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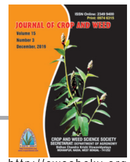

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Modeling crop water requirement using weather model under elevated temperature scenarios for scaling up quality of weather based agro advisory

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ABSTRACT

The rise in water demand for agriculture, industry, domestic and environmental requires sagacious planning and use of this limited resource, particularly in the face of changed climatic scenarios. Majority of the freshwater is being used for agriculture purpose. Precision crop water management requires reliable estimation of crop water requirement (Evapo-transpiration). Elevated temperature in changing climatic scenario has made water scarcity as the most prominent problem and has necessitated the assessment of future crop water requirement. The present study focused on the estimation of ET_0(Reference Evapo-transpiration), effective rainfall and crop water requirement (ETc) determined for all districts of Himachal Pradesh, in North Western Himalayas. The normal weather data of all districts of Himachal Pradesh representing sub-tropical to wet and dry temperate climatic conditions were used to estimate the ET_0 using Modified Penman Method. The crop water requirements for all months were worked using the average seasonal Kc value to the tune of 0.80. The projected increase of crop water requirement with 1°C, 2°C and 3°C rise in maximum and minimum temperature clearly portrayed that water requirement estimated was higher by 2-7% compared to normal weather conditions during rabi season than kharif in districts having sub-tropical to sub temperate climates. However, districts having temperate to wet/dry temperate climates observed higher crop water requirement during kharif season as crops are grown during kharif season only in these districts. ET_0 also followed similar trends in all districts.

Keywords: Crop water requirement, modified penman-monteith method, Himachal Pradesh

Water is the one of the most key input for crop production. Both its shortage and excess adversely affects the crop yield and quality. A liter of water produces about a kilocalories of food. As per the climate change projections the water scarcity is one of the primary world issues and it would be a more crucial challenge for the future. At global scale water use has increased six fold over the past century and is rising by about 1% a year (Anonymous, 2020).The global temperature rises by an average of 2°C and consequently up to one-fifth of the world population is expected to suffer from severe water shortages (Schiermeier, 2014). Agriculture, being the highest (81%) water consumer in India necessitates the judicious and efficient management of water uses in agriculture as the top most priority (Surendran *et al.,* 2014). Evapo-transpiration (ET) is important in understanding and managing water resources system in crop production. The mean annual precipitation over the whole country is 1190mm over 329 M ha of land area equivalent to 400 M ha-m (Million-hectare meters) and about 60% of which goes back to the atmosphere as evaporation and transpiration and 13% contributes to ground water (Anonymous, 2017). Climate change could alter the meteorological parameters and lead to changes in the irrigation water requirement during crop production (Behera *et al.,*2016). Fraiture and Wichelns (2010) estimated 53% increase in cropwater consumption is due to climate change and that about consequently, about 38% more land would be required to meet the food production goals in 2050. Chatterjee *et al*. (2012) also predicted that scenario of changing climate would increase irrigation water requirement by 7 to 8% till 2020 and it may increase to about 14 to 15% during 2050. The evapo-transpiration (ET) is known as the total water requirement of the crop. For agriculture water management, precise estimation of ET is required to model the crop water requirement.

The plausible impacts of climate change would impact the rate of evaporation and the temporal and spatial distribution of precipitation which would change and eventually lead to variation in available water and recharge of ground water. Hence, there arises a need to assess water requirement of the future for agriculture and other sectors. Crop production is affected by climate change, *i.e*., increase in temperature, CO_2 content and rainfall variability. The study assesses the impact of climate change on present and future crop water requirements using Modified Penman Monteith method.

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MATERIALS AND METHODS

In order to validate the ET_0 model with field water balance methods for estimating ET_0, a field experiment was conducted during winter season from October to May (*rabi* season) of 2016 and 2017. The experimental trial was laid in the experimental farm of Department of Agronomy, CSK HPKV, Palampur, Himachal Pradesh**.** Geographically, the site was located in North-Western Himalaya at $32^0$6' N latitude and $76^0$3' E longitude having an elevation of 1290.8 m above mean sea level. Agro-climatically the experimental area falls in sub-temperate and sub-humid zone, characterized by high rainfall with mild summers (19.0-31!) and severe winters (3.5 -13.4 ^{0}C). During crop growing season from October to May in 2016-17, the average weekly maximum and minimum temperatures varied between 10 to 34^0C and 0.5 to 25.5^0C , respectively. The crop experienced well distributed rainfall of 370.8 mm during the crop season. Prior to planning of the experiment, composite soil samples from 0-15 cm depth were collected from the experimental field before the sowing of the crop. The soil samples were then air dried, ground, passed through 2 mm sieve and analyzed for various physico-chemical properties as per standard methods.

Weather data base

Normal weather parameters *viz*. maximum and minimum temperature, rainfall, relative humidity, sunshine hours of all twelve districts of Himachal Pradesh taken from IMD , Pune and were used for estimating the ET_O of all the districts of the state using Modified Penman-Monteith method (Allen *et al*., 1998)**.** The normal weather parameters obtained from IMD for each district of Himachal Pradesh were used for estimating the normal ET_0 and projections for the parameter used in the scenario of enhanced temperature by 1, 2 and 3^{o}C were estimated from normal weather data.

The reference crop evapo-transpiration was estimated using the equation:

$ET_o = W.R_n+(1-W).F(u).(e_a-e_d)$

Here,

ET_o**=** The evapo-transpiration for the reference crop in mm/day (unadjusted).

W = weighing factor related to temperature.

R_n = the net radiation in equivalent evaporation in mm/day.

f(u) = the wind related function estimated by:

$f(u) = 0.27(1+U_2/100)$, where U_2 is the wind velocity at 2m height (km^{-1})

(e_a-e_d) = The difference between the saturated vapour pressure (in m bar) at mean air temperature and the mean actual vapour pressure of the air (in m bar),

Ed = ea x RH(mean)/100.

Also, here,

RH= Relative humidity

Rn=Rns-Rnl (mm day-1) difference between net shortwave (Rns) and the net longwave (Rnl) solar radiation.

The input data requirement was monthly, decadal (ten days) and daily for temperature (minimum and maximum), sunshine, humidity and wind-speed. Standard crop coefficients (Kc) of FAO modelled for local climatic conditions using standard methodology (FAO, 1992) and ETo were used to determine crop water requirements (ETc) using the following equation:

$ET_{crop} = K_c \times ET_o$

The model was run for wheat crop season of Palampur station for five different sowing windows during winter season from 15th October to 15th December, 2016-17. Modified Penman Monteith method was used for calculated the reference evapo-transpiration, crop water requirements and irrigation scheduling by present weather parameter of growing season 2016-2017. The impacts of increasing temperature were assessed for estimating crop water requirement of the crop using 1^{O}C, 2^{O}C and 3^{O}C rise in both maximum and minimum temperature. The other weather parameters *viz.,* humidity, sunshine hours and wind speed were taken as real time observations of 2016-17 during the crop season. The crop water requirement with elevated temperature was estimated and compared with the real time data. The reference evapo-transpiration (ET) estimated by Modified Penman-Monteith method model and Actual profile water depletion (AET) by field water balance method was validated and RMSE was observed for different months during growing season. The RMSE was 11.2. The estimated reference evapo-transpiration (ET) from model was used for developing futuristic crop water requirement of wheat under Palampur agro climatic conditions. The average value of crop coefficients of 0.8 was considered to estimate the crop water requirement in all districts.

The crop water requirement was calculated using the formula Effective rainfall- Crop Evapotranspiration (ET_c). The effective rainfall for each districts of HP was calculated by USDA Soil Conservation Service Method.

$$PE_{eff} = \frac{P_{tot} * 125 - 0.2P_{tot}}{125} \text{ for } P_{tot<250\ mm}$$

$$PE_{eff} = 125 + 0.1 * P_{tot} \text{ for } P_{tot>250\ mm}$$

Where

PE=effective rainfall (mm)

P_{tot}= Total rainfall (mm)

Crop water requirement

Todorovic (2005) stated that the crop water requirements are intimately connected with the crop evapo-transpiration losses as both these refer to the same amount of water. Irrigation water requirements and irrigation scheduling are estimated using CWR, which is expressed mostly in mm/day, mm/month or mm/season. The modified Penman Monteith method is used to estimate the crop water requirement. The crop ET was calculated using average crop coefficients 0.8 for all month to portray the scenarios of net irrigation requirement of crop in different districts.

RESULTS AND DISCUSSION

Effective rainfall

The effective annual and crop season (*rabi* and *kharif* seasons) rainfall for each district of Himachal Pradesh has been presented in Table 1 and 2. The data revealed that effective rainfall was more during the *rabi* season (November to May) due to low amount of rainfall received ranging between 386 to 853 mm in districts falling under high hills dry and wet temperate agro-climatic zones of state whereas other district in mid hill and low agro-climatic zones *rabi* rainfall ranged between 250 to 641 mm. This is the rainfall which ensured soil moisture availability in root zone for crop growth and development. Similarly, the effective rainfall in *kharif* season also ranged between 183.5 to 1567 mm for all districts. The district under high hills dry and wet temperate agro climatic zones of state which received less South-Western monsoon rainfall observed effective rainfall ranged between 342 to 988 mm. The effective rainfall in all districts warrants that *kharif* crop can be successfully grown without irrigation if south-west monsoon distribution rainfall is well distributed. In addition to major cereals crops like maize and rice, vegetables are also grown as rainfed crop in the state. The districts having low percentage of effective rainfall to total rainfall also indicated the surplus runoff to warrant field water harvesting potential for using pre sowing irrigations of *rabi* season crops.

Crop water requirement in different Agro-climatic zones of HP

Dry temperate agro-climatic regions

Two districts Kinnaur and Lahaul-Spiti fall under dry temperate agroclimatic zone of Himachal Pradesh. This region is characterized by dry temperate climate with less cultivable area having 55% effective rainfall and majority of this received during monsoon season. The crop growing season extends from March to October under normal weather conditions with average maximum and minimum temperature range from 9°C and 21.3°C in Lahaul-Spiti and 8.9°C to 20.5°C in Kinnaur with normal rainfall of 1308 mm and 734 mm, respectively. In normal weather conditions and rainfall, the total crop water requirement during crop season was 686 mm and 647 mm in Lahaul-Spiti and Kinnaur districts, respectively. Under the scenarios of elevated temperature, the crop water requirement increased by 2.25 to 8.26% and 1.98 to 7.86% with increased temperature from 1°C to 3°C in Kinnaur and Lahaul-Spiti districts, respectively. Kambale *et al.* (2017) reported similar results which indicated that rise in temperature would increase crop water requirement. Chattaraj *et al.* (2014) made similar observations in the semi-arid Indo-Gangetic plains of India, through computer simulations. They concluded that temperature gradient tunnels resulted in 18% higher crop evapo-transpiration (ETc) eventually leading to a 17% increase in water extraction by roots at 3.6°C elevated temperature as compared to 1.5°C increase over the ambient temperature. Similarly, Shah (2018) reported the crop water requirement for wheat, maize, potato and castor bean were 264.8 mm, 236.9 mm, 363.5 mm and 465.6 mm respectively, in climatic scenarios of Gujarat region.

Wet temperate agro climatic region

The wet temperate agroclimatic region having majority area of the districts Shimla, Kullu, Mandi and Solan have both high and mid hills. In this region the south- west monsoon contributes major part of rainfall *i.e.,* 75% of the total annual rainfall (1100-1550 mm). Under normal weather condition crop water requirement varies from 250 mm in Shimla to 390 mm in Kullu which is less then effective rainfall which ensures rainwater harvesting to the tunes of 100 mm in Shimla and 350 mm in Mandi. During the *rabi* season from November to May 10 (160 days) normal rainfall ranged from 60 to 700 mm with maximum and minimum temperature ranges of 23-28°C and 12-20°C respectively and crop water requirement of this region varied from 290 to 370 mm. During *kharif* season the normal rainfall ranged from 569 mm to 1140 mm. At the climatic grids of elevated temperature of 1°C to 3°C the crop water requirement increased by 2.25 to 8.29% and 2.29 to 7.08% in Kullu, 2.66 to 8.15% and 2.08 to 6.39% in Mandi, 2.36 to 7.76% and 2.63 to 7.71% in Shimla and 2.39 to 7.69% and 1.96 to 5.85% in Solan during *rabi* and *kharif* seasons, respectively (Table 1). Kullu, Mandi, Shimla and Solan received total rainfall of 664 mm, 1553.7 mm, 1105 mm and 1442.2 mm. Out of which 525.1 mm in Kullu, 988 mm in Mandi, 634.5 mm in Shimla and 900.3 mm in Solan contributed as effective rainfall which made 54.5, 63.6, 57.4 and 62.4 per cent of total rainfall, respectively. Similarly, Surendran *et al.*(2014) analyzed that the total crop water requirement of major crops, *viz.*banana, coconut and paddy increased with rising temperature thereby increasing the simulated irrigation water demand. The simulated gross water

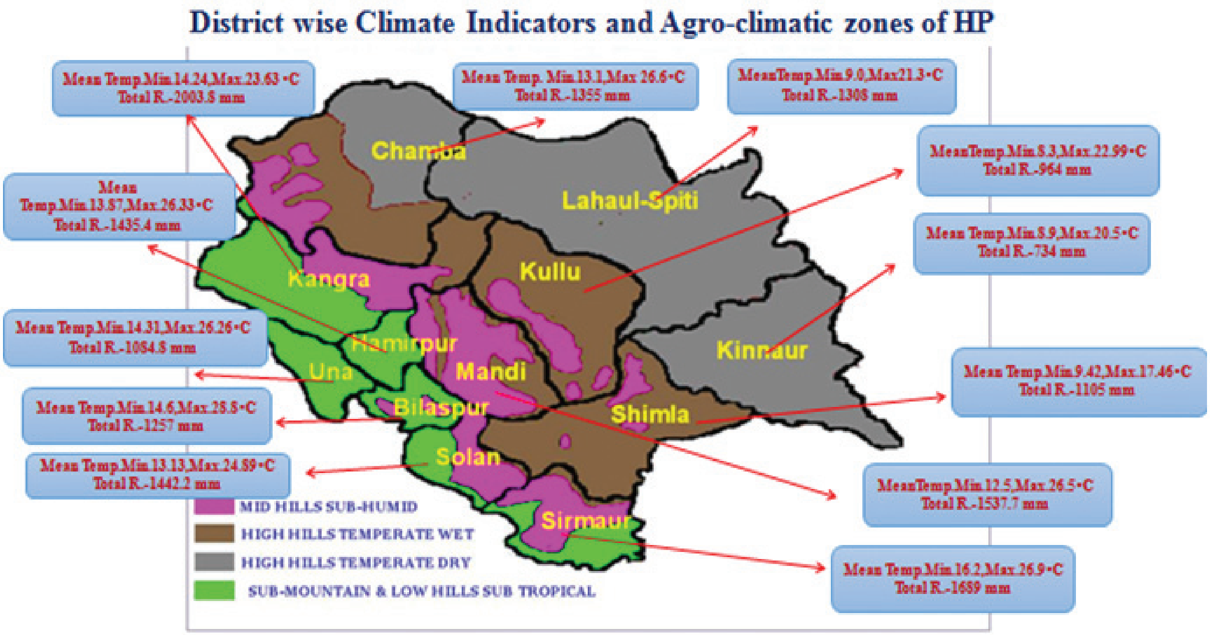

Fig.1: Weather parameters normal for all districts and Agro climatic zones of Himachal Pradesh

demand for an increase in temperature of 0.5, 1.0, 2.0 and 3.0°C will be 1,523, 1,791, 1,822 and 1,853 Mm^3, respectively. Chowdhury *et al.*(2016) also reported similar findings for crop water requirements (CWRs) from 2011 to 2050 in futuristic changing climatic scenarios. They concluded that, 1°C temperature increases may increase the overall crop water requirement by 2.9%. Gemechu (2016) also reported that the higher maximum temperature affected the crop evapo-transpiration of maize more than sorghum. He reported increment in crop evapo-transpiration by 15% and 34% in period of 2020 and 2050 in maize respectively. In case of Sorghum, during 2020, it showed negligible increment (1%) in crop evapo-transpiration and projected increase by 37% in 2050. This could be attributed to the decrease in relative humidity and increase in air temperature predicted in the future. Mehari (2019) reported that higher mean temperatures in the future would be reflected in the higher transpiration and evaporation thus impacting the demands of crop water requirement and net irrigation.

Mid hills sub humid and sub-mountain and low hills sub-tropical regions

The major part of the areas of district like Hamirpur, Kangra, Una, Bilaspur, Chamba and Sirmaur falls under the zone having mid hill to low hills. The normal maximum and minimum temperature ranged between 20-35 and 12- 21°C respectively whereas normal rainfall ranged between 250 to 641 mm in *rabi* season and 714 to 1567 mm in *kharif* season. The cultivated land was more compared to other zones. The crop water requirement under normal weather conditions ranged between 261.3 to 436.8 mm and 373.2 to 476.8 mm in *rabi* and *kharif* seasons, respectively. The contribution of south-west monsoon rainfall to all these districts is more than 75% and remaining 25% rainfall is received during winter season through westerlies. Generally, crop did not experience any soil moisture deficit during *kharif* season due to higher effective rainfall than crop water requirement. At the climatic grids of elevated temperature of 1°C to 3°C the crop water requirement increased by 2.50 to 8.24% and 1.98 to 6.40% in Hamirpur, 2.24 to 7.46% and 1.92 to 6.20% in Kangra, 2.57 to 8.21% and 1.94 to 6.22% in Una, 2.79 to 8.52% and 2.44 to 7.48% in Bilaspur, 2.66 to 8.48% and 2.06 to 6.48% in Chamba and 2.49 to 8.96% and 2.52 to 7.62% in Sirmaur during the *rabi* and *kharif* seasons, respectively (Table1). The contribution of effective rainfall for districts *viz*. Hamirpur, Kangra, Una, Bilaspur, Chamba and Sirmaur were 63.3, 67.3, 59.7, 66.8, 74.9 and 53.6 per cent of total rainfall, respectively (Table 2). Similarly, Chowdhury and Al-Zahrani (2015) also reported that the increase in temperature in such a range can increase evapo-transpiration by 10.3–27.4%. Goyal (2004) also reported an increase of 14.8% in evapo-transpiration (ET) with increase in temperature by 20%. Ziad and Siren (2010) also reported similar findings that irrigation demand would increase by 2.9 × 10^6 m^3 yr^{-1} if temperature increase of 3°C is accompanied by 20% decrease in precipitation levels. Rao and Punia (2011) predicted that if the temperature rises by 4°C, by

Table 1: District wise percent increase of crop water requirement with elevated temperature of 1°C, 2°C and 3°C for Himachal Pradesh

Districts	Increase crop water requirement (%)			Total rainfall (mm)	Effective rainfall (mm)	Effective rainfall (%)
	1 °C	2 °C	3 °C			
Hamirpur						
rabi	2.00	4.26	6.43	342.0	313.3	91.6
kharif	1.58	3.36	5.12	1093.4	550.0	50.3
Kangra						
rabi	1.79	3.89	5.97	436.4	390.7	89.5
kharif	1.54	3.31	4.96	1567.4	621.1	39.6
Kinnaur						
rabi	2.22	4.50	6.61	550.5	477.0	86.6
kharif	1.80	3.64	5.28	183.5	169.3	92.3
Kullu						
rabi	2.02	4.30	6.63	394.2	356.1	90.3
kharif	1.83	3.82	5.67	569.8	420.6	73.8
Lahaul & Spiti						
rabi	1.95	4.24	6.29	853.1	676.5	79.3
kharif	1.59	3.27	5.00	455.7	362.1	79.5
Mandi						
rabi	2.13	4.37	6.52	413.6	373.5	90.3
kharif	1.67	3.42	5.07	1140.1	569.6	50.0
Shimla						
rabi	1.89	4.01	6.21	386.0	350.5	90.8
kharif	2.11	4.05	6.17	719.0	480.8	66.9
Solan						
rabi	1.91	4.06	6.15	404.3	366.0	90.5
kharif	1.57	3.14	4.68	1037.9	554.7	53.4
Una						
rabi	2.05	4.39	6.57	250.4	235.5	94.0
kharif	1.55	3.29	4.98	834.4	481.4	57.7
***B*ilaspur**						
rabi	2.23	4.43	6.82	343.2	315.7	92.0
kharif	1.96	3.93	5.99	913.5	523.9	57.4
Chamba						
rabi	2.13	4.49	6.79	641.0	540.0	82.2
kharif	1.65	3.44	5.19	714.1	475.5	66.6
Sirmaur						
rabi	2.35	4.80	7.17	328.3	303.9	92.6
kharif	2.02	4.06	6.09	1360.4	601.7	44.2

Table 2: District wise total rain fall, effective rain fall and percent effective rainfall of Himachal Pradesh

District	Total rainfall (mm)	Effective rainfall (mm)	Percent effective rainfall of total
Hamirpur	1435.4	907.7	63.2
Kangra	2003.8	1349.0	67.3
Kinnaur	734.0	342	46.6
Kullu	964.0	525.1	54.5
Lahual&Spiti	1308.8	772.8	59.0
Mandi	1553.7	988	63.6
Shimla	1105.0	634.5	57.4
Solan	1442.2	900.3	62.4
Una	1084.8	647.2	59.7
Bilaspur	1257.0	840	66.8
Chamba	1355.0	1016	74.9
Sirmaur	1689.0	906	53.6

the end of 21st century, water requirement in arid Rajasthan would increase from the current level, by 12.9% for cluster bean and pearl millet, 13.2% for moth bean, 17.1% for wheat, 12.8% for green gram and 19.9% for mustard. Another study revealed that 1°C rise in temperature from normal enhanced the annual ET demand from minimum of 35 mm for Ganganagar district to maximum of 96 mm for Jaisalmer district (Goyal *et al*., 2013)

The present study focused on estimation of ET_0, effective rainfall and crop water requirement (ETc) determined for all districts of Himachal Pradesh in North Western Himalayas. The normal weather data of all districts of Himachal Pradesh representing sub-tropical to wet and dry temperate climatic conditions were used to estimate the ET_0 using Modified Penman Method. The projected increase of crop water requirement with 1°C, 2°C and 3°C rise in maximum and minimum temperature clearly portrayed that water requirement estimated was higher by 2-7% compared to normal weather conditions during *rabi* season than *kharif* in districts having sub-tropical to sub temperate climates. Whereas district having temperate to wet/dry temperate climates observed higher crop water requirement during *kharif* season as crops are grown during *kharif* season only in these districts. The crop water requirement vis a-vis weather forecast is more crucial for *rabi* season than *kharif* season crops in districts fall in low and mid hill agro-climatic conditions than districts in high hills having wet/dry temperate climates. The study is thereby useful in planning the crop water requirement integrating with weather forecasts for scaling up quality of weather based agro advisory.

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