"Assessment of Crop Water Requirement & Irrigation Water Requirement for Vegetable Crops over Uttar Pradesh Using Cropwat Model "

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THE CERTIFICATE OF ACCEPTANCE OF EVALUATION COMMITTEE

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CERTIFICATE OF ORIGINAL WORK

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%	:	Percentage
&	:	And
/	:	Per
@	:	At the rate of
ºC	:	Degree Centigrade or Celsius
Avg.	:	Average
Cropwat	:	Crop water
e.g.	:	For example
et al.	:	And others
etc	:	Et cetera
ET	:	Evapotranspiration
ETc	:	Crop water requirement
ETo	:	Reference evapotranspiration
FAO	:	Food Agriculture Organization
FC	:	Field capacity
Fig.	:	Figure
GCM	:	General Circulation Model
GIS	:	Geographical information system
i.e.	:	That is
IMD	:	Indian Meteorological Department
IPCC	:	Intergovernmental Panel on Climate Change
IWR/IR	:	Irrigation water requirement
Kc	:	Crop coefficient
Ky	:	Yield response factor
max.	:	Maximum
min.	:	Minimum
mm	:	Millimeter
mt	:	Metric tonnes
N	:	North
No.	:	Number

pp (s)	:	Page(s)
RAM	:	Readily available moisture
RCP	:	Representative Concentration Pathway
Ref	:	Reference(s)
Res.	:	Research
RH	:	Relative Humidity
Temp.	:	Temperature
Viz	:	Namely

Assessment of Crop Water Requirement & Irrigation Water Requirement for Vegetable Crops over Uttar Pradesh Using Cropwat Model

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ABSTRACT

Water scarcity becomes a major intimidation to crop production. There are a lot of changes in climate that affects on hydrological process. It will fall directly on agricultural production and productivity. Mostly vegetables are grown under irrigation and very quickly suffered from drought. Supplemental irrigation was essential for good yields. In this manner present study was conducted on water requirements on vegetables (Potato, Pea and Cabbage) over Uttar Pradesh with help of Cropwat software using the weather data of minimum temperature, maximum temperature and rainfall for the period 1980-2014. The analysis were performed in two date of sowing 15th October and 15th November. The seasonal crop water requirement (ETc) and irrigation water requirement (IWR) of potato varied between 271 mm (Bijnor) to 409.1 mm (Lalitpur) and 218 to 360.9 mm respectively for 1st date of sowing. While for 2nd date of sowing ETc and IWR ranged between 287.3 mm (Bijnor) to 439.1 mm (Lalitpur, Jhansi & some parts of Mahoba) and 219.2 mm to 392.7 mm respectively. The ETc and IWR of Pea varied between 206.6 mm to 303.6 271 mm and 184.6 mm to 274.1 mm respectively for 1st date of sowing. While for 2nd date of sowing ETc and IWR ranged between 181.5 mm to 279.7 mm and 145.6 mm to 246.6 mm respectively. The ETc and IWR of Cabbage varied between 388.1 mm to 577.4 mm and 309.5 mm to 519.2 mm respectively for 1st date of sowing. While for 2nd date of sowing ETc and IWR ranged between 453.3 mm to 655.9 mm and 368.4 mm to 604.1 mm respectively. The experimental analysis revealed that early date of sowing (15th October) required less ETc and IWR as compared to other date of sowing. Further to observe the effect of long term climate change (year 2020, 2050 and 2080) on ETc and IWR of Potato were estimated using IPCC AR5 data with RCP 4.5 scenario. Results revealed that with the time ETc and IWR has found to be increased. This study is capable for strategic planning in irrigation management and scheduling in the view of water saving technologies.

Keywords: Climate change, ETc, IWR, Cropwat, Arc GIS and Potato, Pea & Cabbage.

Vegetables are part of food, which is rich in vitamins and minerals. Vegetables are being cultivated mainly in Rabi season with irrigation. The water requirements of vegetable crops are less, but unknowingly the farmers are applying more water **Ancy (2016)**. The effective utilization of water is important in the context of increasing water demand. Water is the basic need for agricultural and the economic development of any country. There is a competition between municipal, industrial and agriculture users for the available water. Actual water shortages are observed in many countries particularly in India. Therefore, it is important that the water requirements of crops are known at different management levels within the irrigated area to accomplish effective irrigation management. More than 80% of water resources have been exploited for agricultural irrigation. To cope with the water shortage, it is necessary to adopt water saving agriculture counter measures as efficient use of irrigation water is becoming increasingly important. The main objective of irrigation is to apply water to soil to meet crop evapotranspiration requirement when rainfall is insufficient to raise crop till harvesting. The term crop water requirement means the total amount of water required by the crop and the way in which it requires water from the time of planted up to the time which is harvested. (**Mehanuddin *et al*., 2018).** Irrigation includes application of the right quantity or amount of water at the right time to the soil for plant growth. Hence estimating irrigation water requirements is necessary for water project planning and management.

CROPWAT model is a computer program for irrigation planning and management, developed by the **Land and Water Development Division of FAO (1992)**. Its basic functions include the calculation of reference evapotranspiration, crop water requirements and crop scheme irrigation. Through a daily water balance, the user can stimulate various water supply conditions as well as estimate yield reductions and rainfall efficiencies. Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, the evaluation of irrigation practices, as well as rainfed production and drought effects. There are two new versions of the CROPWAT: one is CROPWAT v 7.0 that contains a completely version in Pascal, developed with the assistance of the Agricultural College Velp Netherlands (**Deo, 2017)**. It overcomes many of the shortcomings of the original 5.7 version. CROPWAT 7.0 is a DOS-application, but it runs without any problem in all MS-WINDOWS environments. Another one is CROPWAT v 8.0

for Windows that is written in Visual Basic and operates in the Windows environment. It has been developed with the assistance of the International Irrigation & Development Institute (IIDS) FAO (1992) in which Penman-Montieth method for calculating the reference crop evapotranspiration is used. These estimates are used in crop water requirements and irrigation scheduling calculations.

POTATO (*Solanum tuberosum)*

Potato is a starchy, tuberous crop from the perennial nightshade. Potatoes have become a staple food in many parts of the world and an integral part of much of the world's food supply. Potato is the world's 4^{th} largest food crop, following maize (corn), rice and wheat. Potato is introduced to Europe in the second half of the 16th century by the Spanish. Water is a very important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing period **Panigrahi *et al.*, 2001.** Moreover, fertilization especially potassium is considered one of the most important factors affecting the growth and yield of potato.

The potato was originally believed to have been domesticated independently in multiple locations, but later genetic testing of the wide variety of cultivars and wild species proved a single origin for potatoes in the area of present-day southern Peru and extreme north western Bolivia, where they were domesticated approx 7,000–10,000 years ago. But the most rapid expansion over the past few decades has occurred in southern and eastern Asia, as of 2014. China led the world in potato production and together with India, produced 37% of the world's potatoes. Uttar Pradesh is the major crop producer in Potato (2017-18), area sown is 614.8 thousand ha. The production of Potato during the year (First Advance Estimate) is estimated to be 1.5% higher as compared to the previous year. However as compared to past 5 years average production, it is 8.7% higher. Potato is short duration crop but particular important in the temperate climates. For higher yields, the water requirements of potato are 500 to 700 mm, depending on climate (FAO) potato may be more sensitive to water stress than any other crops, because it has a sparse root system that is concentrated in the upper 30 cm soil layer (**Van Loon, 1981**). Although potato roots can penetrate to a depth of about one meter below the soil surface, they do not extract water from deep soil layers as effectively as many other crops. Potato is generally considered to be rather sensitive to drought and even short periods of water shortage can result in reduction both of tuber production and of tuber quality (**Miller and Martin, 1987)**.

CABBAGE (*Brassica oleracea*)

Cabbage is a leafy green, red (purple), or white (pale green) biennial plant grown as an annual vegetable crop for its dense-leaved heads. It is descended from the wild cabbage, B. oleracea var. oleracea, and belongs to the "cole crops", meaning it is closely related to broccoli and cauliflower (var. botrytis). Cabbage generally range from 0.5 to 4 kilograms (1 to 9 lb), and can be green, purple or white. Smooth-leafed, firm-headed green cabbages are the most common. Smooth-leafed purple cabbages and crinkle-leafed savoy cabbages of both colours are rarer. It is a multi-layered vegetable. Under conditions of long sunny days, such as those found at high northern latitudes in summer, cabbages can grow quite large. As of 2012, the heaviest cabbage was 62.71 kg (**www.guinnessworldrecords.com)**

Cabbage was most likely domesticated somewhere in Europe before 1000 BC, although not developed until the 16th century AD. By the Middle Ages, cabbage had become a prominent part of European cuisine. Cabbage are generally picked during the first year of the plant's life cycle, but plants intended for seed are allowed to grow a second year and must be kept separate from other cole crops to prevent cross-pollination. The Food and Agriculture Organization of the United Nations (FAO) reported that world production of cabbage and other brassicas for 2014 was 71.8 million metric tonnes. Cabbage has been classified as intermediately susceptible to water stress, with the head formation period being more sensitive than the period before. It was reported that the most critical irrigation period for cabbage occurred during the last 3 to 4 weeks before harvest.

Pea (*Pisum sativum)*

Pea is a most commonly green, occasionally golden yellow, or infrequently purple pod-shaped vegetable, widely grown as a cool season vegetable crop. Water is a major factor determining the kinds and amounts of natural vegetation as well as crop yields in different regions (**Salter and Goode 1967).** The seeds may be planted as soon as the soil temperature reaches 10 °C (50 °F), with the plants growing best at temperatures of 13 to 18 °C (55 to

64 °F). They do not thrive in the summer heat of warmer temperate and lowland tropical climates, but do grow well in cooler, high altitude, tropical areas. Many cultivars reach maturity about 60 days after planting. Peas have both low-growing and wining cultivars. The wining cultivars grow thin tendrils from leaves that coil around any available support and can climb to be 1–2 m high. A traditional approach to supporting climbing peas is to thrust branches pruned from trees or other woody plants upright into the soil, providing a lattice for the peas to climb. Branches used in this fashion are sometimes called pea brush. Metal fences, twine, or netting supported by a frame are used for the same purpose. In dense plantings, peas give each other some measure of mutual support. Pea plants can self-pollinate Peas are starchy, but high in fibre, protein, vitamin-A, vit-B6, vit-C, vit-K, phosphorus, magnesium, copper, iron, zinc and lutein.

The water relations of pea have often been considered in relation to three successive developmental stages: from planting until the start of flowering; during flowering; and the period of pod and seed growth and maturation. Availability of water, whether as rain or from irrigation, has been a major factor influencing the distribution and yield of pea. Consumptive water use (CWU) of these crops varies with species, climatic and soil conditions, and with the growth period. It amounts to between 350 and 500 mm per year **(FAO, 1979).**

Nowadays on worldwide there is a water-shortage, accordingly it is necessary to adopt water saving agriculture as a counter measure as well as efficient use of irrigation water is becoming increasingly important. A lot of water resources have been exploited for irrigation purpose. Therefore, the objective of research was to collect information of crop water requirement and irrigation water requirement of potato, cabbage and pea crops

Objectives:

- To determine reference evapotranspiration (ET_0) by Penman Monteith equation and effective rainfall using CROPWAT model over Uttar Pradesh.
- To estimate crop water requirement and irrigation water requirement of potato, pea & cabbage over Uttar Pradesh.
- To analyse the effects of climate change on crop water requirement and irrigation requirement in 2020, 2050 and 2080.

In the present investigation entitled "Assessment of Crop Water Requirement & Irrigation Water Requirement for Vegetable Crops over Uttar Pradesh Using Cropwat Model". Review of literature has been presented in this chapter. The review of literature has been categorized under following sub heads:

2.1 Reference crop evapotranspiration and effective rainfall using CROPWAT model

2.2 Crop water requirement & Irrigation water requirement through CROPWAT model

2.3 Effect of climate change on water requirement.

2.1 Reference crop evapotranspiration and effective rainfall using CROPWAT model

Nazeer (2009) experiment was conducted on maize crop from the Mardan district of NWFP, Pakistan were collected and analyzed then input the results to the Cropwat irrigation management model for the period 2006. Results showed that the reference crop evapotranspiration is at peak 6.08mm/day at the beginning stage, slightly reduced at growing stage 5.20mm/day, than at mid stage 3.58mm/day and at last stage it reaches to 1.36 mm/day. During the first four irrigation application 73.8mm of water is lost, the first irrigation lost 23.2mm, the second lost 23.2mm, the third 22.8mm and fourth one irrigation lost 4.70 mm water. The main cause for losing of irrigation water is the bare soil. **Qiang *et al.* (2009)** estimated the reference evapotranspiration (ETo), crop water requirement and crop water deficit were calculated using modified Penman-Monteith equation for winter wheat and maize in Hebei. Results showed a significant decrease in reference evapotranspiration and crop water requirement. Decrease in crop water requirement was 26 mm per decade for winter wheat and 9.7 mm and 9.9 mm for summer and spring maize, respectively, differences in water deficit among different crops but the average increase in water deficit was insignificant, which is respectively 345 mm, 20 mm and 29 mm per year for winter wheat, summer maize and spring maize.

Gowda *et al.* (2013) conducted experiment on estimating water requirement of maize (Zea mays L.) for under rainfed condition at Dharwad during kharif season of 2011 in field deep black soil at Main Agricultural Research Station. The field experimental data with the two dates of sowing of maize i.e June 16, 2010 and July 30, 2010 were collected and analyzed. Results shown that the total water requirement of maize sown at an early date was 116.0 mm and that of sown at late date were 183.8 mm. As a result, the water demand was more as compared to early sown maize. Therefore, water requirement of maize varied with planting dates.

Kia (2013) performed a study using FAO Penman-Monteith equation. Required parameters were set for 9 synoptic stations in Iraqi Kurdistan for a period from 2004 to 2012. Sangasar and Karkuk were selected as two different agro-climatic zones. Data were processed by (CROPWAT 8.0) program, and the values of ETo and effective rainfall were calculated. Several crops were selected in the study including alfalfa, barley, beans, cabbage, grapes, maize, potatoes, sunflower, melons, tomatoes and wheat. Crop coefficients (Kc) were taken from tables of FAO under medium soil conditions. The results showed that potential evapotranspiration in Sangasar zone was 0.9 -8 mm/day, whereas in Karkuk zone was 1.5 to12 mm/day. The highest water requirement was estimated for grape in the Sangasar zone (Soran) 987.6mm/day and 1635.1 mm/day for Karkuk zone (Makhmur). In the same way, the minimum water requirement was estimated for alfalfa (first mowing) in Sangasar zone (Penjwen) 224.1mm/day and 269.7mm/day for Karkuk zone (Chamchamal).

Wane and Nagdeve (2014) estimated of reference evapotranspiration and effective rainfall for the Nagpur district in Vidarbha region of Maharashtra state for the period of 2000 to 2009. The results revealed that average peak monthly ETo were estimated at 6.99 and 6.52 mm in the month of May and April, respectively and average minimum ETo were estimated at 3.06 and 3.22 mm day^{-1} in the month of December and January, respectively due to winter months. The average annual effective rainfall was 803.45 mm with maximum effective rainfall occurs in July (221.05 mm) followed by August (194.76 mm), June (150 mm) and September (137.63 mm) months, respectively.

Bouraima *et al.* (2015) conducted study on ETc in semi-arid region for rice crop in Benin's sub-Basin of Niger River of West Africa with help of Cropwat software from the period 1940-2012. The results showed that estimated ETo was 1967 mm, lowest monthly value of 123 mm was observed in August and highest value 210 mm in march. The Etc & IWR were estimated at 651 mm & 383 mm respectively in rainy season and 920 mm & 1148 mm in dry season.

Laouisset & Dellal (2016) estimated the ETo and Water requirements of barley (Hordeum vulgare L.) in Ksar-Chellala region, Algeria, for one dry year by using Cropwat software for period of 23 years (1990-2012), the average rain in this period is 254 mm. The total rain of the dry year is 190 mm. Results revealed that during the vegetative cycle of barley which is 6 months, the calculation of ET0 is 453 mm, the potential water which was used by the crop barley is estimated at 281.4 mm, the efficiency of rainfall is 69 mm and a total water requirements of barley (CWRb) equals to 211 mm.

Anshu *et al.* (2017) conducted an experiment on ETo, crop water and net irrigation requirements for *rabi* crops for Bina command in Madhya Pradesh. Average daily ETo estimated by Penman Monteith method was 4.62mm/day. crop coefficient approach for crop water requirements for wheat, gram pulses and mustard were determined as 349.8,304.1 and 316.9 mm respectively. It was estimated that total crop water and net irrigation demands in Bina command were 232.45 MCM and 212.27 MCM respectively.

Bajirao and Harish (2017) focused on estimating the reference evapotranspiration (ETo) using 32 years meteorological data by Cropwat software for Parbhani in Maharashtra. The monthly average reference evapotranspiration was observed maximum in the month of May (8.4 mm day-1) while minimum in the month of December (3.27 mm day-1). This study provides the necessary information on water requirements for growing different crops in different season.

Patel *et al.* (2017) estimated the reference crop evapotranspiration in Ludhiana, Punjab (India) using Cropwat model for the period 1970-2012. Results revealed that ET_0 was lowest in month of January and February months. The maximum ET_0 occurred from March-October with a peak of 205.2 mm/month in June and gradually declined during November and December months.

2.2 Crop water requirement & Irrigation water requirement through CROPWAT model

Ibrahim and Yacoub (2009) analyzed the sustainability of cotton production depends on the development of irrigation methods at two locations in Syria, Hasakah and Aleppo, and to evaluate the performance of Cropwat model for on farm irrigation application for cotton under arid conditions at these two locations. At each location, experimental plots were established, and treatments consisted of two irrigation methods (basin and drip). Irrigation water was applied before sowing and then each time the soil root zone reached 75%

of field capacity. Results determined local crop water use values in the first year at 850 mm and 890 mm and in the second year 880 mm and 910 mm in Aleppo and Hasaka, respectively. The simulated values by Cropwat model was 825 mm and 906 mm in the first year and 850 mm and 885 mm in the second year in Aleppo and Hasaka, respectively.

Adeniran *et al.* (2010) determined the crop water requirement of some selected crops for the area around Kampe (Omi) Dam Irrigation Project using 25-year climatic data in Cropwat Software Crops were planted during the 2007 Rainy Season and the crop coefficient for each was determined. Results showed that the ETo varied from 3.4 to 4.8 mm/day. Crop evapotranspiration (ETc) and crop water requirement for paddy rice varied from 0.28 to 4.18 mm/day and 2.0 to 102.4 mm/day, for maize from 1.82 to 4.88 and 1.3 to 45.6 mm/day, for tomato from 8.7 to 52.8 and 0.0 to 45.2 mm/day, for vegetable from 3.07 to 4.74 and from 7.4 to 45.6 mm/day, for pepper 3.13 to 4.8 and from 15.1 to 40.7 mm/day, for onion from 1.80 to 38.4 mm/day, and for cabbage from 28.2 to 40.9 mm/day respectively. The peak water requirement was 0.63 l/s/ha or 5.4 mm/day with an application efficiency of 65%. Irrigation water requirement was estimated at about 61.2 MCM while the actual water diverted was 131 MCM. The reservoir capacity was 220 MCM. Thus the dam can conveniently supply the water required for irrigation in the area.

Saravanan (2014) determined the water requirement of main crops in the perumal tank irrigation command area in cuddalore district .The main crops include rice, groundnut and sugarcane. The crop water requirement was determined using 15 year climatic data using Cropwat. In the method reference crop evapotranspiration (ETo) was determined using the FAO Penman - Manteith method and the effective rainfall was calculated using USDA S.C method. The study shows that the dam can conveniently supply the water requirement for irrigation in the area used at present and also in the entire land area. The results obtained from the study can be used as a guide by farmers for selecting the amount and frequently of irrigation water for the main crop.

Surendran *et al*. (2015) studied the crop water requirement using FAO-Cropwat and in Palakkad district of humid tropical Kerala, India for major cultivated crops are rice, coconut, banana, arecanut, vegetables, pulses, rubber, tea, coffee, cotton etc. The total water requirement for these crops in various agro-ecological zones has been computed. Using the evapotranspiration (ETo) and effective rainfall in each agro-ecological unit (AEU), a climatic water balance has been worked out. Results showed that projected future total water demands for irrigation, drinking and industrial purpose will be 3841 Mm3. It identified that if the total area is brought under irrigation there will be deficit years and during such periods deficit irrigation or reduction in command area may have to be adopted.

Babu *et al.* (2015) studied on estimation of reference evapotranspiration, effective rainfall, crop water requirement and irrigation water requirement for the Bapatla region in Andhra Pradesh for vegetable crops for the period of 2009 to 2013 and used as input data for Cropwat. Results revealed that average peak monthly ETo was observed to be 8.09 mm/day for the month of June and followed by the 7.55 mm/ day for the month of May. Whereas average minimum ETo were observed as 3.85 and 3.92 mm/day in the months of December and January, respectively. The average effective rainfall was estimated for the study area as 769.3 mm out of 1060.3 mm annual rainfall. The crop water requirement (ETc) and irrigation water requirement were estimated for vegetable crops during Rabi season in the study area (Bapatla) as 516.3 mm and 470.4 mm, respectively.

Pandram *et al.* (2015) focused on analyzing the irrigation water requirement and irrigation scheduling of wheat crop for *rabi* season using 9 year (2005-2013) climatic data in Cropwat Software of Halali dam command area in Vidisha district of Madhya Pradesh. Results revealed that effective rainfall and crop water requirement was used for determining net irrigation water requirement. By considering the losses due to infiltration into the subsoil and conveyance losses, net irrigation water requirement was estimated. The total crop water requirement of wheat was 209.7 mm due to recurrence of rainfall. It is found that the irrigation scheduling graph of wheat in Loam soil (210) was present different from other Clay Soils 379, 399, 412, while respective clay soils are representing slightly difference from each other in aspect of irrigation scheduling.

Tibebe & Zemadim (2015) analysed the irrigation requirement for major crops at Holetta catchment, awash subbasin, ethiopia. Results revealed that the total irrigation requirement of all three users of Holetta River was 0.305, 0.575, 0.995, 0.865, and 0.332 MCM for January, February, March, April, and May respectively. The analysis also indicated the total water demand of all three major users of Holetta River during the irrigation season from January to May. The total water demand was 0.313, 0.583, 1.004, 0.873 and 0.341 million cubic meters (MCM) for January, February, March, April, and May respectively. The available river flow from January to May was 0.749, 0.419, 0.829, 0.623 and 0.471 MCM respectively. From the five months, the demand and the supply showed a gap during February, March and April. The total shortage of supply during these months was 0.59MCM.

Vashisht *et al.* (2015) determined the irrigation water requirement and irrigation scheduling of Direct Seeded Rice (DSR) with the help of CROPWAT model. The irrigation efficiency of 80% was considered for the study. Results revealed that the irrigation should be done at 40 % critical depletion to achieve 0% yield reduction. In the case of wheat, the total seasonal water requirement and irrigation requirement was found as 411 mm and 334 mm, respectively.

Raju *et al.* (2016) studied on Crop water requirements of crops in Appapuram Channel Command under Krishna Western Delta in Andhra Pradesh for the years 2000 to 2010 were computed with Cropwat using the meteorological parameters on rice and maize. The results revealed that the gross water requirement for Appapuram Channel Command area to irrigate 8880 ha was registered and 4000 ha unregistered ayacut during *kharif* season and maize 4000 ha during *rabi* to be 124.39 M.cum.

Ahmad *et al.*, (2017) studied on irrigation scheduling, to increase crop yield under water scarcity conditions. The crop water requirement was found to be 304 mm and irrigation requirement 288.2 mm. On refilling soil to field capacity with irrigation at critical depletion, irrigate at a given ET crop reduction per stage and irrigate at fixed interval per stage at 70% field efficiency gave a yield reduction of about 0 %, 14.9%, 25.1% respectively. Irrigation should be done at the critical depletion to achieve 0% yield reduction of maize and maximum rainfall efficiency. The research shows that the irrigation management model can effectively and efficiently estimate the crop water requirements.

Beshir (2017) studied on cabbage water requirement; irrigation scheduling and water use efficiency and results revealed that 2.57 - 5.81 mm/day of crop water requirement is more visible for cabbage production.

Mehanuddin *et al.* (2018) determined the crop water requirement of few selected crops for the commanded area in the Shimoga Taluk in Karnataka state, India. The crops include cotton, maize for two seasons and sugarcane using the 10-year climatic data, Crop evapotranspiration (ETc) and Reference crop evapotranspiration (ET0) for each crop were determined using Cropwat 8.0. The study showed that for both cotton and maize crops in *rabi* season effective rainfall is not sufficient to fulfil the crop water requirement. But for the same crops in season effective rainfall is enough to compensate crop water requirement. The crop sugarcane is a perennial crop for its crop period effective rainfall is sufficient to compensate the crop water requirement.

2.3 Effect of climate change on water requirement.

Chatterjee *et al.*, (2012) estimated the climate change impact on crop water requirement in ganga river basin, West Bengal, India. Potato was taken as the refernce crop for its growing period and its high response to irragation. After proper validation of Cropwat, the model was used to determine the irrigation requirement of potato using current and future (prediction years: 2020 and 2050) weather data. It was observed that irrigation water requirement will be increased by 7 to 8% during 2020, while it may increase about 14 to 15% during 2050.

Chowdhury *et al.*, (2013) evaluated the implications of climate change on crop water requirements (CWRs) from 2011 to 2050 in Al-Jouf, Saudi Arabia. CWR were predicted for four scenarios: (i) current temperature and rainfall (S1); (ii) temperature in 2050 and current state of rainfall (S2); (iii) rainfall in 2050 and current state of temperature (S3) and (iv) temperature and rainfall in 2050 (S4). Assuming no change in the regulations relating to agriculture and irrigation in future, CWR were predicted to be 873 and 931 million cubic meters (MCM) per year for the S1 and S4 scenarios, respectively, indicating an increase of 58 MCM from 2011 to 2050. On an average, 1 _C increase in temperature may increase the overall CWR by 2.9% in this region.

Parekh and Prajapati (2013) studied about the impact of climate change on crop water requirement for the crops grown in the Sukhi command area of Vadodara district, Gujarat for the period 2003 to 2009 were used for this study. Results showed that crop water requirement of all hot weather crops (Millet, Ground nut, Maize, Small vegetables and Tomato) was increased in future as compared to base period 2003-2009 while *rabi* crops (Wheat, *rabi* Sorghum, Maize, Small Vegetables, Tomato, Gram and Cowpeas) showed negligible decrease in crop water requirement in the period 2011-2020 but all crops shows considerable increasing water requirement in the period 2021-2030, 2046-2065 and 2080-2099 respectively, as compared to base period 2003-2009.

Lee & Huang (2014) analyzed the impact on irrigation water by climate change in paddy fields for Taoyuan in northern Taiwan for period 2046–2065 are adopted from five downscaled general circulation models. A comparison between the present (2004–2011) and the future (2046–2065) clearly shows that climate change would lead both rainfall and the temperature to rise; this would cause effective rainfall and crop water requirement to increase during cropping seasons in the future. Overall, growing effective rainfall neutralizes increasing crop water requirement, the difference of average irrigation water requirement between the present and future was insignificant (<2.5%). Results showed for future irrigation requirement was 7.1% more than the present in the first cropping season, but it is insignificantly less (2.1%) than the present in the second cropping season.

Behera *et al.* (2016) studied on the impact of climate change on crop water requirement in Sunei command area (Bhudhabalang Basin) of Mayurbhanj district Odisha, India. ETo was calculated using mean monthly climate and rainfall data with help of Cropwat. Future climate data was predicted for the period 2025, 2050 and 2080 considering both A2 and B2 scenario GCM HadCM3. Results shows that both H3A2 and H3B2 scenarios crop water requirements increases whereas for some *rabi* season crops like Dalua rice, Groundnut, Mustard crop water requirements decreases in future for H3B2 scenario. The increase or decrease is consider compared to base period 2010, it confirm the clear impact of climate change on crop water requirement of *kharif* and *rabi* crops.

Acharjeea *et al.* (2017) investigated the impacts of climate change on future water requirements of dry season Boro rice. Climate scenarios for four North-West districts of Bangladesh were constructed from the outputs of five global circulation models using a combination of statistical downscaling and bias correction. The generated climate data were used as input for Cropwat to estimate water requirements of Boro rice for 2050s and 2080s (using 30 year average climate data). ETo is increasing in the future, mainly due to higher temperatures. Results showed that Potential crop water requirement (ETc) of Boro rice, however, will reduce by 6.5% and 10.9% for RCP 4.5 and 8.5, respectively for 2050s; and by 8.3% and 17.6% for RCP 4.5 and 8.5, respectively for 2080s compared to the reference period (1980–2013). Daily water requirements will increase the total net irrigation requirement of Boro rice will decrease by 1.6% in 2050s and 7.4% in 2080s for RCP 8.5 scenario on average for all models and districts.

Chowdary and Abbas (2018) investigated the implications of climate change on wheat crop from 2011-2050 in Al-Jouf, Saudi Arabia. CWR were predicted for four scenarios: (i) current temperature and rainfall(S1); (ii) temperature in 2050 and current state of rainfall (S2); (iii) rainfall in 2050 and current state of temperature(S3); (iv) temperature and rainfall in 2050 (S4). CWR were predicted to be 873 & 931 million cubic meters (MCM) per year. Results revealed that on average increase in 1^0C temperature, there will be 2.9% increase in CWR in study area. Therefore, the study is useful in explaining the negative effects of climate change on CWR in Al-Joufand also for better planning for water resources management.

Manasa & Shivapur (2016) conducted on the effects of climate change on water requirements of the major crops (jowar, groundnut, maize, soyabean, cotton, wheat, sugarcane) grown in Hukkeritaluk of Belagavi district Karnataka using Cropwat software. Future climate data are collected for A1B scenario (2021-2050) using PRECIS model which was established on the basis of Hadley Centre's Regional Climate Modeling System (HadCM3). Results shows that, Groundnut, Cotton, Sugarcane, Jowar (*rabi*), Maize(*rabi*) and Wheat (*rabi*) there is an increase in CWR in the future scenario as compared to BL. Whereas for the remaining crops there is a little decrease in CWR.

An experiment on "Assessment of Crop Water Requirement & Irrigation Water Requirement for Vegetable Crops over Uttar Pradesh Using Cropwat Model" was conducted during 1980-2014. Details of materials used and experimental methodology followed during the course of present study were described in this chapter.

3.1 Experimental Site

Uttar Pradesh is situated in Northern India between 26.8467 ^{0} N Latitude and 80.9462 ^{0} E Longitudes. The state has 75 districts with a total area of 243,290 square kilometres. Uttar Pradesh is India's fourth-largest state in terms of land area. It is situated on the northern spout of India and shares an international boundary with Nepal.

Fig 3.1: Study area map.

3.2 Climate and weather conditions

In UP summers are very hot and winters are bit chilly. Summer season persists from April to June. The day time temperature remains very high and usually touches around 48^0C. Night are relatively cooler typical of extreme climate and the temperature comes down to as low as 28^0C because of the cool breeze. Dew is very common in all the parts of UP. The winter falls around Mid-November and continue till February end. Winters in Uttar Pradesh are cooler with day temperature around 24^0C and nights are chilly with temperature getting as low as 2 to 4^0C across the state. As Uttar Pradesh stretches from North India towards Eastern, the rainfall varies considerably. The average annual rainfall varies from 50-110 cm in Uttar Pradesh. South West Monsoon is very moderate Uttar Pradesh and it rains very heavily in short spells. The Western disturbance brings fair amount of rainfall. Approximately average annual rainfall in the state is around 65-70 cm.

3.3 Software Used

3.3.1 CROPWAT 8.0 model:

CROPWAT is a decision support system developed by the land and water development division of FAO. It is used to estimate (a) Reference evapotranspiration (b) Crop water requirements (c) Crop Irrigation requirements in order to develop irrigation schedules under various management conditions **(FAO, 1992).** It is also used to develop (a) irrigation schedules with various management options (b) Scheme water supply (c) Rainfed production and drought affects (d) Efficiency of irrigation practices and the assessment of production under rainfed conditions or deficit irrigation **(Marica *et al.* 1999).** Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 "Crop water requirements" and No. 33 "Yield response to water". The development of irrigation schedules and evaluation of rainfed irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided in the program (**Smith, 1991**

3.3.2 ARCGIS:

ARCGIS 10.4 version was used in the present study for mapping of temperature, rainfall, effective rain, ETo and water requirements for wheat. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database. 10.4 System software was used for mapping purpose and software was developed by ESRI. Interpolation process is done through Arcgis software.

3.3.3 Weather Cock:

It is the software used for data management, converting the daily data into annual, monthly, seasonal. Software was developed and managed by AICRPAM, CRIDA, Hyderabad.

3.4 Input data for CROPWAT model

3.4.1 Site data

Country and station name, location data, longitude (East or West), latitude (North or South) and altitude (m) were required for site identification in Cropwat.

3.4.2 Climatic data

The daily maximum and minimum temperature were collected from www.imd.com with a grid size of 0.5x0.5 for the period of 1980-2014 over Uttar Pradesh while monthly rainfall data were obtained from Google Earth Pro (CRU) with the grid size of 0.5x0.5 for the study area from 1980-2014.

3.4.3 Crop data

The Cropwat model requires crop data over the different development stages and is defined as follow:

The data input modules of CROPWAT are:

1. Climate/ETo: For the input of measured ETo data or of climatic data that allow calculation of ETo Penman-Monteith;

2. Rain: For the input of rainfall data and calculation of effective rainfall;

3. Crop (selected vegetables): For the input of crop data and planting data

4. Soil: For the input of soil data (only needed for irrigation scheduling)

5. Crop pattern: For the input of a cropping pattern.

Note that in fact climate/ETo and rain modules are not only for data input but also calculate data, namely radiation /ETo and effective rainfall respectively.

The calculation modules of CROPWAT are:

6. CWR -For calculation of Crop Water Requirements

7. Schedules (dry crop or rice) – For the calculation of irrigation schedules

8. Scheme – For the calculation of scheme supply based on a specific cropping pattern.

The crop coefficient (Kc) and yield response factor (Ky) values taken from the FAO **(Doorenbos and Kassam, 1979).** The crop coefficient value of wheat was shown in Table: 3.2 at different growing stages.

Table 3.1 Crop coefficients of Potato, Pea and Cabbage .

Crop	Crop Coefficients		
	Initial (Kc_{1})	Development (Kc_2)	Late Season (Kc_3)
Potato	0.5	1.15	0.75
Cabbage	0.7	1.05	0.95
Pea	0.5	1.15	1.10

3.4.4 Soil data

The soil details which were used in the Cropwat are taken from the departments of the agriculture and groundwater as shown in Table 3.3 (**According to FAO, Rome, Italy, Paper No 24**.)

3.5 Methodology:

3.5.1 Calculation of Reference evapotranspiration (ETo)

The evapotranspiration rate from a reference surface, not short of water, is called the reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions. The reference evapotranspiration (ETo) was computed by Penman Monteith Model **(Allen *et al.* 1998).** The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ETo values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface **(FAO 56, 1998).**

The mathematical expression for the sake of calculation simplified as

$$ETo = \frac{0.408\Delta(Ra-G)+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34u2)}$$

Where, ETo = Reference evapotranspiration (mm per day)

Ra = Net radiation at the crop surface (MJ/m² per day)

G = Soil heat flux density (MH/m² per day)

T = Mean daily air temperature at 2m height (°c)

u_2 = Wind speed at 2m height (m/s)

e_s = Saturation vapor pressure (kPa)

e_a = Actual vapor pressure (kPa)

$e_s - e_a$ = Saturation vapor pressure deficit (kPa)

γ = Psychometric constant

Δ = Slope vapour pressure curve [kPa °C-1]

3.5.2 Effective rainfall (ER)

Total rainfall is not utilized by the plants; effective rainfall is defined as a part of rainfall which is effectively used by the crop after rainfall losses due to surface run off and deep percolation have been accounted **(Babu *et al.* 2015).** According to **Dastane (1974)** effective rainfall is defined as that portion of rainfall which is useful directly and/or indirectly for crop production at the site where it falls. Estimates of effective rainfall are extremely useful for operation planning and management issues including determine optimal cropping pattern; determining optimal operational policies for irrigation systems; design of drainage systems and real-time control. To calculate the effective rainfall from 1980-2014, the USDA Soil Conservation Service method was used. For the present study USDA Soil Conservation Service method **(Smith, 1991)** was chosen for calculating the effective rainfall and estimated by using following formula :

$$Peff = Ptot \times \frac{128 - 0.2 \times Ptot}{128} \qquad \text{for } P_{tot} < 250\text{mm}$$

$$Peff = 125 + 0.1 * Ptot \qquad \text{for } P_{tot} > 250\text{mm}$$

Where,

Peff = Effective rainfall (mm)

Ptot = Total rainfall (mm)

3.5.3 Estimation of Crop Water Requirement (ETc)

Crop Water Requirement is the amount of water needed to meet the water loss through Evapotranspiration. Estimation of the crop water requirement is derived from crop evapotranspiration (crop water use) which is the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc). The reference evapotranspiration (ETo) is estimated based on the FAO Penman-Monteith method, using climatic data **(FAO, 1998).**

$$ETc = ETo \times Kc$$

Where, ETc = Actual evapotranspiration by the crop (mm/day),

ETo= Reference crop evapotranspiration (mm/day);

K_C = Crop coefficient at a certain growth stage.

3.5.4 Estimation of Irrigation Water Requirement (IWR)

Irrigation requirement is the total quantity of water applied to the land surface in supplement to the water supplied through rainfall and soil profile to meet the water needs of crops for optimum growth. Based on the effective rainfall data in the study area, irrigation water requirements can be calculated from the difference between effective rainfall and the total water requirement.

$$IR = ETc - ER$$

3.6 Interpolation Methodology

Click on the Add Data File

⇩

Select the Shape File and Data from the Folder

⇩

Right Click on Data and Display X,Y Co-ordinates

⇩

Click on the out file and Export the data

⇩

Click on Geo Processing (Go to Environment, Processing Extent, Raster analysis Spatial Analysis)

⇩

Spatial Analytic tool

⇩

Interpolation

⇩

IDW

⇩

Save File and Export the Map

Fig 3.2: Flow chart for Interpolation Methodology.

3.7 Impact of climate change on water requirement

The crop water requirement with changing climate can also predicted by CROPWAT model. Climate change will lead to an intensification of extremes of the global hydrological cycle and could have major impacts on water resources. Possible effects of climate change on plant growth can be estimated and evaluated using the crop growth simulation models. Water requirement is directly depends on evapotranspiration while evapotranspiration is influenced by climate variables like radiation, air and surface temperature, relative humidity and wind speed. As the temperature rises more evaporation will take place from soil as well as from plant body this will reduce available moisture content in soil hence more will be the crop water requirement.

Indian agriculture is mostly dependent on monsoon, any variability in rainfall frequency and magnitude brought drought condition because irrigation water demand is so high that it won't able to meet the irrigation needs. Agriculture requires more quantity of water than any other process hence climate change influences are more substantial over agricultural water demand, for better future management and planning of water resources influences of climate variability should be properly analyzed.

To analyses the effect of climate change the climatic scenarios for the year 2020, 2050 & 2080 were obtained from the **Marksim DSSAT IPCC AR5.** MarkSim is a weather generator that uses 720 classes of weather, worldwide. This constitutes 'stochastic downscaling' as it fits a Markov model to the GCM output and uses it to generate weather data for the site indicated. There are two aspects to downscaling: one is to interpolate the results of the GCM spatially; and the other is to ensure that the results are relevant to the local climate. The spatial downscaling is the easiest part. This is usually done with a convolution algorithm in our case it is a bicubic interpolation using the 16 points closest on a 1 degree grid. There are four IPCC Representative Concentration Pathway (RCP). RCP's are green house gas concentration adopted by IPCC for its fifth assessment. **RCP 4.5 Scenario** was used for downloading future data.

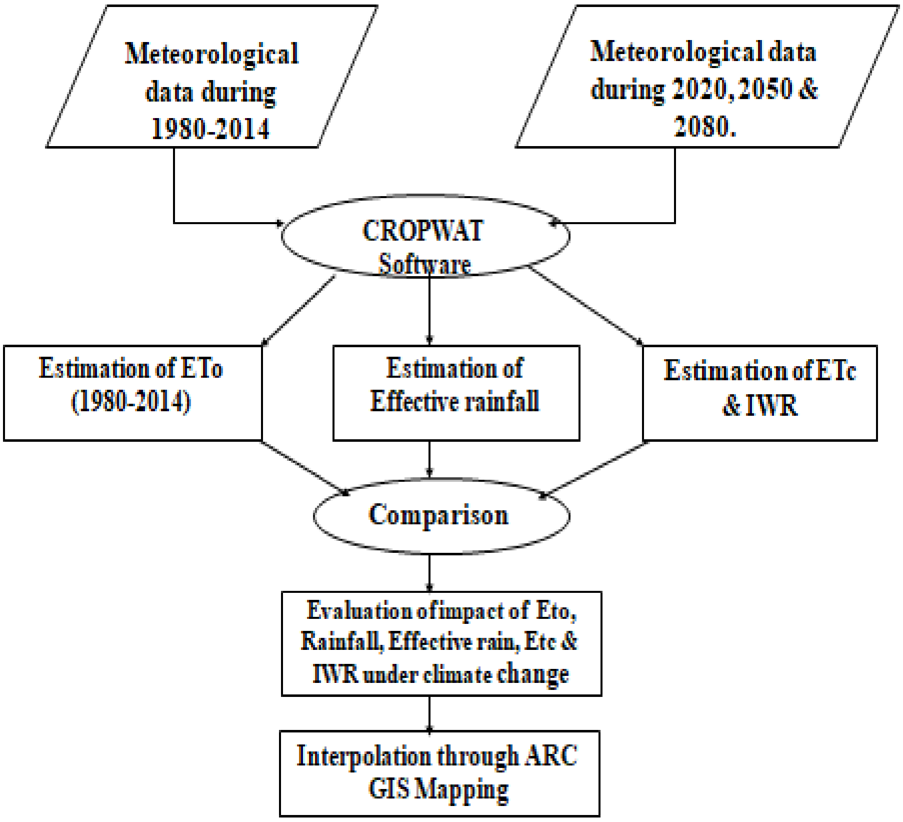


Fig 3.3 Flow diagram of CROPWAT working procedure.

Result obtained from the present investigation on "**Assessment of Crop Water Requirement & Irrigation Water Requirement for Vegetable Crops over Uttar Pradesh Using Cropwat Model**" is summarized under the following subheads:

4.1 Determine Reference Evapotranspiration (ETo) by Penman-Monteith equation

Prediction of the crop water requirement is of vital importance in water resources management. Crop water requirements are normally expressed by the rate of evapotranspitration (ET) in mm day-1 or m period-1. The level of ET has been shown to be related to the evaporative demand of the air. The evaporative demand can be expressed as the reference evapotranspiration (ETo) which, when calculated, predicts the effect of the climate on the level of the crop evapotranspiration. The effect of the weather variable on the water demand of the crop can be analysed by the Cropwat model output. Agrometeorological variables are one of the key inputs required for the operation of the crop simulation models. These include the maximum, minimum temperature, air humidity, wind speed sunshine hours, solar radiation and total rainfall. Out of these temperature and rainfall have direct impact on crop production. The reference crop evapotranspiration shows the highest (7.2 mm day-1) and lowest value (1.89 mm day-1) in the month of May and January, respectively. The increase in ETo during the May to September can be explained by the rising temperature in that particular period. Thus, the air temperature has a direct effect on the reference crop evapotranpitaion (ETo). Relative Humidity is a function of air temperature. Higher the temperature more is the amount of water vapour that can be held by the atmosphere. The extent of evaporation and transpiration depend on the amount of moisture present in the atmosphere.

From thematic map (Fig.4.1) of annual ETo over UP clearly revealed that the annual ETo was found maximum in the lower belt of the state as Jhansi, Mahoba, Banda, Lalitpur etc districts ranged between 1648.3 to 1726.3 mm. The lowest value of ETo was observed in Muzaffarnagar and Bijnor ranged between 1335.9 to 1414.0mm. Average peak monthly ETo was estimated in the month of May and June, respectively due to high temperature during the summer month. Average minimum monthly ETo was observed in the month of January and December, respectively due to winter months.

Table 4.1 Average ETo for the period 1980-2014.

Station	ETo in mm/day												ETo mm/year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Ambedkar nager	2.53	3.31	4.78	6.27	6.55	5.93	4.67	4.33	4.14	4.18	3.57	2.77	1613.3
Auraiya	2.53	3.3	4.7	6.26	6.92	6.37	4.88	4.32	4.29	4.39	3.64	2.78	1653.4
Bahraich	2.37	3.14	4.54	6.11	6.49	5.96	4.6	4.24	4.06	4.09	3.43	2.63	1569.5
Balram pur	2.41	3.17	4.62	6.1	6.34	5.79	4.55	4.25	4.05	4.05	3.45	2.67	1565.8
Banda	2.67	3.42	4.88	6.41	7.03	6.34	4.78	4.22	4.2	4.38	3.67	2.87	1668
Barally	2.14	2.81	4.06	5.65	6.22	5.83	4.62	4.15	4.03	3.92	3.14	2.39	1489.2
Bijnor	1.89	2.42	3.53	4.95	5.59	5.3	4.29	3.9	3.72	3.5	2.72	2.09	1335.9
Etah	2.4	3.16	4.59	6.23	6.98	6.55	5.07	4.44	4.44	4.49	3.56	2.65	1660.7
Farrukhabad	2.32	3.05	4.43	6.06	6.64	6.2	4.8	4.28	4.23	4.23	3.42	2.6	1591.4
Gautam buddh	2.24	2.94	4.25	5.95	6.76	6.48	5.15	4.56	4.51	4.38	3.38	2.49	1613.3
Gazipur	2.59	3.35	4.79	6.25	6.54	5.92	4.72	4.39	4.13	4.07	3.57	2.83	1616.9
Gorakh pur	2.47	3.24	4.66	6.08	6.29	5.75	4.56	4.28	4.04	3.99	3.46	2.72	1569.5
Jaun pur	2.61	3.38	4.81	6.3	6.65	5.99	4.67	4.31	4.13	4.2	3.61	2.83	1627.9
Jhansi	2.76	3.54	4.95	6.45	7.2	6.64	4.97	4.33	4.47	4.69	3.83	2.97	1726.4
Kausambi	2.64	3.43	4.85	6.39	6.93	6.19	4.73	4.23	4.14	4.34	3.66	2.89	1657.1
Kheri	2.19	2.88	4.17	5.7	6.2	5.76	4.55	4.16	3.95	3.9	3.18	2.45	1492.8
Lalit pur	2.96	3.73	5.12	6.51	7.17	6.45	4.71	4.05	4.29	4.64	3.88	3.09	1722.8
Maharaj ganj	2.45	3.22	4.65	6.04	6.2	5.67	4.57	4.3	4.05	3.97	3.45	2.69	1558.5
Mahoba	2.72	3.48	4.93	6.43	7.15	6.54	4.9	4.27	4.33	4.53	3.74	2.92	1700.9
Mathura	2.38	3.1	4.48	6.18	6.94	6.59	5.12	4.53	4.6	4.59	3.58	2.62	1664.4
Moradabad	2.23	2.91	4.25	5.9	6.64	6.3	4.94	4.44	4.32	4.2	3.31	2.46	1580.4
Sitapur	2.34	3.1	4.48	6.04	6.51	6.03	4.66	4.25	4.08	4.12	3.4	2.62	1569.5
Sultan pur	2.47	3.25	4.68	6.19	6.64	6	4.62	4.22	4.11	4.21	3.53	2.75	1602.3
Unnao	2.45	3.22	4.65	6.14	6.69	6.12	4.67	4.25	4.14	4.19	3.51	2.71	1606

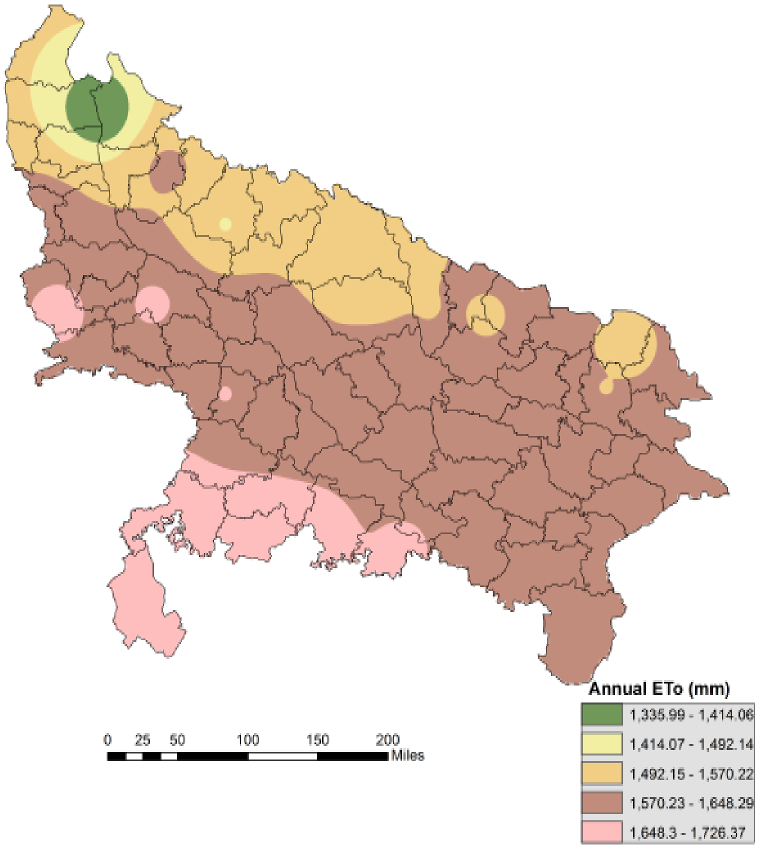


Fig 4.1: Thematic Map of reference evapotranspiration (ETo) over Uttar Pradesh during 1980-2014

Patel, *et al.*, (2017) estimated ETo in Ludhiana from 1970-2012 increased during the March-October, reached maximum value of 205.2 mm/month at June and declined during November and December months. Similar results were reported by **Admasu, *et al.*, (2014).**

4.2 Determination of effective rainfall using Cropwat model

The effective rainfall is a fraction that can contribute to the consumptive use of the crop. In general, the efficiency of rainfall decreases with increasing rainfall. Effective rainfall is related to the moisture available in the plant's root zone, allowing the plant to germinate, emerge and maintain its growth. Soil moisture levels need to remain above the wilting point for better growth of plants. Only a portion of heavy and high intensity rains during July to September can enter and be stored in the root zone, and therefore effectiveness of this type of rainfall is low whereas frequent light rains during October to May are close to 100 per cent effective. The simulated values for the effective rainfall using Cropwat model are shown in the Table.4.2.

Table 4.2 Effective Rainfall over Uttar Pradesh for the period 1980-2014.

Station	Effective Rain in mm/day												ER mm
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ambedkar nager	12.6	12.6	7.2	5.8	18.1	96.8	152.9	149.8	137.7	26.1	3.3	12.6	627.4
Auraiya	16.1	13.4	8.1	3.8	12.3	85	148.3	150.6	129.2	22.9	7.9	16.1	601
Bahraich	14.4	19.8	13.7	14.1	41.5	124.6	159	153.2	146.6	40	4.5	14.4	739.6
Balram pur	11.8	16.1	12.3	12.2	35	125.6	158.4	153.6	147.8	37.3	3.3	11.8	720.8
Banda	17.8	10.1	8.3	4.5	7	94.8	151.2	157	120.3	20.8	7.5	17.8	606.6
Barally	15.4	21.5	13.8	10.4	24.6	93.2	150.5	152.2	118.7	32.5	3.3	15.4	643
Bijnor	19	24.9	17.9	14.1	27.4	86.4	150.1	151.9	112.1	22.1	3.8	19	637.3
Etah	12.3	16.3	9.9	8.9	15.4	71.2	140.1	148.4	106	24.3	4.5	12.3	563.8
Farrukhabad	11.9	12.7	9.1	8	17.5	83.6	141.5	148.9	114.6	31.3	3.9	11.9	589.3
Gautam buddh	13.3	18.6	11.8	10.4	18.2	61.3	136.6	148	103.7	16.6	3.8	13.3	549.4
Gazipur	12.5	11.7	7.3	4.6	20.8	87.6	151.4	150.6	131	29.3	4.2	12.5	613.5
Gorakh pur	13.6	12.3	9.5	13	38.4	123.2	158.5	154.3	146	38.7	3.6	13.6	717.5
Jaun pur	13.4	12.7	6.1	4.4	13.7	86.5	151.1	147.2	132.3	24.6	5.8	13.4	600.5
Jhansi	13.1	11.3	5.5	5.6	9	84.8	153.8	154.9	118.4	17	11.4	13.1	590.5
Kausambi	16.9	14.4	7.9	5.3	10.9	95.3	150	152.6	127.1	20.6	6.4	16.9	613.3
Kheri	18.6	27.9	14.8	16.8	49.4	123.6	159.6	156.2	141.8	47.7	4	18.6	770.3
Lalit pur	14.4	12.3	6.4	4.4	7.7	91.8	156.6	157.3	117.6	16.8	15.3	14.4	607.8
Maharaj ganj	15.4	15.2	17.2	29.4	85.8	148.3	172.2	161.6	156.4	53	3.8	15.4	867.1
Mahoba	8	10.6	15.5	20.9	25	26	24.4	23.6	22.8	18.5	12.9	8	217.1
Mathura	9.1	12.4	7.2	8.4	14.8	51.8	133.7	148.2	94.2	15.9	5.6	9.1	507.2
Moradabad	17.9	23.1	15.3	11.8	25.3	88.3	149.4	152	114.8	24.9	2.4	17.9	632.6
Sitapur	13.9	18.9	12	11.5	33.7	108.5	154	153.1	140.9	46.5	2.9	13.9	703.1
Sultan pur	11.3	10.9	6	3.9	16.8	91.9	152.1	150.3	137	27	3.4	11.3	616.7
Unnao	11.7	12.6	7.1	6.3	15.2	81.5	141.6	148.1	118.1	31.1	2.6	11.7	583.9

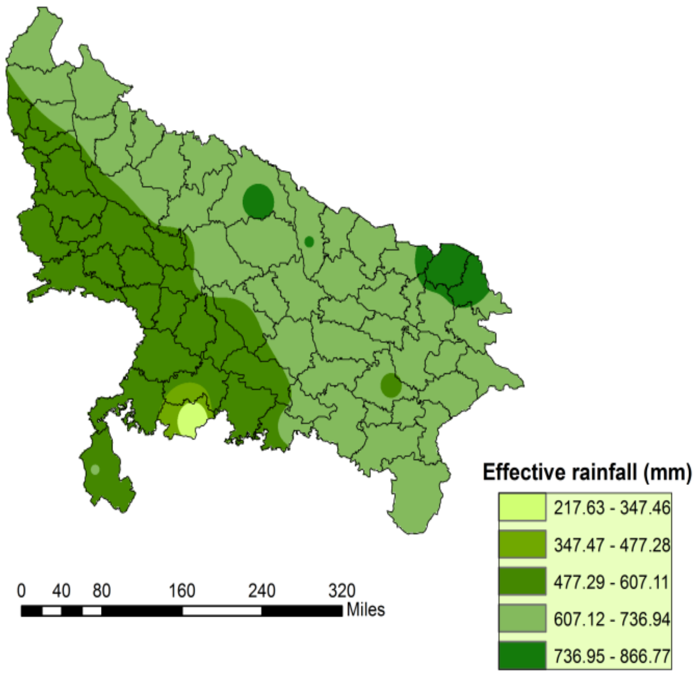


Fig 4.2: Thematic map of Effective rainfall over Uttar Pradesh for the period 1980-2014.

Amount of effective rainfall were high in Maharajganj district ranged 736.9 -.866.7 mm. However the intensity, frequency and amount of effective rainfall (217.6 – 347.4 mm) were low in Mahoba Hamirpur and Jhansi areas. In these areas little amount or almost no water is lost through surface runoff, deep percolation and seepage. Moreover the values of effective rainfall were found highest in the rainy season. Average monthly rainfall with maximum effective rainfall occurred in October whereas minimum value occurred in month of January.

Several researchers had been done similarly kind of study (**Rahman *et al.* (2008),** Similarly **Babu *et al*. (2015)** found that the monthly maximum effective rainfall occurred in October (149.8 mm) followed by September (146 mm), July (118.7 mm) and August (109.5 mm) months through Cropwat Software.

4.3 Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) of Potato, Pea and Cabbage at different date of sowing (15 Oct & 15 Nov)

It is necessary to understand the water management practices making best usage of water for agriculture and adopt practices, which enhance water use efficiency in crop production. In tropics, agricultural crops are extensively cultivated under rainfed, it increases water use efficiency. So, in order to improve water use efficiency, it is essential to understand how much water is required by the crops in different periods. Uttar Pradesh plays a leading role in vegetables cultivation therefore there is need to plan for irrigation system.

4.3.1 ETc and IWR for Potato (*Solanum tuberosum .L*) over Uttar Pradesh for the period 1980-2014.

Potato (*Solanum tubrosum*) is most important vegetables crop over Uttar Pradesh. Poor soil and water management practices increases water demand for agriculture. Climate data, rainfall data, crop data, cropping pattern data and soil data were fed to the Cropwat 8.0 model for the estimating the water requirements and the estimated values for two different date of sowing for Potato crop were presented in the Table 4.3.

The water requirement values were estimated through Cropwat model for Potato crop during period 1980-2014 at two date of sowing. The water requirement of Potato crop over was obtained in 2 date of sowing *i.e.* 15th Oct (fig. 4.3) and 15th Nov (fig. 4.4).

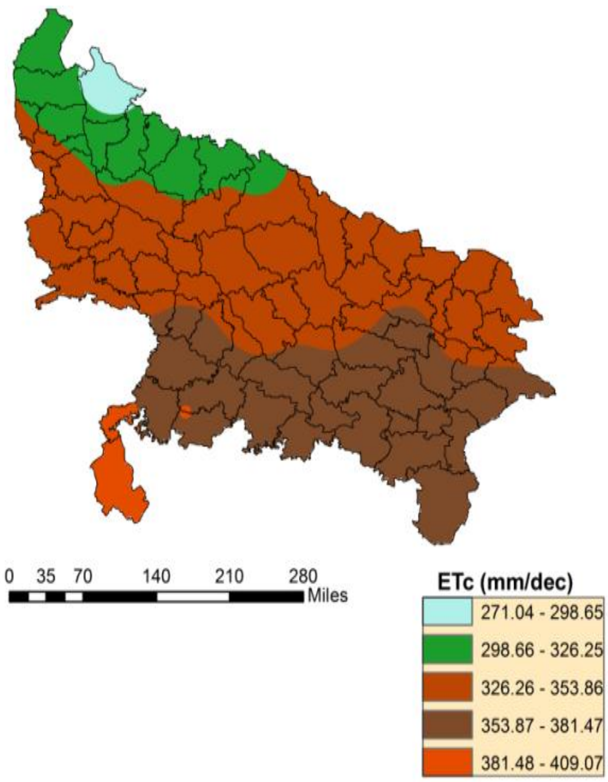


Fig 4.3 Thematic map of Etc for potato 1st date of sowing (15 Oct)

Table 4.3: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Potato (1980-2014)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	356.5	321.7	386.3	350
Auraiya	359.1	317.3	384.3	341.3
Bahraich	339.2	286.5	366.1	311.5
Balram pur	343.9	299.6	372.1	325.8
Banda	373.6	329.6	403	357.6
Barally	309.2	259	329.3	273.2
Bijnor	271	218.3	287.3	219.2
Etah	349.5	308.4	371.6	326.7
Farrukhabad	335.6	295.1	357.9	318.7
Gautam buddh	327.5	287.9	345.4	295.1
Gazipur	361.7	326.5	392.4	358.6
Gorakh pur	348.2	304.8	378.1	337.6
Jaun pur	364.9	328.7	395.2	359.5
Jhansi	390.7	350	416.5	376.8
Kausambi	373.2	330.1	401.7	355.3
Kheri	314.2	246	336.31	266.6
Lalit pur	409.1	360.9	439.1	392.7
Maharaj ganj	344.6	288.3	375	320.9
Mahoba	382.2	336.6	409.7	364.6
Mathura	346.1	313.7	363.9	328.1
Moradabad	323	273	324.9	280.8
Sitapur	337.3	284.5	362.6	311.9
Sultan pur	352.2	317.7	379.6	345.6
Unnao	349.6	309.6	376.8	338.2

At 1st day of sowing, the Etc was found minimum in Bijnor district ranged between 271.0 to 298.8mm while maximum Etc was found in Lalitpur and Jhansi. At 2nd day of sowing, the Etc was found minimum in Bijnor district ranged between 287.3 to 317.6mm while maximum Etc was found in Lalitpur and Jhansi ranged between 408.7 to 439.0mm. Delay in sowing (2nd date of sowing) represents large amount of ETc as compare early sowing.

Therefore it was observed that 1st DOS gave best result for planning of irrigation water for Potato.

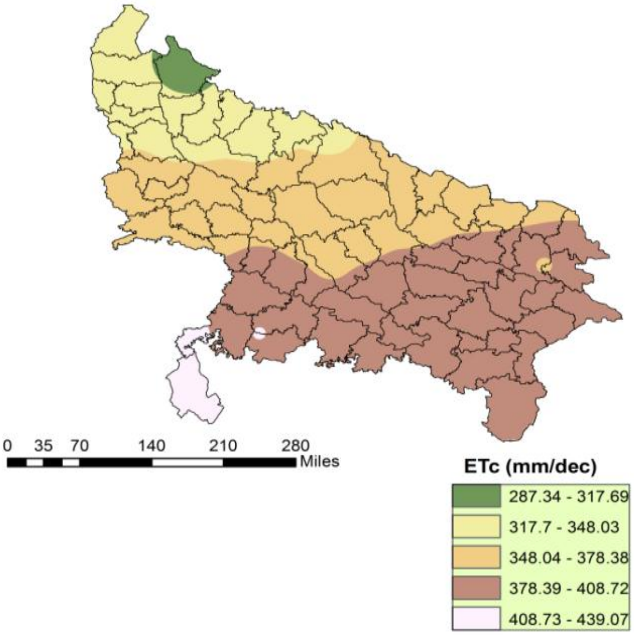


Fig 4.4 Thematic map of Etc for potato 2nd date of sowing (15 Nov)

Thematic map of irrigation water requirement of Potato for 1st DOS was presented in Fig 4.5 and 2nd DOS was presented in Fig 4.6 for the period of 1980-2014 over UP. The irrigation water requirement showed maximum value in in Bijnor district ranged between 218.3 to 246.8 mm at 1st day of sowing, while maximum IWR was found in Lalitpur r and Jhansi. At 2nd day of sowing, the IWR was found minimum in Bijnor district ranged between 219.2 to 253.9 mm while maximum IWR was found in Lalitpur and Jhansi ranged between 358 to 392.6 mm. Therefore, 2nd date of sowing represents large amount of IWR as compare to 1st date of sowing.

Babu *et al.* (2014) was found similar findings as estimation of crop water requirement of Anantapur region for the groundnut *kharif* and *rabi* crop as 591.3 mm and 443.3 mm, respectively, & for vegetables, cotton, rice, pulses and maize as 594.1 mm, 878.6 mm, 1110.6 mm, 659.9 mm and 679.3 mm, respectively through Cropwat software.

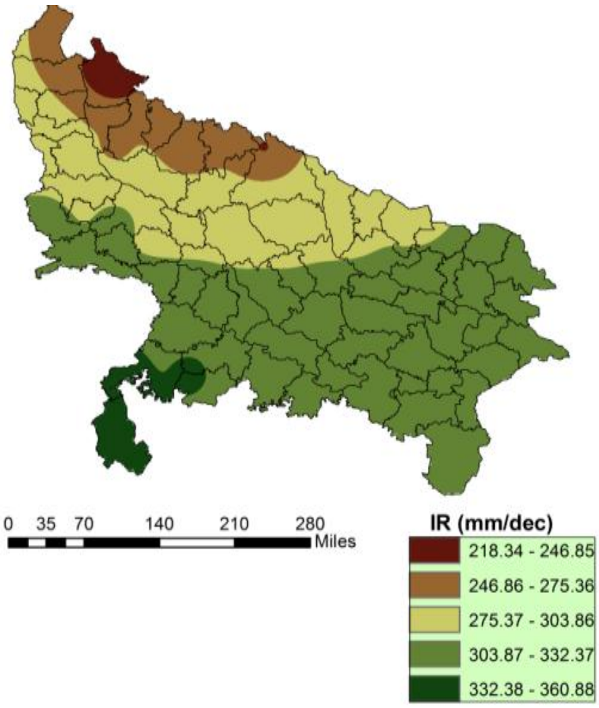
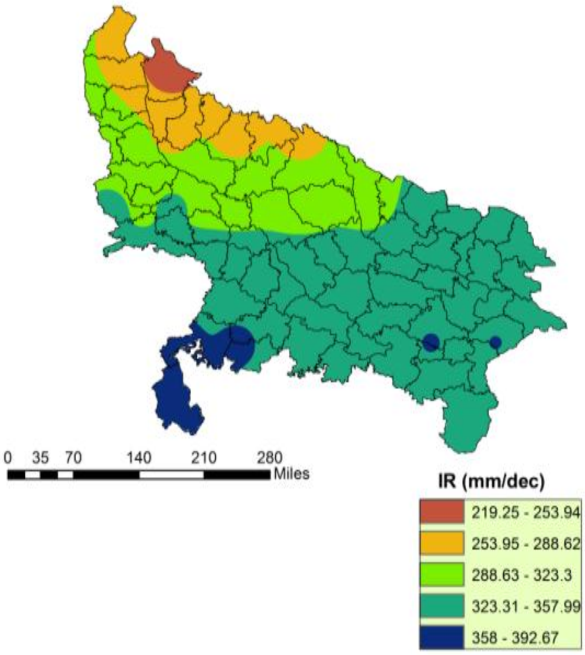


Fig 4.5 Thematic map of IWR for potato 1st date of sowing (15 Oct)



4.6 Thematic map of IWR for potato 2nd date of sowing (15 Nov)

4.3.2 ETc and IWR of pea over Uttar Pradesh for the period 1980-2014.

Pea, (*Pisum sativum* L.) belongs to the family *Leguminosae* (*Fabaceae*). In India it is being grown rainfed conditions and is subjected to unpredictable drought during crop season. But pea is a crop which responses favourably well to irrigation. Even one irrigation, applied at growth or development stage, gives quite good yield of pea **(Behl *et al.*, 1968 and Gautam and Lenka, 1968).** The estimated values for two different date of sowing for Pea crop were presented in the Table 4.4 The water requirement values were estimated through Cropwat model for Pea crop during period 1980-2014 at two date of sowing. The water requirement of Pea crop over was obtained in 2 date of sowing *i.e.* 15th Oct (fig. 4.7) and 15th Nov (fig. 4.8). At 1st day of sowing, the Etc was found minimum in Bijnor district ranged between 206.6 to 226 mm while maximum Etc was found in Lalitpur and Jhansi. At 2nd day of sowing, the Etc was found minimum in Bijnor district ranged between 181.5 to 201.1 mm while maximum Etc was found in Lalitpur and Jhansi ranged between 260.5 to 279.6 mm. 2nd date of sowing represents large amount of ETc as compare to 1st date of sowing. Therefore it was observed that 1st DOS gave best result for planning of irrigation water for Pea.

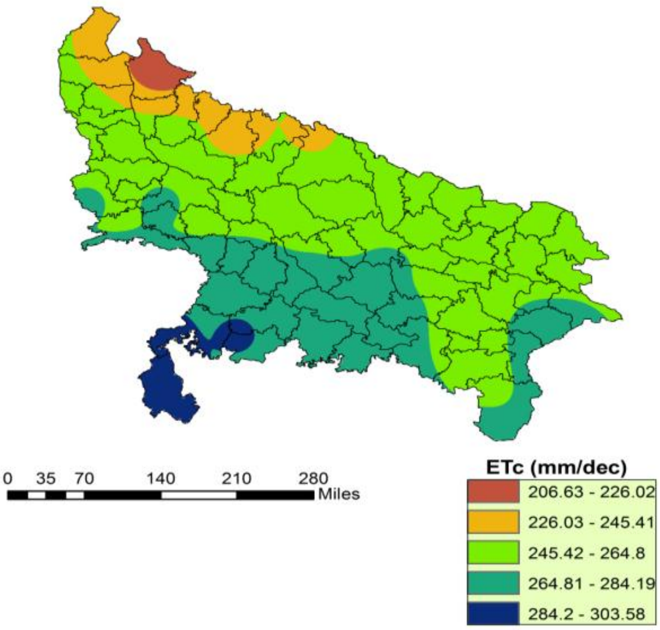


Fig 4.7: Thematic map of ETc for pea 1st date of sowing (15 Oct)

Table 4.4: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Pea (1980-2014).

Station	15 Oct	15Nov

	ETc	IWR	ETc	IWR
Ambedkar nager	253.3	236.3	227.4	205.6
Auraiya	272.6	251.7	241.1	213.7
Bahraich	257.5	228.5	227.8	198.2
Balram pur	260.4	235.3	232	206.9
Banda	281.1	256.5	253.3	221
Barally	236.5	212	206.4	176.6
Bijnor	206.6	184.6	181.5	145.6
Etah	267.5	246.3	231.8	206.4
Farrukhabad	256.7	233.3	225	200.8
Gautam buddh	252.2	234.7	216.3	188.6
Gazipur	271.7	253.8	246.3	226.4
Gorakh pur	262.7	236.7	236.2	211.5
Jaun pur	252.6	230.7	247.7	225.5
Jhansi	294.7	271.2	263.1	235.3
Kausambi	281.4	260.3	252.9	222.4
Kheri	239.8	204.4	210.4	172.2
Lalit pur	303.6	274.1	279.7	246.6
Maharaj ganj	259.5	224.1	233.5	203.6
Mahoba	287.9	262.4	258	224.6
Mathura	266.3	248.8	228.4	207
Moradabad	247.8	226.4	214.4	180.9
Sitapur	256.6	226.6	226.4	198.6
Sultan pur	267.1	248	237.3	215.5
Unnao	265	241.8	235.4	211.1

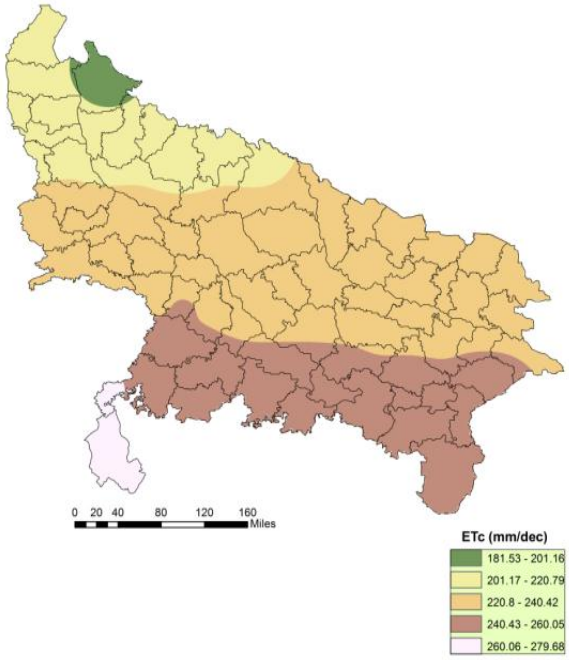


Fig 4.8: Thematic map of ETc for pea 2nd date of sowing (15 Nov)

Thematic map of irrigation water of Pea for 1st DOS was presented in Fig 4.9 and 2nd DOS was presented in Fig 4.10 for the period of 1980-2014 over UP. The irrigation water requirement showed maximum value in in Bijnor district ranged between 184.6 to 202.5 mm at 1st day of sowing, while maximum IWR was found in Lalitpur and Jhansi. At 2nd day of sowing, the IWR was found minimum in Bijnor district ranged between 145.6 to 165.8 mm while maximum IWR was found in Lalitpur and Jhansi ranged between 226.4 to 246.5 mm. Therefore, 2nd date of sowing represents large amount of IWR as compare to 1st date of sowing.

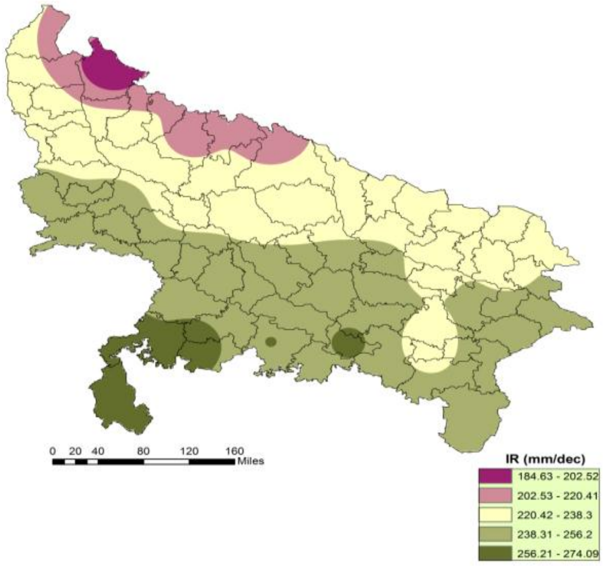


Fig 4.9 Thematic map of IWR for pea 1st date of sowing (15 Oct)

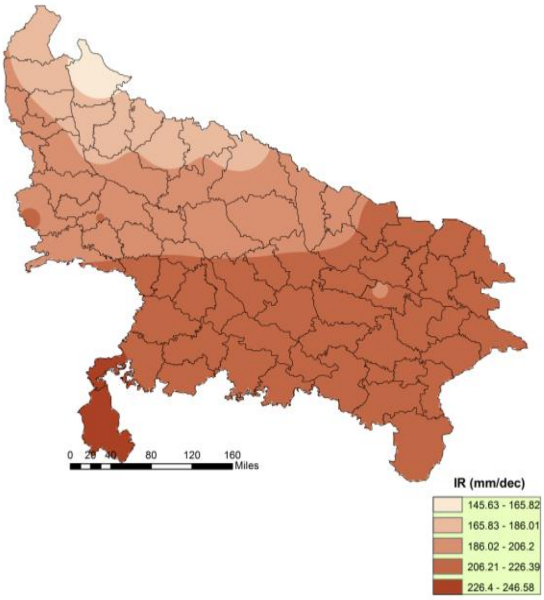


Fig 4.10 Thematic map of IWR for pea 2nd date of sowing (15 Nov).

4.3.3 ETc and IWR of cabbage over Uttar Pradesh for the period 1980-2014.

Estimation of water requirements for cabbage would help farmers avoid water wasting and financial loss related to the traditional techniques. Improved water resources management would promote efficient agricultural production and environmental sustainability. The late planting date requires a little more irrigation water for the whole season compared to the other two planting dates having similar water needs. The estimated values for two different date of sowing for Cabbage crop were presented in the Table 4.5

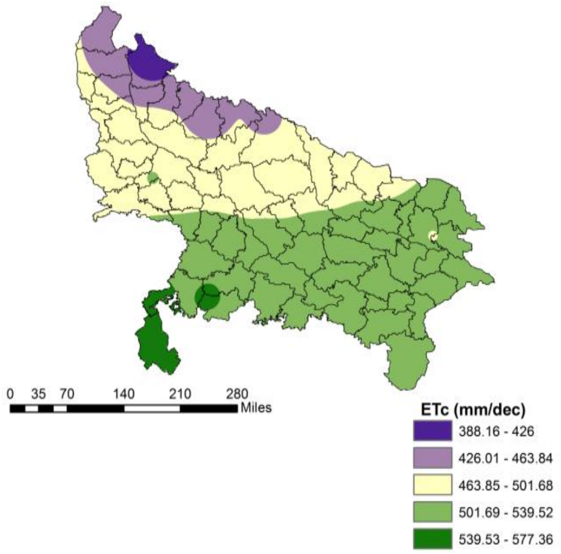


Fig 4.11: Thematic map of ETc for cabbage 1st date of sowing (15 Oct)

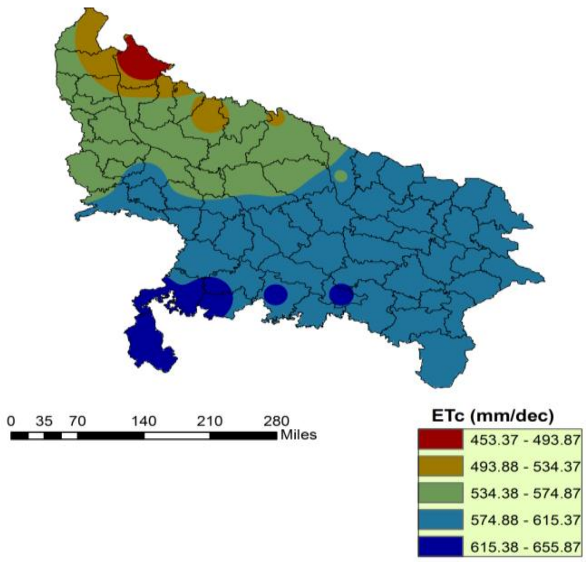


Fig 4.12: Thematic map of ETc for cabbage 2nd date of sowing (15 Nov)

Table 4.5: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Cabbage (1980-2014)

STATION	15 Oct		15 Nov	
	ETc	**IWR**	**ETc**	**IWR**
Ambedkar nager	513.7	467.9	600.1	556.8
Auraiya	514	460.1	594.2	546.7
Bahraich	489.8	417	574.5	503.5
Balram pur	495.9	434.2	580.3	519.8
Banda	534.6	479.3	618.9	567.7
Barally	444.4	373.6	521.9	453.3
Bijnor	388.1	309.5	453.3	368.4
Etah	502.8	446.6	582.2	526.8
Farrukhabad	482.6	429.1	565.1	516.3
Gautam buddh	470.1	412.7	546.2	483.6
Gazipur	518.6	472.5	604.8	565.3
Gorakh pur	501.4	444.5	585.3	530
Jaun pur	523.7	477.6	610.2	569.2
Jhansi	554.9	505.4	633.1	587.1
Kausambi	533.2	477.9	619.6	566.7
Kheri	452.3	360.6	531.1	442.2
Lalit pur	577.4	519.2	655.9	604.1
Maharaj ganj	497.5	418.7	580.8	493.9
Mahoba	545.2	490.3	626.5	575.3
Mathura	495.3	451.8	574.1	528.6
Moradabad	464.5	391.9	544.5	468.1
Sitapur	486	415.2	569	504.8
Sultan pur	506.8	463	591.2	552.5
Unnao	503.2	452.3	587.2	541.1

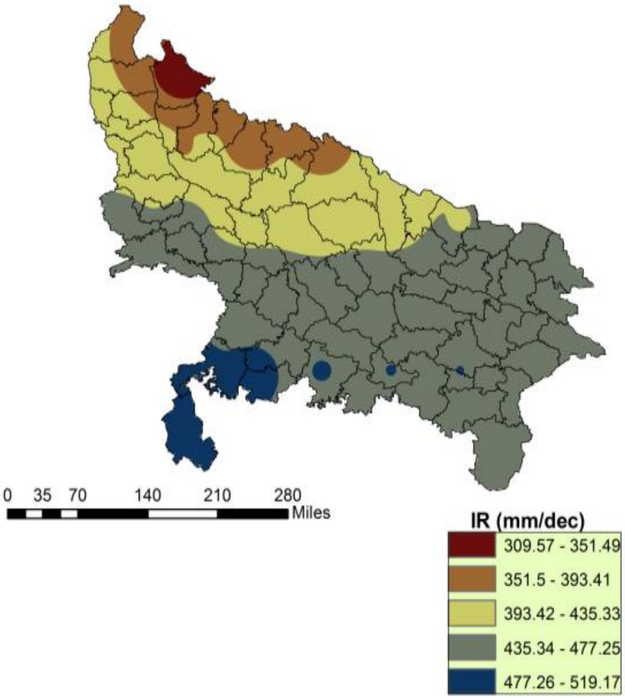


Fig 4.13 Thematic map of IWR for cabbage 1st date of sowing (15 Oct)

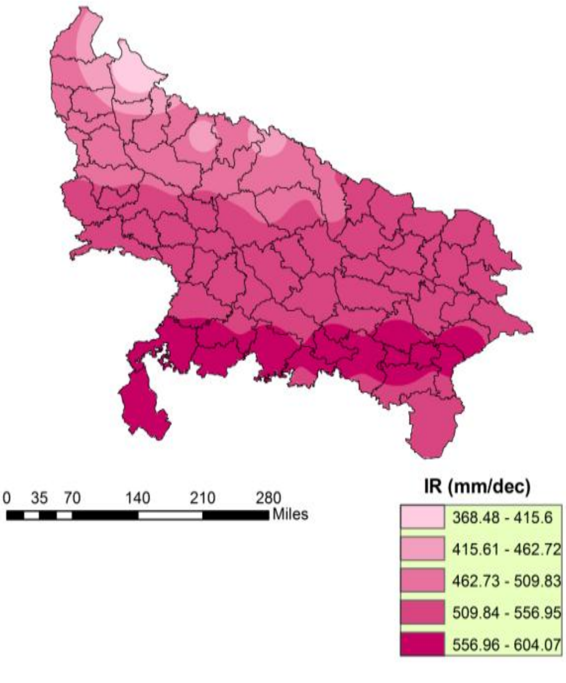


Fig 4.14 Thematic map of IWR for cabbage 2nd date of sowing (15 Nov)

The water requirement values were estimated through Cropwat model for Cabbage crop during period 1980-2014 at two date of sowing. The water requirement of Potato crop over was obtained in 2 date of sowing *i.e.* 15th Oct (fig. 4.11) and 15th Nov (fig. 4.12). At 1st day of sowing, the Etc was found minimum in Bijnor district ranged between 388.1 to 426 mm while maximum Etc was found in Lalitpur and Jhansi. At 2nd day of sowing, the Etc was found minimum in Bijnor district ranged between 453.3 to 498.5 mm while maximum Etc was found in Lalitpur and Jhansi ranged between 615.3 to 655.8 mm. 2nd date of sowing represents large amount of ETc as compare to 1st date of sowing. Therefore it was observed that 1st DOS gave best result for planning of irrigation water for Cabbage. Thematic map of irrigation water of Cabbage for 1st DOS was presented in fig 4.13 and 2nd DOS was presented in fig 4.14 for the period of 1980-2014 over UP. The irrigation water requirement showed maximum value in in Bijnor district ranged between 309.5 to 351.4 mm at 1st day of sowing, while maximum IWR was found in Lalitpur r and Jhansi. At 2nd day of sowing, the IWR was found minimum in Bijnor district ranged between 368.4 to 415.6 mm while maximum IWR was found in Lalitpur and Jhansi ranged between 556.9 to 604 mm. Therefore, 2nd date of sowing represents large amount of IWR as compare to 1st date of sowing.

4.4 Effect of climate change on ETc & IWR on different vegetable crops

Climate is a one of the important factor determining the crop water requirements. Increasing of meteorological factors may have negative effect on water requirements, for better management of agricultural productions, it is important to understand ETc and possible effects of climate change in future. ETc & IWR can be predicted by several methods. Cropwat software is widely used for estimating of ETc values future data for better irrigation management and schedule. The estimated values of two date of sowing in Potato over Uttar Pradesh for 2020, 2050 & 2080 are presented in Appendix Table 1, 2 & 3.

4.4.1 Effect of climate change on ETc & IWR on Potato: The maximum ETc Values for whole development cycle of Potato over 2020 for 1st date of sowing (15 Oct) reached 402.6 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 433.1 mm/dec at Lalitpur and showed minimum for Moradabad district ranges 320 mm/dec for 15 Oct and 15 Nov required 339.4 mm/dec as shown in fig 4.15 respectively. The maximum IWR for potato over 2020 for two date of sowing (15 Oct) and (15 Nov) reached 396.6 mm/dec and 420mm/dec and showed minimum for Bijnor district ranged 238.6 and 266.7 mm/day respectively.

The maximum ETc Values for whole development cycle of Potato over 2050 for 1st date of sowing (15 Oct) reached 419.1 mm/dec at Ambedkar Nagar, and 2nd date of sowing

(15 Nov) reached 443 mm/dec at Ambedkar Nagar and showed minimum for Mathura district ranges 278 mm/dec for 15 Oct and 15 Nov required 339.9 mm/dec in Balrampur as shown in fig 4.15 respectively. The maximum IWR for potato over 2050 for two date of sowing (15 Oct) and (15 Nov) reached 408.8 mm/dec and 436.7 mm/dec at Ambedkar Nagar and showed minimum for Bijnor district ranged 253.2 and 286 mm/day respectively.

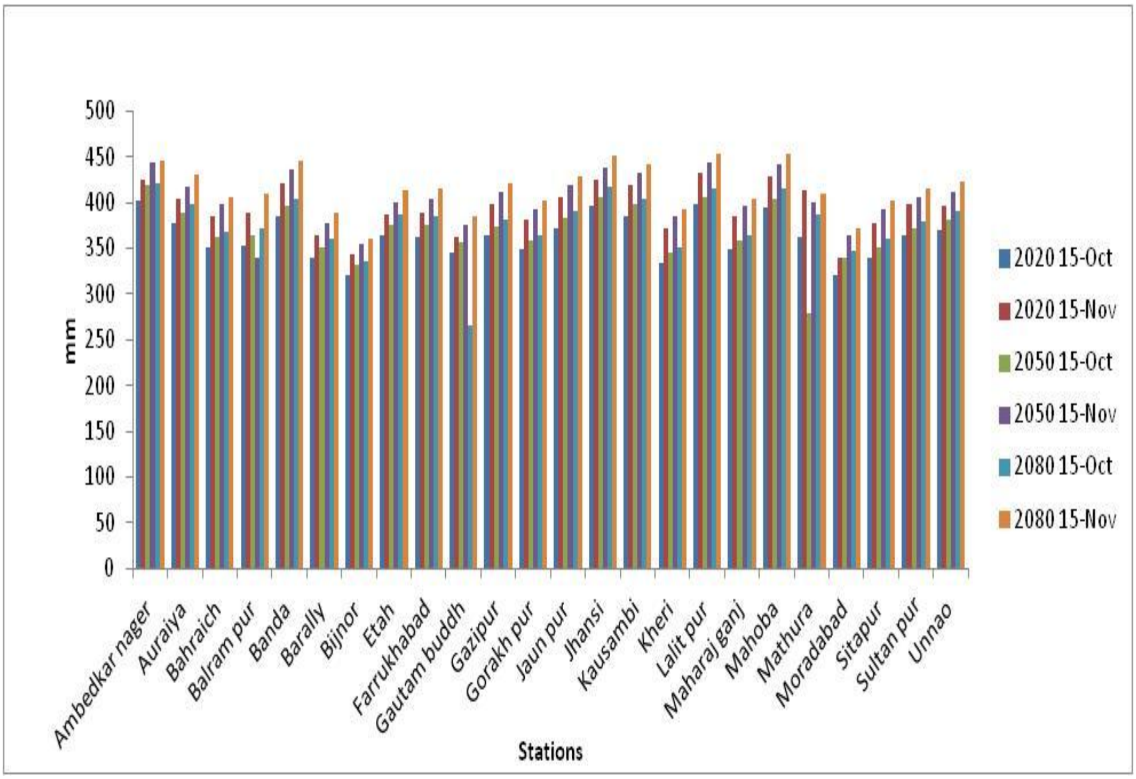


Fig 4.15: Graphical representation of ETc for Potato over Uttar Pradesh (2020, 2050 & 2080)

The maximum ETc Values for whole development cycle of Potato over 2080 for 1st date of sowing (15 Oct) reached 421.7 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 454.1 mm/dec at Lalitpur and showed minimum for Gautam budh nagar district ranges 265.8 mm/dec for 15 Oct and 15 Nov required 360 mm/dec as shown in fig 4.15 respectively. The maximum IWR for potato over 2080 for two date of sowing (15 Oct) and (15 Nov) reached 410.5 mm/dec and 439.5 mm/dec at Ambedkar Nagar and showed minimum for Bijnor district ranged 255.2 and 286.7 mm/day respectively.

4.4.2 Effect of climate change on ETc & IWR on Pea: The maximum ETc Values for whole development cycle of Pea over 2020 for 1st date of sowing (15 Oct) reached 303.2 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 276.1 mm/dec at Kaushambi and showed minimum for Moradabad district ranges 238.4 mm/dec for 15 Oct and 15 Nov required 215.2 mm/dec at Banda as shown in fig 4.16 respectively. The maximum IWR for Pea over 2020 for two date of sowing (15 Oct) and (15 Nov) reached 297.8 mm/dec and 247.8 mm/dec for Ambedkar nagar, Ghorakhpur and showed minimum for Bijnor district ranged 195.3 and 165.4 mm/day at Banda respectively.

The maximum ETc Values for whole development cycle of Pea over 2050 for 1st date of sowing (15 Oct) reached 311.4 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 282.1 mm/dec at Lalitpur and showed minimum for Bijnor district ranges 252 mm/dec for 15 Oct and 15 Nov required 223.6 mm/dec as shown in fig 4.16 respectively. The maximum IWR for Pea over 2050 for two date of sowing (15 Oct) and (15 Nov) reached 301.7 mm/dec and 275.9 mm/dec at Ambedkar Nagar and showed minimum for Bijnor district ranged 205.2 and 177.9 mm/day respectively.

The maximum ETc Values for whole development cycle of Pea over 2080 for 1st date of sowing (15 Oct) reached 314 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 289.1 mm/dec at Lalitpur and showed minimum for Bijnor district ranges 256.4 mm/dec for 15 Oct and 15 Nov required 252.7 mm/dec as shown in fig 4.16 respectively. The maximum IWR for Pea over 2080 for two date of sowing (15 Oct) and (15 Nov) reached 303.3 mm/dec and 277.9 mm/dec at Ambedkar Nagar and showed minimum for Bijnor district ranged 209.3 and 176.8 mm/day respectively.

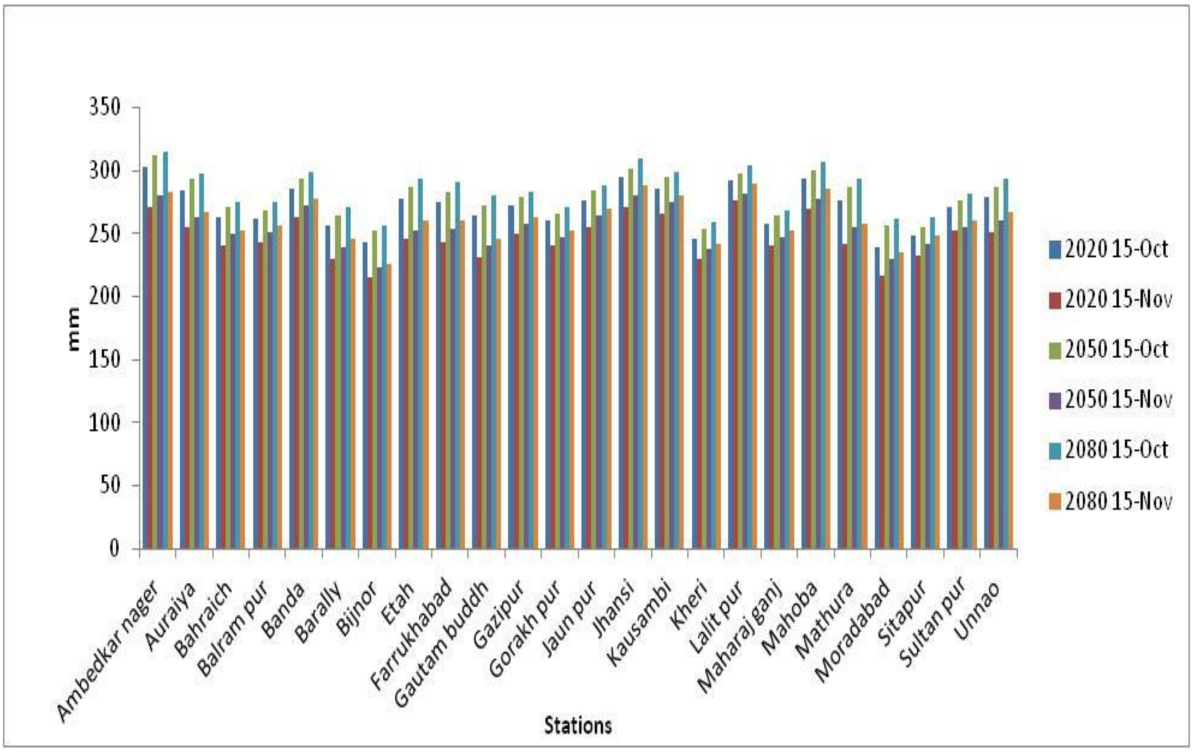


Fig 4.16: Graphical representation of ETc for Pea over Uttar Pradesh (2020, 2050 & 2080)

4.4.3 Effect of climate change on ETc & IWR on Cabbage: The maximum ETc Values for whole development cycle of Cabbage over 2020 for 1st date of sowing (15 Oct) reached 566 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 647.4 mm/dec at Mahoba and showed minimum for Moradabad district ranges 453.9 mm/dec for 15 Oct and 15 Nov required 522 mm/dec at Moradabad as shown in fig 4.17 respectively. The maximum IWR for Cabbage over 2020 for two date of sowing (15 Oct) and (15 Nov) reached 557.9 mm/dec and 624.2 mm/dec for Ambedkar nagar and showed minimum for Bijnor district ranged 358.4 and 450.7 mm/day respectively.

The maximum ETc Values for whole development cycle of Cabbage over 2050 for 1st date of sowing (15 Oct) reached 582 mm/dec at Ambedkar Nagar, and 2nd date of sowing (15 Nov) reached 666.9 mm/dec at Mahoba and showed minimum for Bijnor district ranges 476.5 mm/dec for 15 Oct and 15 Nov required 557.2 mm/dec as shown in fig 4.17 respectively. The maximum IWR for Cabbage over 2050 for two date of sowing (15 Oct) and

(15 Nov) reached 570.2 mm/dec and 641.4 mm/dec at Ambedkar Nagar and showed minimum for Bijnor district ranged 381.3 and 478.4 mm/day respectively.

The maximum ETc Values for whole development cycle of Cabbage over 2080 for 1st date of sowing (15 Oct) reached 592.2 mm/dec and 2nd date of sowing (15 Nov) reached 684 mm/dec at Mahoba and showed minimum for Bijnor district ranges 483.5 mm/dec for 15 Oct and 15 Nov required 565.9 mm/dec as shown in fig 4.17 respectively. The maximum IWR for Cabbage over 2080 for two date of sowing (15 Oct) and (15 Nov) reached 579.2 mm/dec and 651.7 mm/dec at Ambedkar Nagar and showed minimum for Bijnor district ranged 384.6 and 482.2 mm/day respectively.

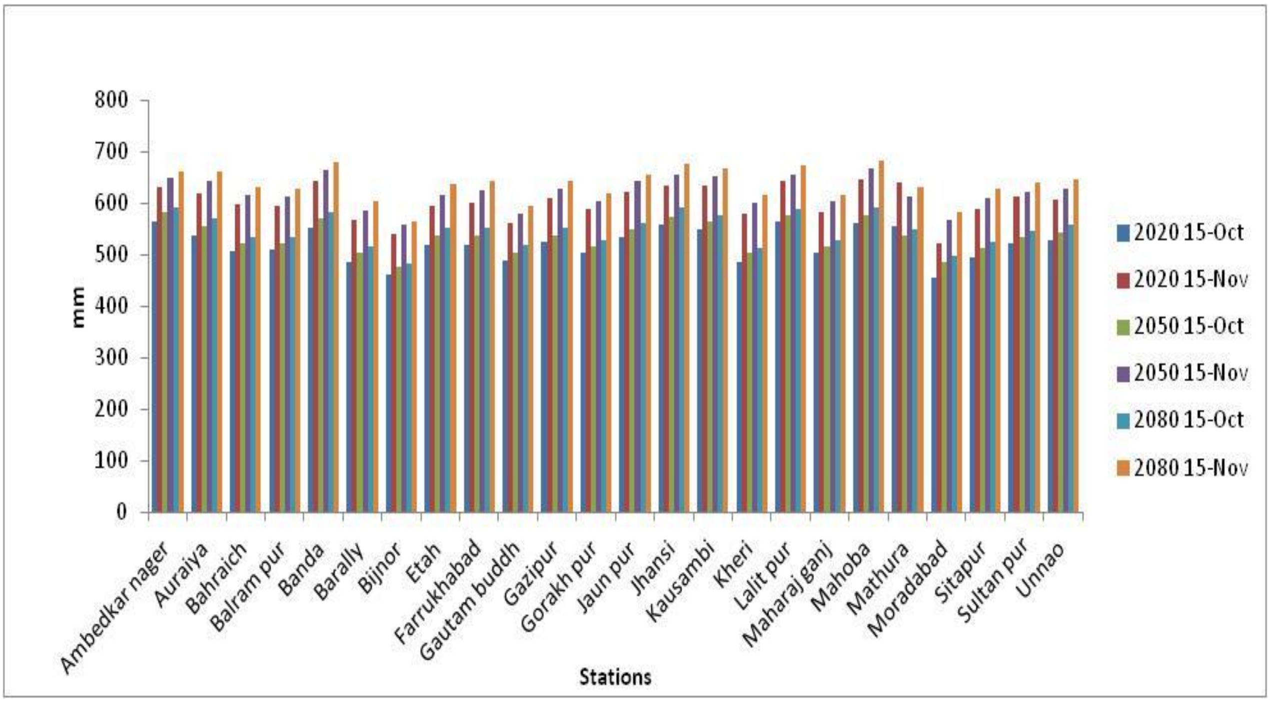


Fig 4.17: Graphical representation of ETc for Cabbage over Uttar Pradesh (2020, 2050 & 2080)

1) Average peak monthly ETo was estimated in the month of May and April, respectively due to high temperature during the summer month. Annual ETo over UP clearly shows that maximum ETo occurred in Lalitpur, Jhansi, Mahoba and some area of Banda the value ranges between 1600-1728.3 mm and minimum ETo covers some areas of Bijnor & Muzzafanagar districts ranges between 1300-1414 mm over the period 1980-2014.

2) In general, the efficiency of rainfall decreases with increasing rainfall. Maximum annual rainfall & effective rainfall was observe in Maharajganj district and some parts of Kheri ranges upto 1157 – 1275 mm & 762.8 -.833.8 mm respectively while Gautambudh Nagar, Mathura and some parts of Etah received minimum annual rainfall and effective rainfall i.e. 688 – 808 mm & 477.8 – 549.0 mm respectively. Only a small portion water could be stored in the root zone through high intensity rains during July to September could enter and, and therefore effectiveness of this type of rainfall is low. It clearly showed that there would be increase of rainfall in future 2020, 2050, 2080 respectively.

3) The annual ETo was found maximum in the lower belt of the state as Jhansi, Mahoba Banda, Lalitpur etc districts and the lowest value of Eto was observed in Muzaffarnagar and Bijnor etc. The average minimum monthly ETo was observed in the month of January and December, respectively due to winter months.

4) For Potato crop at 1st date of sowing, the Etc was found minimum in Bijnor district ranged between 271.0 to 298.8mm while maximum Etc was found in Lalitpur and Jhansi. At 2nd day of sowing, the Etc was found minimum in Bijnor district ranged between 287.3 to 317.6mm while maximum Etc was found in Lalitpur and Jhansi ranged between 408.7 to 439.0mm. Delay in sowing (2nd date of sowing) represents large amount of ETc as compare early sowing. Similar trends were observed for IWR in case of Potato.

5) For Pea crop at 1st date of sowing, the Etc was found minimum in Bijnor district ranged between 206.6 to 226 mm while maximum Etc was found in Lalitpur and Jhansi. At 2nd date of sowing, the Etc was found minimum in Bijnor district ranged between 181.5 to 201.1 mm while maximum Etc was found in Lalitpur and Jhansi ranged between 260.5 to 279.6 mm. It

was also observed that delay in sowing gave best result for planning of irrigation water for Pea. Similar results were observed for IWR in case of pea.

6) For Cabbage crop 1st date of sowing, the Etc was found minimum in Bijnor district ranged between 388.1 to 426 mm while maximum Etc was found in Lalitpur and Jhansi. At 2nd date of sowing, the Etc was found minimum in Bijnor district ranged between 453.3 to 498.5 mm while maximum Etc was found in Lalitpur and Jhansi ranged between 615.3 to 655.8 mm. Similar trends were observed for IWR in case of cabbage.

7) Crop and irrigation water requirement was estimated for future purpose at different dates of sowing (15 Oct and 15 Nov). It was observed that 1st date of sowing was the best sowing period for potato and cabbage crops over Uttar Pradesh while for Pea delay in sowing showed minimum requirement of crop and irrigation water.

8) It is necessary to adopt water saving agriculture counter measures as efficient use of irrigation water.

9) CROPWAT is a best program for irrigation planning and management.

10) Therefore it is essential to develop irrigation scheduling strategies under local climatic conditions to utilize scarce water resources efficiently and effectively for crop production.

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Table 1: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Potato. (2020)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	402.6	396.6	424.5	420
Auraiya	377.3	311.8	403.7	359.3
Bahraich	351.3	279.5	384.5	329.7
Balram pur	353.7	295.6	388.4	345.2
Banda	384.1	324.8	421.7	376.9
Barally	339.9	290	364.9	314
Bijnor	320.8	238.6	343	266.7
Etah	364.8	311.9	386.3	345.9
Farrukhabad	361.5	287.8	388	337.1
Gautam buddh	345.4	292.6	362.8	320.4
Gazipur	364.7	315.1	398.7	358.2
Gorakh pur	348.9	287.9	382	337.9
Jaun pur	372	323.2	405.8	366.8
Jhansi	396.2	352.7	425.5	391.6
Kausambi	385.4	338.3	418.3	376.2
Kheri	333.9	260.2	371.2	314
Lalit pur	398.9	342.4	433.1	387.2
Maharaj ganj	348.5	288.4	385.5	345.7
Mahoba	394.5	348.5	428.6	389.6
Mathura	362.3	326.2	414.3	385.5
Moradabad	320	249.8	339.4	279.3
Sitapur	338.7	269.1	378.2	324.5
Sultan pur	363.9	307.4	398.9	359.1
Unnao	369.6	299.5	396.9	345.8

Table 2: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Potato. (2050)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	419.1	408.8	443	436.7
Auraiya	388.5	320.5	417.8	375.1
Bahraich	363.1	294.4	398	349.7
Balram pur	363.6	307.3	339.9	363.1
Banda	396.4	335.7	436.3	393
Barally	351.2	282.4	378	329.6
Bijnor	332.4	253.2	355.6	286.8
Etah	376.2	322.4	400.3	362.3
Farrukhabad	374.8	300	404.1	355.2
Gautam buddh	356.8	305.7	375.9	337.6
Gazipur	374.3	326	410.7	375.6
Gorakh pur	357.6	295.3	392.2	351.9
Jaun pur	383.4	337.1	418.9	385.1
Jhansi	406.7	358.3	438.8	405.4
Kausambi	398.3	350.6	432.1	393.2
Kheri	345.6	273.6	384.8	332.6
Lalit pur	406.3	344.6	442.9	397.2
Maharaj ganj	358	296.8	396.3	360.2
Mahoba	404.9	355.7	442.2	403.8
Mathura	278	341	400.8	373.7
Moradabad	338.9	287.4	363.4	311
Sitapur	350.1	280.9	392.1	342.4
Sultan pur	371.5	317	405.4	370.3
Unnao	381.8	310.2	410.9	362.2

Table 3: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Potato. (2080)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	421.7	410.5	445	439.5
Auraiya	398.3	326.3	429.8	384.1
Bahraich	368.6	291.1	405.1	350.9
Balram pur	371.6	310.9	409.6	366.9
Banda	404.7	338.3	446.4	399.3
Barally	361.1	287.8	388.9	336.6
Bijnor	336.7	255.2	360	286.7
Etah	386.9	329.5	412.8	372.7
Farrukhabad	385.5	307.2	415.9	363.4
Gautam buddh	265.8	309.7	385.6	343.8
Gazipur	381.8	324.6	420.7	378.4
Gorakh pur	365.1	299.7	401.5	356.1
Jaun pur	390.4	336.4	428.5	388.8
Jhansi	418	363.5	452.2	414.9
Kausambi	404.8	349.5	441.1	396.7
Kheri	351.5	275.7	392.7	335.4
Lalit pur	415.8	347.9	454.1	404.7
Maharaj ganj	364.4	301.3	404.3	363.7
Mahoba	414.6	358.9	453.5	410.9
Mathura	386.2	344	409.8	378.7
Moradabad	347.1	276.9	372.6	315.5
Sitapur	359.5	286.4	402.4	348.2
Sultan pur	379.7	318.7	415.6	374.9
Unnao	391.2	314.8	422.5	369.8

Table 4: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Pea.(2020)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	303.2	297.8	240.5	202.9
Auraiya	284.6	237	243.5	214.1
Bahraich	262.3	218.9	262.4	229.6
Balram pur	261.7	223.7	230.1	200.6
Banda	285	244.2	215.2	165.4
Barally	256.2	220.1	245.1	220.4
Bijnor	243.5	195.3	243.5	206.6
Etah	277.2	240.8	231.7	202
Farrukhabad	274.3	220.5	249.6	221.3
Gautam buddh	264.3	228.2	239.8	210.7
Gazipur	272.6	244.7	255.3	228.5
Gorakh pur	260.5	222.8	271.5	247.8
Jaun pur	276.7	246.6	265.2	237.4
Jhansi	294.5	266.6	229.5	192.4
Kausambi	286	257.7	276.1	238.9
Kheri	245.2	197.9	240.2	212.7
Lalit pur	292.7	256.1	269.5	239.7
Maharaj ganj	257.4	217.3	242.3	224.8
Mahoba	292.8	267.5	216.4	179.4
Mathura	276.4	251.9	233	198.3
Moradabad	238.4	197.4	252.2	224
Sitapur	247.8	200.8	251	210.9
Sultan pur	271.3	234.1	240.5	202.9
Unnao	278.3	231.3	243.5	214.1

Table 5: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Pea. (2050)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	311.4	301.7	280.6	275.9
Auraiya	292.8	241.6	263	230
Bahraich	270.4	227.5	249.4	217.1
Balram pur	268.5	229.8	250.8	227.1
Banda	293.1	250	271.9	240.7
Barally	264.2	219.1	238.4	209.3
Bijnor	252	205.2	223.6	177.9
Etah	286.2	247.7	252.5	229.5
Farrukhabad	283.1	226.4	253.5	217.9
Gautam buddh	272.4	237	240.1	213.5
Gazipur	278.5	248.7	257.3	234.8
Gorakh pur	266	224	246.5	221.9
Jaun pur	284.4	254.1	264	242.2
Jhansi	301.3	268.4	279.6	256.1
Kausambi	294.6	264	274.6	250.2
Kheri	253.7	205.2	238.2	204.2
Lalit pur	297.1	255.1	282.1	244.8
Maharaj ganj	263.6	219.5	247.6	223.6
Mahoba	299.4	270.1	277.9	248.6
Mathura	286.3	260.7	254.5	238.5
Moradabad	255.8	218.4	229.2	198.4
Sitapur	255.3	206.1	241.6	209.9
Sultan pur	276.4	238.9	254.7	231.3
Unnao	286.6	236.5	260.2	222.5

Table 6 : Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Pea.(2080)

Station	**15 Oct**		**15Nov**	
	ETc	**IWR**	**ETc**	**IWR**
Ambedkar nager	314	303.3	282.8	277.9
Auraiya	297.4	244.1	267	231.8
Bahraich	275.3	230.7	252.4	215.1
Balram pur	274.2	234.1	256.4	227.4
Banda	298.6	251.4	277.8	243.7
Barally	271.5	224.7	245.3	213.8
Bijnor	256.4	209.3	225.7	176.8
Etah	294	253.6	259.8	235.5
Farrukhabad	291	233.1	260.9	222.8
Gautam buddh	279.5	240.4	246	216.6
Gazipur	283.4	246.7	262.6	233
Gorakh pur	271.3	228.9	251.9	222.1
Jaun pur	288.6	252.6	269.2	241.2
Jhansi	309	271.2	287.5	261.1
Kausambi	299	262.4	279.8	250.5
Kheri	258.5	209.5	241.5	204.1
Lalit pur	303.6	256.2	289.1	249.2
Maharaj ganj	268.3	225.2	252	223.9
Mahoba	306.1	271.7	284.9	252.5
Mathura	293.6	264	258.2	239.7
Moradabad	261.8	220.8	234.8	196.6
Sitapur	262.5	212.5	248.2	213
Sultan pur	281.8	240.2	260.8	231.8
Unnao	293	240.6	266.7	225.7

Table 6: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Cabbage. (2020)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	566	557.9	630.4	624.2
Auraiya	537.4	461.2	619.2	573.4
Bahraich	506.6	422.2	596.8	533.2
Balram pur	508.6	438.4	594.3	541
Banda	553.6	482.3	642	595.7
Barally	486.7	416.3	566.7	491.8
Bijnor	460.6	358.4	538.8	450.7
Etah	518	450.6	594.2	550.3
Farrukhabad	518	428.5	601.5	548
Gautam buddh	488.5	424.2	561.4	512.5
Gazipur	524.7	465.8	608.9	562
Gorakh pur	503.5	430.3	588.6	534.9
Jaun pur	533.5	479.7	621.5	572.4
Jhansi	559.3	509.3	634.5	595.7
Kausambi	548.4	491.6	634.1	584.9
Kheri	486.6	392	579.5	517.4
Lalit pur	564.1	502.8	642.6	586.9
Maharaj ganj	504.2	430.5	582.5	531.6
Mahoba	562.9	511	647.4	608
Mathura	556	509.6	641.5	608.8
Moradabad	453.9	366.8	522	454.6
Sitapur	495.1	403.5	589.5	530
Sultan pur	520.8	459.6	612.6	561.3
Unnao	527	447.1	608.1	555.9

Table 7: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Cabbage.(2050)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	582	570.2	649.1	641.4
Auraiya	554.8	476.3	642.4	594.4
Bahraich	523	442	616.2	560.2
Balram pur	522.6	454.7	612.5	566.3
Banda	570.8	497.9	663.1	618.3
Barally	502.8	418.3	586.7	531.8
Bijnor	476.5	381.3	557.2	478.4
Etah	536.1	468.7	617.3	576.5
Farrukhabad	537.3	447.4	625.7	574.8
Gautam buddh	504.5	443.5	579.8	536.1
Gazipur	538.5	479.9	626.8	585.4
Gorakh pur	515.6	440.1	602.9	552.8
Jaun pur	549.2	498	642.9	599.1
Jhansi	575	520.7	655.5	617.3
Kausambi	565.6	507.9	653.9	608
Kheri	503.3	411.8	600.4	545.2
Lalit pur	575.4	509.5	656.7	601.3
Maharaj ganj	517	441.5	604.1	557
Mahoba	578	522.8	666.9	628.1
Mathura	536.2	489.7	614.3	584.2
Moradabad	485.3	412.9	567.3	490.5
Sitapur	511.8	421.3	610.9	556.6
Sultan pur	533.4	474.1	623.2	576.9
Unnao	544	462.4	629.3	579.5

Table 8: Crop Water Requirement (ETc) and Irrigation Water Requirement (IWR) at different date of sowing (15 Oct & 15 Nov) for Cabbage. (2080)

Station	15 Oct		15Nov	
	ETc	IWR	ETc	IWR
Ambedkar nager	592	579.2	660.4	651.7
Auraiya	570.2	482.2	661.4	614.3
Bahraich	533.1	447.5	629.8	567.9
Balram pur	535	462.5	626.9	574.8
Banda	583.5	504	679	630.3
Barally	516.9	427.9	603.7	544.9
Bijnor	483.5	384.6	565.9	482.2
Etah	552.6	481.2	638.3	595.7
Farrukhabad	552.5	458.6	644.5	590
Gautam buddh	517.7	451.2	596.1	549.1
Gazipur	551.1	483.1	643.8	595.4
Gorakh pur	527.4	448.7	618.2	563.4
Jaun pur	560.8	502	655.1	605.8
Jhansi	591.8	530.7	675.4	633.2
Kausambi	575.9	509.7	667.6	616.4
Kheri	514.2	418.6	615.1	554.6
Lalit pur	589.2	516.4	673.1	613.4
Maharaj ganj	527.4	449.4	617.3	566
Mahoba	592.2	529.6	684	640.9
Mathura	549.3	497.2	631	596.9
Moradabad	497.1	411.5	581.6	518.6
Sitapur	525.2	430.6	627.1	568.4
Sultan pur	545.7	479.9	641.4	589.6
Unnao	558.7	471.9	647.1	593.2