Estimation of crop water requirements within Wainganga sub-basin for Kharif and Rabi season using spatial analysis

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Abstract. In India, largest user of the water is agriculture sector is the, so it is important to do the proper management of available water. Aim of this study to estimate crop water requirements (CWR) for Kharif and Rabi seasons within Wainganga sub-basin by using remote sensing and GIS technique. For this, reference evapotranspiration (ET₀) is estimated by using the Food and Agricultural Organization (FAO) Penman-Monteith method. Weather data from 8 weather stations has been collected to estimate ET₀. The crop coefficient (Kc) is estimated by using linear relationship with Normalized Difference Vegetation Index (NDVI). The MODIS NDVI dataset is used for calculation of crop coefficient. The effective precipitation (Pe) has been calculated to estimate CWR by using FAO recommended empirical method. The spatial variation maps for ET₀, Kc, actual evapotranspiration (ETa) and CWR are generated using Inverse Distance Weightage (IDW) interpolation technique in ArcGIS software. The results show that ET₀ and ETa are higher in Kharif season than the Rabi season. The Kc is also found higher in kharif than in rabi. Since the Pe is negligible in Rabi season, CWR in Rabi season is found to be higher than kharif season. The CWR in Rabi varies between 320 mm to 378 mm and in kharif season it varies between 94 mm to 263 mm. It is concluded that the seasonal estimation of CWR helps in understanding the peak water demand in that season in better way. It is required to provide sufficient irrigation to the crops in Rabi season especially as the agricultural production completely depends on the irrigation facilities in the study area because there is no rainfall in this season.

Keywords: Crop water requirement, kharif and rabi season, spatial analysis, reference and actual evapotranspiration, effective precipitation.

1. Introduction

Water is the most important component for the agriculture production. There is increase in demand of freshwater due to rising population, urbanization and industrialization. Due to global warming, temperature increases rapidly and hence, demand of freshwater increases as well. Due to the rise in temperature and variation in climatic factors, crop production and crop water requirements are significantly affected [1]. As the effective precipitation is the key factor for the crop water requirement estimation, it is important to analyse the effects of climate change on precipitation. There is need to get thorough knowledge about the climate change effect on reference evapotranspiration, actual evapotranspiration and effective precipitation to monitor and control the future agricultural policy, research and development [2].

In recent studies, researchers have estimated reference crop evapotranspiration by using many methods such as crop models based on climatic parameters or surface observations, remote sensing...
techniques and FAO Penman-Monteith method. Montazar et al 2020 [3] used residual of energy balance approach for estimation of $ET_a$ and $K_c$ in California with the aim to better manage limited water resources by gaining more accurate knowledge regarding evapotranspiration of crops.

Many researchers give the different models and methods for the crop water requirements. Li et al. 2020 [4] estimated irrigation water requirements based on GIS techniques and Penman-Monteith formula for three main crops (wheat, cotton and corn) during their growing periods in Xinjiang province, China. It was concluded that planting area of crops were generally more sensitive to irrigation water requirements than rising temperature. Wang et al. 2020 [1] used CROPWAT 8.0 to estimate crop water requirements in Heilongjiang Province, China. Mann-Kendall trend test was used to analyse the changing trend of $ET_0$, $ET_a$ and $P_e$. Usman et al. 2021 [5] used surface energy balance system model to estimate $E_a$ and FAO-56 Penman-Monteith method to estimate $ET_0$ and comparison between them.

The main objective of the study is to calculate the CWR within Wainganga river sub-basin, Nagpur, Maharashtra. For this weather data from 8 weather stations has been obtained and analysed. The $ET_0$ was calculated by using FAO Penman-Monteith method and $K_c$ was estimated by using MODIS NDVI data. $P_e$ was calculated by using FAO based empirical method. IDW method is used for interpolation of weather data in GIS environment. The spatial variation of $K_c$, $ET_0$ and CWR for kharif and Rabi season was also estimated.

The objectives of the present study are as follow:

1) To calculate the Crop water requirement of the study area for both Kharif and Rabi seasons for the years 2001, 2005, 2010 and 2013.
2) To calculate and analyse spatial variation of $ET_0$, $K_c$ and $ET_a$ in the study area.
3) To calculate effective precipitation within study area.
4) To analyse the spatial variation of crop water requirement in study area due to climate change for Kharif and Rabi seasons.

2. Study Area

Wainganga River sub-basin is located in Nagpur district, Maharashtra, India. It lies between 21°10′0″N to 21°40′0″N latitude and 78°30′0″ E to 79°20′0″ E longitude (Figure 1). The Wainganga River sub-basin has elevation range from 304 m to 467 m above mean sea level. The total area is 1677.2911 Sq. Km. Wainganga River basin within Nagpur District has 40 sub-watersheds [6], out of them 8 sub-watersheds are selected for study. The geographical location map of the study area is shown in Figure 1.
Figure 1. Location map of the Wainganga river sub-basin

3. Data Used

3.1 Meteorological Data
Meteorological data is obtained from CFSR (Climate Forecast System Reanalysis) which is coupled atmosphere, ocean and land system developed at NOAA-NCEP. The spatial resolution of CFSR data is 0.35°. CFSR provides the maximum and minimum temperatures (°C), precipitation (mm), wind velocity (m/s), humidity (%) and solar radiation (MJ/m²) values from 1979 [7]. Meteorological data obtained from CFSR is useful to estimate ET₀ by FAO Penman Monteith method.

3.2 MODIS NDVI Data
MODIS NDVI data was downloaded and analysed. There are two platforms from where datasets are collected viz. Aqua and Terra. MOD13Q1 data has spatial resolution of 250 m and temporal resolution of 16 days. The NDVI is a vegetation index, which gives the information about the actual growth condition of the vegetation. NDVI value varies between -1 to +1. During a year, minimum NDVI occurs in May and maximum NDVI occurs in September.
4. Methodology

The main objective of study is to estimate the CWR for the part of Wainganga sub-basin which is situated within Nagpur for kharif and rabi seasons. For this, precipitation, wind speed, relative humidity, solar radiations and temperature were collected. ET₀ was estimated by using Penman-Monteith method [8, 9]. The Penman-Monteith method is widely used all over the world for estimating ET₀. For the estimation of KC, MODIS NDVI data is used. The ET₀ was calculated by using KC and ET₀. The Pe was calculated by using empirical formula which is suggested by FAO using total monthly precipitation. Finally, the CWR is estimated by using Et₀ and Pe.

The overall methodology adopted for the calculation of CWR is given in flowchart (Figure 2) as follows:

![Flowchart](image)

**Figure 2.** Overall methodology adopted for calculation of crop water requirements

4.1 FAO Penman-Monteith method for Calculation of ET₀

The FAO Penman-Monteith method is now mostly recommended method for estimation of ET₀ which is applicable in almost all regions and climatic conditions. The Penman-Monteith method uses precipitation, daily mean temperature, relative humidity, solar radiations and wind speed. Zotarelli, et.al (2010) [10] provides steps for calculation of ET₀. The equation for the estimation of ET₀ is given as Eq. 1.

\[ ET₀ = \frac{0.408 \Delta (R_n - G) + \gamma \left[ \frac{900}{T+273} \right] u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \]

\[ \text{Eq. 1} \]

Where, ET₀ is reference evapotranspiration [mmday⁻¹];
Rn is net radiation at the crop surface [MJ/m²/day];
G is soil heat flux density [MJm⁻²day⁻¹];
T is mean daily air temperature at 2 m height [°C];
u₂ is wind speed at 2 m height [ms⁻¹];
e_s is saturation vapour pressure [kPa];
ea is actual vapour pressure [kPa];
e_s-e_a is saturation vapour pressure deficit [kPa];
Δ is slope vapour pressure curve [kPa/°C] and
γ is psychrometric constant [kPa/°C].

4.2 Estimation of crop coefficient (KC) by using satellite-based vegetation index

The crop coefficient is determined by using NDVI. The different models were developed to estimate crop coefficient directly with the help of NDVI. Kamble et al. (2013) [11] developed simple linear relation model for crop coefficient estimation. The linear relation between KC and NDVI is given as Eq. 2.

\[ KC = 1.457 \times (NDVI) - 0.1725 \]  
Eq. 2

Where, KC - Crop Coefficient;
NDVI - Normalised Difference Vegetation Index.

4.3 Calculation of Crop water Requirements (CWR)

The crop water requirement is the actual water required to that crop during its growth period. The crop water requirement estimation formula [4] is given as follows,

\[ CWR = ET_a - P_e \]  
Eq. 3

Where, ET_a - Actual evapotranspiration in mm/day;
P_e - Effective precipitation in mm.

The ET_a in mm for 3 months was calculated and also effective precipitation for 3 months for each season was calculated. The obtained CWR values were interpolated by IDW tool in ArcGIS software. The spatial variation maps of CWR for kharif and Rabi season were generated.

5. Results and Discussion

The estimated results of ET_0 obtained from the FAO Penman-Monteith method are analysed for kharif and rabi seasons for years 2001, 2005, 2010 and 2013. The KC estimated by using MODIS NDVI data, ET_a by using ET_0 and CWR using ET_a and P_e within study area for kharif and rabi seasons are compared and analysed.

Statistical summary of the ET_0 (mm/day), KC, ET_a ((mm/day)) and CWR (mm) over study area for kharif and rabi seasons are summarized in Table 1.

|       | ET_0   | KC      | ET_a   | CWR    |
|-------|--------|---------|--------|--------|
|       | Kharif | Rabi    | Kharif | Rabi   | Kharif | Rabi   |
| 2001  | 4.686  | 3.931   | 0.739  | 0.371  | 3.460  | 1.457  | 201.555| 359.723|
| 2005  | 3.853  | 4.046   | 0.757  | 0.415  | 2.914  | 1.681  | 49.138 | 369.789|
| 2010  | 3.841  | 3.606   | 0.775  | 0.506  | 2.976  | 1.824  | 38.985 | 327.015|
| 2013  | 3.503  | 3.485   | 0.714  | 0.472  | 2.499  | 1.645  | 20.455 | 316.903|

The statistical values of CWR in Table 1 indicate that the CWR for rabi season is much more as compared to the kharif season. This is because of the effective precipitation is zero in rabi season as
there is no precipitation and more effective precipitation during kharif season due to monsoon rainfall. This affects the requirement of the crop water in the different seasons in the study area.

5.1 Spatial variation of ET₀ for Kharif and Rabi season

The accurate estimation of ET₀ is important for ETₐ estimation. These weather data is collected from 8 weather stations for year 2001, 2005, 2010 and 2013 which is further interpolated in ArcGIS. The spatial variation maps are prepared for years 2001, 2005, 2010 and 2013. The spatial variation maps for kharif and rabi season for respective years are as shown in Figure 3.

![Figure 3](image_url)

The results show that the ET₀ varies in Kharif season ranges from 3.38 mm/day to 4.78 mm/day. The ET₀ value slightly decreases from 2001 to 2013 for kharif season. The rate of ET₀ is maximum at western side of Wainganga basin within Nagpur for year 2001 and then moved to the eastern part of the study area for year 2005. ET₀ rate is less in northern part of the study area.

Variation of ET₀ in Rabi season ranges from 3.4 mm/day to 4.17 mm/day. The rate of ET₀ is slightly increases from year 2001 to 2005 and then decreases for year 2010 and then again decreases for year 2013. The rate of ET₀ is slightly lower at western part of the study area. As the available moisture content in atmosphere is less in rabi season than kharif season, ET₀ rate is lower in Rabi season.

5.2 Spatial variation of crop coefficient (Kₐ) for Kharif and Rabi season

The Kₐ depends on the growth stages of the crop, canopy of crop and area under crop. The Kₐ is higher at peak growth stage and then decreases when the crop attends maturity. The MODIS data was processed in ArcGIS and Kₐ was calculated by using Raster Calculator tool in ArcGIS. Spatial variation maps of Kₐ are shown in Figure 4.
Results of spatial variation of $K_C$ show that the $K_C$ value varies from -0.047 to +1.10 in kharif season. The negative values are indicating the presence of water body. The spatial variation maps of $K_C$ indicate that in Rabi season $K_C$ value ranges from -0.30 to +0.86. The result shows that the $K_C$ is higher in Kharif season than Rabi season. The reason behind this may be the initial growth stage of the crop. The $ET_a$ is affected by the $K_C$ value. $K_C$ is the simply ratio of $ET_a$ to $ET_0$.

### 5.3 Spatial variation of $ET_a$ for Kharif and Rabi season

The $ET_a$ is the loss of water due to evaporation and transpiration from actual crop field. Spatial variation maps of $ET_a$ are shown in Figure 5.

The results show that, $ET_a$ value varies up to 4.78 mm/day in Kharif season and 3.51 mm/day in Rabi season. It is clearly revealed that $ET_a$ is higher in kharif season than Rabi season. The maximum $ET_a$ in kharif season was found to be 4.78 mm/day in year 2001, 4.18 mm/day in 2005, 4.05 mm/day in 2010 and 3.62 mm/day in 2013. Whereas in Rabi season, maximum $ET_a$ was found to be 2.88 mm/day in year 2001, 3.51 mm/day in year 2005, 2.98 mm/day in year 2010 and 2.78 mm/day in year 2013.
The crop water requirement varies with the crop as well as for the different seasons. Here the spatial variation maps for CWR are prepared for kharif as well as rabi season for years 2001, 2005, 2010 and 2013. CWR for given study area was estimated with the help of actual evapotranspiration rate for 3 months in mm and effective precipitation for equivalent 3 months in mm. The spatial variation maps for CWR for kharif and Rabi season are given in Figure 6.

The results show that the maximum CWR varies from 320 mm to 378 mm for Rabi season and it varies from 94 mm to 263 mm in Kharif season. The results show that water requirement for crops is maximum in rabi season as compared to Kharif season. The precipitation is the important affecting factor. During the Rabi season the precipitation is very less or negligible; so effective precipitation is found to be zero and hence, CWR is maximum in rabi season than kharif season. Also in Kharif season, the precipitation is quite sufficient to fulfil the water requirements of the crops. The results also show that the CWR in Rabi season decreases gradually from year 2001 to year 2013. This is because of the changing climate and other anthropogenic activities related to the agriculture.

6. Conclusion

The main objective is to estimation of crop water requirements within Wainganga sub-basin for kharif and rabi season. And the spatial variation maps for ET₀, ETₐ and CWR are also prepared and analysed. The results show that ET₀ is lower in Rabi season than because of the variation in soil moisture content in Kharif and Rabi season.

The spatial variation maps of K_c show that value of K_c is higher in Rabi season than Kharif season. The K_c directly affects the actual evapotranspiration rate. The K_c was estimated by using MODIS NDVI data. As NDVI directly related to the crop coefficient, it represents the growth stages of crop and crop type. The ETₐ map shows that ETₐ is higher in kharif season than Rabi season as ET₀ is maximum in kharif season because of higher temperature.

The spatial variation maps of CWR shows that the CWR in Rabi season is higher than Kharif season. The maximum CWR found in rabi season which range from 320 mm to 378 mm and in kharif season, CWR is range from 94 mm to 263 mm. The rainfall reduces the amount of irrigation water requirement as water requirements is fulfilled by rainfall mostly. It is concluded that the seasonal estimation of CWR helps in better understanding the peak crop water demand. It is required to select
sufficient irrigation discharge to the crop field in rabi season specially as the agricultural production is completely depends on the irrigation water because of no rainfall in this season. Hence, the remote sensing and GIS techniques proved to be most reliable technique as all the data required for CWR estimation is easily available and it can be used to generate spatial variation maps of all the parameters.

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