mm)

P_i = Precipitation on day i (mm)

ROi = Surface runoff water on day i in mm

I_i = net depth of irrigation water which infiltrates into the soil in (mm)

C_{ri} = Capillary rise from the ground water table on day i (mm)

ET_{ci} = Crop evapotranspiration on day i (mm) and

DP_i = Water loss of root zone on day i (mm)

2.7 *Irrigation scheduling (IS)*

Irrigation Scheduling is defined as the management techniques of allocating irrigation water based on the individual crop water requirement with an objective to maximize crop production. It determines the correct amount of water to irrigate and the correct time for watering. The CROPWAT model determines the ET_0, CWR and IR for formulating the irrigation schedules under different conditions of administration and water supply (14)

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3. Result and Discussion

The data used into the CROPWAT and CLIMWAT software included the country (Nepal), climate station (Chandragadi), type of crop (monsoon rice, wheat, maize, potato, vegetables and spring rice), date of cultivation (keeping base period as 15 days) and soil type (silty- loam). Once all the data were entered into the software, it calculates the climatic parameters, ET_0, effective rainfall, and total irrigation requirements for the studied crop.

Different outputs of the CROPWAT software are presented below in the form of tables and charts. Table 1 contains data about the different crops grown in the study area. Table 2 contains the climatic characteristics of the study area of Kankai Irrigation System.

Table1: Data of existing Crops grown in the study area

Crop	Date		Critical depletion fraction	Rooting depth (cm)	Crop growth periods (days)					Total Crop Period
	Planting	Harvesting			nursery	initial	development	mid-season	Late-season	days
M Rice	07-Jul	03-Nov	0.2	60	30	20	30	40	30	150
Wheat	06-Dec	14-Apr	0.55	120		30	30	40	30	130
Maize	01-Dec	04-Apr	0.55	100	-	20	35	40	30	125
Potato	07-Nov	16-Mar	0.5	60		25	30	45	30	130
Veg	01-Nov	10-Mar	0.45	60		20	30	30	15	95
S Rice	01-Mar	28-Jun	0.2	60	30	20	30	40	30	150

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Table 2. *Climate characteristics and ET_0 of Chandragadhi, (average for 2004-2018) obtained from CROPWAT software*

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ET_0	Rain	Eff Rain
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	mm	mm
January	10.5	23.4	66	86	7.9	14.6	2.26	6	5.9
February	11.9	26.3	63	104	8.4	17.3	3.02	18	17.5
March	15.9	32	56	121	8.8	20.4	4.38	19	18.4
April	20.2	34.8	37	147	8.8	22.3	5.92	62	55.8
May	23.1	34	67	147	8.1	22.1	5.38	188	131.4
June	25.1	33	77	130	5.3	18.1	4.38	390	164
July	25.3	32.2	82	121	4.2	16.3	3.86	730	198
August	24.9	32.3	84	104	4.6	16.3	3.74	406	165.6
September	24	31.7	86	95	5.7	16.6	3.62	456	170.6
October	21.7	31.4	74	86	7.1	16.3	3.52	111	91.3
November	15.4	29.8	69	78	8.1	15.2	2.93	9	8.9
December	10.9	24.7	76	78	7.8	13.7	2.16	8	7.9
Average	19.1	30.5	70	108	7.1	17.4	3.76	200.25	86.28

3.1 *Estimation of effective rainfall and Reference Evapotranspiration*

Effective rainfall is the part of the total rainfall that replaces corresponding net quantity of required irrigation water after deducting surface runoff and infiltration losses. This quantity of water is effectively used by the crop and is useful to evaluate crop water requirement. The key feature of rainfall is its amount, length and frequency which are spatially and temporarily different. USDA S.C. method is used to estimate the effective rainfall from the average annual rainfall of past 15 years (2004-2018) of the Chandragadhi station. CROPWAT software calculate the crop water requirements and irrigation schedules of the five major crops (8).The results indicate that the average annual rainfall values was 200.25mm and effective rainfall is about 86.28 mm as shown in Table2. Table 3 to 8 shows that 761.2%, 68.3%, 55%, 42.8%, 45.1% and 399% of effective rainfall has been used by monsoon rice, wheat, maize, potato, vegetables and spring rice respectively.

FAO recommends a method called Penman-Monteith method to estimate reference crop evapotranspiration (ET_0) by using radiation, air temperature, humidity and wind speed data. The reference crop is a hypothetical grass crop with an assumed crop height of 0.12m, fixed surface resistance 70sm-1 and an albedo of 0.23. The potential evapotranspiration of any other crop (ETc) is calculated by multiplying the reference crop evapotranspiration by a crop coefficient k_c, the value of which changes with the growth stage of the crop. Thus

$$ET_c = ET_0 (K_c) \qquad (5)$$

The CROPWAT software gives the values of ET_0 for different months as shown in Table 2.The value of ET_0 is high in summer due to the high temperature and highest value was in April (5.92mm/day). Due to low temperature, it decreases in winter and the lowest value was in December (2.16mm/day). The annual average value of ET_0 is 3.76mm/day.

The value of ET_0 is different for different months as shown in Table 2; this is due to the effect of different weather parameters. The high temperature, high wind speed and low relative humidity increase the evapotranspiration rate during the dry seasons (18). Table 4-9 shows that the value of ET_c of different crops increases with the increase of growth stages and start to decrease at the later stages. Similarly, the value of ET_c changes due to the change in crop coefficient value which is different for different growth stages of the crop. The value of ET_c is lower at the initial and last stage whereas it is more in the middle stages for all the existing crops.

3.2 *Crop Water Requirement of five major crops in the study area*

Crop water requirement (CWR) is defined as the depth of water (mm) required to meet the water consumed through evapotranspiration (ET_c) by a disease-free crop, growing in large fields under nonrestricting soil conditions including soil water and fertility. CWR depends upon place to place, climate, type of soil, cultivation methods and effective rainfall. The total water required for crop growth is unequally distributed over the crop life period. In this study, the irrigation water requirements (IRs) for the existing crops are presented in mm/dec are as shown in the Table 3.

Table 3: Irrigation Water Requirement of different crops in the study area

Crop type	Irrigation Water Requirement (mm/dec)
Monsoon Rice	154.1
Wheat	269
Maize	265.2
Potato	277.1
Vegetables	265.1
Spring Rice	626.3

Table 4-9 derived from CROPWAT software shows the effective rainfall and Irrigation Requirement of existing crops in the study area.

Table No 4: Crop Water Requirement (CWR) for monsoon Rice

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Nurs	1.2	0.57	2.3	20.4	0
Jun	2	Nurs/LPr	1.15	2.18	21.8	54.6	35.3
Jun	3	Nurs/LPr	1.06	4.48	44.8	58.4	0
Jul	1	Init	1.08	4.35	43.5	64.3	90
Jul	2	Init	1.1	4.25	42.5	69.1	0
Jul	3	Deve	1.1	4.21	46.3	64.5	0
Aug	1	Deve	1.11	4.19	41.9	57.6	0
Aug	2	Deve	1.11	4.17	41.7	53.5	0
Aug	3	Mid	1.12	4.15	45.6	54.6	0
Sep	1	Mid	1.12	4.1	41	59	0
Sep	2	Mid	1.12	4.06	40.6	60.9	0
Sep	3	Mid	1.12	4.02	40.2	50.7	0
Oct	1	Late	1.11	3.95	39.5	39.3	0.2
Oct	2	Late	1.07	3.77	37.7	30.5	7.2
Oct	3	Late	1.03	3.41	37.5	21.3	16.2
Nov	1	Late	1	3.12	9.3	2.5	5.2
					576.3	761.2	154.1

Table 5: Crop Water Requirement (CWR) for Wheat

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.3	0.73	3.6	1.4	2.3
Dec	2	Init	0.3	0.65	6.5	2.6	3.8
Dec	3	Init	0.3	0.66	7.2	2.4	4.8
Jan	1	Deve	0.36	0.8	8	1.8	6.2
Jan	2	Deve	0.62	1.41	14.1	1.4	12.7
Jan	3	Deve	0.92	2.31	25.4	2.9	22.5
Feb	1	Mid	1.14	3.14	31.4	4.8	26.6
Feb	2	Mid	1.14	3.45	34.5	6.3	28.2
Feb	3	Mid	1.14	3.97	31.8	6.2	25.5
Mar	1	Mid	1.14	4.49	44.9	4.9	40
Mar	2	Late	1.1	4.83	48.3	4.4	43.9
Mar	3	Late	0.83	4.09	44.9	9.2	35.8
Apr	1	Late	0.54	2.99	29.9	13.3	16.6
Apr	2	Late	0.34	2.09	8.4	6.7	0
					339	68.3	269

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Table 6: Crop Water Requirement (CWR) for Maize

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.3	0.73	7.3	2.7	4.5
Dec	2	Init	0.3	0.65	6.5	2.6	3.8
Dec	3	Deve	0.45	0.99	10.9	2.4	8.5
Jan	1	Deve	0.72	1.6	16	1.8	14.2
Jan	2	Deve	0.97	2.19	21.9	1.4	20.6
Jan	3	Mid	1.17	2.94	32.4	2.9	29.5
Feb	1	Mid	1.19	3.28	32.8	4.8	27.9
Feb	2	Mid	1.19	3.58	35.8	6.3	29.5
Feb	3	Mid	1.19	4.12	32.9	6.2	26.7
Mar	1	Late	1.14	4.49	44.9	4.9	40
Mar	2	Late	0.89	3.91	39.1	4.4	34.7
Mar	3	Late	0.6	2.94	32.3	9.2	23.2
Apr	1	Late	0.39	2.17	8.7	5.3	2.1
					321.5	55	265.2

Table 7: Crop Water Requirement (CWR) for Potato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.5	1.56	6.3	3.3	2.1
Nov	2	Init	0.5	1.47	14.7	0	14.7
Nov	3	Init	0.5	1.34	13.4	0.7	12.7
Dec	1	Deve	0.59	1.44	14.4	2.7	11.6
Dec	2	Deve	0.81	1.74	17.4	2.6	14.8
Dec	3	Deve	1.03	2.25	24.8	2.4	22.4
Jan	1	Mid	1.13	2.52	25.2	1.8	23.4
Jan	2	Mid	1.13	2.56	25.6	1.4	24.2
Jan	3	Mid	1.13	2.84	31.3	2.9	28.4
Feb	1	Mid	1.13	3.13	31.3	4.8	26.4
Feb	2	Late	1.1	3.33	33.3	6.3	27
Feb	3	Late	1	3.46	27.7	6.2	21.5
Mar	1	Late	0.88	3.46	34.6	4.9	29.7
Mar	2	Late	0.78	3.41	20.5	2.7	18.3
					320.3	42.8	277.1

Table 8: Crop water requirement for Vegetable

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.5	1.56	15.6	8.3	7.4
Nov	2	Init	0.5	1.47	14.7	0	14.7
Nov	3	Deve	0.53	1.42	14.2	0.7	13.5
Dec	1	Deve	0.72	1.74	17.4	2.7	14.7
Dec	2	Deve	0.93	2.01	20.1	2.6	17.5
Dec	3	Mid	1.11	2.44	26.8	2.4	24.4
Jan	1	Mid	1.13	2.52	25.2	1.8	23.4
Jan	2	Mid	1.13	2.56	25.6	1.4	24.2
Jan	3	Mid	1.13	2.84	31.2	2.9	28.4
Feb	1	Late	1.13	3.11	31.1	4.8	26.3
Feb	2	Late	1.03	3.12	31.2	6.3	24.9
Feb	3	Late	0.92	3.19	25.5	6.2	19.3
Mar	1	Late	0.8	3.15	31.5	4.9	26.6
					310.1	45.1	265.1

Table No: 9 *Crop water requirements (CWR) for spring rice*

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Nurs	1.2	0.33	2.7	3.9	0
Feb	2	Nurs/LPr	1.09	2.64	26.4	6.3	107.2
Feb	3	Nurs/LPr	1.06	3.7	29.6	6.2	113.3
Mar	1	Init	1.09	4.26	42.6	4.9	92.6
Mar	2	Init	1.1	4.82	48.2	4.4	43.8
Mar	3	Deve	1.11	5.41	59.6	9.2	50.4
Apr	1	Deve	1.13	6.26	62.6	13.3	49.3
Apr	2	Deve	1.15	7.06	70.6	16.8	53.8
Apr	3	Mid	1.17	6.88	68.8	25.8	43
May	1	Mid	1.17	6.51	65.1	36.7	28.4
May	2	Mid	1.17	6.3	63	45.8	17.2
May	3	Mid	1.17	5.91	65	48.8	16.3
Jun	1	Late	1.15	5.41	54.1	51	3.1
Jun	2	Late	1.09	4.76	47.6	54.6	0
Jun	3	Late	1.02	4.3	43	58.4	0
Jul	1	Late	0.99	3.97	7.9	12.9	7.9
					756.9	399	626.3

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3.3 *Irrigation Time Schedule and Net irrigation requirement*

Irrigation time schedule is the decision of when and how much water is to be applied to the field to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil water to the desired level. Irrigation time schedule saves water and energy.

The importance of irrigation time schedule is that it enables the farmers to apply the actual amount of water to achieve maximum crop yield. Over irrigation wastes the scarce water resource, energy and labor reducing soil aeration and crop yields.

Table 10-15 and Figure 2-7 shows the irrigation schedules of the five major crops in the study area.

The total gross irrigation mean and the total net irrigation mean for wheat crop are 201.2mm and 140.8mm, for maize crop 161.5mm and 113mm, for potato 68.7mm and 48.1mm and for small vegetables 80mm and 56mm. There are four irrigation schedules for monsoon rice, wheat and maize, six for small vegetables and spring rice and nine for potato.

Net irrigation requirement (NIR) is the net amount of water that must be applied to supplement stored soil water and rainfall and supply the water required for the full-fledged nourishment of the crops. NIR depends on climate, cropping pattern and irrigation efficiency. Irrigation water is lost during the process of transportation and application to the field in the form of evaporation, percolation and surface run off. In addition, agricultural processes such as land preparation and transplantation also require the supply of irrigation water.

NIR of different crops of the study area are calculated by using the following equation:

$NIR = ET_c - R_{eff}$ (6)

Where, NIR = net irrigation requirement in mm; ET_c = potential crop evapotranspiration in mm and R_{eff} = Effective rainfall mm.

NIR of existing crops in the study area is estimated by ET_c and R_{eff} values. Effective rainfall (Reff) of the study area is determined by U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS) method [19]. Determination of NIR value is very important since the selection of a particular crop to grow in a particular season depends on the NIR value of the crop.

Table 10: Irrigation Schedule for monsoon rice

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
17-Jun	-19	PrePu	61.7	1	100	Prep	16.3	0	35.9	0	35.9
02-Jul	-4	Puddl	0	1	100	Prep	0	4	90	0	40
29-Oct	115	End	0	1	100	OK	3.1	0	95.5	0	-4.5
03-Nov	End	End	0	1	0	OK	0	0			

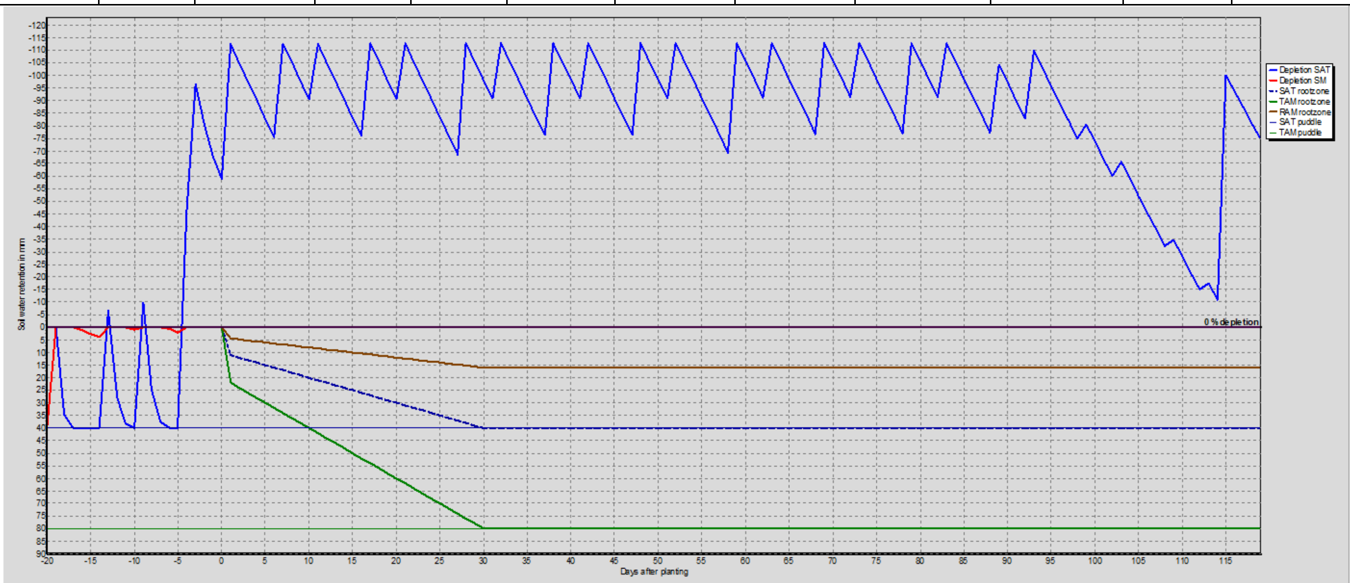

Figure 2: Irrigation Schedule for monsoon rice

Table 11: Irrigation Schedule for wheat

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
16-Dec	11	Init	0	1	100	55	51.6	0	0	73.7	0.78
05-Feb	62	Mid	0	1	100	56	133.9	0	0	191.4	0.43
18-Mar	103	End	0	1	100	59	140.8	0	0	201.2	0.57
14-Apr	End	End	0	1	0	25					

Figure 3: Irrigation Schedule for wheat

Table 12: Irrigation Schedule for Maize

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10-Dec	10	Init	0	1	100	56	47.4	0	0	67.8	0.78
22-Jan	53	Dev	0	1	100	56	108.7	0	0	155.3	0.42
01-Mar	91	Mid	0	1	100	57	113	0	0	161.5	0.49
04-Apr	End	End	0	1	0	46					

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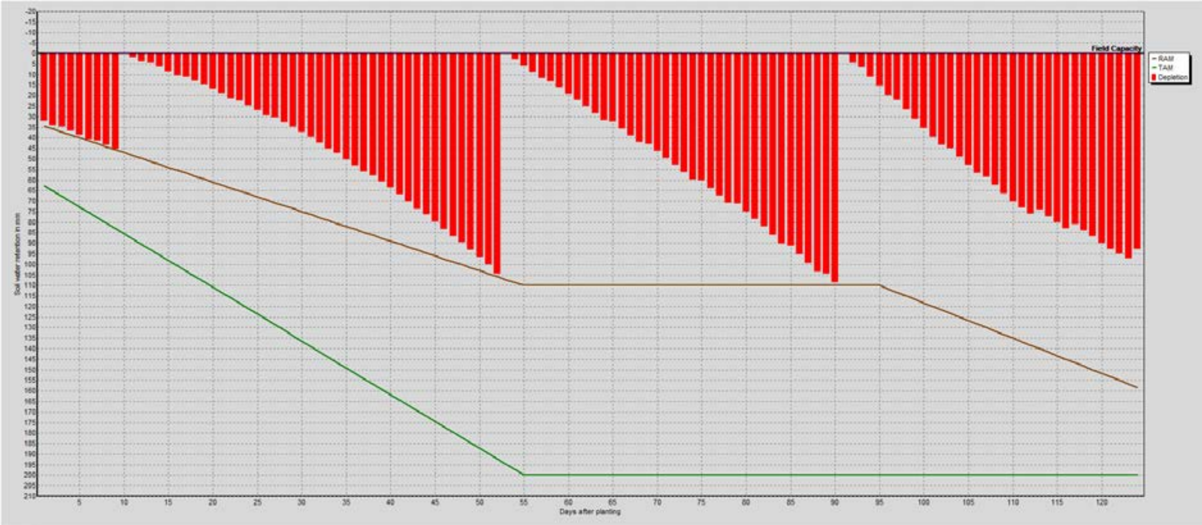

Figure 4 : Irrigation Schedule for Maize

Table 13: Irrigation Schedule for Potato

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
07-Nov	1	Init	4.3	0.76	76	45	27.5	0	0	39.3	4.55
16-Nov	10	Init	0	1	100	26	18.5	0	0	26.4	0.34
28-Nov	22	Init	0	1	100	27	22.6	0	0	32.3	0.31
14-Dec	38	Dev	0	1	100	28	28.8	0	0	41.1	0.3
29-Dec	53	Dev	0	1	100	30	35.3	0	0	50.4	0.39
14-Jan	69	Mid	0	1	100	32	38	0	0	54.3	0.39
29-Jan	84	Mid	0	1	100	31	37.4	0	0	53.4	0.41
12-Feb	98	Mid	0	1	100	32	38.6	0	0	55.2	0.46
01-Mar	115	End	0	1	100	40	48.1	0	0	68.7	0.47
16-Mar	End	End	0	1	0	34					

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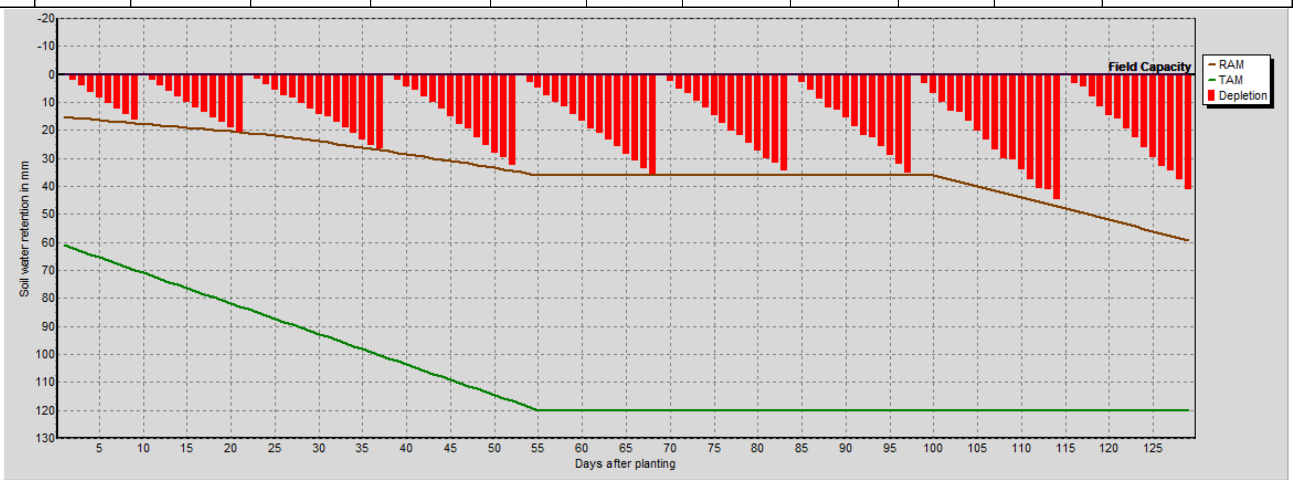

Figure 5 : Irrigation Schedule for Potato

Table 14: Irrigation Schedule for vegetables

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
01-Nov	1	Init	0	0.71	71	53	27.3	0	0	39	4.51
11-Nov	11	Init	0	1	100	33	21.5	0	0	30.7	0.36
20-Nov	20	Init	0	1	100	32	24.6	0	0	35.2	0.45
04-Dec	34	Dev	0	1	100	37	36.4	0	0	52	0.43
28-Dec	58	Mid	0	1	100	46	55.8	0	0	79.7	0.38
23-Jan	84	End	1.4	1	100	47	56	0	0	80	0.36
03-Feb	End	End	0	1	0	18					

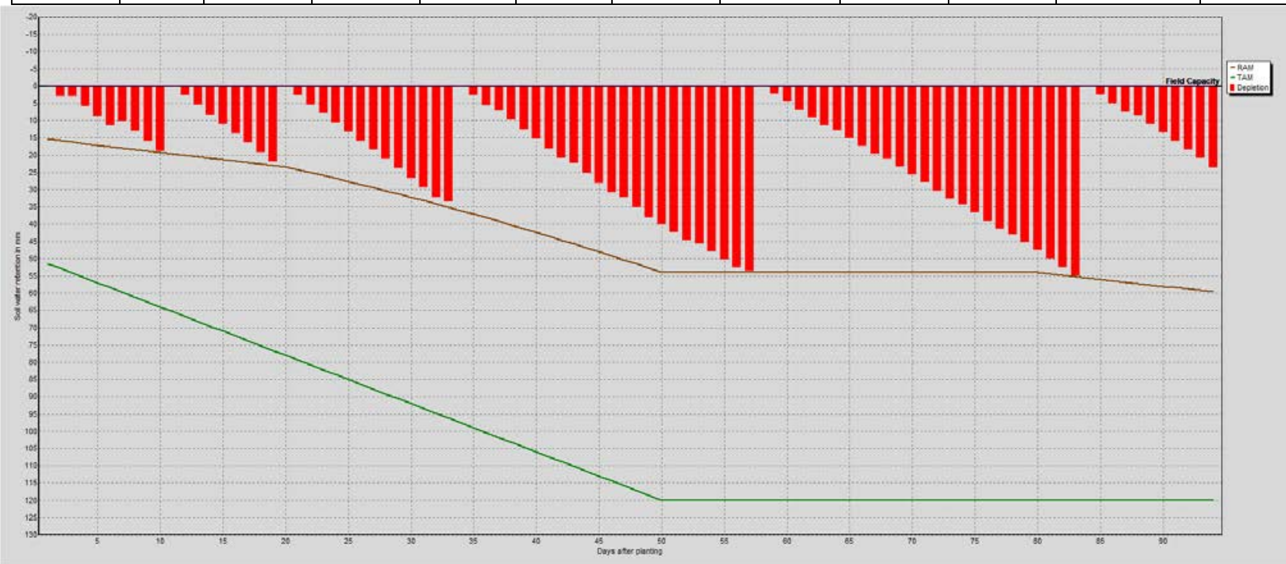

Figure 5 : Irrigation Schedule for vegetables

Table 15: Irrigation Schedule for Spring Rice

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
09-Feb	-19	PrePu	0	0.9	90	Prep	0	41	90.9	0	40
24-Feb	-4	Puddl	0	1	100	Prep	0	4	90	0	40
27-Feb	-1	Puddl	3.2	1	100	OK	7.7	0	51	0	1
06-Mar	6	Init	0	1	100	OK	3.1	0	100.6	0	0.6
20-Mar	20	Init	0	1	100	OK	3.1	0	102.1	0	2.1
02-Apr	33	Dev	0	1	100	OK	3.1	0	103.3	0	3.3
15-Apr	46	Dev	0	1	100	OK	3.1	0	105.1	0	5.1
29-Apr	60	Mid	0	1	100	OK	3.1	0	101	0	1
20-May	81	Mid	0	1	100	OK	3.1	0	95.5	0	-4.5
28-Jun	End	End	0	1	0	OK	0	0			

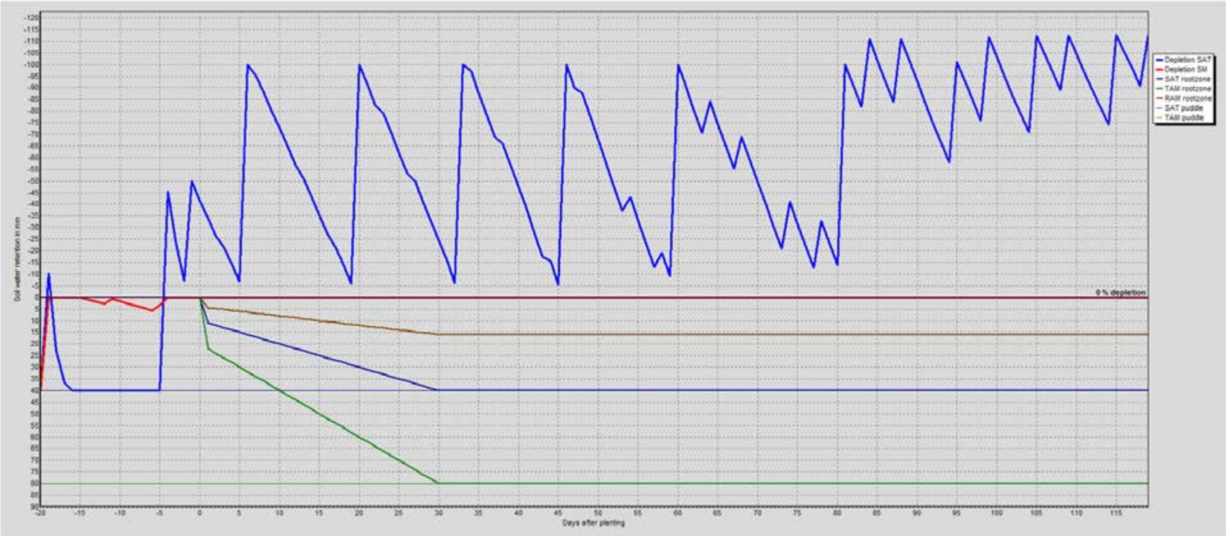

Figure 6: Irrigation Schedule for Spring Rice

In the above figure,

TAM = Total available moisture to the crop in mm

RAM = radially available moisture that the crop can extract from the soil at normal condition (without facing water stress, $k_s = 1$)

In Kankai Irrigation System, water is diverted through head works to the main canal and reaches to the farmers' field through distribution systems, must of them made of earthen canals that suffers substantial water loss due to percolation, absorption and evaporation losses. Irrigation is especially used for rice crop during summer which is cultivated in more than 90% of the command area. The main irrigated winter crops are wheat, maize, potato and vegetables which cover about 75% of the command area. The only spring crop is rice which is grown in more than 50% of the total command area. Agriculture still holds as a major sector in Nepalese economy. About 30% of national economy directly depends on agriculture (20).The availability of natural resources such as water and land is limited and less of these resources will be available for irrigated agriculture in future.

Five major crops grown in the KIS with corresponding cultivated area and crop yield are shown in Table 1

Table 16: Command Area of Five Major Crops and their Crop Yield

Total Command Area				6950 ha
Season	Crop Type	Crop Area(ha)	% Crop Area	Crop Yield (Mton/He)
Monsoon	Rice	6354	91	5.67
Winter	Wheat	844	12	3.13
	Maize	1103	16	4.33
	Potato	539	8	20.00
	Vegetables	396	6	19.87
Spring	Rice	2025	53	5.13

There is a growing need to reform farming and irrigation system to increase the crop productivity. Reforms in irrigation system should emphasize on water availability, soil property, and value of crop along with type of irrigation system. During dry season, water becomes scarce for the winter crops so modern methods and techniques will help to save water and increase productivity.

4. Conclusion

Crop water requirements and irrigation schedules are specific for a particular type of crop due to the effect of climate parameters and soil properties of a place. CROPWAT software generated some interesting findings regarding the evapotranspiration, CWR and irrigation schedule of the five major crops in the study area. Evapotranspiration for rice crop grown in the season of spring and summer is higher than that with four other crops grown in winter. Among winter crops, wheat has higher evapotranspiration than maize, potato or vegetables. Similarly, monsoon rice requires less irrigation water as there is sufficient rainfall during monsoon season. Similarly due to high evapotranspiration in spring season and less rainfall, rice in spring season has more irrigation water requirement. Among winter crops, water requirement for potato is slightly more than that of vegetables. Frequency of irrigation scheduling is 10 times for potato, 7 times for vegetables and four times for other crops.

The results of the study enhance our understanding of the water requirements of some of major crops in KIS, thus helping to improve water resource management and productivity through policies based on those findings. Using scientific instruments such as CROPWAT and CLIMWAT can assess the CWRs with a high degree of accuracy and suggest the crop pattern and crop rotation that farmers can readily accept. The results of this research study can be used by water resource planners to save water in meeting the CWRs for future planning and can be used as a guide for farmers to choose the amount and frequency of irrigation water for the five major crops in the studied area.

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