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IMPACT OF WHEAT AND MUSTARD CROP WATER REQUIREMENTS ON WATER RESOURCES MANAGEMENT OF DEVELOPMENT CORRIDOR

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Abstract

Irrigation water requirement of Kushkheda-Bhiwadi-Neemrana Investment Region (KBNIR) has been estimated based on climate, rainfall, crop sown area, crop properties and soil data obtained from different sources. CROPWAT software of FAO has been used to estimate the reference evapotranspiration (ET_o) for different months. Combining with ET_o and crop cofficient (K_c), irrigation water requirement is estimated for mustard (*Brassica juncea*) and wheat (*Triticum aestivum*). *Rabi* crops based on different rainfall conditions such as wet, normal and dry years. Total crop water requirement of wheat and mustard are estimated to be 318.3 mm and 403.0 mm, respectively. The months of December and January have the highest irrigation water requirement.

Key words : Irrigation water requirement, crop coefficient (Kc), wheat, mustard, evapotranspiration.

Introduction

Kushkheda - Bhiwadi - Neemrana Investment Region (KBNIR), Rajasthan is located geographically in semi arid area. This region is proposed to be developed as industrial and residential area in the Mumbai-Delhi freight corridor. Some of the greatest challenges in KBNIR are severe water scarcity, increase in water demand driven by rapid population growth, increased food requirement, industrialization and domestic water demand leading to over exploitation of groundwater. Water is a necessary natural resource for sustainability of life on the earth. Effective management of water resources is crucial for any development area (Tiwari *et al*., 2015). Presently ground water is the only resource of fresh water in winter season for agriculture and is therefore fully exploited. Studies of the water resources planning and management require the analysis of various hydrological parameters such as rainfall, evapotranspiration, irrigation water requirement and domestic water demand, surface runoff, etc. The agriculture sector is a major consumer of the water resource to fulfill the requirement of irrigation and its dependency on ground water is 70-90 % (Tiwari *et al*., 2015). To prepare a sustainable management and development approach for water resource, it is important to understand the requirement of irrigation water.

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Lysimetersis adevice, used for the measurement of evapotranspiration (ET_c) for a particular vegetation type directly in the field. In the absence of consistent field data, different methods are available for estimation of ET_c using meteorological data. Various methods *e.g.* Food and Agriculture Organization (FAO) Penman Monteith method, Hargreaves method, Blaney Criddle method, Thornthwaite method, Makkink and Modified Penman Monteith method have been used by various researcher to estimate ET_c (Winter *et al*., 1995; Kumar *et al*., 2012). The FAO have proposed Penman-Monteith method (FAO-56 PM) as the standard method for estimating reference evapotranspiration (ET_o), which is the evapotranspiration rate of a short green crop (grass), completely shading the ground, of uniform height and with adequate water status in the soil profile. ET_0 can be used for estimating the various crop water requirements based on crop coefficients (K_c) of different crops (Allen *et al*., 1998). The K_c value

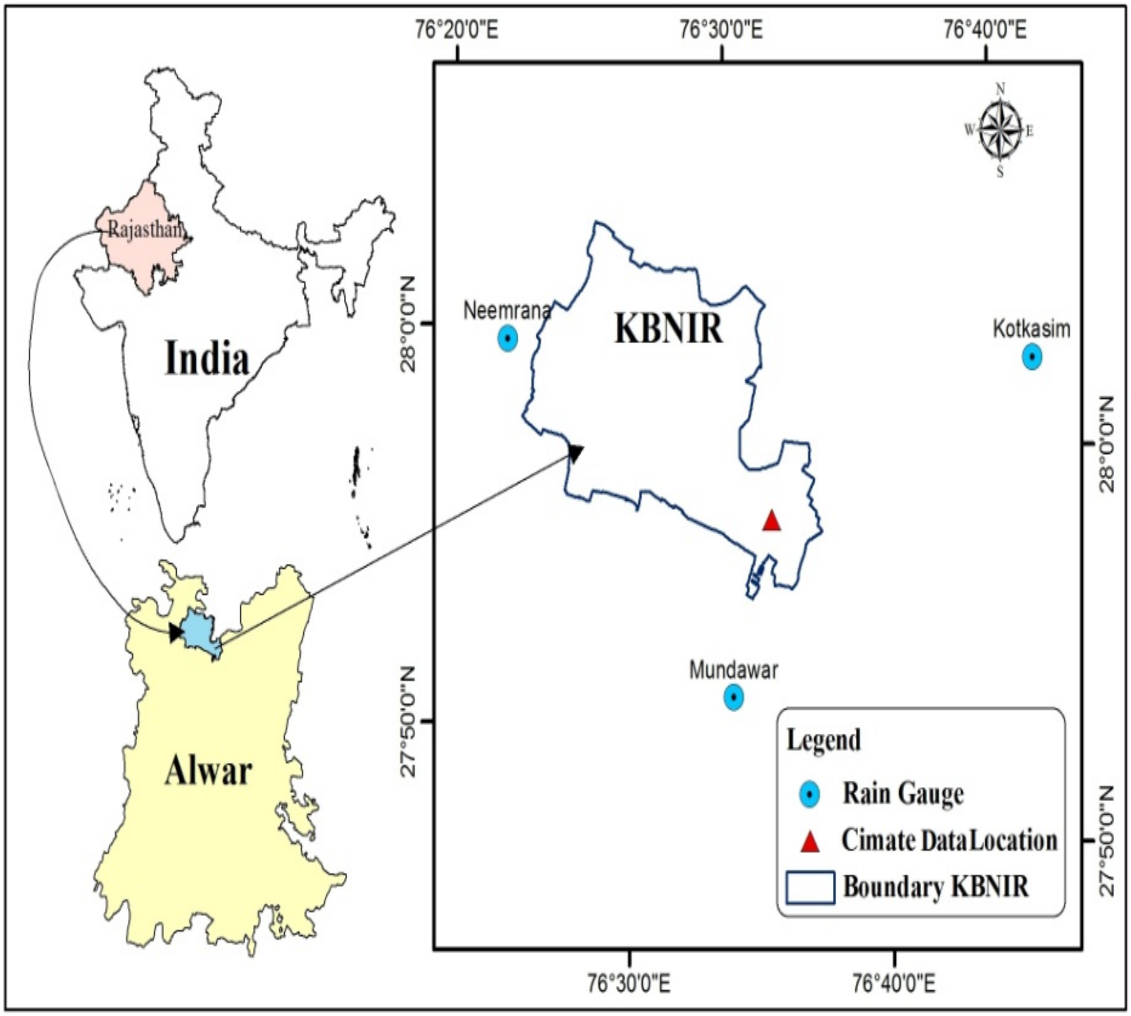

Fig. 1 : Location of the Study Area and Rain Gauge Stations.

represents water use by specific crop at different growth stage and is essential for accurate estimation of irrigation requirement of different crops in any area (Tyagi *et al*., 2000). Mustard (*Brassica juncea*) is most important oil crop and wheat (*Triticum aestivum*) is the most demanding food grain crop in India. These crops are grown mostly in irrigated conditions in winter season under different soil and climatic conditions (Pimpale *et al*., 2015) and are also the main crops grown in KBNIR. Knowledge of crop water requirement (ET_c) of the mustard and wheat is therefore necessary for appropriate irrigation management as well as water resources management of the study area.

In this paper, attempt have been made to estimate ET_o, ET_c and Irrigation water requirement (IWR) for wheat and mustard crop in KBNIR using long period gridded weather data and rainfall data of different stations for better management of water resource in the development area of KBNIR.

Methods and Materials

Study area

The KBNIR is situated between 27°54'33" N and 28°03'20" North latitudes and 76°24'06" E and 76°35'40" East longitudes and lies in the Alwar district, Rajasthan state, India, as shown in fig. 1. KBNIR covers 162.4 km^2 geographical area and falls in semi-arid climate zone. The maximum temperature of the region goes up to 48°C and the minimum reaches to the level of freezing point. Average annual temperature is 26°C and average annual rainfall is 588 mm. Older alluvial soils are found in major part of the area covering 75.45% of KBNIR. Older alluvial soil lies in loamy sand texture group, which is suitable for agriculture. The major crops grown in this area in *Rabi* season (winter) are wheat and mustard and in Kharif season (monsoon) are Pearl millet (*Pennisetum glaucum*) and cluster bean (*Cyamopsis Tetragonoloba*).

Data collection

Daily meteorological data were collected for the time period 1/1/1980 to 31/12/2014 from Soil & Water Assessment Tool (SWAT) website where meteorological data is available in gridded format at daily time resolution and 0.5° horizontal resolution. One location point was falling within KBNIR as shown in fig. 1 and data of that location has been downloaded. The meteorological data include maximum and minimum temperature, sunshine hours, wind speed and solar radiation. Soil information were obtained from FAO irrigation and drainage paper 56 (Allen *et al*., 1998) for older alluvial soil which is distributed across the KBNIR. Rainfall data for the period 1/1/1980 to 31/12/2014 was downloaded from Rajasthan water resources department website (RWRD, 2015) for three rain gauge stations (namely Neemrana, Kotkasim and Mundawar) surrounding KBNIR, location of which are shown in fig. 1. Data product of Landsat-8 sensor on board Operational Land Imager (OLI) with 15-meter panchromatic band and 30-meter multi-spectral band spatial resolutions along a 185 km (115 miles) wide swath, was downloaded from LP DAAC, USGS (2015) for crop type classification and crop area estimation for the study area. OLI sensor uses red, and near-infrared reflectances, centered at 655-nanometers, and 858-nanometers, respectively, to determine the normalized difference vegetation index (NDVI).

Crop type classification

Land use/land cover classification has been performed to find out the agriculture and non-agriculture area using IRS Resourcesat-1 LISS-III data at 23.5 m spatial resolution based on methodology discussed in Tiwari and Khanduri (2011). Further OLI data has been resampled from 30 m to 23.5 m spatial resolution and masked with agriculture area to keep only wheat, mustard and other crops fields. Reclassification method was applied to the OLI-NDVI time series to produce the vegetation types. Different crops can be characterized using their seasonal (or phonological) variations in the NDVI time series, so wheat and mustard crops were delineated by examining NDVI temporal profiles from the crop growing season (Goyal *et al*., 2016).

Evapotranspiration estimation

The estimation of ET_0 is important to find irrigation water demand for plant growth. FAO Penman Monteith method was adopted to estimate ET_0 (Allen *et al*., 1998; Mehta and Pandey, 2016) using monthly climate data by following equation:

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

Where, ET_o is reference evapotranspiration (mm/day), R_n is net radiation at the crop surface (MJ/m/day), G is soil heat flux density (MJ/m/day),g is psychrometric constant (kPa°C) T is mean daily air temperature (°C), u_2 is wind speed at 2 m height (m/s), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), e_s - e_a is saturation vapor pressure deficit (kPa) and D represents the slope of the saturation vapour pressure - temperature curve (kPa/°C).

An estimate of the respective rainfall for normal, dry and wet conditions can be obtained through plotting probabilities from the last 35 years rainfall data using following equation:

$$F_a = 100 * m/(N + 1) \quad (2)$$

Where, F_a = probability of exceedance, N = number of records, m = rank number.

Rainfall with probably of exceedance of 20% is referred as wet year rainfall, 50% would be normal rainfall and 80% would be dry year rainfall.

$$R_{eff} = R_{mon}*(125-0.2*R_{mon})/125, \text{ if } R_{mon} <= 250\text{mm} \quad (3)$$

$$R_{eff} = 125 + 0.1 * R_{mon}, \text{ if } P_{mon} > 250 \text{ mm} \quad (4)$$

Where, R_{eff} is effective rainfall for particular month calculated by USDA soil conservation service method and R_{mon} is monthly rainfall for that month (Obreza and Pitts, 2002).

In the present study, crop coefficient approach has been used for estimation of crop water requirements as discussed in Doorenbos and Pruitt (1975). ET_c can be calculated by multiplying the ET_0 by Crop coefficient K_c (eq. 5). CROPWAT software is being used to calculate IWR of wheat and mustard crops based on soil, climate and crop data (eq. 6). CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO.

$$ET_c = ET_0 \times K_c \quad (5)$$

$$IWR = ET_c - R_{eff} \quad (6)$$

Results and Discussion

Different rainfall case *viz*. wet, normal and dry years has been defined based on probability of exceedance of rainfall of 20, 50 and 80%, representing respectively a wet, normal and dry year. These different cases are useful for the planning of irrigation supply and to optimally manage water resources of the area. The rainfall in normal years (50% probability) is similar to calculation by the average rainfall but could be different in value from average rainfall. In order to calculate wet, normal and dry rainfall, a probability graph between the probability of exceedance and annual rainfall has been plotted as

Table 1 : Average, dry, normal or wet monthly rainfall (mm) based on 1980 to 2014.

Month	Average	Dry	Normal	Wet
January	10.20	7.20	9.43	13.79
February	18.30	12.91	16.92	24.74
March	8.90	6.28	8.23	12.03
April	8.40	5.93	7.77	11.36
May	24.60	17.36	22.75	33.26
June	81.10	57.22	74.99	109.66
July	189.70	133.85	175.41	256.49
August	198.40	139.99	183.45	268.26
September	91.00	64.21	84.14	123.04
October	12.60	8.89	11.65	17.04
November	4.50	3.18	4.16	6.08
December	4.10	2.89	3.79	5.54
Total	651.80	459.91	602.69	881.29

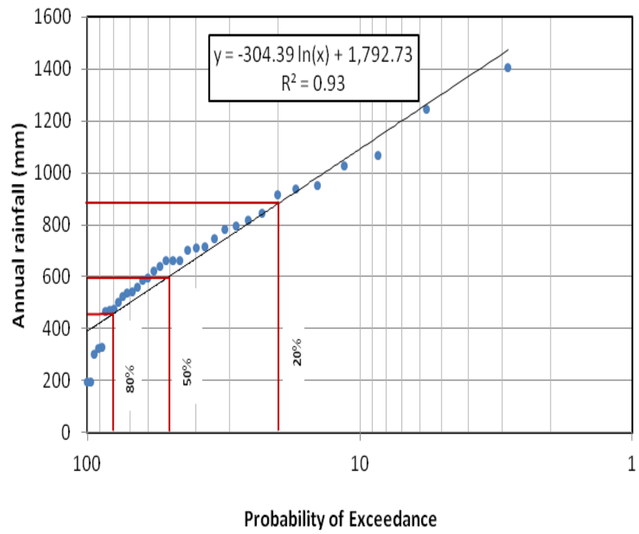

Fig. 2 : Annual rainfall for wet, normal & dry years.

Table 2 : Crop data for mustard and wheat.

Stage	Mustard					Wheat				
	Initial	Develop	Mid	Late	Total	Initial	Develop	Mid	Late	Total
Length (days)	17	30	35	25	107	30	30	40	30	130
K_c Values	0.23	-	1.28	0.3		0.3	-	1.15	0.3	
Rooting depth (m)	0.2	-	0.9	0.9		0.3	-	1.2	1.2	
Critical depletion	0.45	-	0.45	0.6		0.55	-	0.55	0.8	
Yield response f.	0.2	0.6	1	0.2	1.2	0.4	0.6	0.8	0.4	1.2
Crop height (m)			0.95					1		

shown in fig. 2. Estimated rainfall for all three case on monthly basis is shown in table 1.

In order to compute IWR of two major crops of the area, mustard and wheat for Rabi season, crop data, as shown in table 2, has been collected from different agencies, experts opinion, field visit and farmers response during field visit (Tiwari *et al*., 2017).

To determine the irrigation requirements of the KBNIR an assessment is made of the different crops grown under that area presently. Last five year data about sowing area for different crops from three blocks, namely Neemrana, Behror and Mandawar was obtained from Alwar district and has been used in the analysis. It was found that for the years 2009-10 to the year 2012-13 Neemrana block data was merged with Behror block data and was not available separately. Hence, Neemrana block data of these years have been calculated based on the distribution of total geographical areas of these blocks, assuming average conditions are same in both the blocks. Table 3 below gives the plantation area of major crop for Neemrana and Mandawar blocks. It has been found that major Rabi crops of the region are mustard and Wheat, with average crop areas of 66.4% and 30%, respectively.

Based on the data in table 3, agricultural area of Neemrana and Mandawar block of KBNIR has been determined. Accordingly assuming linear distribution of cropping area, block wise and cropping season wise area has been calculated shown in table 4.

A crop type map was generated using GIS tools as shown in fig. 3. The area estimated for mustard crop was 63.80, km^2, for wheat crop 49.79 km^2 and other crops was 12.04 km^2. There was little difference between the estimated crop area by the satellite data and the crop area statistics collected from Agriculture Department, Government of Rajasthan.

Here, it can be seen from table 5 that Average ET_0 for the period 1980 to 2014 is computed as 6.17 mm/month. Minimum and maximum ET_0 is estimated to be 3.05 mm/day for the month of January and 9.76 mm/day for the month of May. The average monthly humidity is 41% and its temporal variability over the year varies from 18% in May to 61% in August. The total ET_o works out to be 2.23 m per annum in KBNIR.

Table 3 : Major crop area for Neemrana and Mandawar Block in ha.

S. no.	Year	***Rabi* crop area in ha (% area)**			
		Mustard	**Wheat**	**Other crops**	**Total area**
1	2009-10	46966 (68.5%)	19699 (28.7%)	1889 (2.8%)	68554
2	2010-11	43808 (65.5%)	20006 (29.9%)	3051 (4.6%)	66865
3	2011-12	46465 (69.0%)	18653 (27.7%)	2227 (3.3%)	67346
4	2012-13	43103 (64.6%)	21545 (32.3%)	2067 (3.1%)	66715
5	2013-14	42722 (64.4%)	20910 (31.5%)	2708 (4.1 %)	66340
Average		44613 (66.4%)	20163 (30.0%)	2388 (3.6%)	67164

Table 4 : Major crop sown area for KBNIR in ha.

S. no.	Year	***Rabi* crops (ha)**			
		Mustard	**Wheat**	**Other Crops**	**Total Area**
1	2009-10	8664 (71.5%)	3292 (27.2%)	155 (1.3%)	12111
2	2010-11	7792 (66.8%)	3419 (29.3%)	453 (3.9%)	11664
3	2011-12	8225 (70.5%)	3133 (26.8%)	315 (2.7%)	11673
4	2012-13	7625 (66.4%)	3555 (30.9%)	308 (2.7%)	11488
5	2013-14	7495 (66.1%)	3559 (31.4%)	286 (2.5%)	11340
Average		7961 (68.3%)	3391 (29.1%)	303 (2.6%)	11655

Table 5 : Calculation of ET_o for KBNIR region.

Month	**Min Temp (°C)**	**Max Temp (°C)**	**Humidity (%)**	**Wind (km/day)**	**Sunshine (hours)**	**Rad (MJ/m²/day)**	**ETo (mm/day)**
January	5.3	21.7	54	214	8.0	14.3	3.05
February	8.0	25.6	47	238	8.6	17.1	4.18
March	12.6	32.6	33	235	9.5	21.0	6.15
April	19.4	39.1	20	238	10.3	24.4	8.26
May	25.3	43.2	18	254	10.6	25.8	9.76
June	28.9	43.0	28	251	10.1	25.2	9.63
July	28.4	37.9	52	226	9.1	23.6	7.47
August	26.8	35.7	61	205	9.1	22.8	6.38
September	24.1	35.8	51	203	9.2	21.2	6.26
October	17.9	34.5	34	177	9.0	18.3	5.56
November	11.6	28.9	39	177	8.3	15.0	4.18
December	7.1	23.6	49	195	7.8	13.3	3.22
Average	17.9	33.5	41	218	9.1	20.2	6.18

Now with climate, rainfall, crop and soil data, crop water requirements (CWR) of mustard and wheat could be obtained for different rainfall conditions e.g. wet, dry, normal and average. Decadal (10 days) CWR and IWR for wheat and mustard crop are shown in tables 6 and 7 respectively, which were based on calculated value of decadal crop coefficients. Total CWR of wheat and mustard are estimated to be 318.3 mm and 403 mm, respectively. Wheat crop had the highest crop water demand at 40.8 mm for second decade of February month with K_c value of 1.14. Mustard was estimated to require 44.1 mm using K_c value of 1.32 which occurs during the peak of mustard water demand in second decade of December. The months of December and January have the highest IWR.

Table 8 shows the annual IWR and effective rainfall for KBNIR for different rainfall conditions assuming ideal availability of water resource for the crop. Therefore, present IWR of KBNIR for average conditions of last 35 years is 36.70 MCM and that for normal, wet and dry years are 36.97, 35.44 and 37.75 MCM, respectively. Therefore, it could be assessed that during the good rainfall

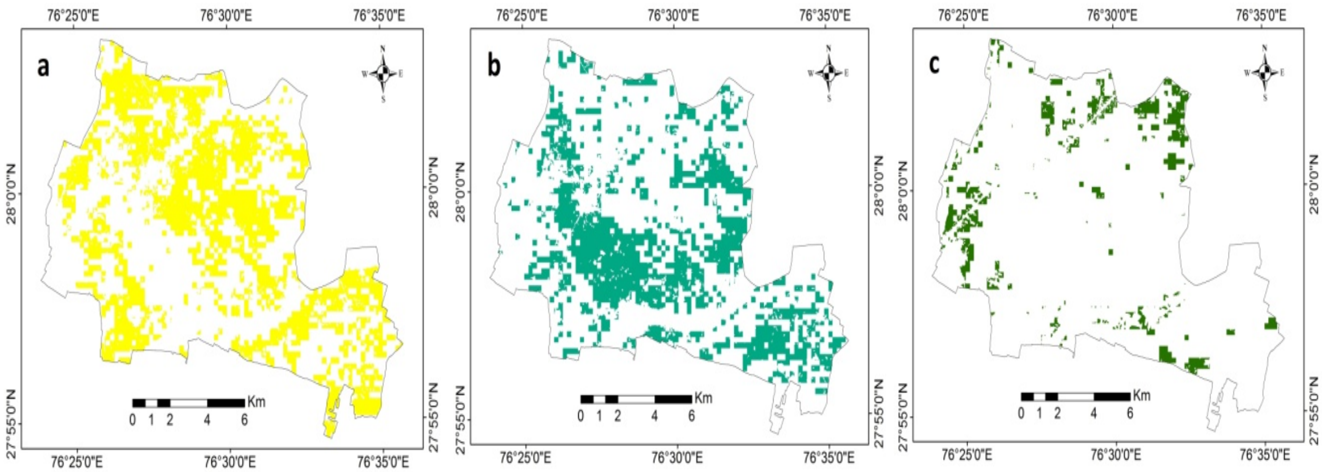

Fig. 3 : Distribution of crops in KBNIR area in 2014-15 (a) wheat (b) mustard (c) other crops.

Table 6 : Decade wise IWR of mustard crop for different cases.

Decade	K_c	ET_c	Average-IWR	Dry-IWR	Normal-IWR	Wet-IWR
Oct, 3rd	0.23	9.4	8.7	8.9	8.7	8.3
Nov, 1st	0.23	10.8	8.7	9.3	8.8	8.0
Nov, 2nd	0.47	19.5	18.3	18.6	18.4	17.9
Nov,3rd	0.83	32.0	30.7	31.1	30.8	30.3
Dec, 1st	1.19	42.1	40.8	41.2	40.9	40.4
Dec, 2nd	1.32	42.5	41.4	41.7	41.5	41.0
Dec, 3rd	1.32	45.9	44.1	44.6	44.2	43.4
Jan, 1st	1.32	40.1	37.5	38.2	37.7	36.5
Jan, 2nd	1.21	35.6	32.3	33.2	32.5	31.1
Jan, 3rd	0.79	29.2	25.0	26.2	25.3	23.6
Feb, 1st	0.42	11.2	5.7	7.3	6.1	3.8
Total	9.33	318.3	293.2	300.3	294.9	284.3

Where, decade is ten days of the month; ET_c and IWR are in mm/decade.

year, approximately 1.5 MCM less water is required for irrigation purpose than a normal year, however in a drought like situation only additional 0.8 MCM water is required. During the field visit (Tiwari *et al*., 2017), present water management conditions were assessed and it was found be significantly lower than ideal water management conditions and therefore IWR may be

Table 7 : Decade wise IWR of wheat crop for different cases.

Decade	K_c	ET_c	Average-IWR	Dry-IWR	Normal-IWR	Wet-IWR
Nov, 1st	0.30	12.5	10.4	11.0	10.5	9.6
Nov, 2nd	0.30	12.5	11.3	11.7	11.4	11.0
Nov,3rd	0.30	11.6	10.3	10.7	10.4	9.9
Dec, 1st	0.43	15.4	14.2	14.5	14.3	13.7
Dec, 2nd	0.73	23.7	22.5	22.9	22.6	22.2
Dec, 3rd	1.05	36.5	34.6	35.2	34.8	34.0
Jan, 1st	1.20	36.4	33.8	34.5	34.0	32.9
Jan, 2nd	1.20	35.3	32.0	33.0	32.3	30.9
Jan, 3rd	1.20	44.3	40.1	41.3	40.4	38.7
Feb, 1st	1.20	45.6	40.0	41.6	40.4	38.1
Feb, 2nd	1.14	47.5	40.8	42.7	41.3	38.6
Feb, 3rd	0.88	34.2	28.8	30.3	29.2	26.9
Mar, 1st	0.61	33.7	30.0	31.1	30.3	28.8
Mar, 2nd	0.37	13.8	12.5	12.9	12.6	12.1
Total	10.91	403.0	361.3	373.4	364.5	347.4

Where, decade is ten days of the month; ET_c and IWR are in mm/decade.

Table 8 : Total irrigation water requirement for KBNIR.

Rainfall condition	Mustard			Wheat		
	IWR (mm)	Eff rainfall (mm)	IWR (MCM)	IWR (mm)	Eff rainfall (mm)	IWR (MCM)
Average	293.0	23.8	18.70	361.5	41.6	18.0
Dry	300.2	17.0	19.15	373.4	29.6	18.6
Normal	294.9	22.0	18.81	364.7	38.4	18.2
Wet	284.4	32.0	18.14	347.5	55.6	17.3

reduced by a factor to determine present water requirement of KBNIR.

Conclusion

In present study, irrigation water requirement has been estimated for normal, dry and wet years. These values could be used for developing effective water management strategies for the study area for different conditions like drought or heavy rainfall. Based on estimation of runoff available, water harvesting could be adopted in and around study area. Also based on water availability and requirement of water for proposed industrial and residential development, government could implement optimized cropping pattern and the agriculture practices in that area. Water saving especially in agriculture fields should be promoted by policy makers, irrigation planners and agriculture researcher. Agricultural water-saving techniques are still in limited use in the study area. Water saving measures adoption such as the mulching techniques, drought resistant crop varieties, changing in cropping patterns, use of deficit irrigation methods and advanced tillage techniques could decrease water requirement (Yang *et al*., 2010; Yadav and Singh, 2014) by a significant quantity.

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