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Estimation of Net Irrigation Requirements of Crops in the Deterministic and Stochastic Regimes for Limbasi Canal Command Area

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Abstract

Estimation of Net Irrigation Requirement (NIR) of crops is essential for agricultural planning, irrigation scheduling, regional water balance studies and optimal allocation of land and water resources in a canal command area. In the present study, NIR estimation of different crops of Limbasi Canal command area, Gujarat, India is carried out in the deterministic and stochastic regimes for nineteen years of available data. In the deterministic regime, the estimated average NIR of 19 years for kharif crops paddy & vegetables was 229.8 & 92.9mm ; rabi crops sorghum, tobacco, wheat & vegetables was 355.5, 391, 427.2 & 407.1mm and hot weather crops paddy, pearl millet & vegetables was 863.9, 600.6 & 754.7 mm respectively. In the stochastic regime, NIR of different crops was predicted at Probability of Exceedance (PE) levels of 0.02, 0.05, 0.08, 0.10, 0.15, 0.20, 0.25, 0.35 and 0.40 using 19 years of NIR. MATLAB was used for prediction of NIR. The goodness of fit was tested by Kolmogorov – Smirnov test and normal distribution was found as the best fit.

1 Introduction

Net Irrigation Requirement (NIR) of crops mainly depends on reference crop evapotranspiration (ET_o) and hence, accurate estimate of ET_o is a key component in hydrological studies. ET_o depends on several climatological factors, such as temperature, humidity, wind speed, radiation, type and stage of growth of the crop and so on.

ET_o can be measured directly using lysimeter or water balance approaches. However, measurement of ET_o using lysimeter is a time-consuming method. It also needs precise and carefully planned experiments. Hence, it is not always possible to measure ET_o by using lysimeter. Under such

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circumstances, ET_o is estimated indirectly using climatological data. The indirect methods of ET_o estimation using climatological data vary from empirical relationships to complex methods such as the Penman Monteith method based on physical processes. The different methods of ET_o estimation can be grouped into temperature methods, radiation methods, combination theory types and pan evaporation methods.

FAO-56 Penman-Monteith method was used by [1] for estimation of ET_o for different irrigation project sites in Andhra Pradesh, India. Estimation of ET_o for eight irrigation project sites located in Andhra Pradesh, India was carried out by [2]. ET_o estimation for the humid areas of Agartala (Tripura) and Umiam (Meghalaya), India using revised Blaney Criddle, Christiansen and Thornthwaite methods was carried out by [3]. Hargreaves - Samani method for ET_o estimation was used by [4], [5] and [6] for different locations. A comparative study of ET_o estimation in the Limbasi canal command area using Hargreaves - Samani method and Modified Penman's method was carried out by [7]. The FAO-56 Penman-Monteith and two Valiantzas equations' accuracy were evaluated by [8] for daily ET_o estimation under limited climatic data and four other radiation based ET_o equations across Tanzania and swestern Kenya.

Crop water requirement is estimated using ET_o values. Water requirement of crops under the command area of Singnapur and Lohagaon minors Jayakwadi project, India, was estimated by [9] using CRIWAR software. Water requirement of crops of the Anantapur district, Andhra Pradesh, India was estimated by [10] using CROPWAT model. Irrigation water requirement of different crops of Limbasi canal command area, Gujarat, India was estimated by [11]. Water requirement of different crops of middle Gujarat, India was estimated by [12] using FAO Penman- Monteith method.

In all the above studies, estimation of NIR was carried out in the deterministic regime. However, dependence of NIR on precipitation, evapotranspiration and other climatic factors makes it stochastic in nature. The chance aspect of NIR is due to randomness in precipitation, evapotranspiration and other similar climatic conditions of irrigated area [13]. Hence, estimation of NIR in the stochastic regime is necessary for real field situations. Forecasting of irrigation water requirement of paddy field area using the fuzzy theory was carried out by [14]. NIR of crops of at various Probability of Exceedance (PE) levels was estimated by [6], [13] and [15]. Uncertainties in the estimation of NIR using fuzzy logic approach were quantified by [16]. Usefulness of multi-model ensemble predictions and sophisticated model averaging techniques in predicting irrigation demand was investigated by [17], in which, irrigation water requirement for wheat in the Murray–Darling Basin, Australia was estimated and the importance of the model structural versus model parametric uncertainty for irrigation simulations was investigated. The model structural uncertainty among reference ET was found more important than model parametric uncertainty introduced by crop coefficients.

2 Materials and Methods

2.1 Study Area

The study area is a Limbasi canal command area situated between latitudes of 22° 31' 33.2'' to 22° 36' 11.8''N and longitudes of 72° 32' 8.6'' to 72° 48' 18.7''E. Fig.1 shows the index plan of Limbasi canal [18]. It has a Gross Command Area (GCA) of 23405 ha and Culturable Command Area (CCA) of 15764 ha. The study area is situated at an elevation from 35 to 90m above MSL having flat topography towards the Gulf of Cambay with an average slope gradient less than 1% in the length of 58 km. There are no well defined natural existing drains in the command area.

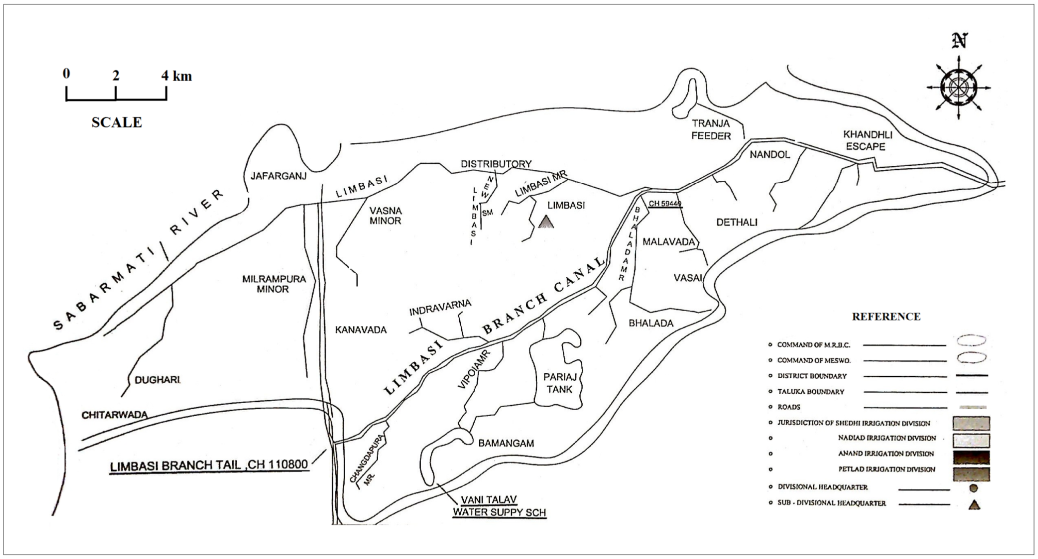

Figure 1: Index map of Limbasi canal (Source – Mahi Irrigation Circle, Nadiad)

Paddy is the major crop in kharif season and covers about 97% of the area in the kharif season. Wheat is the major crop in rabi season and covers about 93% of the area in the rabi season. Pearl millet sorghum, tobacco, and vegetables are also cultivated in the command area.

The study area is located in the agro-climatic zone GJ-3 (middle Gujarat zone) with semi – arid climate. The maximum recorded temperature in the study area was 46.7°C in June, 2010 while minimum temperature was 4.2°C in the February, 2005. The average annual rainfall is 786mm with most of the rainfall restricted to monsoon months of June to September. The maximum value of relative humidity was 100.0% in July (and August) 2008 while the minimum relative humidity was 3.6% in December 2011 [19]. The mean annual soil temperature is more than 22°C and the difference between mean summer and mean winter soil temperature is more than 5°C [20].

The study area is bounded on north by river Watrak, on the south by Gulf of Cambay, on east by river Shedhi and on west by the river Sabarmati. The soil of north-east part of the study area is influenced by river Shedhi which forms the complex nature of parent material mainly like sandstone, schist and phylites. The soil of this area is light to medium texture with yellowish brown to dark brown in colour. The soil of the western part of the study area is influenced by the river Watrak and Sabarmati which forms the complex nature of parent material, mainly like basalt and granite. The soil of this area is medium to heavy in texture with dark brown to very dark grayish brown in colour.

In the surface soil (depth up to 30cm below ground level) nearly 39.2% area exhibit coarse to medium texture while in the sub-surface soil (depth from 30 to 90cm below ground level) nearly 31.9% area exhibits coarse to medium texture. Nearly 60.8% area in the surface soil and 68.1% area in sub-surface soil have moderately fine to fine texture. In the entire command of Limbasi branch canal, the depth of the soil is more than 90cm i.e. very deep [20]. The infiltration rate vary from 0.14 to 1.38 cm/hr.

2.2 Data Acquisition and Analysis

Daily rainfall data of six rain gauge stations namely Matar, Limbasi, Petlad, Khambhat, Sojitra and Kanewal located in and around the study area were collected from [18]. The length of data collection was 23 years (1990 to 2012).

Daily minimum and maximum temperature data of the Navagam weather station located nearby the Limbasi canal command area were collected from [19]. The length of data collection was 20 years (1993 to 2013 except the year 2001 for which data were not available).

2.3 Reference Crop Evapotranspiration Estimation

Reference crop evapotranspiration (ET_o) is to be estimated first for the estimation of Net Irrigation Requirement (NIR) of crops. Several methods are available for estimation of ET_o. For the study area, daily ET_o estimation using Hargreaves - Samani method was carried out by [7] and compared with daily ET_o estimation using Modified Penman's method carried out by Water and Land Management Institute (WALMI), Anand, Gujarat. Several comparisons were obtained through the simple linear regression analysis technique and a set of statistical parameters.

It was found that there was a good agreement between ET_o estimates by two methods. It was also found that Modified Penman method requires detailed climatological data (which are not often available with required degree of preciseness), while Hargreaves-Samani method uses limited data like air temperature and extraterrestrial solar radiation only to give reasonably good estimate of ET_o. Hence, in the present analysis, Hargreaves-Samani method [21] is adopted for ET_o estimation of the study area. This method computes daily mean ET_o using (1).

$$ET_O = 0.0023 * R_a * \left(T_{avg} + 17.8\right) * \sqrt{(T_{max} - T_{min})} \quad (1)$$

Where, ET_o = reference crop evapotranspiration (mm/day); R_a = extraterrestrial solar radiation (mm/day); T_{avg}, T_{max} and T_{min} are daily average, maximum and minimum air temperatures (°C). The values of extraterrestrial solar radiation (R_a) depend on month of the year and latitude of the place as given by [22]. Daily ET_o values as estimated by (4) were multiplied by number of days in a given month to determine monthly ET_o values.

2.4 Potential Crop Evapotranspiration Estimation

Potential crop evapotranspiration (ET_c) of different crops of the study area were estimated from reference crop evapotranspiration (ET_o) by using (2).

$$ET_c = ET_o * K_C \quad (2)$$

Where, ET_c = potential crop evapotranspiration (mm); ET_o = reference crop evapotranspiration (mm); K_c = crop coefficient for a given crop.

Monthly ET_c values of different crops of the study area were determined by multiplying monthly ET_o values by suitable crop coefficient (K_c). For K_c values of different crops of the study area, reference was made to [23].

2.5 Net Irrigation Requirement (NIR) Estimation

NIR of different crops of the study area was estimated from potential crop evapotranspiration (ET_c) by using (3).

$$NIR = ET_c - R_{eff} \quad (3)$$

Where, NIR = net irrigation requirement (mm); ET_c = potential crop evapotranspiration (mm) ; R_{eff} = effective rainfall (mm).

Monthly NIR of different crops of the study area was estimated by ET_c and R_{eff} values. Effective rainfall (R_{eff}) was determined by U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS) method [24]. According to this method the effective rainfall (R_{eff}) for paddy was estimated as R_{eff} (t) = 0.8*R(t), while for non-paddy crops, it was estimated as R_{eff} (t) = 0.7*R(t). Effective rainfall was considered for the monsoon months of June to September only, as in the remaining months, significant rainfall does not occur regularly in the command area and hence, effective rainfall is zero during this period. If the monthly NIR was negative (for $R_{eff} > ET_c$), for a particular crop, then the

NIR of that crop for that month was considered as zero. From monthly NIR, seasonal NIR of crops was computed by adding the monthly NIR of corresponding crops [13].

In the present analysis, NIR of different crops of the study area in the deterministic regime was estimated for 19 years (1993-1994 to 2012-2013). For prediction of NIR values in the stochastic regime at various Probability of Exceedance (PE) levels, NIR in the deterministic regime for 19 years was used as input in the MATLAB. Weibull's distribution was considered as reference. The goodness of fit was tested by Kolmogorov – Smirnov test and normal distribution was found as best fit. The expected NIR values at Probability of Exceedance (PE) levels of 0.02, 0.05, 0.08, 0.10, 0.15, 0.20, 0.25, 0.35 and 0.40 were obtained in the stochastic regime.

3 Results and Discussions

In the deterministic regime, NIR of different crops of the study area was estimated for 19 years (1993-1994 to 2012-2013). Details are given in Table-1. The estimated average NIR of 19 years for kharif crops paddy & vegetables was 229.8 & 92.9mm ; rabi crops sorghum, tobacco, wheat & vegetables was 355.5, 391, 427.2 & 407.1mm and hot weather crops paddy, pearl millet & vegetables was 863.9, 600.6 & 754.7 mm respectively.

In the stochastic regime, NIR of 19 years as estimated above was used as input in the MATLAB to predict NIR of different crops at Probability of Exceedance (PE) levels of 0.02, 0.05, 0.08, 0.10, 0.15, 0.20, 0.25, 0.35 and 0.40. The goodness of fit was tested by Kolmogorov – Smirnov test and normal distribution was found as best fit. In this test, actual cumulative probability, $P(x_i)$ was calculated using Weibull's formula and theoretical cumulative probability, F(xi) was calculated using normal distribution. The test statistic Δ, which is the maximum of the absolute difference between $P(x_i)$ and $F(x_i)$ was 0.189 while the critical value of the test statistic Δ_o was 0.2714 for no. of years (n) =19 and 10% significance level. Thus, $\Delta < \Delta_{o,}$ and hence, the hypothesis of normal distribution was accepted. Table-2 shows NIR of different crops of the study area in the stochastic regime. NIR of crops was found to decrease with increase in PE levels. Fig.2, 3, and 4 shows the variation of NIR of kharif, rabi and hot weather crops respectively with different PE levels in the stochastic regime.

4 Conclusions

Net irrigation requirement estimation of different crops of the Limbasi Canal command is carried out in the deterministic and stochastic regimes. In the deterministic regime, the estimated average NIR of 19 years for kharif crops paddy & vegetables was 229.8 & 92.9mm; rabi crops sorghum, tobacco, wheat & vegetables was 355.5, 391, 427.2 & 407.1mm and hot weather crops paddy, pearl millet & vegetables was 863.9, 600.6 & 754.7 mm respectively. In the stochastic regime, NIR estimation of different crops is carried out at Probability of Exceedance (PE) levels of 0.02, 0.05, 0.08, 0.10, 0.15, 0.20, 0.25, 0.35 and 0.40. The goodness of fit was tested by Kolmogorov – Smirnov test and normal distribution was found as best fit. NIR of crops was found to decrease with increase in PE levels in the stochastic regime.

Table 1: Net Irrigation Requirement of different crops of the study area in the deterministic regime

	Net irrigation requirement (mm)								
Season	Kharif		Rabi				Hot weather		
Year \ Crop	Paddy	Veg	Sorghum	Tobacco	Wheat	Veg	Paddy	Pearl millet	Veg
1993-1994	400.6	218.7	370.5	407.7	444.4	423.8	860.1	598.9	751
1994-1995	92.4	0	359.1	395.2	432.1	412.1	856.1	590.4	749.9
1995-1996	317	136.8	361.8	397.8	435	412.8	881.5	612.5	768.5
1996-1997	137	15.6	356.5	392.2	428	408	856.6	590	745.8
1997-1998	119.4	58.1	335.8	368.6	403.2	385.2	882.1	610.4	775.8
1998-1999	177.1	32.4	358.5	394.7	430	409.4	865.4	609.2	754.1
1999-2000	296.5	203.5	359.5	395.4	430.9	410.7	854.2	599.9	741.2
2000-2001	434.2	251.1	377.3	414.9	454.2	431.8	871.4	605.9	763.6
2002-2003	356.8	146.6	375.7	413.2	452.5	430.2	861.2	597.9	755.1
2003-2004	154	46	357.7	393.3	430	409.3	893.1	624.8	774.8
2004-2005	284.4	127	344.3	378.5	413.7	392.9	862.4	599.4	759.9
2005-2006	0	0	348.3	382.6	418.4	398.5	824.2	564	710.8
2006-2007	250.8	99.5	346.1	380.6	415.7	396.5	839	585.8	729.7
2007-2008	119.3	0	350.6	385.2	421.7	400.7	837.9	583.1	733.1
2008-2009	153.2	20.6	351.4	386.3	422.5	402.2	877.5	612.7	765.9
2009-2010	392.4	217.3	355	390.6	426.9	408.7	918.9	640.3	808.4
2010-2011	185.4	37.9	332.1	365.7	398.9	384.7	859.5	600.3	752.1
2011-2012	256.9	104.6	358.8	394.7	431.3	410	852.2	590.8	742.5
2012-2013	238.1	49.1	355.2	390.8	427.1	406.5	861.8	595.4	758.1
Average	**229.8**	**92.9**	**355.5**	**391**	**427.2**	**407.1**	**863.9**	**600.6**	**754.7**

(Veg. – Vegetables)

Table 2: Net Irrigation Requirement of different crops of the study area in the stochastic regime

	Net irrigation requirement (mm)								
Season	Kharif		Rabi				Hot weather		
PE level \ Crop	Paddy	Veg	Sorghum	Tobacco	Wheat	Veg	Paddy	Pearl millet	Veg
0.02	472.2	263.2	379.4	417.4	456.3	433.4	907.3	634.4	797.1
0.05	424	229.3	374.6	412.1	450.5	428.1	898.7	627.7	788.6
0.08	395.7	209.4	371.9	409.1	447.1	425.1	893.6	623.7	783.7
0.10	381.1	199.2	370.4	407.5	445.4	423.5	891	621.7	781.2
0.15	352.1	178.9	367.6	404.3	441.9	420.3	885.8	617.6	776.1
0.20	329.1	162.7	365.3	401.8	439.1	417.8	881.7	614.4	772.1
0.25	309.4	148.8	363.3	399.6	436.7	415.7	878.2	611.7	768.7
0.35	275.3	124.8	360	395.9	432.6	412	872.1	606.9	762.7
0.40	259.7	113.9	358.4	394.2	430.8	410.3	869.3	604.8	760

(Veg. – Vegetables)

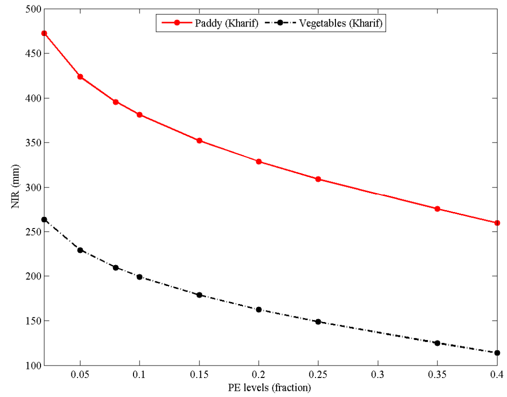

Figure 2: Variation of NIR of kharif crops at different PE levels

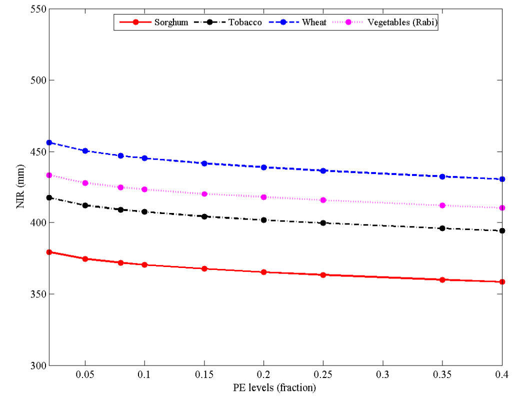

Figure 3: Variation of NIR of rabi crops at different PE levels

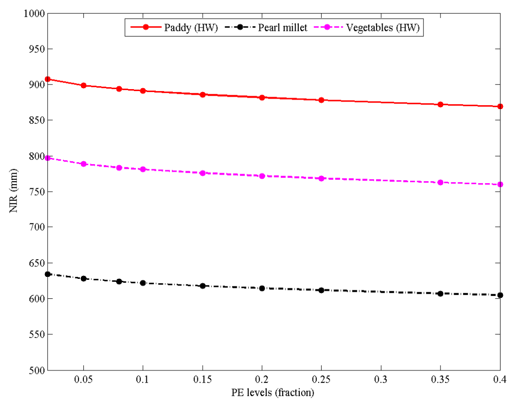

Figure 4: Variation of NIR of hot weather crops at different PE levels

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