

**CROP WATER REQUIREMENT IN CONTEXT OF CLIMATE
VARIABILITY**

by

Gade Shubham Anil

(Reg. No. 2018/11)



**DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING
DR. ANNASHEB SHINDE COLLEGE OF AGRICULTURAL ENGINEERING AND
TECHNOLOGY**

**MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI - 413 722, DIST-AHMEDNAGAR
MAHARASHTRA, (INDIA)**

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In partial fulfilment of the requirements for the degree

of

MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)

in

Irrigation and Drainage Engineering



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2020

Dedication

Affectionately Dedicated to

Parents,

Teachers, Farmers and well wishers

..... Mr. Gade Shubham Anil

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institute
for Degree or
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Place: MPKV, Rahuri

Date: / / 2020

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This is to certify that the thesis entitled. “**CROP WATER REQUIREMENT IN CONTEXT OF CLIMATE VARIABILITY**” submitted to the Faculty of Agriculture Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) in partial fulfillment of the requirement for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **IRRIGATION AND DRAINAGE ENGINEERING**, embodies the result of a piece of bonafide research work carried out by **MR. GADE SHUBHAM ANIL** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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Place: MPKV, Rahuri

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Date: / /2020

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Needless to say, all omissions and errors are mine.

Place: MPKV, Rahuri

Date: / / 2020

(Shubham Anil Gade)

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LIST OF ABBREVIATIONS

Abbreviations	Description
ANN	: Artificial neural network
BSS	: Bright Sunshine hours
CAAST - CSAWM	: Center for Advanced Agricultural Science and Technology - Climate Smart Agriculture and Water Management
CCIS	: Canadian Climate Impact Scenarios
CGCM3	: The Third Generation Couple Global Climate Model
CV	: Coefficient of Variation
CWR	: Crop Water Requirement
Dr. ASCAE&T	: Dr. Annaseheb Shinde College of Agricultural Engineering and Technology
ET	: Evapotranspiration
ET _c	: Crop evapotranspiration
ET ₀	: Reference evapotranspiration
E_{ns}	: Nash-Sutcliffe efficiency
FAO	: Food and Agriculture Organization
Fig.	: Figure
GCM	: General Circulation Models
GIS	: Geographical Information System
GPS	: Global Positioning System
HADCM3	: Hadley Centre Coupled Model Version 3
IDE	: Irrigation and Drainage Engineering
IDW	: Inverse Distance Weighting
IMD	: Indian Meteorological Department
IPCC	: Intergovernmental Panel on Climate Change
IR	: Irrigation Requirement
IWR	: Irrigation Water Requirement
IWM	: Irrigation Water Management
IWRAS	: Irrigation Water Requirement Advisory Service
K _c	: Crop Coefficient
LARS-WG	: Long Ashton Research Station Weather Generator
MAD	: Mean Absolute Deviation
MAPE	: Mean Absolute Percentage Error
MK	: Mann Kendall
MLR	: Multiple Linear Regression
MPKV	: Mahatma Phule Krishi Vidyapeeth
NCEP	: National Centre for Environmental Prediction

OLS	:	Ordinary Least Square
PET	:	Potential Evapotranspiration
RH _{max}	:	Maximum Relative Humidity
RH _{min}	:	Maximum Relative Humidity
RKVY	:	Rashtriya Krishi Vikas Yojna
RMSE	:	Root Mean Square Error
RS	:	Remote Sensing
SAU	:	State Agriculture University
SD	:	Standard Deviation
SE	:	Standard Error
SDSM	:	Statistical Downscaling Model
SWG	:	Stochastic Weather Generator
TM	:	Thematic Mapper
T _{max}	:	Maximum Temperature
T _{min}	:	Minimum Temperature
WS	:	Wind Speed

LIST OF SYMBOLS

Symbols	Description
%	: Per cent
°C	: Degree Celsius
<i>et al.</i>	: And Others
ha	: Hectare
i.e.	: That is
km ²	: Square Kilometer
m	: Metre
MCM	: Million Cubic Meter
M-ha	: Million Hectare
mm	: Millimeter
mm day ⁻¹	: Millimeter per Day
R ²	: Coefficient of Determination
hPa	: Hectopascal
kpa	: Kilo Pascal
MJ	: Million Joule
m/s	: Meter per Sec
μ	: Mean

ABSTRACT

Crop Water Requirement in Context of Climate Variability

by

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**Master of Technology
(Agricultural Engineering)**

in

Irrigation and Drainage Engineering

Mahatma Phule Krishi Vidyapeeth, Rahuri,

Dist. – Ahmednagar (Maharashtra)

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Research Guide : Dr. D. D. Khedkar

Department : Irrigation and Drainage Engineering

The crop water requirement plays a key role in crop production and it is one of the major parameter affected by climate change. An investigation was undertaken for the Western Maharashtra region at nine selected stations *viz.*, Dhule, Jalgaon, Niphad, Pune, Rahuri, Solapur, K Digraj, Padegaon, and Kolhapur as each of one districts. Four main crops of the region i.e. Cotton, *Rabi* onion, Soybean and *Suru* sugarcane were selected for the entire analysis. The study included estimation of crop water requirement and its trend analysis, periodic changes i.e. decadal variation in crop water requirement and future estimation of CWR by projecting reference evapotranspiration (ET_0) using SDSM software. The long term average weekly meteorological data was collected from the India Meteorological Department (IMD), Pune and SAU, Rahuri. The NCEP and GCM i.e. HadCM3 data required for downscaling was downloaded for the study area. The ET_0 was estimated using FAO 56 Penman-Monteith method.

The trend analysis was carried out to study the variability of CWR and to examine weather trend is present in the data. Non parametric Mann Kendall and Sen's Slope estimator tests were employed to detect the trend in CWR for cotton, *rabi* onion, soybean and *suru* sugarcane. The spatial distribution of trend in CWR were interpreted with the inverse distance weighted (IDW) method. The periodic changes in CWR was examined by finding percentage increase/decrease within successive decades i.e. 1980s, 1990s, 2000s and 2010s. The spatial analysis of average CWR over different decades were carried out for better understanding the fluctuation in water requirement over the region. Three stations i.e. Pune, Rahuri and Solapur were selected for estimation of future CWR as per availability of daily meteorological data. The daily ET_0 data for the period 1968 – 2000 of Solapur, 1975 – 2000 of Rahuri and 1970 – 2000 of Pune station were downscaled using SDSM software in correlation with GCM data. The downscaling process mostly involved selection of predictors, calibration and validation of model, weather generation and lastly generation of scenario for the future period. The ET_0 were estimated for 2030s, 2050s and 2080s period depending on base period. The future CWR of cotton, *rabi* onion, soybean and *suru* sugarcane were estimated using projected values of ET_0 and present values of crop coefficients.

The decreasing trends in CWR was observed for all crops i.e. cotton, *rabi* onion, soybean and *suru* sugarcane for all stations excepts no trends in CWR showed to cotton and soybean for Solapur, *rabi* onion for Padegaon and all crops at K. Digraj station. Spatial analysis of the trends in CWR will help the planners of all sectors for planning of cotton, *rabi* onion, soybean, and *suru* sugarcane, and identifying the water requirement zones in Western Maharashtra for better resource management. The spatial analysis of resulted 'Z' values of Mann Kendall test for cotton, *rabi* onion, soybean and *suru* sugarcane showed that 'Z' values were minimum at central part of study area, whereas they have been relatively decreased towards north side and relatively increased towards south side of study area. This particularizes there is more decreasing trends towards north part than south part of study area i.e. Western Maharashtra.

Among decadal changes in CWR, it was observed that there was decrease in CWR varied from -1.57 to -17.57 % for all stations for all crops during 1980s to 1990s decade. For the decades of 1990s to 2000s, all stations showed decrease (-1.38 to -15.57 %) in CWR for all crops except Solapur for cotton and soybean, and Rahuri for all crops. For decades of 2000s to 2010s, it was also observed that all stations showed decrease (-0.11 to -15.50 %) in CWR for all crops, except Solapur and K. Digraj for cotton, soybean and *suru* sugarcane, and Niphad for all crops showed increase in CWR (0.74 to 3.26 %). The highest decrease in CWR i.e. -17.57 % was observed for *rabi* onion crop in Rahuri during decades of 1980s to 1990s. Whereas, highest increase in CWR i.e. 6.53 % was observed for soybean crop in K. Digraj during decades of 2000s to 2010s. The spatial maps for average decadal values of CWR for all crops generally revealed increasing values towards the north part of study area and decreasing along central and south region of study area. The spatial maps revealed shifting of CWR from south-east to north-east as proceeded from 1990s, 2000s and 2010s decades sequentially.

The SDSM performs well in downscaling ET_0 during both calibration and validation periods for selected stations i.e. Pune, Rahuri and Solapur. The results of ET_0 series downscaled from the SDSM compared with estimated series of FAO P-M method exhibits better performance with the values more than 0.6 for R^2 and E_{ns} and less than 1.32 and 18%, for RMSE and MAPE, respectively. The projected changes showed increase in ET_0 for all months (in summer, winter and pre-monsoon seasons) except decrease in ET_0 from June to September (monsoon season) during 2030s, 2050s, and 2080s period as compare to base period for Pune, Rahuri and Solapur stations under both H3A2 and H3B2 scenario. This particularizes decrease in projected CWR for *Kharif* season whereas increase in CWR for *rabi* and *summer* season. The estimated variation in future CWR for *Kharif* crop (cotton and soybean) showed marginal decrease or approximately same as compare to base period during 2030s, 2050s, and 2080s for Pune and Rahuri station whereas, relative increase in CWR at Solapur station for same periods under both H3A2 and H3B2 scenario. The estimated variation in future CWR for *rabi* crop (onion) and *perennial* crop (*suru* sugarcane) showed increment in CWR during 2030s, 2050s, and 2080s period as compare to base period for Pune, Rahuri and Solapur stations under both H3A2 and H3B2 scenario.

The outcomes of the study would contribute in the planning of the irrigation water management of region and also in furthering the climate change study using modelled data in the context of India. The Theil-Sen Slope estimator for CWR trends in the study depict a good consistency with the Mann-Kendall test results. The results indicated by SDSM profound good applicability in downscaling. The findings of this study can be incorporated as reference to agriculture, water resource, and eco-environment management strategies in the Western Maharashtra.

1. INTRODUCTION

Climate change is becoming a serious trouble and the hottest topic to the entire globe. Climate change may be referred as variation in mean weather patterns or in other words time change of weather throughout the long haul normal conditions i.e. higher or lesser major climatic events. Climate may change in different ways, over different time scales and at different geographical scales. Since climate is changing, scientists have become interested in global warming, due to mankind's impact on the climate system, through the enhancement of the natural greenhouse effect. Environment and societies have always been vulnerable to extreme weather and a drastic shift in the distribution of weather patterns. Globally climate change has caught increasing attention in the research field due to its direct and indirect impacts on all major sectors, such as hydro-meteorological, ecological, biological and socio-economic sectors. Worldwide, major changes in the climate are expected due to global warming, which leads to variations in crop water requirement.

The knowledge of the water requirement of different crops is to estimate the demand for water and to touch and to match these with the variability of water for appropriate management. In recent decades, global agriculture has threatened by climate change and is one of the important challenges to increase food production for the rapidly growing population under increased environment stress. There is a need for an increase in agricultural production to overcome problems of insufficient food by effective use of available water resources and intensive water management programs. Many uncertain factors that affect water management are soil characteristics, availability of water resources, irrigation efficiency, climate variability and bio-physical interactions (Yinhong *et al.* 2009). Among all these, climate variability issue caught more and more attention because of its significant impacts on agriculture and water resource sector in recent decades.

The regional cropping calendar, cropping system, growing season, crop water requirement (CWR) and irrigation requirement (IR) for different agro-climatic zone depends on the respective climate variables such as precipitation, temperature, relative humidity, evapotranspiration (ET), wind speed, sunshine hours, etc. (Thomas, 2008; Goyal, 2004). Furthermore, the agriculture sector and CWR are more sensitive and affected by climate variability particularly through climate extreme events such as drought, flood, and heatwaves (Anonymous, 2018 (a)).

Past studies (IPCC 2002, 2007 and 2013; Pandey *et al.*, 2007) have shown that climatic variables such as precipitation, temperature, evapotranspiration (ET), wind speed, sunshine hours, etc. are fluctuating from the normal due to both natural and anthropogenic factors in last century over world-wide. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), a 0.74 °C rise in the global mean surface temperature was reported in the last hundred years specifically between 1906 and 2005. Globally, it has been estimated that

the occurrence of precipitation is increased by 10 to 15 % but at a regional scale, both decreasing and increasing trends were projected (IPCC, 2007). Temperature is a very important climatic variable for the water resources planner and agricultural sector after the precipitation (Duhan *et al.* 2013). From the past studies, it was also found that trend of temperature is increasing with latitudes in the Northern hemisphere (IPCC, 2007). Indian subcontinent also has experienced similar nature of trend in precipitation and temperature but the magnitude is varying with seasons (Sharma and Singh, 2007). Since the soil-water-plant relationship is interdependent on each other, the fluctuation of precipitation and increase in air temperature over region significant changes the effective rainfall, evapotranspiration rate, crop growth period, crop yield and consequently the CWR. Goyal, 2004 conducted a sensitivity of the evapotranspiration rate over Rajasthan, India and suggested that the evapotranspiration rate increased by 14.8% with an increase in temperature by 20%.

Crop evapotranspiration (ET_c) differs distinctly from reference evapotranspiration (ET_0) as the ground cover, canopy properties and aerodynamic resistance of the crop. Differences in leaf anatomy, stomatal characteristics, aerodynamic properties, and even albedo cause crop evapotranspiration to differ from reference evapotranspiration under the same climatic conditions. Due to variations in the crop characteristics throughout its growing season, crop coefficients for a given crop changes from sowing till harvest. Consequently, different crops will have different crop coefficients. The changing characteristics of the crop over the growing season also affect the crop coefficient. The Penman-Monteith method is the sole standard method under all climatic conditions as per recommendation of FAO 56 (Allen *et al.* 1998).

Chattopadhyay and Hulme, 1996 conducted research work on ET_0 trends over India and suggested that most of the stations showed decreasing trends in ET_0 between 1961 and 1992 in all seasons, ET_0 decreased by the greatest amount in the monsoon and post-monsoon seasons. The change of climatic situation has huge impacts on agricultural water resources through the changes in demand and supply, consequently on the socio-economic and environmental sectors. Verma *et al.* (2007) studied ET_0 trends over India and demonstrated that, the annual $d(ET_0)/dt$ values varies from -3.0 to -20.06 mm/year and mean annual $d(ET_0)/dt$ over India was found to be -9.36 mm/year with major variation in ET_0 observed in 1980 to 2017 with considerable decrease in most part of India. Fan and Thomas, 2018 revealed that even though temperatures had increased, ET_0 and observed pan evaporation (Epan) rates in general had been declining during the last decades, both in China as well on a global scale with decline of solar radiation rates (global dimming) and wind speeds (stilling) to be the main cause for decreased ET_0 rates.

Potential changes in climate can impact on agriculture and water resources. A changing climate could lead to more drought and alter the water requirements for crop production. Due to this, the crop production sector should be aware of efficient methods of water application and conservation

for the future. Doria *et al.* (2006) showed that a simulation-based on both natural and anthropogenic radiative forcing is in closer agreement with observed data that only takes into account natural climate variability.

Many downscaling methods have been developed during the last two decades which consider the temporal and spatial mismatch between regional scales and coarse scales. In the beginning, these methods were mostly applied in Europe and in the USA (Wilby and Wigley, 1997). General Circulation Models (GCMs) are widely used tools to assess potential impacts of global climate warming. However, their outputs are difficult to use in regional impact studies with regard to water resources because of their coarse spatial resolution. Downscaling techniques have emerged as useful tools to reduce the problem of discordant scales by deriving regional climate information from global climate data (Gagnon *et al.* 2005). The statistical downscaling is based on few assumptions, these assumptions are that the predictor – predictand relationships are valid under future climatic conditions, and predictor variables and their changes are well characterized by GCMs (Wilby and Wigly, 2000; Saraf and Regulwar, 2016). Studies in Tibetan plateau by Wang *et al.* (2013) projected ET_0 on the plateau during 2011–2100 from the HadCM3 (Hadley Centre Coupled Model version 3) under A2 and B2 emission scenarios and CGCM3 (The Third Generation Couple Global Climate Model) under A2 and A1B emission scenarios, where SDSM performed fairly well in reproducing ET_0 and the continuous increase in ET_0 in the 21st century was revealed by both climate models. In general, Statistical downscaling techniques are classified into three main categories as weather classification, regression models and weather generators. Weather classification methods classify large scale atmospheric variables of GCMs into finite number of states and relate them to basin scale climate variables. Regression methods build up linear or nonlinear functions between predictors and predictand. Weather generators produce a synthetic series of climate data, while preserving statistical attributes of the observations of climate variables. To date, many statistical models have been developed and are available. SDSM is being used widely throughout the world to downscale the most important climate variables such as temperature, precipitation, and evaporation, etc. for assessing hydrologic responses in climate change scenarios (Huang *et al.* 2011). As per Guo *et al.* (2018), through the analysis of the evaluation indices in the calibration and validation periods, the results show that both downscaling models (ASD and SDSM) simulate the temperature and evapotranspiration well. This SDSM model is developed through a combination of multiple linear regression and the stochastic weather generator (Gebremeskel *et al.*, (2005); Mahmood and Babel, 2012). The statistical downscaling technique utilized in this study was SDSM version 4.2 developed by Rob Wilby (Wilby *et al.* 2004) to simulate temperature and precipitation for future time periods. Although future generations of rainfall and temperature are frequent, there had been limited study of the future generation of evapotranspiration or CWR. However, evapotranspiration is not only major climatic

parameters controlling water balance but also a major factor controlling crop production. In the areas of limited rainfall or rainfall based agricultural season (as in the case of the study area i.e. Western Maharashtra), variation in crop water requirement may create a problem. In this region of study area the future generation of evapotranspiration has not been done before. Therefore, it is necessary to study monthly variation in ET_0 for future period to assess their effects in the future to develop better management strategies.

The total geographical area of India is 328 M-ha of which the cultivable area is around 186 M-ha. In India, irrigated agriculture represents 20 percent of total cultivated land but contributes about 40 per cent of the total food produced (Anonymous, 2016). The geographical area of the Maharashtra state is 30.7 M-ha and cultivable area is about 22.5 M-ha. The irrigation potential of 4.826 M-ha has been created by the Water Resources Department of state through 3,712 completed and ongoing projects (Anonymous, 2018 (b)). Physio-graphically, Maharashtra state may be divided into three natural divisions: the coastal strip (the Konkan), the Sahyadri or the western ghat, and the plateau. The Sahyadri hills run parallel to the seacoast, with many offshoots branching (Satmala, Ajanta, Harishchandra, Balaghat and Mahadev) eastwards from the main ranges. The slopes of the Sahyadri gently descending towards the east and south-east. Most of the rivers in Maharashtra originate in the Sahyadri and then divide to join the eastward and westward flowing rivers. The westward flowing rivers reaches in Arabian sea through Konkan region while eastward flowing rivers reaches in the Bay of Bengal through most part of state. As per the cropping practices state has divided into four regions as Konkan, Western Maharashtra, Marathwada and Vidarbha. Western Maharashtra is more irrigated as compare to rest of the Maharashtra. Geology of the area is dominantly covered by basaltic rock. The Western Maharashtra comprises two administrative divisions with ten districts of Maharashtra state *viz.*, Nandurbar, Dhule, Jalgaon, Nasik, Ahmednagar, Pune, Solapur, Satara, Sangli, and Kolhapur. The western Maharashtra includes the part of four major river basins *viz.*, Tapi, Godavari, Bhima and Krishna. It covers the major or minor irrigation projects as Gangapur, Bhandardara, Mula, Khadakwasala, Panshet, Koyna and Ujani etc. Western Maharashtra region occupied largest share (50 percent) in gross irrigated area of the state (Chitale, 1999), because the most of rivers of state originates from Sahyadri and diverts eastward through Western Maharashtra.

Considering the potential for the management of water resources and efficient utilization of water in the area, Western Maharashtra was selected as study area. There are various ways for efficient use of water; as proper irrigation water management under canal commands, irrigation scheduling, adoption of advanced irrigation methods such as drip and sprinkler, crop planning and cropping pattern. Most of all these options basically needs to study the crop water requirement in context of climate variability.

Hence, it was proposed to study the “Crop water requirement in context of climate variability” to achieve the stable and sustainable crop-water management and minimize its effects in Western Maharashtra with the following objectives,

- 1) To analyze trends of crop water requirement.
- 2) To study periodic changes in crop water requirement.
- 3) To estimate future crop water requirement.

2. REVIEW OF LITERATURE

A resume of conceptual frame work relating to “Crop water requirement in context of climate variability” is presented in this chapter. An acquaintance with earlier pertinent studies was necessary for better understanding of research problem and to develop appropriate research methodology. The relevant studies and their findings were limited. However, an attempt was made to orient much on the theoretical views of different authors/scientists on the subject and closely related results are reported. Keeping in view the objectives, an extensive review of research literature has been made on the lines of objectives contemplated to facilitate devising an appropriate methodology towards accomplishing the entire research topic.

2.1 Trend Analysis in Crop Water Requirement

Chunqiang *et al.* (2008) worked on the climate change and its effect on reference crop evapotranspiration and crop water requirement in Hebei province, China during 1965-1999. The Penman-Monteith equation was used for estimation of reference evapotranspiration. The change in trends of ET_0 was analyzed for annual, summer, spring, autumn and winter season. The results showed that reference crop evapotranspiration was decreased with time for all seasons. The main reason for decreasing of ET_0 and crop water requirement was due to the reduction of wind speed and sunshine hours.

Liang *et al.* (2010) carried out temporal variation of reference crop evapotranspiration during 1961-2005 in the Taoer river basin of the north-east China. The monthly ET_0 were calculated by using the FAO Penman-Monteith method which was derived for growing season and annual total ET_0 time series. The Mann Kendall method, moving test was conducted for analyzing significance of test. The results showed that in terms of the seasonal cycle, monthly reference evapotranspiration (ET_0) reaches its peak in May and growing season ET_0 accounts for 60.7% of total annual. High positive values of ET_0 were obtained for the upper reach and negative values in the south-east study area in the lower reach.

Jain and Kumar (2011) reviewed studies pertaining to trends in rainfall, rainy days and temperature over India. Sen’s non-parametric estimator of slope had been frequently used to estimate the magnitude of trend, whose statistical significance was assessed by the Mann–Kendall test. Spatial units for trend analysis vary from station data to sub-division to sub-basin/ river basins. There were differences in the results of the various studies, and a clear and consistent picture of rainfall trend had not emerged. Although the different units (sub-basins or sub-divisions) may have a non-zero slope

value, few values are statistically significant. In the study on basin-wise trend analysis, 15 basins had decreasing trend in annual rainfall and only one basin showed significant decreasing trend at 95% confidence level. Regarding trends in temperature, the mean maximum temperature series showed a rising trend at most of the stations, it also showed a falling trend at some stations. The mean minimum temperature showed a rising as well as a falling trend. Increasing trend was mostly found at the stations in the south, central and western parts of India. Few stations located in the north and northeastern India showed a falling trend in annual mean temperature.

Liu *et al.* (2012) calculated temporal trends of annual reference evapotranspiration using the FAO Penman-Monteith equation with the observed daily meteorological data at six stations i.e. Datong, Weichang, Qinhuangdao, Tianjin, Beijing and Huimin of Haihe River Basin, China. Trends were detected with the help of parametric t-test and Mann Kendall (MK) analysis. The six stations were divided in three different classes representing mountains (Datong and Weichang), continentals (Beijing and Huimin) and coastal areas (Qinhuangdao and Tianjin) respectively. The result showed that there was a significant upward trend in ET_0 at mountain area of the Haihe River Basin. On the contrary, a significant downward trend in ET_0 can be found at coastal area. Moreover, the analyses of ET_0 at continental area indicate that after 1960, ET_0 of Beijing showed a sharp significant increase, while a moderate variation was presented for ET_0 at Huimin.

Patle *et al.* (2013) studied the temporal variability in climatic parameters and potential evapotranspiration (PET) of crop. Time series data (1981-2011) of mean daily minimum and maximum temperature, mean daily temperature, relative humidity, wind speed and sunshine hours were analyzed using Mann Kendall test and Sen's slope estimator to establish the trend. Overall analysis showed that minimum temperature, mean daily temperature, relative humidity and wind speed showed increasing trend, whereas sunshine hours and ET_0 had decreasing trend. Results revealed that mean daily minimum and mean daily temperature increased by $0.02^\circ\text{C}/\text{year}$ and $0.01^\circ\text{C}/\text{year}$ respectively. Mean daily maximum temperature remained constant over the period as indicated by the Sen's slope. Mean daily relative humidity and wind speed increased by 0.11% per year and 0.57 km/year during 1981–2011. Mean daily sunshine hours and reference evapotranspiration decreased by 0.06 hour/year and 0.01 mm/year, respectively during 1981–2011.

Lee *et al.* (2014) evaluated trends in the temporal and spatial patterns in potential evapotranspiration over southwestern China for the period of 1961-2009, based on data from 111 standard meteorological stations. The results showed that southwestern China was experiencing a statistical decrease of ET_0 at a rate of 5.0 mm/10 year during 1961-2009. This decrease mainly started

in the 1980s when accelerated warming occurred, which reflected the existence of the “evaporation paradox”. However, autumn ET_0 showed a similar inter-annual variation with temperature rise. In spatial characteristics, the statistically significant of ET_0 in the lower altitude region mainly decreases, whereas stations with increases or non-significant decreases are mainly in higher altitude region.

Shan *et al.* (2015) evaluated temporal and spatial patterns in ET_0 in the Beijing–Tianjin Sand Source Control Project Region, China for the period 1959–2011 based on daily data from 46 meteorological stations using Mann–Kendall test, Sen’s slope estimator, and multivariate regression. The results indicated that annual ET_0 had an insignificant decreasing trend in the study area, in which 15 stations showed significant negative trends and only 1 station showed significant positive trend at the 95% confidence level. It was also inferred that better understanding ET_0 response to climate change will enable efficient use of water resources and vegetation management, which could improve the ecological and environmental quality in Beijing, Tianjin, and the surrounding areas.

Zhang *et al.* (2015) investigated the temporal trends and spatial distributions of reference evapotranspiration in the Yellow river basin, China from 1961 to 2012. The non-parametric Mann Kendall method, wavelet transform and simple linear regression were applied in the research. The results showed that the annual mean ET_0 had a significant declining trend at the rate of 1.29 mm per year from 1961 to 2012. The abrupt change used by the M-K method revealed that the year of abrupt change for ET_0 was in 1983 and 1993.

Lokhande *et al.* (2017) aimed to characterize the trend in maximum temperature and crop water requirement over a last decade at Akola station (Maharashtra State), because of changing trend in meteorological parameters. Trend analysis was accompanied by statistical parameters like mean, coefficient of variation, coefficient of skewness, and coefficient of kurtosis. Monthly maximum air temperature showed slightly decreasing trend over summer season while increasing trend over monsoon and winter season. On the contrary, the monthly reference evapotranspiration showed decreasing linear trend over monsoon and winter season, while increasing trend over summer season. The study concluded that as the monthly reference evapotranspiration showed decreasing linear trend over cropping seasons i.e. monsoon and winter, the crop water requirement at Akola station shall decrease in future.

Machiwal *et al.* (2018) investigated trends in 35 years (1979–2013) temperature maximum, T_{max} and minimum, T_{min} and rainfall at annual and seasonal (pre-monsoon, monsoon, post-monsoon, and winter) scales for 31 grid points in a coastal arid region of India. Trends were examined by applying various tests, as Kendall rank correlation (KRC), Spearman rank order correlation (SROC), Mann-

Kendall (MK), four modified MK tests, and innovative trend analysis (ITA). Trend magnitudes were quantified by Sen's slope estimator, and a new method was adopted to assess the significance of linear trends in MK-test statistics. The KRC and MK tests yielded similar results in close resemblance with the SROC test. The performance of two modified MK tests considering variance correction approaches was found superior to the KRC, MK, modified MK with pre-whitening, and ITA tests. Significantly increasing trends were more prominent in T_{\min} other than T_{\max} . Further, both the annual and monsoon rainfall time series have a significantly increasing trend of 9 mm/year. The sequential significance of linear trend in MK test-statistics was very strong ($R^2 \geq 0.90$) in the annual and pre-monsoon T_{\min} (90% grid points), and strong ($R^2 \geq 0.75$) in monsoon T_{\max} (68% grid points), monsoon, post-monsoon, and winter T_{\min} (respectively 65, 55, and 48% grid points), as well as in the annual and monsoon rainfalls (respectively 68 and 61% grid points). Finally, research recommended use of variance-corrected MK test for the precise identification of trends. It was also emphasized that the rising T_{\max} may hamper crop growth due to enhanced metabolic-activities and shortened crop-duration. Likewise, increased T_{\min} may result in lesser crop and biomass yields owing to the increased respiration.

2.2 Periodic Changes in Crop Water Requirement

Shekhar (2012) conducted research on changes in evapotranspiration in context of changing climate. The weather data 2002 – 2011 was taken from Ozone unit, Indian Meteorological Department, Banaras Hindu University (BHU), Varanasi. The data had been analysed for the changes in temperature, wind speed and net radiation. It was found that an increase in 14.87% of total ET_0 demand using FAO 56 P-M model with increase in temperature by 20 %, which is followed by net radiation (13.6%) and wind speed (4.16%) in comparison with temperature. While temperature based method showed the highest change (21.87%) to temperature and solar radiation (R_s) based Irmak model evaluates least change (5.5%) for 20 % increase in temperature. Moreover, the details of the various combinations of changes in different parameters have been analysed. Further, it was found that approximately 1°C increase in temperature could increase ET_0 by 30 mm/year. It means it would require a huge amount of extra water to cater the need of several thousands of hectares of crops per year.

Tabari et al. (2012) analyzed the spatial distribution and the annual, seasonal and monthly trends of the Penman–Monteith ET_0 for 21 stations in the arid and semi-arid regions of Iran. Three statistical tests the Mann-Kendall, Sen's slope estimator and linear regression were used for the analysis. The analysis revealed that ET_0 increased from January to July and decreased from July to December at

almost all stations. Additionally, higher annual ET_0 values were found in the southeast of the study region and lower values in the northwest of the region. Although the results showed both positive and negative trends in annual ET_0 series. ET_0 generally increased significantly in six (30%) of the stations. At the sites where increasing ET_0 trends were statistically significant, the rate of increase varied from 8-36 mm/year at Mashhad station to 31-68 mm/year at Iranshahr station. On average, an increasing trend of 4-42 mm/year was obtained for the whole study area during the last four decades. Seasonal and monthly ET_0 have also tended to increase at the majority of the stations. The greatest numbers of significant trends were observed in winter on the seasonal time-scale and in September on the monthly time-scale.

Piticar and Dumitru (2016) investigated the spatial distribution and changes in reference evapotranspiration (ET_0) in the Republic of Moldova. Monthly meteorological data recorded at 14 weather stations over a period of 52 years (1961–2012) were used to estimate ET_0 by FAO Penman-Monteith formula. The annual and growing period of winter wheat and maize as seasonal time series were analyzed for the 1981–2012 period as well for 1961–1980. The trends and statistical significance in ET_0 series were detected using Mann-Kendall and t test, whereas the magnitude of the trends was estimated using Sen's slope and linear regression. The results showed that the last three decades (1981-2012) were characterized by a generalized increase of ET_0 statistically significant in about 70% of the analyzed time series, while the 1961–1980 period was dominated by decreasing trends also significant in most of the series. The magnitude of positive trends in annual ET_0 series ranged between 13.80 and 72.07 mm/decade. In the growing seasons of winter wheat and maize, the results were similar to those found in the annual series. By analyzing the trends of contributing climatic variables in ET_0 calculation, the results suggested that the increase of ET_0 was largely influenced by the positive slopes of air temperature and sunshine duration and negative trends of relative humidity. The spatial distribution analysis of ET_0 was characterized by a general increasing from the northern to the southern part of the country.

Mallappa (2016) examined climate variability and its impacts on agricultural water resources in the state of Karnataka, India. Analysis of water requirement of different crops at zonal-wise showed that there was significant impact of climate variability in the study area and was heterogeneous in nature. In the Northern dry zone of study area irrigation requirement (IR) was increased by 107.9, 33.1 and 314.4% for the cotton, ground nut and maize crops respectively. The water requirement was decreased by -50.9 to -53.3, -0.30 to -82.3, and -1.1 to -100 % for the cotton, ground nut and maize crops respectively. Water requirement of wheat was increased by 121.5% in the Northern transition

zone, whereas for the remaining zones water requirement is decreased. The climate variability has positive effect in terms of IR on four zones of study area such as Eastern dry zone, North eastern transition zone, Central dry zone and North eastern dry zone. Analysis of water requirement of different crops at zonal-wise showed that there was significant of impact of climate variability in the study area.

Sonali and Kumar (2016) analyzed the climate change impact on the hydrological cycle, by studying spatio-temporal changes in potential evapotranspiration (PET) along with maximum and minimum temperatures (T_{\max} and T_{\min}) over India in 20th century (1950–2005) both at monthly and seasonal scale. From the observed monthly climatology of PET over India, high values of PET were envisioned during the months of March, April, May and June. Temperature was one of the significant factors in explaining changes in PET. Seasonal correlations of PET with T_{\max} and T_{\min} were analyzed using Spearman rank correlation. Correlation of PET with T_{\max} was found to be higher compared to that with T_{\min} . Seasonal variability of trend at each grid point over India was studied for T_{\max} , T_{\min} and PET separately. A significant trend was observed in T_{\min} compared to T_{\max} and PET. Significant upward trends in T_{\max} , T_{\min} and PET were observed over most of the grid points in the interior peninsular region.

Xing et al. (2016) studied periodic fluctuation of reference evapotranspiration during the past five decades in China. Study provide a nationwide investigation of spatiotemporal change of ET_0 using meteorological data from 602 stations with the updated data (1961–2011). The trigger mechanism was explored by quantitative assessment on the contribution of climatic factors to ET_0 change based on a differential equation method. The results suggested that the ET_0 generally showed decadal variations rather than monotonic response to climate change reported in previous studies. The significant decrease in net radiation dominated the decrease in ET_0 before early 1990s in southern regions. While observed near-surface wind speed was the primary contributor to the variations of ET_0 for the rest regions during the same periods.

Jadhav et al. (2017) conducted research work on comparatively analyzed of three interpolation methods (Inverse distance weighting, Ordinary kriging, and Simple kriging) to determine the spatial distribution of monthly reference evapotranspiration (ET_0) values calculated using the Hargreaves-Samani method (ET_0 -HG) for ten districts of western Maharashtra. The spatial maps of monthly reference crop evapotranspiration were developed by using GIS interpolation techniques. Simple kriging interpolation technique was found suitable to map average reference crop evapotranspiration

(ET_0) for all the months except february based on RMSE values. Spatial distribution maps can be used to derive location specific values of ET_0 required for the estimation of crop water requirement.

Fan and Thomas (2018) conducted research on decadal changes of reference crop evapotranspiration attribution over China 1960–2011. FAO Penman-Monteith reference crop evapotranspiration rates were estimated for 644 meteorological stations over China for the period 1960–2011 to analyze spatial and temporal attribution variability. It was found that attribution of climatic variables to reference crop evapotranspiration rates was not stable over the study period. While for all of China the contribution of sunshine duration remained relatively stable, the importance of relative humidity increased considerably during the last two decades, particularly in winter. Changes in the Asian Monsoon circulation may be responsible for altered patterns of cloudiness and a general decrease of wind speeds over China. The continuously low importance of temperature confirms that global warming does not necessarily lead to rising atmospheric evaporative demand.

Adnan *et al.* (2019) investigated impact of probable variation in four important meteorological parameters i.e. temperature (T), net solar radiation (Rn), vapour pressure (ea) and wind speed (U) on ET to estimate possible changes in reference ET in a humid zone of Pakistan by employing observed climatological records for 30 years (1981–2010). Analysis was done on the basis of possible $\pm 20\%$ changes in climatological mean values of the observed meteorological parameters. It was also indicated that 20% rise in observed values of T, Rn and U increases value of total (annual) ET demand in the zone up to 11.93%, 16.37% and 2.83% respectively, and 20% rise in the observed values of vapour pressure decreases value of total (annual) ET till -2.5% . Moreover, the analysis also showed that ET is more sensitive to T and Rn in monsoon, vapour pressure in winter, and wind speed in summer.

2.3 Estimation of Future Crop Water Requirement

Doria *et al.* (2006) determined the impacts of potential climate change on daily and total crop water requirements of peaches in Southern Ontario using CROPWAT in conjunction with the climate scenarios derived from SDSM. The climate parameters of temperature, precipitation, relative humidity, sunshine duration and wind speed were downscaled using the SDSM (version 3.1). For downscaling baseline climate was 30 year-period, 1971-2000 of the mean monthly normal, and two time periods in the future centered on the decades of 2020s (2010-2039) and 2050s (2040-2069). The CROPWAT model was used to simulate the daily and the seasonal CWR and irrigation requirements for the present and the future decades for determination of the future crop water requirement. Downscaled results when compared to baseline climate showed an increase in CWR by 6.0 % (39

mm) per season using the SDSM-CGCM1 model for 2020s and 3.0 % (20 mm) per season using both the SDSM-HADCM3 A2 & B2 models for 2020s. Moreover, about 8 % (56 mm) increase in using the SDSM-CGCM1 and HADMC3 A2 models for 2050s, and 7.0 % (43 mm) per season. However, the irrigation requirements decreased, compared to the current situation, by 6.0 % (18 mm) (assuming 90% irrigation efficiency) using the SDSM-CGCM1 for 2020s and by 27% (81 mm) for both SDSM-HADCM3 A2 & B2 models for 2020s. While in 2050s, a decrease of 2.71% (8mm), 21% (64mm) and 6% (59mm) using the SDSM-CGCM1, SDSM-HADCM3 A2 and SDSM-HADCM3 B2, respectively for 2050s.

Chatterjee *et al.* (2012) carried out research to assess the impact of climate change on crop water requirement. In the study, potato was taken as the reference crop for its growing period and due to its high response to irrigation. The ET values from the potato field were measured using field water balance method and the data was used to validate the CROPWAT model. After proper validation of CROPWAT model, 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) investigated 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. Following linear pattern of increase, slope of CWR was determined as 1.5 MCM/year from 2011, which was equivalent to the CWR of producing approximately 600 tons of wheat/year. The increase in CWR was due to the increase in temperature mainly, while the effect of rainfall changes was minimal.

Parekh and Prajapati, (2013) carried research to assess the impact of climate change on crop water requirement for the crops grown in the Sukhi command area of Vadodara district, Gujarat. For this study, daily meteorological data like maximum temperature, minimum temperature, wind speed, sunshine hours and rainfall for the period 2003 to 2009 were used. Cropping pattern data and crop data were also used. Future climate data were predicted for the periods of 2011-2030, 2046-2065 and

2080-2099 considering A2 scenario of (IPCC SRES) using stochastic weather generator named Long Ashton Research Station Weather Generator (LARS-WG 5.0) and considering HADCM3 scenario file. Reference crop evapotranspiration (ET_0) was determined using mean monthly meteorological data with the help of CROPWAT 8.0 and then crop water requirement was determined. Results showed that crop water requirement of all hot weather crops in all future periods was increasing as compared to base period 2003-2009. Crop water requirement of rabi crops showed negligible decrease in crop water requirement in the period 2011-2020 but all crops showed considerable increasing water requirement in the period 2021-2030 including the periods 2046-2065 and 2080-2099 as compared to base period 2003-2009.

Lee and Huang, (2014) assessed the impact on irrigation water by climate change in Taoyuan in northern Taiwan. Projected rainfall and temperature during 2046–2065 was adopted from five downscaled general circulation models. The Hamon method was used to derive the future evapotranspiration and corrected with the quadrant transformation method. On the basis of projections and a water balance model in paddy fields, the future crop water requirement, effective rainfall and the demand for water for irrigation was calculated. Comparison between the present (2004–2011) and the future (2046–2065) results, clearly showed that climate change would lead both rainfall and the temperature to rise causing effective rainfall and crop water requirement to increase during cropping seasons in the future. The results concluded that on the basis of a five year return period the future irrigation requirement was 7.1% more than the present in the first cropping season, but it was insignificantly less (2.1%) than the present in the second cropping season.

Mohan and Ramsundram (2014) studied the influence of climatic variability on irrigation water requirements in an arid region on a temporal scale. A climate crop water requirement (CCWR) integrated framework was developed to estimate the irrigation requirement in Manimuthar river basin, Tamilnadu, India, incorporating variation in climatic parameters over temporal scale. Based on the existing land use pattern and economic development prevailing in the study area, the most likely climatic scenario has been identified as A1B. The results revealed that the crop water requirement increases consequently and irrigation water requirement was likely to be increased by 5% from 2010 to 2020.

Behera *et al.* (2016) studied changes in meteorological parameters which directly lead to changes in irrigation water requirement in agriculture. The impact of climate change on crop water requirement was studied in Sunei command area Bhudhabalang basin of Mayurbhanj district, Odisha, India. Daily meteorological data *viz.*, maximum temperature, minimum temperature, wind speed, sunshine hours,

humidity and precipitation data were used for analysis. Future climate data predicated for the period 2025, 2050 and 2080 considering both A2 and B2 scenario using GCM HadCM3. Evapotranspiration (ET_0) was calculated using mean monthly climate and rainfall data with help of CROPWAT 8.0. The crop water requirement (CWR) was determined for each crop of the project area of the study area. It was showed 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 were consider compared to base period 2010.

Kundu *et al.* (2016) studied the changes in the future rainfall, minimum and maximum temperature, and ET_0 by downscaling the HadCM3 model data. The study area was located in a part of the Narmada river basin area in Madhya Pradesh in central India. The downscaled outputs of projected rainfall, ET_0 and temperatures had been shown for the 21st century with the HADCM3 data of A2 scenario by the Least Square Support Vector Machine (LS-SVM) model. The efficiency of the LS-SVM model was measured by different statistical methods. The selected predictors showed considerable correlation with the rainfall and temperature. Results showed an increase in the future rainfall, temperatures and ET_0 . The temperature increased was projected with high rise of minimum temperature in winter time and the highest increase in maximum temperature in the pre-monsoon season or from March to May. Highest increase was projected in the 2080s in 2081–2091 and 2091–2099 in maximum temperature and 2091–2099 in minimum temperature for all the stations. High rainfall was observed with higher ET_0 in some decades. Two increased peak in ET_0 were observed in in the April-May and in the October month.

Manasa *et al.* (2016) verified the effects of climate change on water requirements of the major crops grown in Hukkeri taluk of Belagavi district, Karnataka, India on considering global climate change and an increase in the temperature as detrimental effects on the available water. In the analysis, daily climatic data *viz.*, minimum temperature, maximum temperature, humidity, sunshine hours, wind speed, and rainfall for baseline scenario were used in addition to crop data and soil data. Using the PRECIS model which was established on the basis of Hadley Centre's Regional Climate Modeling System (HadCM3) future climate data were collected for the A1B scenario (2021-2050). The crop water requirement was calculated using reference evapotranspiration (ET_0) of the crop using a monthly average of climatic data. At last the crop water requirement value obtained for baseline conditions was compared with A1B scenario and adaptation strategies for A1B climate change scenarios were suggested. Results showed that, ET_0 values varied from 2.43 mm/day in July to 6.15

mm/day in May for the decade 2021-30, from 2.22 mm/day in July to 6.91 mm/day in May for 2031-40 and from 2.17 mm/day in July to 7.51 mm/day in May.

Reddy *et al.* (2016) studied climate change impact on crop water balance on maize in lower Krishna river basin of south India. They analysed a long-term crop water balance for maize in two sowing windows for A1b climate change scenario using the downscaled climate data from the GCM model ECHAM5. Various parameters such as rainfall, effective rainfall, crop evapotranspiration (ET) and irrigation requirements of maize during the two sowing windows were estimated using the CROPWAT model for the base period (1961–90) and long-term period (2011–50; 2037–2050). In the normal sowing window of maize, there was significant variation in the decadal crop ET (24% to 28%) and irrigation requirements (–7% to 26%) having increasing trend during 2011–2050 over base period. The amount of average decadal rainfall and effective rainfall decreased during 2011–2050 in the range 6% to –23% and 10% to –7% respectively, over the base period. The decadal average rainfall and effective rainfall showed increasing trends of 147–151% and 96–110% respectively, over base period in late sowing window. Also, the crop ET and irrigation requirements exhibited a decreasing trend. The study indicated a shift in the seasonal rainfall in normal sowing window during June to July and was extends up to October and November after the season, indicated more rainfall in late sowing window of maize and scope for rainwater harvesting.

Parvaze *et al.* (2016) studied the effect of climate change on weather parameters like highest possible temperature, lowest possible temperature, average temperature and precipitation. Multiple linear Regression (MLR), Artificial Neural Network (ANN) and Statistical Downscaling Model (SDSM) models were tested in the Dal lake catchment area of Jammu and Kashmir State. Twenty seven year weather data (1985-2012) obtained from SKUAST-Kashmir weather station was used for the study. The modeling results showed a first-rate agreement between the observed data and predicted values for temperature series with high coefficient of determination R^2 values varying from (0.87 to 0.97) for different models. In case of precipitation, R^2 values varied from (0.112 to 0.219) for different models. The low values of coefficient of determination in precipitation time series are due to lot of uncertainty in occurrence of precipitation which could not be defined by the selected models. The SDSM showed the best results of the three models tested for prediction of weather parameters. Thus SDSM was used for climate scenario generation. By comparing daily precipitation and temperature series for 1985-2012 with 2015-2030, an overall increasing pattern of 0.46%, 1.96%, 0.95% and 2.66% was observed for monthly, highest possible temperature, lowest possible temperature, average temperature and precipitation.

Rajabi and Babakhani (2017) demonstrated changes in potential evaporation (PET) in Iran due to climate change. Daily minimum and maximum temperature, solar radiation and precipitation weather parameters were downscaled by global circulation model (GCM) and Lars-WG outputs. Weather data had been estimated according to the HadCM3 GCM and by A1B, A2 and B1 scenarios in three periods: 2011-2030, 2045-2046 and 2080-2099. In all five stations, all three scenarios and in all three periods, PET was increased. The highest increase was occurred in the A1B scenario followed by A1 scenario. The lowest increase was occurred in the B1 scenario. In the 2020 decade, the highest increase in PET for three scenarios was occurred in Khorramabad followed by Hamedan. Kermanshah, Sanandaj and Ilam stations come at third to fifth place, respectively, with a close increase in amount. In the 2050 decade, the increase in PET percentages in all scenarios were close to each other in all the five stations. In the 2080 decade, the increase in PET percentages in all scenarios will be close to each other in four stations, namely, Kermanshah, Sanandaj, Khorramabad and Hamedan, and Ilam station had a higher increase compared to four stations.

Zhou *et al.* (2017) studied the effects of climate change on crop irrigation requirement (CIR). The study applied SDSM to simulate future meteorological parameters in the Hetao irrigation district (HID) in the time periods 2041–2070 and 2071–2099. Penman–Monteith equation was used to calculate reference crop evapotranspiration (ET_0), which was further used to calculate crop evapotranspiration (ET_c) and crop water requirement (CWR). Obtained CWR and predicted future precipitation were used to calculate CIR. The final result showed that the climate in the HID will become warmer and wetter; ET_0 would increase by 4% to 7%. ET_c and CWR have the same trend as ET_0 , but different crops have different increase rates. Research exposed increased CWR, decrease of effective precipitation and overall increase in CIR due increase in crop coefficient. As of current growing area, the CIR would increase by 198×10^6 to $242 \times 10^6 \text{ m}^3$ by the year 2041–2070, and by 342×10^6 to $456 \times 10^6 \text{ m}^3$ by the years 2071–2099 respectively. Future climate change will bring greater challenges to regional agricultural water use.

Guo *et al.* (2018) verified that climate change had a significant impact on the hydrological cycle. The study was mostly focused on comparison of the statistical down scaling model (SDSM) and the automated statistical downscaling model (ASD), which were applied to global climate model (GCM) predictions for the Beijing region. Through the analysis of the evaluation indices in the calibration and validation periods, the results showed that both downscaling models simulate the temperature and evapotranspiration well, but the simulation of precipitation was not as good as that of other climate factors. The overall performance of ASD model was slightly superior to that of SDSM model,

especially in the process of predictor's selection. The future climate change downscaled by the two models shows an analogous trend as well. The temperature and evapotranspiration showed a general increasing trend. The precipitation shows a different trend with an increasing trend in the south and a decreasing trend in the north.

2.4 Concluding Remarks

As per the review's, it was observed that there is drastic shift in climate in recent 40 years. Trend among different parameters showed mixed variations. For effective water resource management, the knowledge of trend analysis of crop water requirement is essential. So far considerable studies have been conducted to detect the ET_0 trends on annual, seasonal, and monthly basis using the non-parametric Mann Kendall test, and Sen's slope estimator test. The Mann Kendall test is a ranked non-parametric test used to analyze trends of hydro meteorological series. The trend magnitude is calculated by slope estimator methods. The above review found useful to understand the water requirement scenarios on long term basis at different places.

Global circulation models (GCMs) are the primary instrument used to predict future climate changes. Downscaling of atmospheric parameters as temperature, rainfall, evapotranspiration, etc. were well cite performed in SDSM model. Downscaling of temperature (min and max) showed that temperature is likely to be increase in future. Considerable variation was also found in rainfall. Downscaling of reference evapotranspiration (ET_0) showed that CWR is increase at various places. Climate change has the potential to change the intensity and frequency of extremes. More severe climate change can cause dramatic impacts with unpredictable consequences. Therefore, the projection of climate extremes is critical information that is needed to assess the impact of potential climate change on human beings and on the natural environment. Such information also helps with long-term planning at both regional and national levels for mitigation and adaptation strategies because it opens up a space for a set of potential responses. So it will be a prudent step to use downscaling technique through SDSM, to identify changes in water requirement of commonly grown crops.

3. MATERIALS AND METHODS

The chapter deals with the description of the study area, data acquisition and methods used for data processing. Furthermore, methodologies for estimation of crop water requirement for performing trend analysis using Mann Kendall statistical test is explained in detail, periodic changes in crop water requirement is done by estimating decadal changes and analyzing percentage increase/decrease within successive decades. Lastly, downscaling of ET_0 for estimation of future crop water requirement was done using SDSM and step by step procedure for estimation is described in detail. Materials used and methodologies adopted are presented in following text of the chapter.

3.1 Details of Study Area

Investigation was undertaken for the Western Maharashtra, agro-climatic region of Maharashtra to analyze the variability of crop water requirement of major crops grown in the region. The major crops grown in the study area are cotton, onion, soybean, sugarcane, groundnut, sorghum, maize, etc. The geographical area is 11.55 M-ha while total area under irrigation is 1.69 M-ha and population is 34.09 million. The average annual rainfall in the region ranges 608-635 mm. Climate of Western Maharashtra is hot and dry. The 89% of annual rainfall in the central part is received during southwest monsoon rainfall (June to September) with 37 rainy days out of 122 days having daily rainfall ($r \geq 2.5$) (Guhathakurta *et al.* 2020). The average annual rainfall decreases from 852 mm in southern side to 567.5 mm in the north side (TERI, 2014). The western side of region is bounded by mountain of Sahyadri with average height of 1200 m. Soils of Western Maharashtra are slight alkaline and black colour type which are deep black or reddish in colours. Due to variation in topography and soils, the vegetation of Western Maharashtra varies in its composition. However the forests are mostly of dry deciduous type and scrub jungles, interspersed with semi-evergreen vegetation in some area on Sahyadri. As of 2019 the east side of region witnessed with excess rainfall (120 % more) as compared to normal rainfall conditions (Anonymous, 2019). Less intensive drought occurs after two to three years and after every ten years and these districts experiences severe drought. The conditions adversely affects on the socio-economic conditions of the people, who are mainly dependent on agriculture. It also has a phenomenal impact on crop water requirement.

3.2 Location of Study Area

The proposed area for the study is Western Maharashtra region which is bounded by latitude $15^{\circ} 40'$ to $22^{\circ} 00'$ N and longitude $73^{\circ} 11'$ to $76^{\circ} 24'$ E. The selected stations over region with name, latitude, longitude and altitude are presented in Table 3.1. The boundary map of study area with selected stations is depicted in Fig. 3.1.

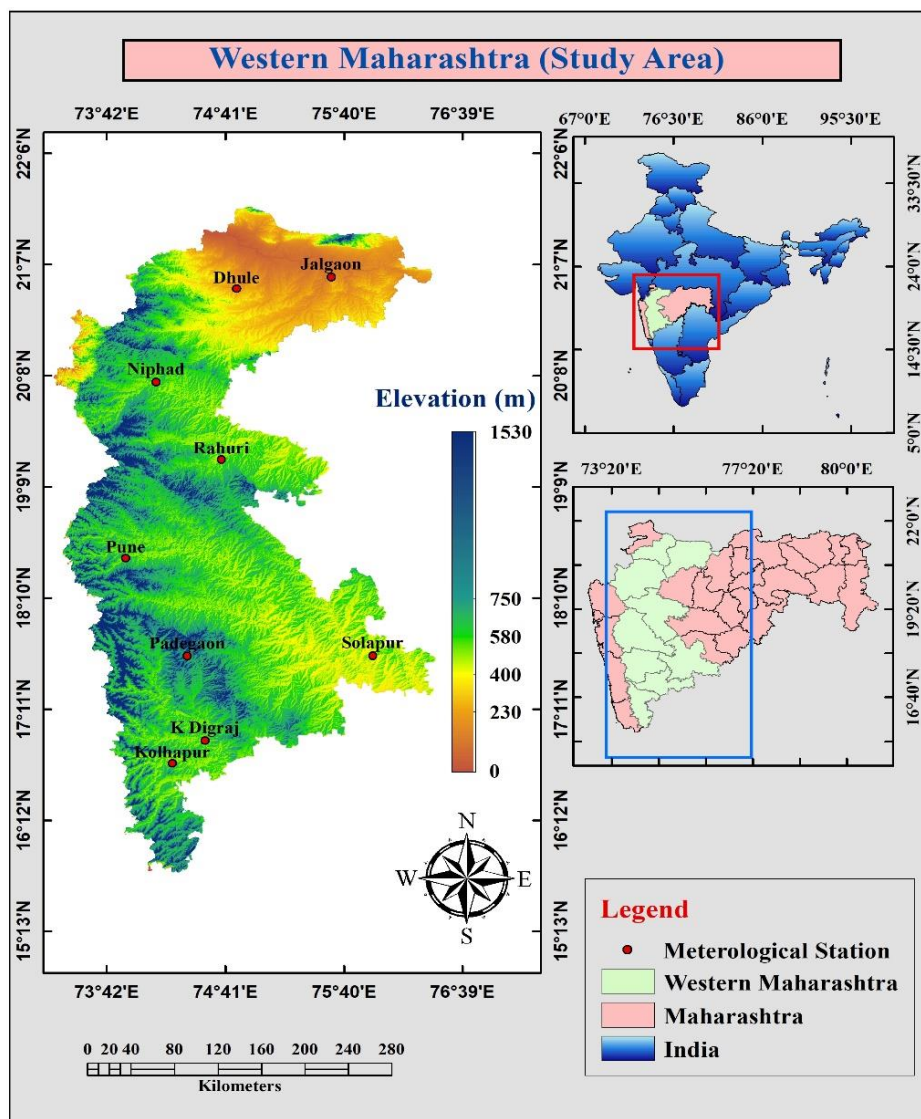


Fig. 3.1 Study Area

Table 3.1 The details of the meteorological stations under the study area

Sr. No	District	Station	Latitude	Longitude	Altitude	Data
1.	Kolhapur	Kolhapur	16° 41' 29"N	74° 14' 41"E	577.34 m	1990 - 2017
2.	Sangli	Kasbe Digraj	16° 53' 25"N	74° 30' 45"E	552.93 m	1995 - 2017
3.	Satara	Padegaon	18° 04' 17"N	74° 13' 26"E	567.68 m	1990 - 2017
4.	Solapur	Solapur	17° 40' 08"N	75° 54' 24"E	483.50 m	1980 - 2017
5.	Pune	Pune	18° 31' 13"N	73° 51' 24"E	559.90 m	1980 - 2017
6.	A. Nagar	Rahuri	19° 23' 33"N	74° 38' 56"E	514.55 m	1980 - 2017
7.	Nashik	Niphad	20° 04' 48"N	74° 06' 33"E	550.28 m	1980 - 2017
8.	Dhule	Dhule	20° 54' 15"N	74° 46' 29"E	263.15 m	1980 - 2017
9.	Jalgaon	Jalgaon	20° 59' 52"N	75° 34' 00"E	232.95 m	1980 - 2017

3.3 Data Acquisition

3.3.1 Geographical Data:

The geographical data included location. The details of latitude, longitude, and altitude were presented in Table 3.1.

3.3.2 Meteorological Data:

The details of data period of available average weekly meteorological data *viz.*, maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sunshine hour and wind speed data were presented in Table 3.1. The data was acquired from Indian Meteorological Department (IMD), Pune and SAU, Rahuri. Out of nine stations, three stations *viz.*, Pune, Rahuri and Solapur were selected for determination of future crop water requirement as per availability of continuous record of daily data.

3.3.3 Reanalysis Data:

The estimation of future crop water requirement by downscaling of ET_0 , it is required reanalysis of NCEP and GCM data with observed meteorological data of Western Maharashtra. The National Centre for Environmental Prediction (NCEP) provides daily reanalysis data of 26 factors including mean temperature, mean sea level pressure, near surface relative humidity, near surface specific humidity, 500 hPa geopotential height, 850 hPa geopotential height, and relative humidity, geostrophic airflow velocity, vorticity, zonal velocity component, meridional velocity component, wind direction and divergence at surface, 500 hPa height, and 850 hPa height (Zhou *et al.* 2017). The grid resolution was 2.5 degrees of latitude by 2.5 degrees of longitude. These data was available from the Canadian Climate Impact Scenarios (CCIS) website (Guo *et al.* 2018).

3.3.4 GCM Data:

The General circulation model (GCM) data was used for scenario generation. The GCM selected was Hadley Centre Coupled Model version 3 (HadCM3). HadCM3 is a coupled climate model with a horizontal resolution of 2.5 degrees of latitude by 3.75 degrees of longitude, and the predictors were the same as NCEP data. The output of the HadCM3 consisted of two scenarios H3A2 and H3B2, both scenarios were used in the study.

3.4 Software's / Programs Used

- a) **Microsoft Office Excel Workbook:** Microsoft office sub-module MS-Office 2013 was used for data analysis. The formulation and conditional statements was also executed in MS office excel.
- b) **Phule Jal:** The software developed by IWRAS, Department of IDE, MPKV, Rahuri was used to calculate reference evapotranspiration (ET_0) based on Penman-Monteith method.

- c) **Makesen's Excel Template:** The trend analysis was carried out using MAKESEN's excel template which is based on non-parametric Mann-Kendall test and Sen's Slope estimator method.
- d) **Arc GIS:** The Arc Map 10.5 version developed by esri was used for preparing location map, spatial maps of trend analysis and decadal changes in crop water requirement.
- e) **SDSM:** The Statistical Downscaling Model version 4.2 developed by Wilby (2004) was used for downscaling of ET_0 and projecting scenario of ET_0 .

3.5 Methodology

3.5.1 Estimation of Crop Water Requirement:

The estimation of the water requirement (WR) of crops is one of the basic needs for crop planning of any irrigation project. Water requirement may be defined as the quantity of water regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place (Michael, 2008).

Water requirement includes the losses due to crop evapotranspiration (ET_c) or consumptive use (C_u) plus the losses during the application of water (unavoidable losses) and the quantity of water required for special operation.

$$WR = ET_c \text{ or } C_u + \text{application losses} + \text{special needs} \quad \dots (3.1)$$

Water requirement is therefore a 'demand' and the 'supply' would consist of contribution from any of the source of water, the major source being the irrigation water (IR), effective rainfall (ER) and soil profile contribution (S) (Michael, 2008).

Here, water requirement was estimated considering demand side and nullifying the losses due to application and special needs as these parameters varies from place to place. The crop evapotranspiration is calculated by following relationship,

$$ET_c = ET_0 \times K_c \quad \dots (3.2)$$

Where,

ET_c = Crop evapotranspiration (mm/day),

ET_0 = Reference evapotranspiration (mm/day) and,

K_c = Crop coefficient (dimensionless)

The FAO 56 Penman-Monteith method is recommended as the sole method for determining ET_0 (Allen *et al.* 1998). The combination formula recommended by the Expert Consultation on FAO Methodologies for Crop Water requirement (UNFAO, 1990) derived by combining the equation of aerodynamic resistance and surface resistance is stated below:

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T + 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * U_2)} \quad \dots (3.3)$$

Where,

ET_0 = Reference evapotranspiration (mm/day),

Δ = Slope of saturation vapour pressure temperature curve (kPa/ $^{\circ}$ C),

γ = Psychometric constant (kPa/ $^{\circ}$ C),

T= Mean air temperature ($^{\circ}$ C),

e_s = Saturated vapour pressure (kPa),

e_a = Actual vapour pressure (kPa),

R_n = Net radiation (MJ/m²/day),

G = Soil heat flux density (MJ/m²/day),

U_2 = Wind speed at 2m height (m/s) and,

$(e_s - e_a)$ = Saturated vapour pressure deficit (kPa)

Equation 3.3 determines the ET_0 from an assumed grass reference surface and serves as a standard to which evapotranspiration in different periods of the year and in other region can be compared to which ET_0 of different crops can be related.

3.5.2 Details of Selected Crops

For the estimation of crop water requirement and fulfilling the objectives, the selected crops were cotton, *rabi* onion, soybean and *suru* sugarcane which are majorly mostly grown in the study region. The details of selected crops for analysis along with their growth period, duration and seasons are presented in Table 3.2.

Table 3.2 Details of selected crop with growth period

Crops	Sowing Date	Harvesting Date	Duration	Season
Cotton	15 May	10 Nov	180 Days	Kharif
<i>Rabi</i> onion	15 Oct	11 Feb	120 Days	Rabi
Soybean	1 July	8 Oct	100 Days	Kharif
<i>Suru</i> sugarcane	30 Jan	29 Jan	365 Days	Perennial

3.5.3 Crop Coefficient (Kc) Equations

Crop coefficient varies with crop growth stages. Here, Kc values for initial stage, development mid-season stage, and late season stages are interpolated. The daily Kc values for different crops

for Rahuri region during their entire growth were calculated by the polynomial equations generated by Department of Irrigation and Drainage Engineering and recommended by MPKV, Rahuri (Anonymous, 2017). These daily Kc were further converted into weekly basis depending on need. It was assumed that this equations are valid over entire study area and do not change with respect to place and time.

Initial stage (Init)

During this period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the Kc during the initial period is large when the soil is wet from irrigation or rainfall and is low when the soil surface is dry.

Development stage (Deve)

As the crop develops and shades more and more on the ground, the evaporation becomes more restricted and transpiration gradually becomes the major process.

Mid-season stage (Mid)

At this stage the Kc reaches its maximum value.

Late season stage (Late)

The Kc value at the end of the late season stage reflects crop and water management practices. This value is high if the crop is frequently irrigated until harvested fresh. If the crop is allowed to senescence and to dry out in the field before harvest the Kc value will be small, due to less efficient stomata conductance of leaf surfaces.

The details of Kc equation for different crops i.e. cotton, *rabi* onion, soybean and *suru* sugarcane are well-illustrated through Fig. 3.2 to 3.5 as below;

- 1) **Cotton:** The cotton crop is grown mostly in *Kharif* season. The crop coefficient (Kc) curve and polynomial equation of cotton crop used for the analysis is presented in following Fig. 3.2 and Equation 3.4.

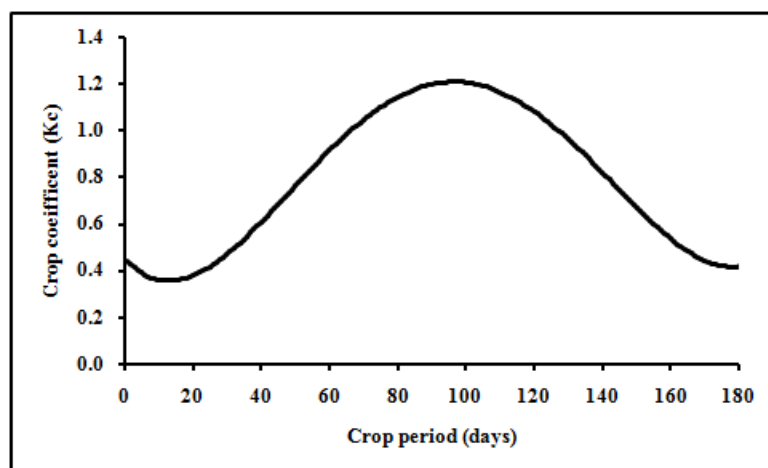


Fig. 3.2 Crop coefficient for cotton

The polynomial equation for estimating the crop coefficient (Kc) for cotton crop is given as;

$$K_{ct} = 18.78 * \left(\frac{t}{T}\right)^4 - 39.98 * \left(\frac{t}{T}\right)^3 + 24.06 * \left(\frac{t}{T}\right)^2 - 2.895 * \left(\frac{t}{T}\right) + 0.453 \quad \dots (3.4)$$

Where,

K_{ct} = Crop coefficient of cotton on t^{th} day

t = Day since sowing

T = Total crop growth period in days

- 2) **Rabi onion:** The onion selected for analysis is *rabi* onion. The crop coefficient (Kc) curve and polynomial equation of *rabi* onion crop used for the analysis are presented in following Fig. 3.3 and Equation 3.5.

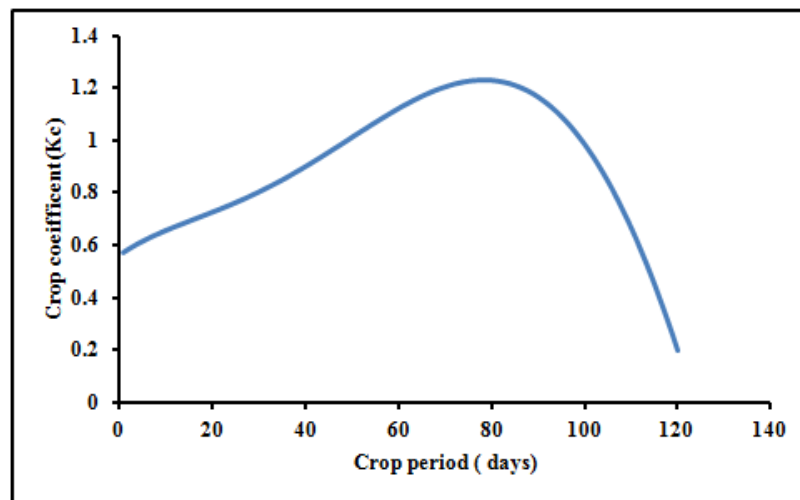


Fig. 3.3 Crop coefficient for *rabi* onion

Polynomial equation for estimating the crop coefficient (Kc) for *rabi* onion is given as crop as;

$$K_{ct} = 8.062 * \left(\frac{t}{T}\right)^5 - 24.31 * \left(\frac{t}{T}\right)^4 + 20.15 * \left(\frac{t}{T}\right)^3 - 5.761 * \left(\frac{t}{T}\right)^2 + 1.498 * \left(\frac{t}{T}\right) + 0.561 \quad \dots (3.5)$$

Where,

K_{ct} = Crop coefficient of *rabi* onion on t^{th} day

t = Day since sowing

T = Total crop growth period in days

- 3) **Soybean:** The soybean crop is grown in *Kharif* season. The crop coefficient (Kc) curve and polynomial equation of soybean crop used for the analysis are presented in Fig. 3.4 and Equation 3.6.

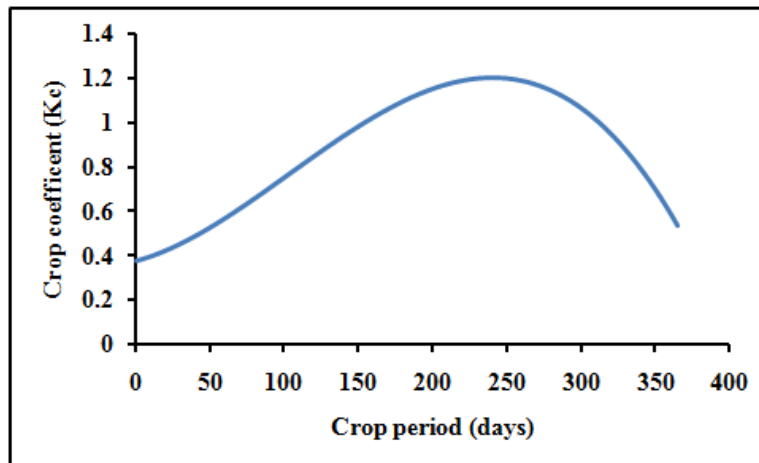


Fig. 3.4 Crop coefficient for soybean

Polynomial equation for estimating the crop coefficient (Kc) for soybean crop as;

$$K_{ct} = 2.647 * \left(\frac{t}{T}\right)^5 + 0.14 * \left(\frac{t}{T}\right)^4 - 8.761 * \left(\frac{t}{T}\right)^3 + 5.862 * \left(\frac{t}{T}\right)^2 + 0.26 * \left(\frac{t}{T}\right) + 0.494 \quad \dots (3.6)$$

Where,

K_{ct} = Crop coefficient of soybean on t^{th} day

t = Day since sowing

T = Total crop growth period in days

4) **Suru sugarcane:** The *suru* sugarcane crop is grown throughout the year. The crop coefficient (Kc) curve and polynomial equation of *suru* sugarcane crop used for the analysis are presented in Fig. 3.5 and Equation 3.7.

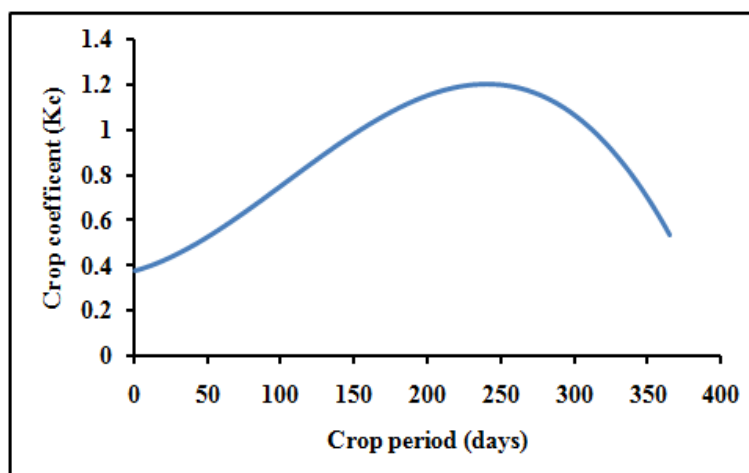


Fig. 3.5 Crop coefficient for *suru* sugarcane

Polynomial equation for estimating the crop coefficient (Kc) for *suru* sugarcane crop as;

$$K_{ct} = 0.484 * \left(\frac{t}{T}\right)^4 - 4.948 * \left(\frac{t}{T}\right)^3 + 3.988 * \left(\frac{t}{T}\right)^2 + 0.636 * \left(\frac{t}{T}\right) + 1.498 \quad \dots (3.7)$$

Where,

Kc_t = Crop coefficient of *suru* sugarcane on t^{th} day

t = Day since sowing

T = Total crop growth period in days

3.6 Trends in Crop Water Requirement

Trend analysis can be simply described as analysis of change over the time. Long term meteorological data collected from the India Meteorological Department, Pune and SAU, Rahuri was used to calculate crop water requirement. Yearly trend analysis of crop water requirement for cotton, *rabi* onion, soybean and *suru* sugarcane for nine stations were carried out to study the variability of CWR and to examine weather trend is present or not in the data. Non-parametric Mann Kendall and Sen's Slope estimator tests were employed to detect the trend in CWR.

3.6.1 Mann-Kendall Test

This is a statistical method which is mostly used to check the null hypothesis of no trend versus alternate hypothesis of the existence of alternative monotonic increasing or decreasing trend of hydro-climatic time series data. Mann Kendall test (Non-parametric test), is one of the commonly used tools for examining climatic and hydrologic time series data. The test was first applied by Mann (1945) and Kendall (1975) and covariance between Mann–Kendall statistics were developed by Dietz and Kileen, 1981. For time series less than 10 points S-test can be used and for more than 10 data point's normal approximation (Z-test) is used (Gilbert, 1987). Here, seasonal data values of CWR were evaluated as ordered time series.

The Mann Kendall statistic (S) is given by Equation 3.8,

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(X_j - X_k) \quad \dots (3.8)$$

Where, n is the length of the data series; X_j and X_k are the sequential data in the series and

$$\text{sign}(X_j - X_k) = \begin{cases} 1 & \text{if } (X_j - X_k) > 0 \\ 0 & \text{if } (X_j - X_k) = 0 \\ -1 & \text{if } (X_j - X_k) < 0 \end{cases} \quad \dots (3.9)$$

$$\text{VAR}(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right] \quad \dots (3.10)$$

Where,

q = Number of tied groups

t_p = Number of data values in the p^{th} group

n = Number of years for which data is available

The standard test statistics Z computed as follows:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad \dots (3.11)$$

The presence of a statistically significant trend was evaluated using the ‘ Z ’ value. A positive or negative value of ‘ Z ’ indicates rising or declining trend. Positive or negative trends are determined by the test statistic ‘ Z ’ at confidence levels of 99, 95, and 90 per cent. At the 99 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 2.575$; at the 95 per cent significance level null hypothesis of no trend is rejected at if $|Z| > 1.96$; and at the 90 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 1.645$. In present study, trend analysis was done at 95 % confidence level.

To test for monotonic trend at α significance level, the null hypothesis of no trend is rejected if the absolute value of the standardized test statistics Z is greater than $Z_{1-\alpha/2}$ obtained from the standard normal cumulative distribution tables and for 5 % significance level the value of $Z_{1-\alpha/2}$ is $1.96 < Z < -1.96$.

3.6.2 Sen's Slope Estimator

Using the method of Sen (1968), the magnitude of the slope can be obtained. To estimate the true slope of an existing trend (as the change per year) the Sen’s non-parametric method is used. The Sen’s slope method can be used in cases where trend can be assumed as linear. If a linear trend is present in a time series, then the true slope i.e. change per unit time was estimated by using a simple non-parametric procedure developed by Sen (1968). Sen’s method calculates the slope of the line using all data pairs, as shown by following equation;

$$Q_t = \frac{X_j - X_k}{j - k} \quad \dots (3.12)$$

Provided, $j = 1, 2, 3, N$ and $j > k$. If there are n values X_j in the time series, we get as many as slope estimate Q_t . Sen’s estimator of slope is simply given by the median of these N values of Q_t ’s.

$$Q_t = \begin{cases} \frac{Q_{\frac{N+1}{2}}}{2} & \text{if } N \text{ is odd} \\ \frac{1}{2} \left(Q_N + \frac{Q_{N+1}}{2} \right) & \text{if } N \text{ is even} \end{cases} \quad \dots (3.13)$$

Sen’s estimator is computed as $Q_{\text{med}} = Q_{(N+1)/2}$ if N appears odd and it is considered as $Q_{\text{med}} = [Q_{N/2} + Q_{(N+2)/2}]/2$ if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1- α) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive

value of Q indicates an upward or increasing trend and a negative value of Q indicates a downward or decreasing trend in the time series.

3.7 Periodic Changes in Crop Water Requirement

From previous few decades, it was observed that climate is getting warmer and water requirement of crop is supposed to be changing. Hence, it was necessary to study the changes in water requirement of crops for the different periods over a region.

The periodical changes in crop water requirement for selected crops were carried out on decadal basis over a study area. The changes in crop water requirement was analyzed by finding the percent increase or decrease of water requirement over previous of decades for each selected crop at each selected stations over the study area. The percent increase or decrease in crop water requirement data for any crop will be useful in future irrigation planning or for alteration of crop with more benefits.

The decadal crop water requirement was estimated by considering average of 10 years CWR data for respective station and respective crop. Thus, one value will represent for each decade and station. The percentage variation among two successive decades is estimated as following relationship;

$$\text{Percentage Change (\%)} = \frac{\text{Post decade} - \text{Pre decade}}{\text{Pre decade}} \quad \dots (3.14)$$

Ex: If percentage change among 1980s and 1990s decade was to be estimated then 1980s was considered as pre decade and 1990s was considered as post decade.

3.7.1 Spatial Analysis of CWR

The spatial analysis of CWR was done using interpolation technique in ArcGIS software. Interpolation is the process of using points with known values or sample points to estimate values at other unknown points. It can be used to predict unknown values for any geographic point data, such as elevation, rainfall, meteorological parameters, chemical concentrations, noise levels, and so on. There are various interpolation methods *viz.*, Inverse Distance weighted (IDW), Kriging, Spline, etc. (Rossiter, 2015). The Inverse Distance Weighting interpolator assumes that each input point has a local influence with the near distance. It estimates unknown values with specifying search distance and closest points. This method assuming principle that closer values are more related than further values. The formulation of IDW technique is given in equation 3.15.

$$Z_p = \frac{\sum_{i=1}^n \left(\frac{Z_i}{d_i}\right)}{\sum_{i=1}^n \left(\frac{1}{d_i^p}\right)} \quad \dots (3.15)$$

Where,

Z_p = Value to be estimated

Z_i = Values of known points

d_i = Distances from the i data points to the point estimated i

The average CWR i.e. Z_i value of selected station along with latitude and longitude were given as input to ArcGIS software. The spatial analysis of CWR over study area was done during different decades (1980s, 1990s, 2000s, and 2010s) for cotton, *rabi* onion, soybean and *suru* sugarcane.

3.8 Estimation of Future Crop Water Requirement

General circulation models (GCMs) can simulate the important characteristics of future climate on a large scale very well in the study of regional climate change. However, the GCMs have limited value because they have a low spatial resolution and lack the regional climate information. Currently, there are two ways to make up for the inadequacy of GCMs in predicting regional climate change: one is to develop new GCMs with higher resolution, and another is to downscale GCMs to the regional scale. Downscaling techniques is further divided into Dynamical Downscaling and Statistical Downscaling. Dynamical downscaling is actually to build a regional climate model which has a clear physical meaning and will not be affected by the observation data. However, it also has some disadvantages. For example, it requires significant computing resources and is not readily transferred to new regions or domains. Statistical downscaling is based on the view that the regional climate is conditioned by the large-scale climatic state and local physiographic features (Zhou *et al.* 2017).

SDSM developed by R. L. Wilby and C. W. Dawson started its life in summer 2000. The combination of multiple linear regression (MLR) and stochastic weather generator (SWG) methods are used in this model (Wilby *et al.* 2002). MLR is used to establish empirical relationship between predictors (NCEP) and predictand (observed local scale data), and generate regression parameters, whereby stochastic weather generator (SWG) is used to simulate up to 100 daily time series from predictors of NCEP and GCMs based on the regression parameters (Mahmood and Babel, 2013).

3.8.1 Theoretical Consideration of SDSM

SDSM (Statistical Downscaling Model) is a decision support tool for assessing local climate change impacts using a robust statistical downscaling technique. SDSM facilitates the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future regional climate forcing. Additionally, the software performs ancillary tasks of predictor variable pre-screening, model calibration, basic diagnostic testing, statistical analyses and graphing of climate data.

Using the daily meteorological data for 33, 31 and 26 years for Solapur, Pune and Rahuri stations respectively retrieved from IMD, Pune was used to develop daily scenes of ET_0 which was further used for the simulation using SDSM and projecting ET_0 through model. The statistical downscaling technique utilized in this study was SDSM version 4.2 developed by Rob Wilby (Wilby *et al.* 2004) to simulate crop evapotranspiration for future time periods centered on the 2030s, 2050s and 2080s period. The step by step procedure using SDSM is summarized further.

National Center for Environmental Prediction (NCEP) predictors relates the strength of each predictor-predictand relationships, the calibration and validation step involves the establishment of statistical relationships between the selected predictors and the surface predictand (Gagnon *et al.* 2005). In this process, simulation of observed data was done with predictors from the National Center of Environmental Prediction re-analysis data, while for the 2030s, 2050s and 2080s global climate models, HADCM3 data with emission scenarios H3A2 and H3B2 were used.

The IPCC has grouped future emission scenarios as four major classes or groups namely: a) A1, b) A2, c) B1, and d) B2 based on level on economic development and environmental concern. It is to be observed (Table 3.3) that scenario group or class A2 is concerned more about activities which will improve the economic development of the world while, B2 is concerned more about environmental sustainability of the world.

Table 3.3 Climatic scenario classes

Scenario Classes	Concerns	Remarks
A2	<ul style="list-style-type: none"> • Rapid economic growth • Low population growth • Rapid new technology • Concern to wealth rather than environment 	<ul style="list-style-type: none"> • Homogenous world on economic development • Cultural convergence • No difference in per capita income
B2	<ul style="list-style-type: none"> • Diverse technological change • Emphasis on community initiative • Concern on environment rather than economic development 	<ul style="list-style-type: none"> • Heterogeneous world • Local solutions for environmental and social sustainability

The GCM outputs used in this study come from the United Kingdom meteorological office Hadley Centre's coupled ocean/atmosphere climate model, version 3 (HadCM3), which includes the A2 (high greenhouse gas emission) and B2 (low greenhouse gas emission) scenarios; and were daily time-series from the year 1961 to 2099 with a grid size of $2.5^\circ \times 3.75^\circ$. The NCEP reanalysed dataset is daily time-series from the year 1961 to 2000, including 26 large-scale weather factors.

The variable number, the abbreviation and the description of the 26 GCM or NCEP weather factors is shown in Table 3.4.

Table 3.4 Details of predictors used in the present study

Sr. No	Predictor	Description
1	p_f	Surface airflow strength
2	p_u	Surface zonal velocity
3	p_v	Surface meridional velocity
4	p_z	Surface velocity
5	p_th	Surface wind direction
6	p_zh	Surface divergence
7	rhum	Surface relative humidity
8	p5_f	500 hPa airflow strength
9	p5_u	500 hPa zonal velocity
10	p5_v	500 hPa meridional velocity
11	p5_z	500 hPa vorticity
12	p5th	500 hPa wind direction
13	p5zh	500 hPa divergence
14	r500	500 hPa relative humidity
15	p8_f	850 hPa airflow strength
16	p8_u	850 hPa zonal velocity
17	p8_v	850 hPa meridional velocity
18	p8_z	850 hPa vorticity
19	p8th	850 hPa wind direction
20	p8zh	850 hPa divergence
21	r850	850 hPa relative humidity
22	p500	500 hPa geopotential height
23	p850	850 hPa geopotential height
24	temp	Mean temperature at 2m height
25	shum	Surface-specific humidity
26	mslp	Mean sea level pressure

Downscaling involved the following major steps as; quality check of data, transformation of data, screening of predictors, calibration of sub model using observed data (predictand) and selected NCEP predictors, generation of present and future scenarios from gridded datasets of NCEP and GCMs, and statistical analysis. For this study, the following major steps were adopted;

3.8.2 Quality Control Check and Transformation of Observed Data (Predictand)

The quality control check function is used to check all data from meteorological stations which may have errors or missing of records. All missing data or records are replaced with the identifier value/code i.e. -999. The second step after quality control check is transformation of data. SDSM provides the facilities to transform data before calibration using different types of transformations such as logarithm, power, inverse, binomial, etc. (Saraf and Regulwar, 2016).

3.8.3 Selection of Large-Scaled Predictor

The selection of large-scaled predictors is a key step in the statistical downscaling modelling process. The selection of predictors should follow four principles (Amin and Islam, 2014; Guo *et al.* 2018) as below:

- 1 There is a clear physical link between predictor and predictand.
- 2 There is a strong correlation and agreement between predictor and predictand.
- 3 The selected predictor can be simulated by the GCM.
- 4 The selected predictors should maintain independence or at worst weak dependence.

The predictors of the SDSM model were selected by screening of possible predictor variables. Correlation analysis, scatter plots, and seasonal variance tools of the SDSM model were used to screen the predictors that were strongly correlated with the predictand. The number of control predictors is limited to 12 in the recursive algorithm adopted by SDSM, while the predictors in GCM or NCEP is usually more than 20, which makes the correlation screening analysis more complex and cannot be accomplished in one step.

After the selection of the large-scaled predictor, the selected predictors from the reanalysis data NCEP and observed station data (predictand) were used to establish the statistical relationships for the study area

3.8.4 Calibration and Validation of Model

Based on the available observed daily data, dataset was used in the calibration and validation of reference evapotranspiration. In the present study, the SDSM was developed based on the selected NCEP predictors using monthly sub model. Unconditional sub model was used without transformation, and optimization of the best fit by ordinary least square (OLS).

The model developed for the ET_0 was simulated using NCEP, H3A2, and H3B2 predictors for 1968-2000, 1970-2000, and 1975-2000 for Solapur, Pune, and Rahuri station respectively as per availability of data. A total of 20 ensembles were generated using the annual and monthly SDSM and the mean of these ensembles was used in this study (Mahmood and Babel, 2013). SDSM have the capacity to generate up to 100 ensembles and can be used to research the uncertainty analysis

of climate scenario (Saraf and Regulwar, 2016). 2/3rd of the total data was used for calibration and 1/3rd of the remaining data was used for validation. The calibration period for Pune, Rahuri, and Solapur were 1970- 1990, 1975-1990, and 1968-1989 respectively. Whereas, the validation period for Pune, Rahuri, and Solapur were 1991-2000, 1991-2000, and 1990-2000 respectively.

3.8.4.1 Statistical analysis for model performance

The mean (μ), explained variance, coefficient of determination (R^2), nash-sutcliffe evaluation (E_{ns}), root mean square error (RSME), standard deviation (SD), standard error in mean (SE- μ), mean absolute deviation (MAD) and mean absolute percentage error (MAPE) for all three stations during the calibration and validation were used to evaluate the performance of SDSM (Huang et al. 2007; Mahmood and Babel, 2013). The general equation of all statistical terms are described below.

1) Coefficient of determination (R^2)

Coefficient of determination was used to show the accuracy of the model in predicting data. The coefficient of determination (R^2) is presented in Equation 3.16.

$$R^2 = \frac{\sum(X_i - X') * (Y_i - Y')}{\sqrt{\sum(X - X')^2 * (Y - Y')^2}} \quad \dots (3.16)$$

The value of R^2 explains the correlation between observed and downscaled values and lies between 0 and 1, where 0 indicates poor and 1 for the best.

2) Nash-Sutcliffe evaluation (E_{ns})

Nash-Sutcliffe (E_{ns}) evaluation index (Equation 3.17) was used to assess the model applicability by comparing observed data with output of SDSM.

$$E_{ns} = 1 - \frac{\sum_{i=1}^n (X_i - Y_i)^2}{\sum_{i=1}^n (X_i - X')^2} \quad \dots (3.17)$$

X_i , and Y_i are time-series of observed value X and simulated value Y ; and X' , Y' are mean of observed value X and simulated value Y . Nash-Sutcliffe (E_{ns}) index ranges from $-\infty$ to 1, the closer the model efficiency is to 1, the more is accuracy (Guo *et al.* 2018).

3) Root Mean Square Error (RMSE)

The Root Mean Square Error (RMSE) is a measure of difference between values predicted by a model and the values actually observed from the environment that is being modeled.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (X_{obs,i} - Y_{mod,i})^2}{n}} \quad \dots (3.18)$$

Where $X_{obs,i}$ are observed value and $Y_{mod,i}$ are projected modeled value.

4) Mean Absolute Percentage Error (MAPE)

The Mean Absolute Percentage Error (MAPE) is a measure of prediction accuracy of a forecasting method. It measures the size of the error in percentage terms. The statistical formula of MAPE is given in Equation 3.19.

$$MAPE = 100 * \frac{1}{n} * \sum_{i=1}^n \left| \frac{X_i - Y_i}{X_i} \right| \quad \dots (3.19)$$

Where X_i and Y_i are individual values of observed and modelled data respectively.

5) Mean Absolute Deviation (MAD)

The Mean Absolute Deviation (MAD) of a data set is the average distance between each data value and the mean. Mean absolute deviation is a way to describe variation in a data set. The statistical formula of MAPE is given in Equation 3.20.

$$MAD = \frac{\sum |X - X'|}{n} \quad \dots (3.20)$$

6) Standard Error Mean (SE- μ) and Standard Deviation (SD)

The Standard Error in mean (SE- μ) was used to observe the variability of the data predicted by the model and was given by Equation 3.21. The Standard Deviation (SD) is a measure of variability or the scatter or the dispersion about the mean value. It is given by the following Equation 3.22.

$$SE = \sqrt{\frac{\sum_{i=1}^n (Y' - X')^2}{n}} \quad \dots (3.21)$$

Where n is the number of time series and other notation same as above.

$$SD = \sqrt{\frac{\sum_{i=1}^N (X_i - X')^2}{N}} \quad \dots (3.22)$$

Where, X_i is variable, X' is mean, and N is total number of variables

3.8.5 Generation of Present and Future Time Series for Reference Evapotranspiration (ET₀)

After calibration and validation of model, weather generator function was applied to generate assembles of synthesis daily time series of ET₀ presenting climate from selected set of NCEP predictors. The generated daily time series of ET₀ was compared statistically with the observed records to check how close it was to the present climate. Finally the scenario generator function was used to stimulate future time series of reference evapotranspiration using output from GCMs (HadCM3) under H3A2 and H3B2 scenarios.

Daily Reference Evapotranspiration (ET_0) data of the observed period for the mentioned stations was provided in (.DAT) format to SDSM model, and the model input files have been established according to this. The downscaled data as per requirements had been simulated for three future periods based on base period. As discussed earlier downscaling was done for three time periods 2030s, 2050s and 2080s. Here selection of analysis period for all three periods i.e. 2030s, 2050s and 2080s depends on the observed data.

Let's consider for Solapur: Here observed data was 33 years. The years were divided as (16 +1 + 16) where first 16 is considered as initial years and next 16 as final years. Thus, the analysis period for 2030s was 2014 – 2046 keeping year 2030 at center. The same procedure was followed for 2050s, 2080s and for remaining stations.

Table 3.5 Analysis period for projecting future scenarios in ET_0

Periods	Solapur	Pune	Rahuri
Base/Observed Period	1968 – 2000	1970 – 2000	1975 – 2000
First period (2030s)	2014 – 2046	2015 – 2045	2017 – 2043
Second period (2050s)	2034 – 2066	2035 – 2065	2037 – 2063
Third period (2080s)	2064 – 2096	2065 – 2095	2067 – 2093

The steps involved in downscaling and scenario generation is shown in Fig. 3.6.

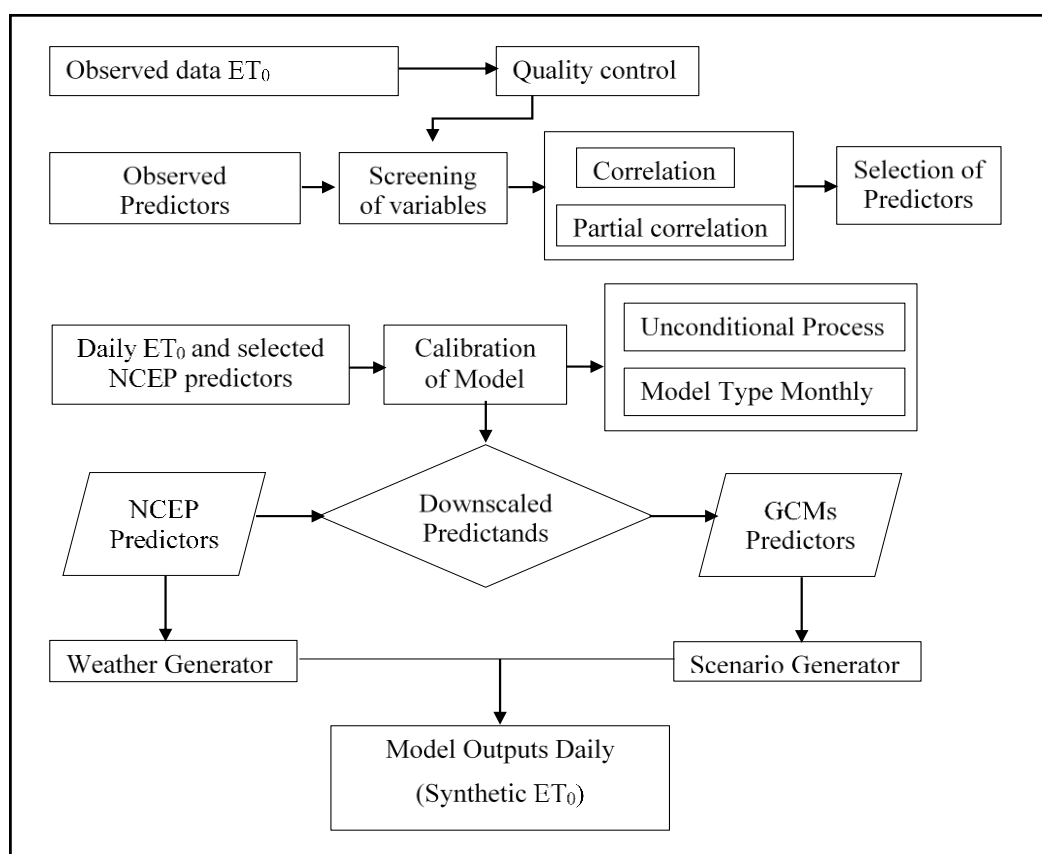


Fig. 3.6 Flow chart showing steps involved in downscaling and scenario generation

4. RESULTS AND DISCUSSION

The study had been undertaken to study variability in crop water requirement for the present and future atmospheric conditions and detailed analysis was carried out in three sections. The meteorological data were analyzed to reveal the trends using Mann Kendall and Theil-Sen's slope estimator test at a 5% significance level for annual mean. The second part covers periodic changes i.e. decadal variation in crop water requirements for four decadal periods *viz.*, 1980s, 1990s, 2000s and 2010s at all stations. The future crop water requirement was estimated for selected stations i.e. Pune, Rahuri, and Solapur stations and discussed in the third section. The investigations were carried out at a different interval of periods to better understand the fluctuation of crop water requirement from the normal value and variation of CWR with climate change scenario over the study area i.e. Western Maharashtra. The results obtained from the study had been presented and discussed under the following heads.

4.1 Trend Analysis in Crop Water Requirement

4.1.1 Estimation of Crop Water Requirement

In the present study, to analyze changes in CWR over a period, four crops were selected *viz.*, cotton, *rabi* onion, soybean, and *suru* sugarcane over the study area. The water requirement was calculated for selected crops at selected stations as per methodology explained in section 3.5.1. The water requirement was estimated for 38 years during 1980 – 2017 for Solapur, Rahuri, Pune, Niphad, Dhule, and Jalgaon station, while 28 years during 1990 – 2017 for Kolhapur and Padegaon station and 23 year during 1995 – 2017 for Kasbe Digraj station as per the availability of the data. The results showed that there were variation in water requirements of crops throughout the study area. The variation in crop water requirement for cotton, *rabi* onion, soybean, and *suru* sugarcane are shown (Fig. 4.1 to 4.4).

4.1.1.1 Cotton

The average water requirements for cotton were obtained as 618.1, 735.6, 570.8, 628.9, 662.4, 591.2, 488.1, 529.0, and 557.4 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and K. Digraj station, respectively. It was also depicted (Fig 4.1) that peak WR corresponding to all stations was observed during year 1982 to 1997 period. The lowest value among the entire analysis was estimated during year 2013 and 2016 for most of the stations. The detail data of estimated values of CWR of cotton were given in Appendix A (Table A.2).

It was observed that before year 2000 the values of CWR obtained for Jalgaon followed by Solapur, Rahuri and Dhule station were overestimated and the values obtained for Kolhapur followed by Padegaon station were underestimated as compared to average CWR for respective stations (Fig. 4.1). Jalgaon, Solapur and Rahuri station corresponded higher CWR during the initial period whereas, Pune and Niphad station observed lower values (Appendix Table A.1). Dhule and

Jalgaon station showed an abrupt change i.e. decrease in CWR within the time series from the end of 1993 to 1995. Notable variations were also observed for Pune and Niphad station during 1987 to 1995 and 1992 to 1999 respectively. The remaining stations showed a little rise but overall decrease in water requirement between studied periods.

4.1.1.2 *Rabi* onion

Rabi onion has average water requirements as 338.6, 446.4, 355.7, 344.1, 406.3, 349.4, 377.4, 315.0, and 364.1 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and K. Digraj station, respectively. The highest values in crop water requirement was observed during year 1985 to 1993 for all stations except K. Digraj station (Fig. 4.2). K. Digraj station showed peak value for the year 2002 this might be due to non-availability of data from 1980 to 1994. The minimum values of CWR for all nine stations in entire analysis was noted during year 2013 to 2017. The Jalgaon and Solapur station reported highest values as compared to other stations. The detail data of estimated values of CWR of *rabi* onion were given in Appendix A (Table A.2).

It was also observed that values of CWR obtained for Jalgaon and Solapur station were overestimated and the values obtained by Padegaon followed by Dhule station were underestimated (Fig. 4.2). During the initial period i.e. 1980 to 1992, Jalgaon and Solapur station corresponded higher crop water requirement. Jalgaon reported higher CWR values during year 1980 to 1991, which later lowered and observed lowest value in year 2016 i.e. 283.2 mm. Similarly, for Rahuri station during year 1989 to 1999 CWR was minimum, which further increased and later manifested lower values during 2014 to 2016 period. The decreasing values were also observed for Solapur station from year 1993 to 2001. The lowest values in CWR amongst all nine stations was observed for K. Digraj station. A continuous decrease in CWR was seen for Kolhapur station from 2012 to 2015 period with the year 2015 recording the least value i.e. 291.5 mm. Padegaon and K. Digraj station resembled mixed variation in CWR.

4.1.1.3 Soybean

Soybean and *rabi* onion had almost similar range in crop water requirement with soybean having values slightly lower values in CWR than *rabi* onion. The average water requirements for soybean were obtained as 362.9, 412.0, 340.5, 386.0, 402.2, 347.3, 291.5, 326.9, and 343.7 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and K. Digraj station, respectively. The peak values in CWR were observed during year 1982 to 1997 (Fig. 4.3). Most of the station i.e. Dhule, Pune, Rahuri, Kolhapur and Padegaon had lowest values in CWR corresponding all years in 2016 (Fig 4.3 and Appendix Table A.3). Similar, outcomes of lowest water requirement was also observed for cotton and *rabi* onion in year 2016 for most of the stations.

Similar to cotton, it was observed that values obtained for Jalgaon followed by Rahuri and Solapur station were overestimated and the values obtained for Kolhapur and Padegaon station were

underestimated. Jalgaon, Rahuri and Solapur station observed higher values during initial period while Kolhapur and Padegaon station having lower range in CWR.

4.1.1.4 *Suru* sugarcane

Suru sugarcane is perennial crop. It requires maximum amount of water and corresponded higher values in CWR as compared to other crops. The average water requirements for all stations were obtained as 1448.6, 1819.2, 1368.1, 1409.1, 1546.2, 1397.7, 1267.6, 1220.4, and 1312 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and K. Digraj station, respectively. The lowest values of CWR for most stations were observed during year 2011 to 2017. The water requirement for Jalgaon, Dhule and Niphad station drastically decrease from year 1995 (Fig. 4.4). The remaining stations bestowed mixed variation with slight increase in the middle years with an overall decreasing trend in the analyzed period.

It was also observed that CWR values obtained for Jalgaon followed by Solapur and Dhule station were overestimated and the values obtained for Padegaon followed by Kolhapur and Pune station were underestimated (Fig. 4.4). Maximum crop water requirement was observed during the initial years for Jalgaon, followed by Solapur, Dhule and Rahuri station. Jalgaon accounted highest values as compared to other stations ranging from 1354 to 2271 mm (Appendix Table A.4). The crop water requirement decreased after year 1986 for Dhule, Solapur and Rahuri while after year 1991 for Jalgaon station.

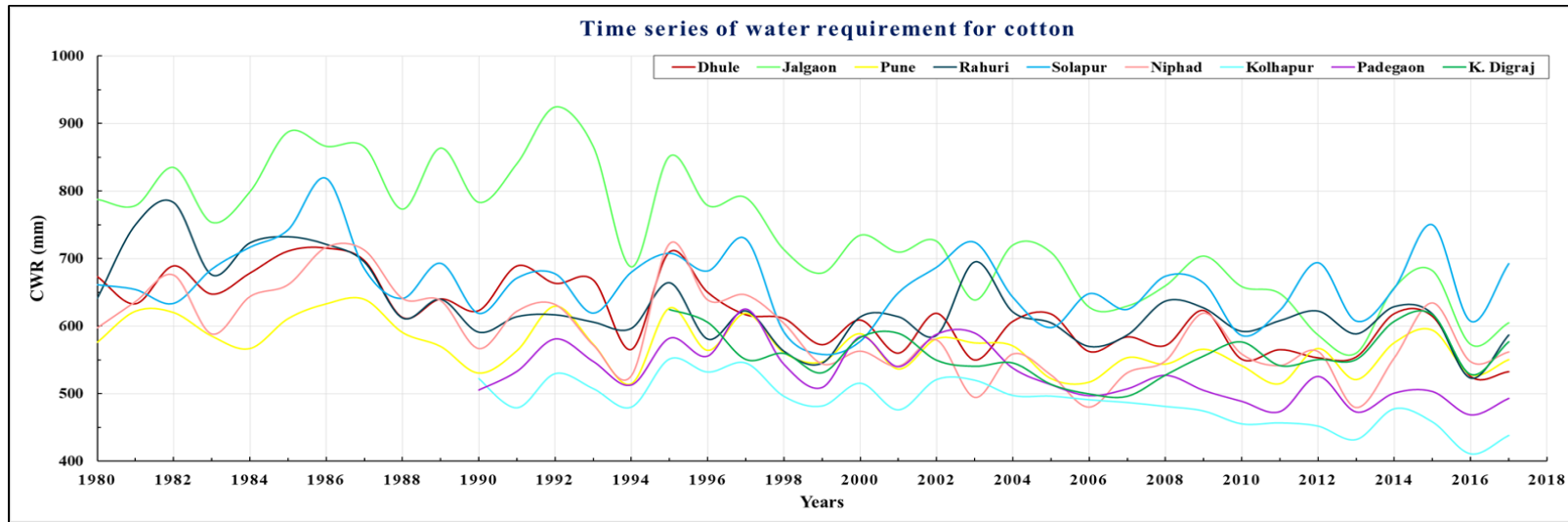


Fig. 4.1 Time series of water requirement for cotton

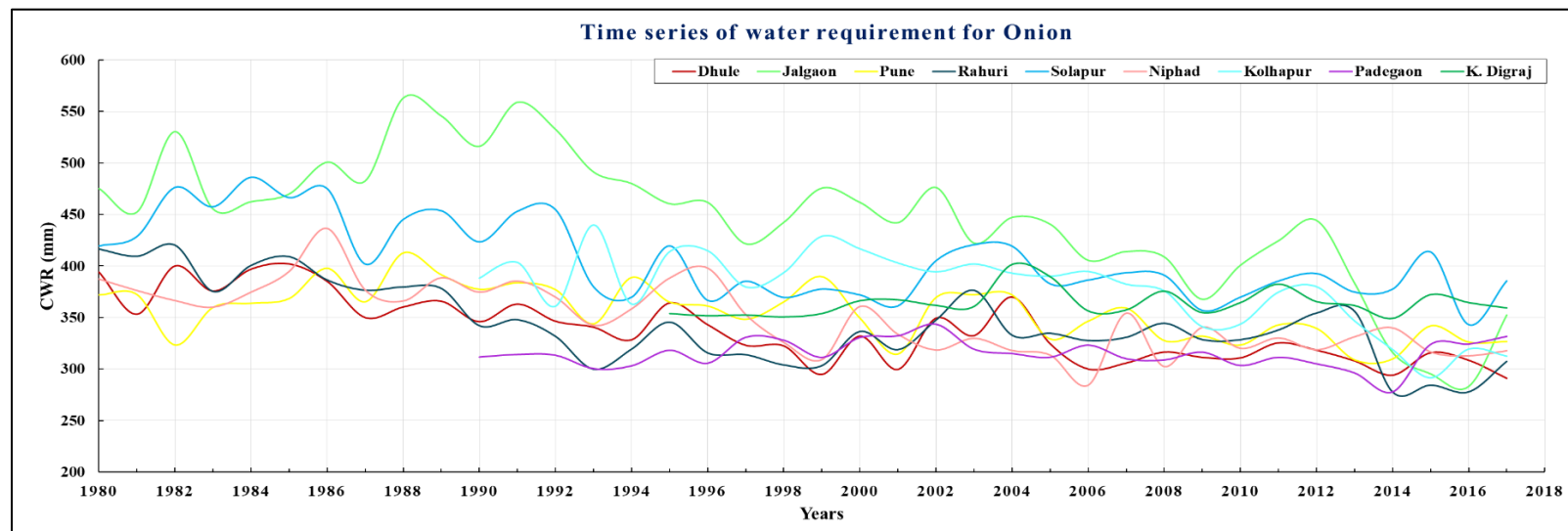


Fig. 4.2 Time series of water requirement for *rabi* onion

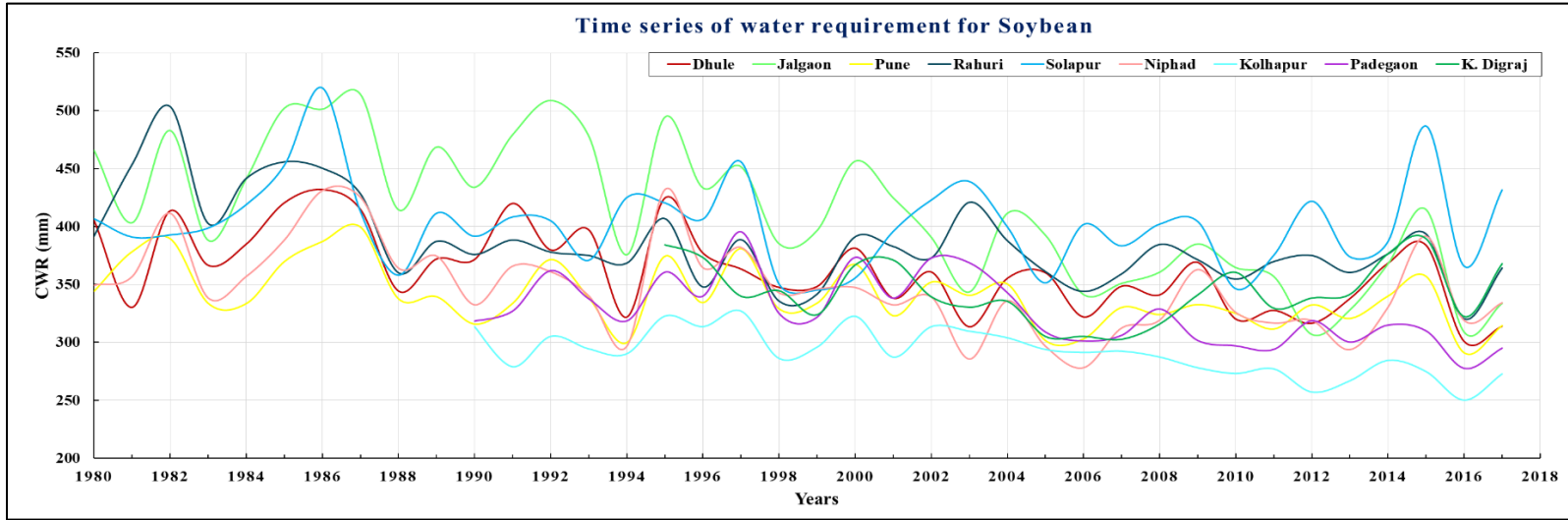


Fig. 4.3 Time series of water requirement for soybean

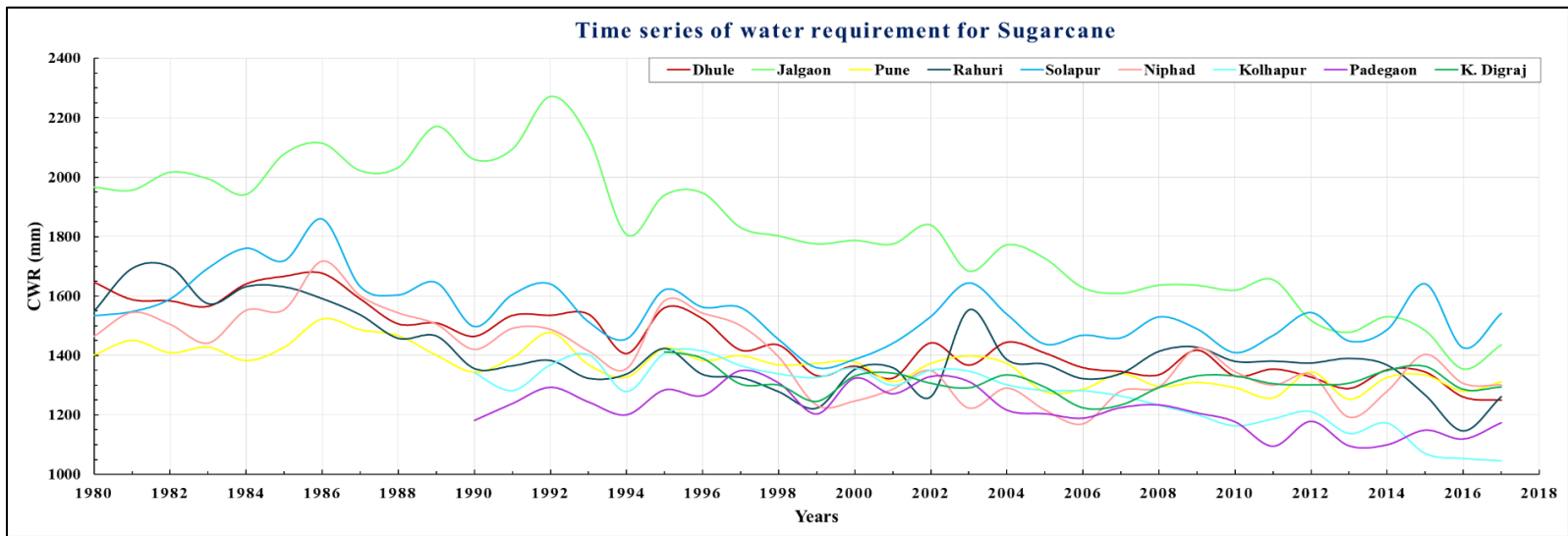


Fig. 4.4 Time series of water requirement for *suru* sugarcane

4.1.2 Trends in Crop Water Requirement

The trend of calculated water requirement for cotton, *rabi* onion, soybean, and *suru* sugarcane over the period of last 37 years (1980 to 2017) at Dhule, Jalgaon, Pune, Rahuri, Niphad, Solapur whereas the period of 28 years (1990 – 2017) at Kolhapur, Padegaon and 23 years (1995 – 2017) for K. Digraj are presented below. The temporal variation in CWR in the form of change in their magnitude is important in the study of climate change. Hence, in this study, annual CWR values were used for performing trend. The trend was said to be increasing or decreasing based on the positive or negative values of the Mann-Kendall test ‘Z’ and its magnitude was given by Sen’s slope ‘Q’ values as discussed in methodology section 3.6.1.

4.1.2.1 Trend in CWR for cotton

Mann – Kendall test

The temporal variation of water requirement for cotton for nine stations in Western Maharashtra were shown in Table 4.1. The result showed that all stations showed a significantly decreasing trend at a 5 % significance level except for Solapur and K. Digraj were showed no trend was observed in water requirement for cotton. It was also observed that the resulted ‘Z’ values of Mann Kendall test for Solapur and K. Digraj were negative which intimated a decreasing trend even though they were statistically not significant. The least Z value was observed for Jalgaon (-5.48) followed by Dhule and Kolhapur -4.88 and -4.41 sequentially. Khedkar, (2017) observed a significant decreasing trend in ET_0 over Western Maharashtra using 34 years (1980-2014) data and resulted in Mann- Kendall ‘Z’ values as -6.08, -5.88, -4.46, -3.01, -5.40, -3.55, -2.45, -4.74 and -2.10 for Dhule, Jalgaon, Niphad, Rahuri, Pune, Solapur, Padegaon, Kolhapur and K. Digraj stations respectively.

Table 4.1 The statistical tests of CWR for cotton over the study area

Cotton	MK trend		Sen's slope estimate (mm/year)		
	Test Z values	Trend	Q	Q _{min95}	Q _{max95}
Dhule	-4.88	Decreasing	-3.73	-5.15	-2.60
Jalgaon	-5.48	Decreasing	-7.06	-9.03	-5.37
Pune	-3.22	Decreasing	-1.79	-2.78	-0.75
Rahuri	-3.32	Decreasing	-2.62	-4.47	-1.15
Solapur	-1.13	No trend	-0.95	-2.65	0.72
Niphad	-3.75	Decreasing	-3.25	-4.76	-1.61
Kolhapur	-4.41	Decreasing	-3.71	-4.82	-2.28
Padegaon	-3.50	Decreasing	-2.91	-4.77	-1.31
K. Digraj	-0.48	No trend	-0.60	-3.49	2.34

*Note: - 1.96 < Z < 1.96 = No trend; Z > 1.96 = Increase in trend; Z < -1.96 = Decrease in trend

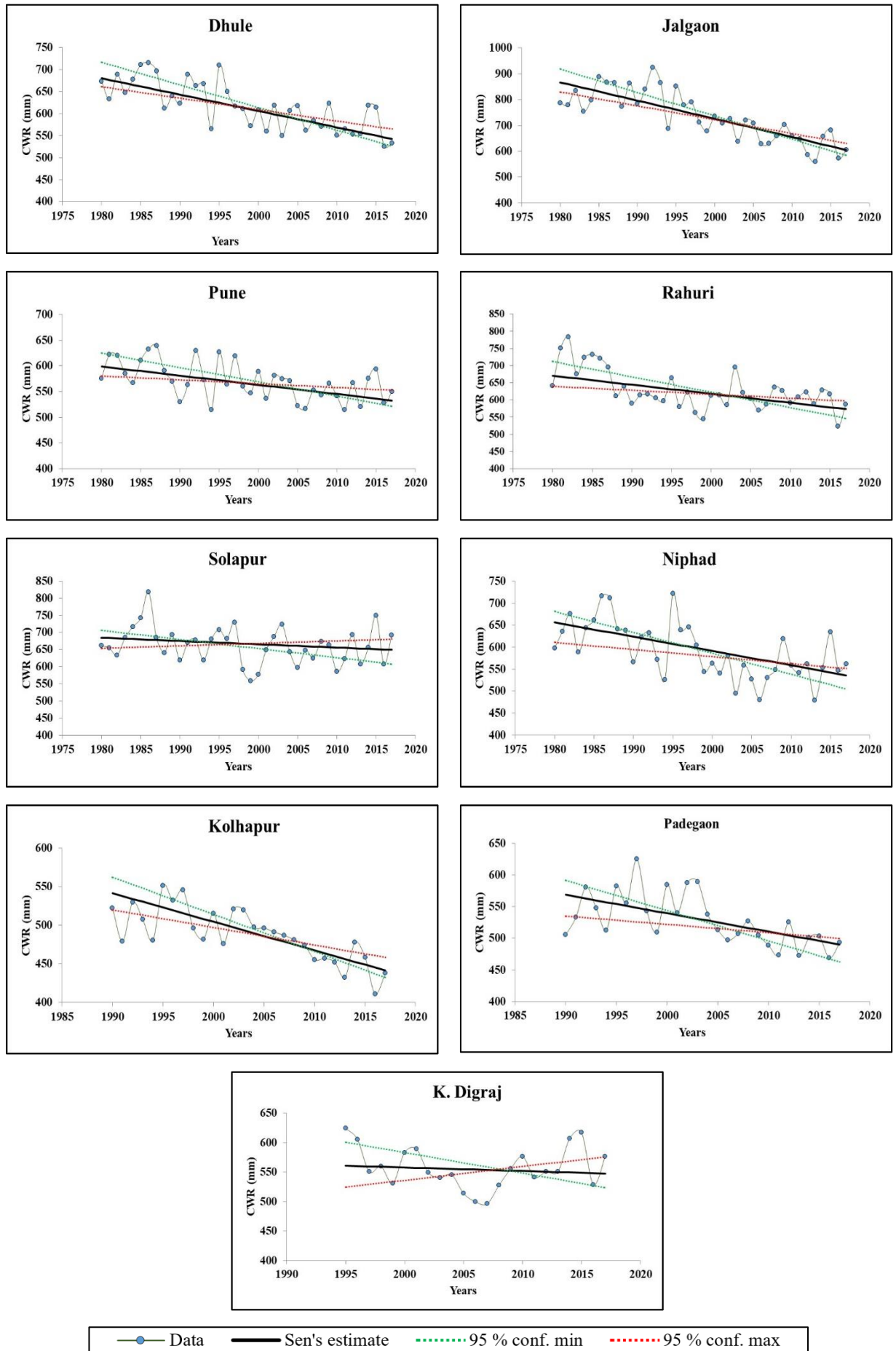


Fig. 4.5 Annual time series and trend statistics of crop water requirement for cotton

Sen's Slope estimator test

Annual time series and trend statistics of water requirement of cotton for nine stations were showed in Fig. 4.5 and Table 4.1. The Sen's slope estimate 'Q' values of all the stations except Solapur and K. Digraj resulted decreasing trends of water requirement. The decreasing trend magnitude was found as -1.79 to -7.06 mm/year. The maximum decrease in the magnitude of trend variation was observed for Jalgaon i.e. -7.06 mm/year whereas minimum for Pune (-1.79 mm/year). Guhathakurta *et al.* (2013) observed that during monsoon season, districts along with the western coast/western parts of Maharashtra *viz.*, Dhule, Nashik, Pune, Satara, and Kolhapur had shown a significant increase in rainfall from 1901 – 2006, which suggests less water demand in these regions as cotton often grown in the *Kharif* season (May – Nov).

4.1.2.2 Trend in CWR for *rabi* onion

Mann Kendall test

The results of the trend analysis using Mann-Kendall test at 5 per cent significance level for water requirement values of *rabi* onion at nine stations over Western Maharashtra were presented in Table 4.2. The resulted 'Z' value were obtained as -5.61, -5.41, -4.00, -4.15, -3.85, -4.83, -3.89, -0.18, and 1.32 for Dhule, Jalgaon, Pune, Rahuri, Niphad, Solapur, Kolhapur, Padegaon and K. Digraj stations, respectively. It was observed that there was decreasing trend in water requirement for all stations except Padegaon and K. Digraj. The resulted 'Z' value was minimum for Dhule (-5.61) followed by Jalgaon (-5.41) which implied a massive decrease in CWR whereas slightly maximum Z value was observed for Solapur (-3.85). Mahmood, (1997) reported that under each 1°C warmer and cooler air temperature conditions, total seasonal evapotranspiration increases and decrease by 5% and 4%, respectively which suggested temperature playing a vital role in CWR.

Table 4.2 The statistical tests of CWR for *rabi* onion over the study area

Onion	MK trend		Sen's slope estimate (mm/year)		
	Test Z values	Trend	Q	Q _{min95}	Q _{max95}
Dhule	-5.61	Decreasing	-2.39	-2.93	-1.75
Jalgaon	-5.41	Decreasing	-4.65	-6.12	-3.16
Pune	-4.00	Decreasing	-1.53	-2.19	-0.88
Rahuri	-4.15	Decreasing	-2.48	-3.40	-1.58
Solapur	-3.85	Decreasing	-2.35	-3.27	-1.35
Niphad	-4.83	Decreasing	-2.10	-2.79	-1.45
Kolhapur	-3.89	Decreasing	-3.36	-4.89	-1.96
Padegaon	-0.18	No trend	-0.04	-0.80	0.61
K. Digraj	1.32	No trend	0.46	-0.22	0.95

*Note: - 1.96 < Z < 1.96 = No trend; Z > 1.96 = Increase in trend; Z < -1.96 = Decrease in trend

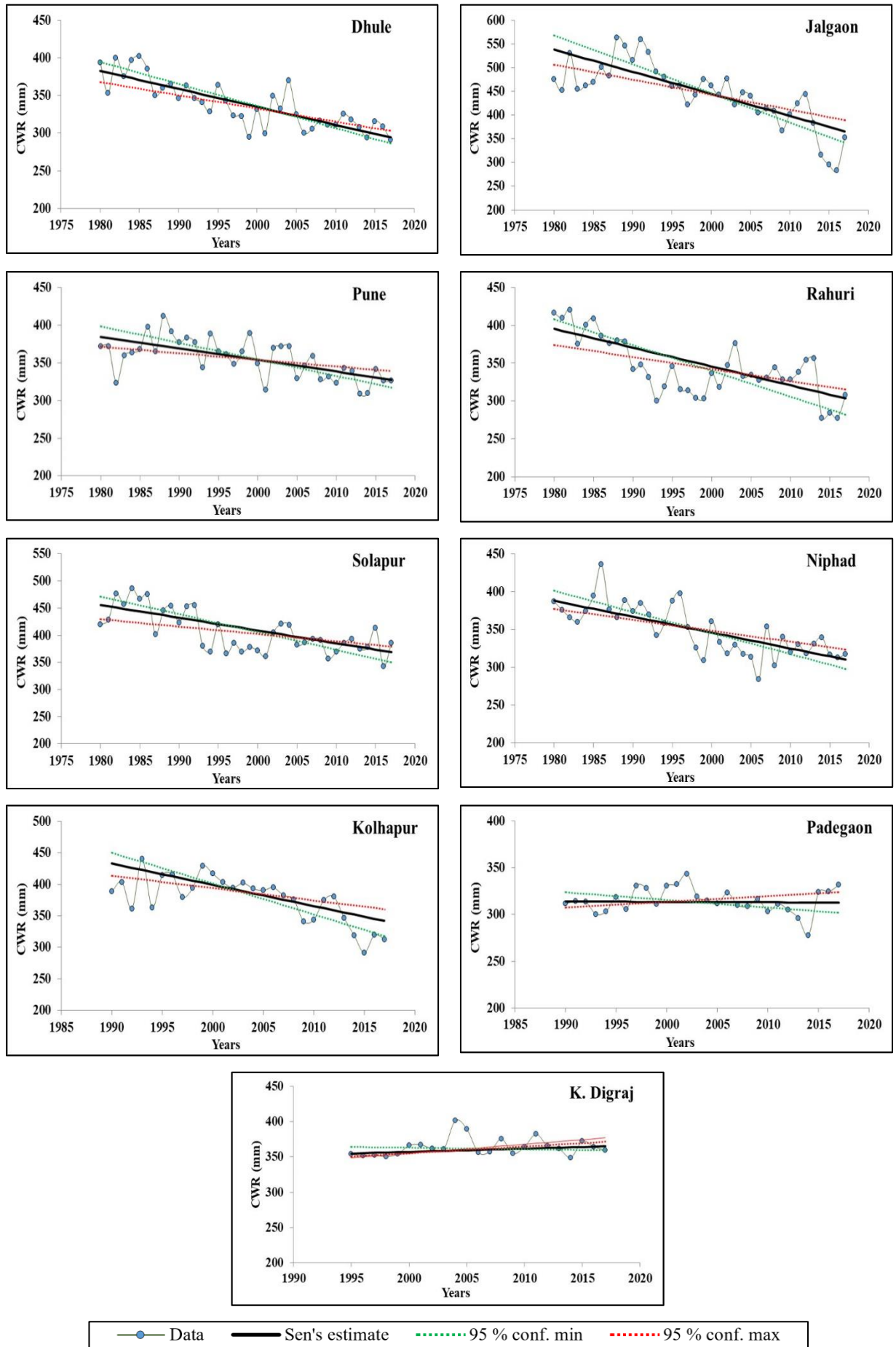


Fig. 4.6 Annual time series and trend statistics of crop water requirement for *rabi* onion

Sen's slope estimator test

The magnitude of trend (mm/year) for CWR of *rabi* onion among nine stations implied decrease in water requirement (Table 4.2 and Fig. 4.6). As analysed for the cotton likewise maximum decrease in water requirement was depicted for Jalgaon (-4.65 mm/year) followed by Kolhapur, Rahuri, Solapur, and Dhule and having Q values as -3.36, -2.48, -2.35 and -2.39 mm/year respectively. Jadhav *et al.* (2017) analyzed 38 years of daily meteorological data of Rahuri and indicated that the energy balance component of ET_0 had shown an increasing trend, while a decreasing trend was seen in the aerodynamic component as well as in reference Evapotranspiration (ET_0). Roderick and Farquhar, (2002) showed the decrease in evaporation was consistent widespread which was due to a decrease in sunlight resulting from increasing cloud coverage and aerosol concentration affecting the decrease in ET_0 .

4.1.2.3 Trend in CWR for soybean

Mann Kendall test

The temporal variation of crop water requirement for soybean at nine stations over Western Maharashtra were shown in Table 4.3 and Fig. 4.5. The analysis of trend variation for soybean was quite similar as of cotton for respective stations in the study period. Result showed that for the period (1980 – 2017) for Solapur and the period (1995 – 2017) for K. Digraj no trend in water requirement was observed at 95% confidence level. However, Dhule, Jalgaon, Pune, Rahuri, and Niphad station from the period (1980 – 2017) and Kolhapur and Padegaon during 1990 to 2017 resembled decreasing trend at 5 % significance level. The resulted 'Z' value for nine stations ranged from -0.32 to -4.74. The minimum 'Z' value among all stations was observed for Jalgaon (-4.74) followed by Kolhapur (-4.05).

Table 4.3 The statistical tests of CWR for soybean over the study area

Soybean	MK trend		Sen's slope estimate (mm/year)			Presence of Trend
	Test Z values	Trend	Q	$Q_{\min 95}$	$Q_{\max 95}$	
Dhule	-3.72	Decreasing	-2.11	-2.98	-1.09	*
Jalgaon	-4.75	Decreasing	-4.21	-5.71	-2.79	*
Pune	-3.12	Decreasing	-1.04	-1.95	-0.42	*
Rahuri	-3.57	Decreasing	-1.73	-2.79	-0.78	*
Solapur	-0.83	No trend	-0.47	-1.56	0.63	
Niphad	-3.42	Decreasing	-1.71	-2.74	-0.79	*
Kolhapur	-4.05	Decreasing	-1.83	-2.72	-0.97	*
Padegaon	-3.34	Decreasing	-2.12	-3.04	-1.01	*
K. Digraj	-0.32	No trend	-0.21	-2.48	1.71	

*Note: - 1.96 < Z < 1.96 = No trend; Z > 1.96 = Increase in trend; Z < -1.96 = Decrease in trend

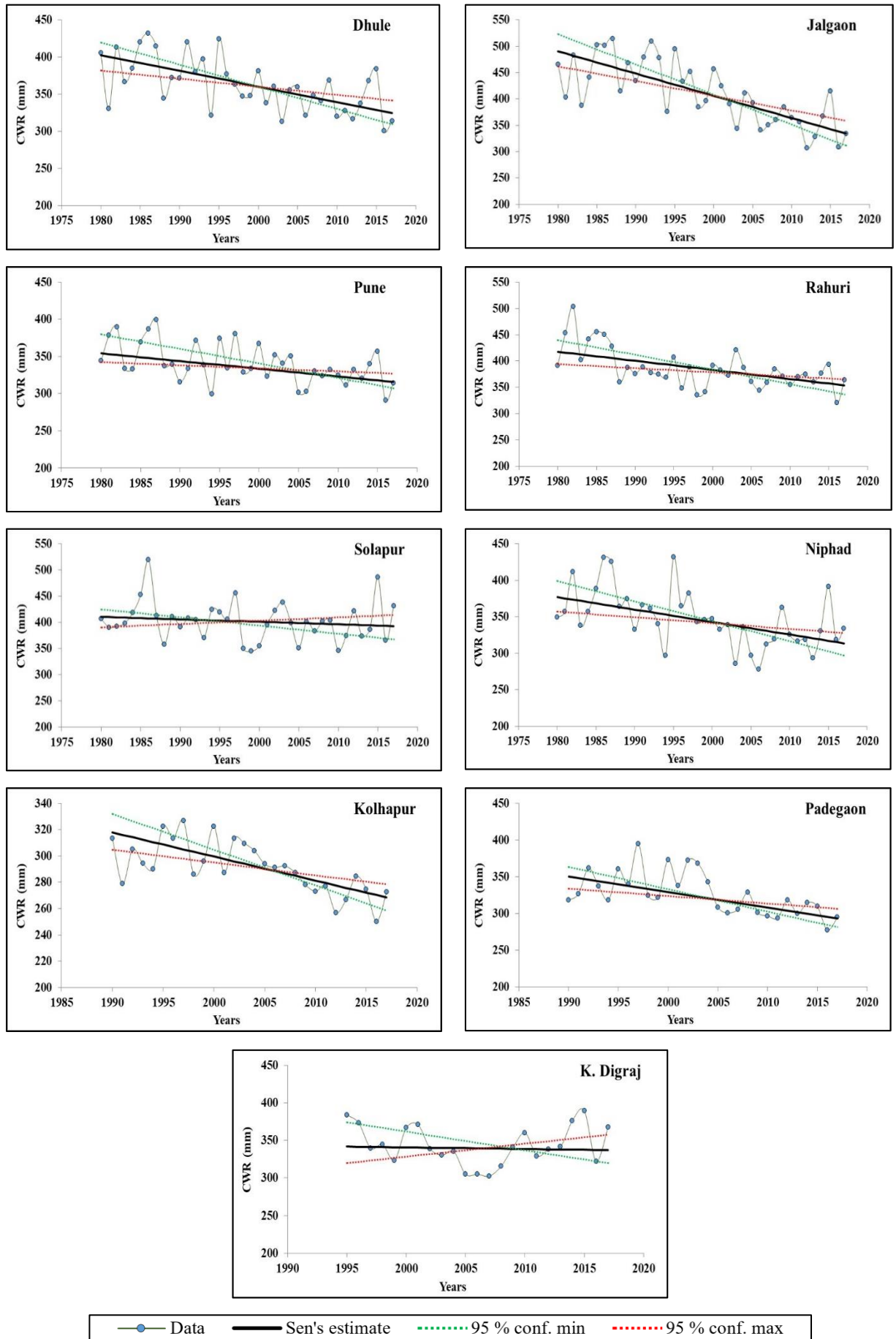


Fig. 4.7 Annual time series and trend statistics of crop water requirement for soybean

Sen's Slope estimator test

The magnitude of trend estimated by Sen's slope estimator test for all stations showed decreasing trend and revealed variation per year in the water requirement for soybean (Fig. 4.7). The test resulted magnitude of maximum decrease in water requirement for Jalgaon -4.21 mm/year accompanied by Padegaon, Dhule, Kolhapur, Rahuri and Niphad having 'Q' values as -2.12, -2.11, -1.83, -1.73 and -1.71 mm/year respectively (Table 4.3). Pune station exhibited the least 'Q' value with a magnitude of -1.04 mm/year which contributed to the fact of less decrease in water requirement per year, however Solapur had resulted minimum 'Q' values as -0.47 followed by Padegaon stations i.e. -0.21 mm/year, respectively but was showed non-significant as per Mann Kendall test. Rao and Wani, (2011) analyzed ET_0 at a semi-arid location of southern India and observed a decreasing trend of ET_0 with a 10% reduction in *kharif* and 14% in *rabi* season.

4.1.2.4 Trend in CWR for *suru* sugarcane

Mann Kendall test

Suru sugarcane showed greater fluctuation in water requirement for all stations compared to all crops i.e. cotton, *rabi* onion, soybean. All stations resembled significantly decreasing trend at a 5 % significance level except for K. Digraj where showed no trend in water requirement for *suru* sugarcane (Table 4.4). The resulted Mann Kendall 'Z' values were most negative for CWR of *suru* sugarcane compared to all crops. It was also recognized that the value of Mann-Kendall test 'Z' and Sen's Slope estimate 'Q' of K. Digraj were negative indicating a decreasing trend even though statistically not significant. The least 'Z' Value was observed for Jalgaon (-6.26) and Dhule (-6.24) followed by Kolhapur and Niphad. Dhorde *et al.* (2016) observed insignificant decreasing and increasing trend at Solapur and Pune at a 5 % significance level in annual temperature.

Table 4.4 The statistical tests of CWR for *suru* sugarcane over the study area

Sugarcane	MK trend		Sen's slope estimate (mm/year)			Presence of Trend
	Test Z values	Trend	Q	Q _{min95}	Q _{max95}	
Dhule	-6.24	Decreasing	-9.53	-11.39	-8.10	*
Jalgaon	-6.26	Decreasing	-18.84	-21.94	-15.48	*
Pune	-5.28	Decreasing	-4.38	-5.85	-3.04	*
Rahuri	-3.75	Decreasing	-8.06	-11.18	-4.13	*
Solapur	-3.14	Decreasing	-5.10	-7.76	-2.09	*
Niphad	-4.35	Decreasing	-8.03	-11.47	-5.14	*
Kolhapur	-5.31	Decreasing	-12.42	-15.19	-9.28	*
Padegaon	-3.22	Decreasing	-6.07	-9.19	-2.56	*
K. Digraj	-0.58	No trend	-0.77	-3.80	1.88	

*Note: - 1.96 < Z < 1.96 = No trend; Z > 1.96 = Increase in trend; Z < -1.96 = Decrease in trend

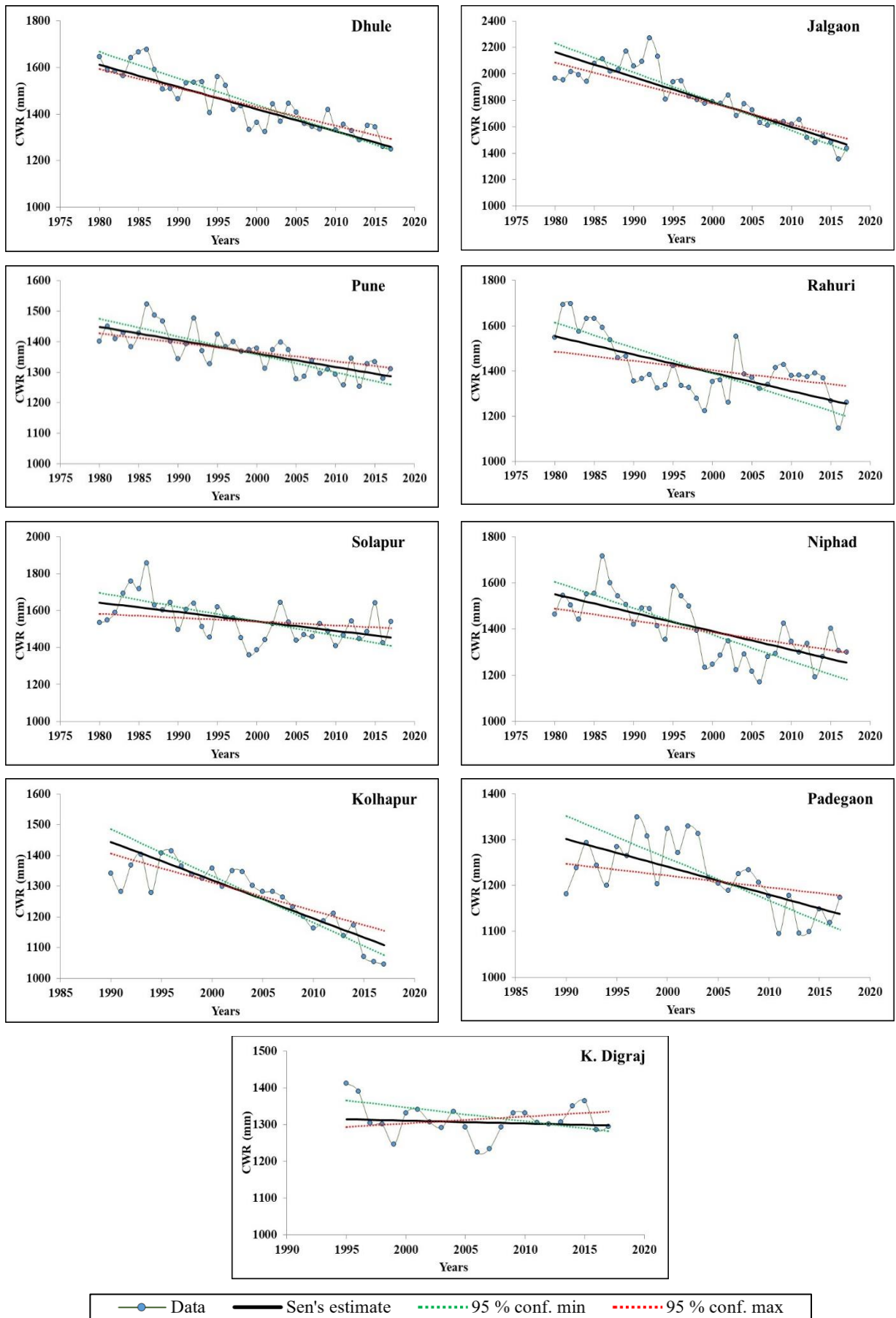


Fig. 4.8 Annual time series and trend statistics of crop water requirement for *suru* sugarcane

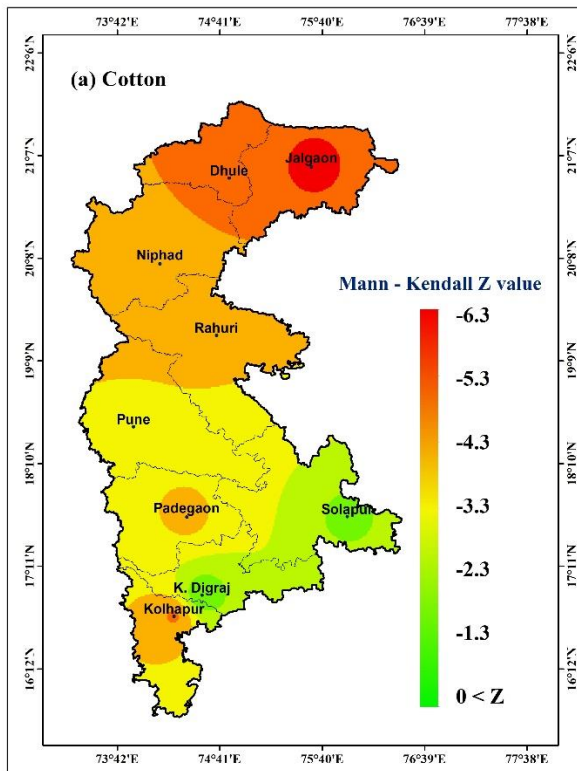
Sen's Slope estimator test

The magnitude of the decrease in water requirement for *suru* sugarcane was maximum for Jalgaon (-18.84 mm/year). The minimum and maximum Q values at 95% confidence level for the same i.e. Jalgaon were -21.94 and -15.48 mm/year respectively, which implied the highest decrease in water requirement (Fig. 4.8). The extent of decrease was also found maximum for Kolhapur i.e. -12.42 mm/year. K. Digraj exhibited the least decrease in CWR (-0.77 mm/year) in an entire analysis, whereas Dhule, Pune, Rahuri, Niphad, and Padegaon had a magnitude of decrease at the rate of -9.53, -4.38, -8.06, -8.03, and -6.07 mm/year respectively (Table 4.4 and Fig. 4.8). Verma *et al.* (2009) observed significant decreasing trend in annual ET_0 at seventeen location out of twenty two over India using 1971 – 2000 dataset with mean annual dET_0/dt decreasing at rate of -9.36 mm/year.

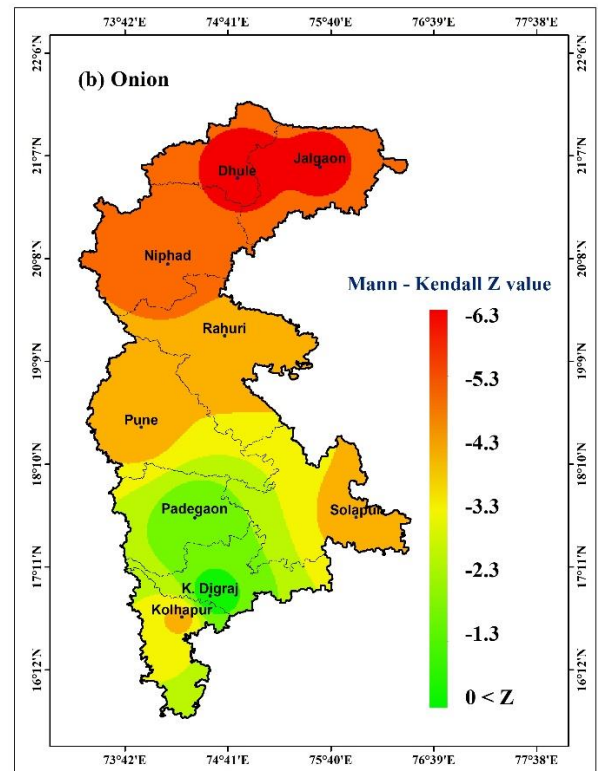
4.1.2.5 Spatial distribution of trends for CWR

The spatial analysis of Mann Kendall resulted 'Z' values over the period for cotton, *rabi* onion, soybean and *suru* sugarcane showed that 'Z' values relatively decreased with increase in latitude, however, central part of study area showed relatively less '-Z' values (Fig. 4.9). In this study, negative values indicated that there was negative trend in the CWR at alternative hypothesis. Considering all crops i.e. cotton, *rabi* onion, soybean and *suru* sugarcane the severity of trend was strong for the *suru* sugarcane at 5% significant level over the study area. The variation in Mann Kendall 'Z' values were broadly categorized into three sections; least decrease ($Z > -3.3$), moderate decrease (-3.3 to -5.3) and highest decrease ($Z < -5.3$), whereas no trend ($Z > -1.96$). The cotton and soybean crop resembled similar variation in the spatial distribution of Z values due to similar seasons except the stations of Dhule and Jalgaon. *Suru* sugarcane corresponded to higher decrease with most negative 'Z' values in northern region. For *rabi* onion, the corresponding area of Padegaon and K. Digraj stations had ($Z < -2.3$) signifying lesser decrease in water requirement as compared to other stations. In case of soybean the Z values are mostly in least and moderate decrease as discussed above.

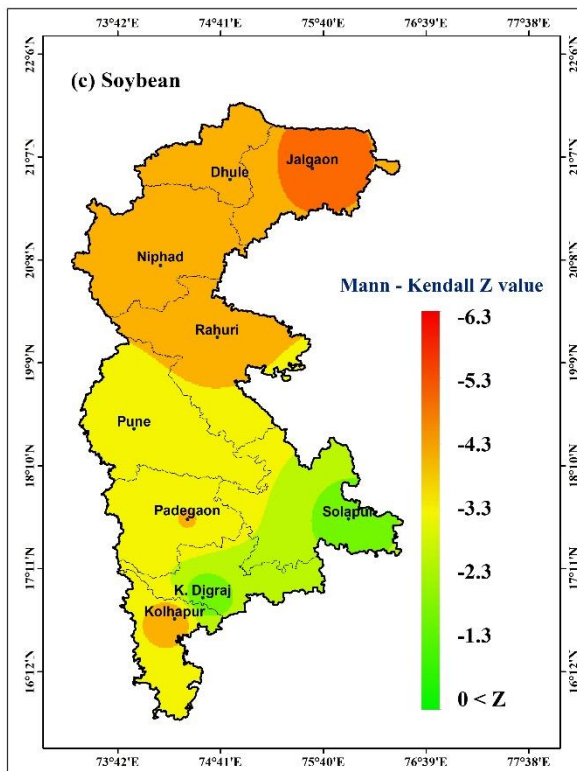
The spatial map of cotton and soybean resulted in similar distribution pattern of Mann Kendall 'Z' value but with different magnitude (Fig. 4.9 (a) and (b)). The 'Z' value decreased from south-east (Solapur station) to north-east (Jalgaon station). The map of *rabi* onion and *suru* sugarcane intimated decrease in Mann Kendall 'Z' value from south (K. Digraj) to south-east (Jalgaon station). The spatial distribution of Mann Kendall 'Z' value for *suru* sugarcane observed most negative 'Z' value (-5.3 to -6.3) in the north part (Dhule and Jalgaon station). Patle *et al.* (2013) observed decreasing trend in the time series for reference evapotranspiration (ET_0) with 'Z' value as -2.37 and Sen slope's 'Q' value as -0.01 mm/year.



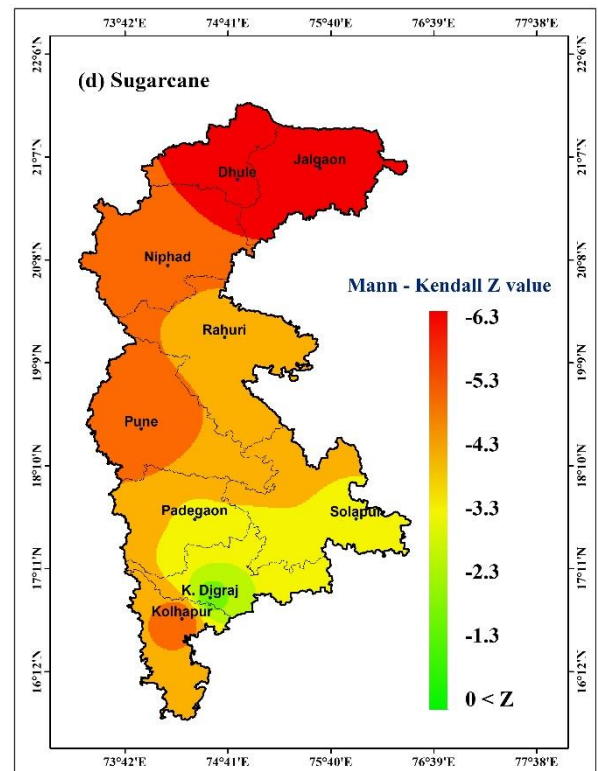
(a)



(b)



(c)



(d)

Fig. 4.9 Spatial distribution of CWR for (a) Cotton, (b) *Rabi* onion, (c) Soybean and (d) *Suru* sugarcane using Mann – Kendall ‘Z’ value

4.1.3 Trend Analysis of Meteorological Parameters at Rahuri Station

An additional analysis was carried out in a view to support above findings of trends of CWR and to determine maximum contributing factor i.e. meteorological parameter for the decrease in CWR. The annual mean T_{\max} , T_{\min} , RH_{\max} , RH_{\min} , WS, BSS and Evaporation data for the period 1980 to 2017 of Rahuri station was analysed using Mann-Kendall test and Sen's slope estimator method. The analysis was done with considering all meteorological parameters required for estimation of ET_0 using FAO56 Penman Monteith equation discussed in section 3.5.1.

4.1.3.1 Mann Kendall test

The resulted Z values were observed as 1.35, -1.26, 4.43, 2.34, -3.62, and -3.12 for T_{\max} , T_{\min} , RH_{\max} , RH_{\min} , WS, and BSS respectively for Rahuri station and presented in Table 4.5. The annual T_{\max} and T_{\min} resembled no trend at 95 % confidence level, whereas RH_{\max} and RH_{\min} showed an increase in trend statistics. Remaining parameters i.e. WS and BSS showed decrease in trend. Here, decrease in WS and BSS whereas, increase in relative humidity were considered significant for decrease in CWR. Thus, aerodynamic component plays prominent role for decrease in CWR.

Table 4.5 The statistical tests of meteorological parameters for Rahuri station

Met. Parameter	MK trend		Sen's slope estimate		
	Test Z values	Trend	Q	$Q_{\min 95}$	$Q_{\max 95}$
T_{\max}	1.35	No trend	0.01	-0.004	0.021
T_{\min}	-1.26	No trend	-0.02	-0.049	0.011
RH_{\max}	4.43	Increasing	0.56	0.376	0.674
RH_{\min}	2.34	Increasing	0.10	0.015	0.175
WS	-3.62	Decreasing	-0.11	-0.157	-0.060
BSS	-3.12	Decreasing	-0.01	-0.021	-0.006

*Note: $-1.96 < Z < 1.96 =$ No trend; $Z > 1.96 =$ Increase in trend; $Z < -1.96 =$ Decrease in trend

4.1.3.2 Sen's Slope estimator test

The annual time series and trend statistics of T_{\max} , T_{\min} , RH_{\max} , RH_{\min} , WS, and BSS for the period of 1980 to 2017 at Rahuri station were presented in Fig. 4.10. The magnitude of trend 'Q' i.e. change per year was well studied by Sen's slope estimator test. The rate of increasing trend for maximum and minimum relative humidity were 0.56 and 0.10 %/year respectively. The magnitude of decrease for WS and BSS were -0.11 Km/hour/year and -0.006 hours/year respectively. The magnitude of trend in annual T_{\max} and T_{\min} were 0.01 and -0.02 °C/year respectively but was considered non-significant according to Mann Kendall test (Table 4.5).

As reference evapotranspiration (ET_0) inversely proportional to relative humidity (RH) and directly proportional to temperature (T), wind speed (WS) and bright sunshine hours (BSS) it can be concluded that decrease in CWR for Rahuri and all other stations was due to the increase of

relative humidity and decrease of wind speed and bright sunshine hours. Bandyopadhyay *et al.* (2009) found significant decreasing trend in ET_0 all over India using 32 years (1972-2002) data, it was mainly caused by significant increase in the relative humidity, decrease in wind speed and solar radiation throughout the country.

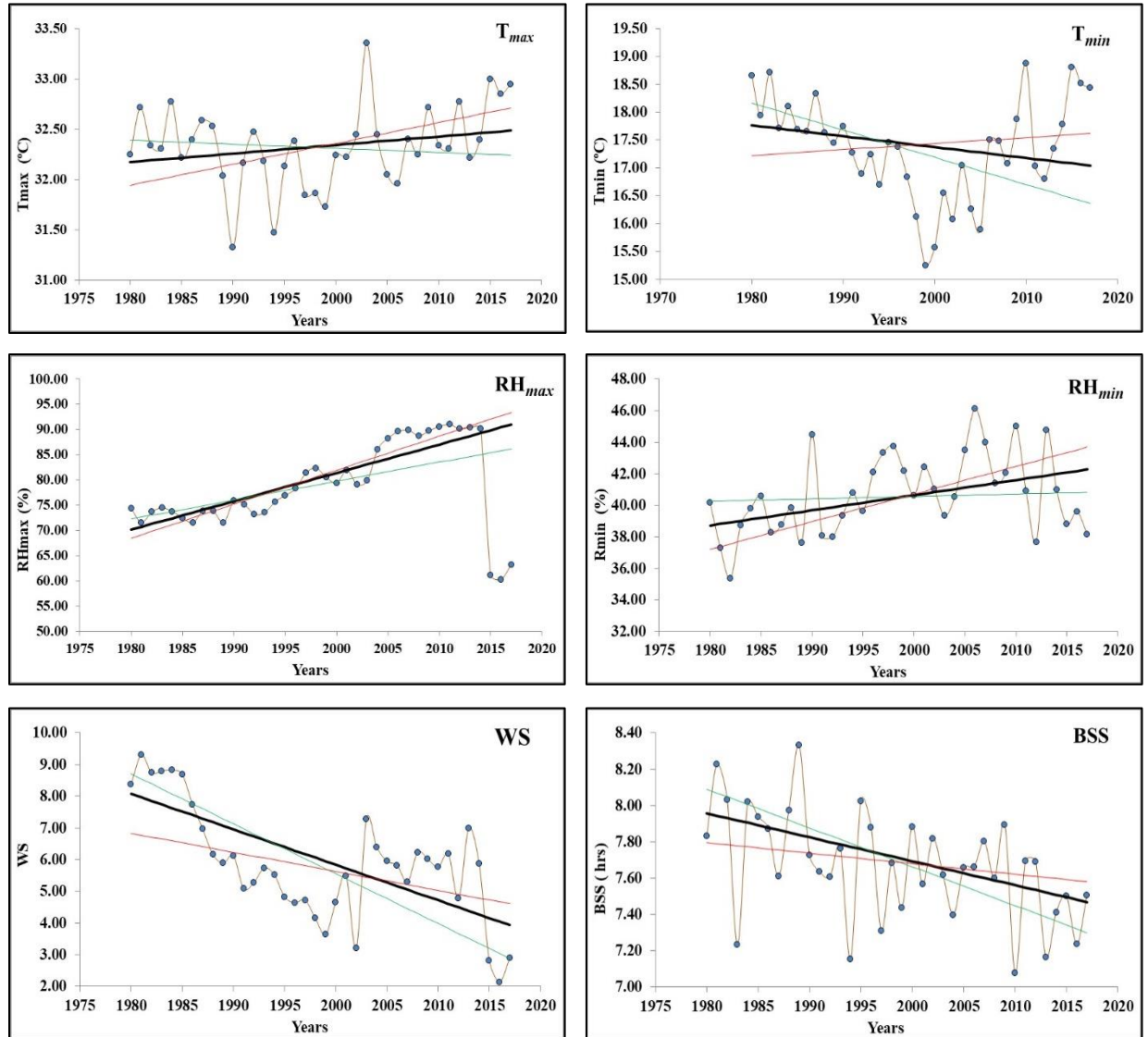


Fig. 4.10 Annual time series and trend statistics of meteorological parameters for Rahuri during 1980–2017

4.2 Periodic Changes in Crop Water Requirement

The periodic changes in CWR for different crops i.e. cotton, *rabi* onion, soybean, and *suru* sugarcane were carried out using methodology discussed in section 3.7. The decadal average of crop water requirement i.e. ten years width *viz.*, 1981–1990 (1980s), 1991–2000 (1990s), 2001–2010 (2000s) and 2011–2017 (2010s) were considered to study periodic changes in CWR over study area. The analysis mostly specified percentage changes as either increase or decrease. Changes in potential evapotranspiration (PET) over space and time provide a clearer picture of the movement of the water cycle (Bates *et al.* 2008).

4.2.1 Cotton

The results of average decadal crop water requirement of cotton at selected stations were presented in Table 4.6. The maximum average crop water requirement of 817.5, 786.5, and 678.3 mm for the decades 1980s, 1990s and 2000s respectively were observed for Jalgaon station, whereas the highest crop water requirement of 661.5 mm was observed for the decade 2010s at Solapur station. The minimum average crop water requirement of 595 mm for 1980s decade was observed for Pune station and 512.84, 489.9, 446.6 mm for remaining 1990s, 2000s, 2010s decades, respectively were reported for Kolhapur station. The resulted range of average crop water requirement as 595 to 817 mm, 512 to 786 mm, 489 to 678 mm, and 446 to 661 mm were observed in 1980s, 1990s, 2000s and 2010s decades sequentially, over study area i.e. Western Maharashtra.

Table 4.6 Periodic changes in crop water requirement of cotton over western Maharashtra

Stations	Crop water requirement (mm)				CWR of cotton increase or decrease, %		
	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2017	(1981-1990) to (1991-2000)	(1991-2000) to (2001-2010)	(2001-2010) to (2011-2017)
Dhule	665.55	635.57	584.63	566.29	-4.50	-8.02	-3.14
Jalgaon	817.49	786.51	678.32	616.08	-3.79	-13.76	-9.18
Pune	595.03	578.78	550.76	550.15	-2.73	-4.84	-0.11
Rahuri	687.70	602.32	613.46	596.57	-12.42	1.85	-2.75
Solapur	686.31	649.33	649.83	661.58	-5.39	0.08	1.81
Niphad	643.45	607.10	543.89	554.34	-5.65	-10.41	1.92
Kolhapur	NA	512.84	489.97	446.60	NA	-4.46	-8.85
Padegaon	NA	552.78	529.40	491.13	NA	-4.23	-7.23
K. Digraj	NA	575.80	539.47	567.50	NA	-6.31	5.20

(*NA- Not available due to unavailability of data)

The values of percent change of CWR of cotton i.e. either increase or decrease with respect to different decades were presented in Table 4.6 and Fig. 4.11. It was observed that there was decrease in CWR of cotton with respect to decades sequentially for all stations, except Rahuri for the decades 1990s to 2000s; and Solapur, Niphad, and K. Digraj for the decades 2000s to 2010s

showed increase in CWR of cotton (Fig. 4.11). In between the 1980s and 1990s decades, the maximum decrease (-12.42 %) in CWR of cotton was observed for Rahuri station whereas the lowest decrease (-2.73 %) was observed for Pune station. For the decades 1990s and 2000s, all stations showed a decrease in CWR of cotton in the range i.e. -4.23 % to -13.76 %, except Rahuri (1.85 %) and Solapur (0.08 %) showed increase in CWR. Jalgaon showed a higher decrease (-13.76 %) followed by Niphad (-10.41 %) and Dhule (-8.02) whereas, Padegaon station resembled minimum reduction (-4.23%) in CWR. In between 2000s and 2010s decade, all stations observed decrease in CWR of cotton, except Solapur (1.81 %), Niphad (1.92 %) and K. Digraj (5.20%) observed increase in CWR. The highest decrease was showed for Jalgaon (-9.18 %), whereas Pune recorded the lowest decrease (-0.11 %.) in CWR of cotton.

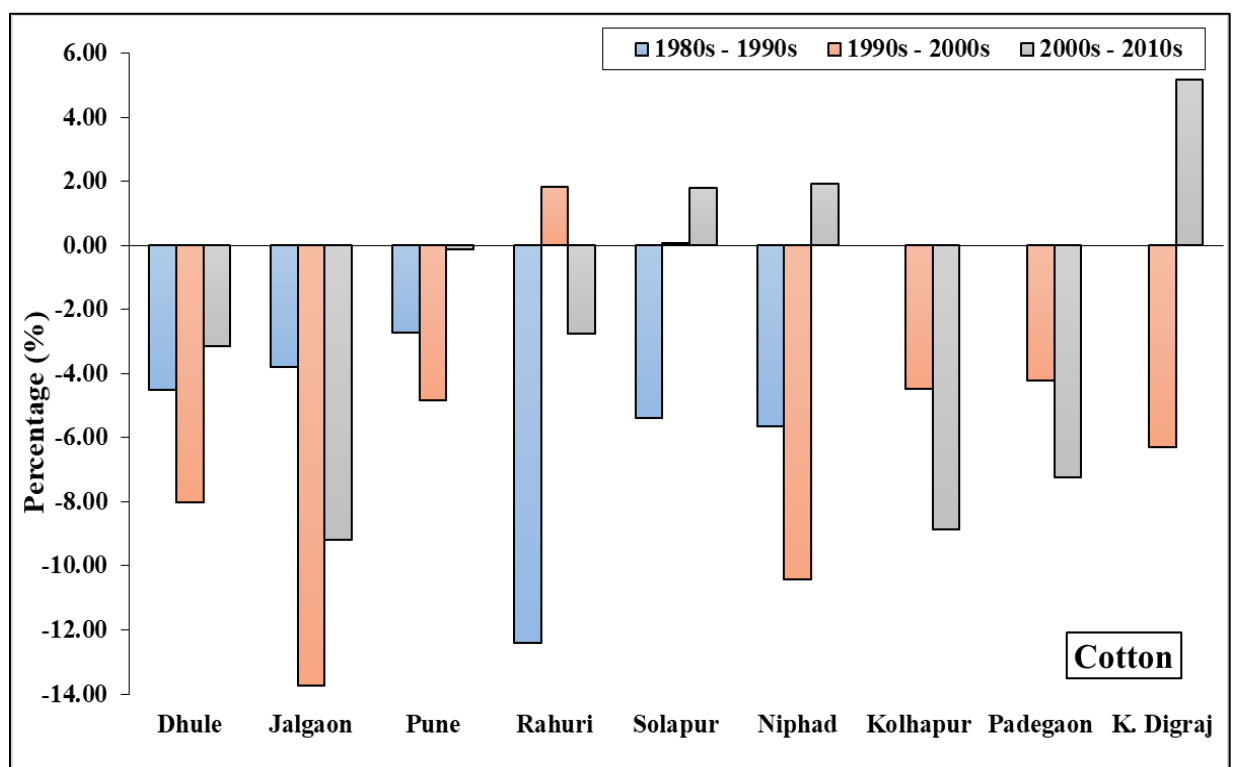


Fig. 4.11 Percentage variation in decadal water requirement of cotton

The spatial distribution maps of average decadal values of CWR for cotton have been prepared separately using inverse distance weighted (IDW) method described in methodology section 3.7.1. The resultant maps of 1980s, 1990s, 2000s and 2010s decades for average CWR values of cotton were depicted in Fig. 4.12.

The spatial map of 1980s decade was prepared considering CWR values of only six stations (Dhule, Jalgaon, Pune, Rahuri, Niphad and Solapur) and the CWR of remaining stations i.e. Kolhapur, Padegaon, and K. Digraj station were estimated using IDW interpolation technique. The analysis revealed average CWR varying from 500 to 800 mm over the study area. The maximum value of CWR (750 – 800 mm) obtained at north-east part (Jalgaon station). The minimum value of CWR (500 – 550 mm) were obtained at central part over Pune station. The maximum

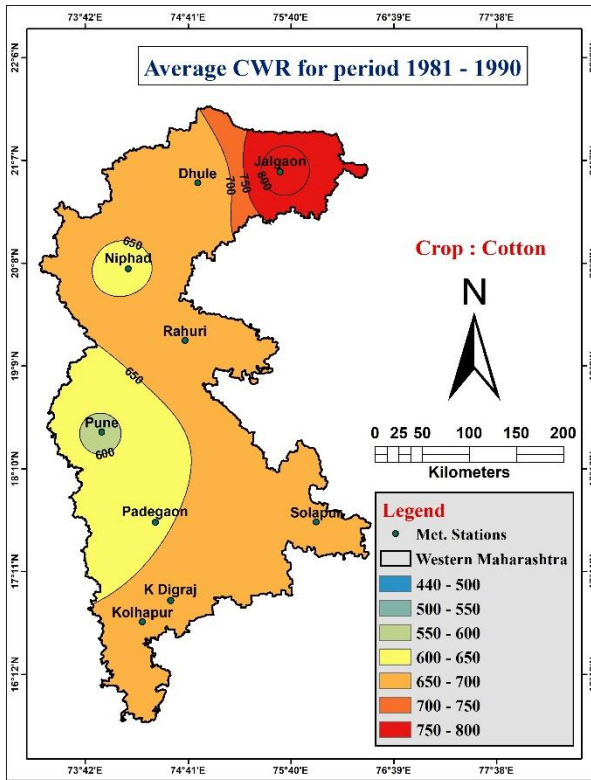
contributed part over study area i.e. Western Maharashtra had CWR in the range as 650 – 700 mm (Fig. 4.12 (a)).

It was observed that the average CWR values for 1990s decadal period varied from 500 to 800 mm over study area. The minimum value of CWR (500 to 550 mm) obtained at part of Kolhapur station, while maximum value (750 to 800 mm) obtained at part of Jalgaon station. It was also observed that the values of CWR increases from southern part of study area (Kolhapur region) towards north-east (Jalgaon region) of study (Fig. 4.12 (b)). The CWR also increased with increase in latitude. The maximum study area had CWR in the range as 550 to 650 mm at the central part. Sonali *et al.* (2016) observed good correlation between PET and T_{\max} above 95% in the spatial maps for winter season mostly in northern region of Western Maharashtra which contributed to the fact of higher water requirement in Jalgaon due to higher temperature.

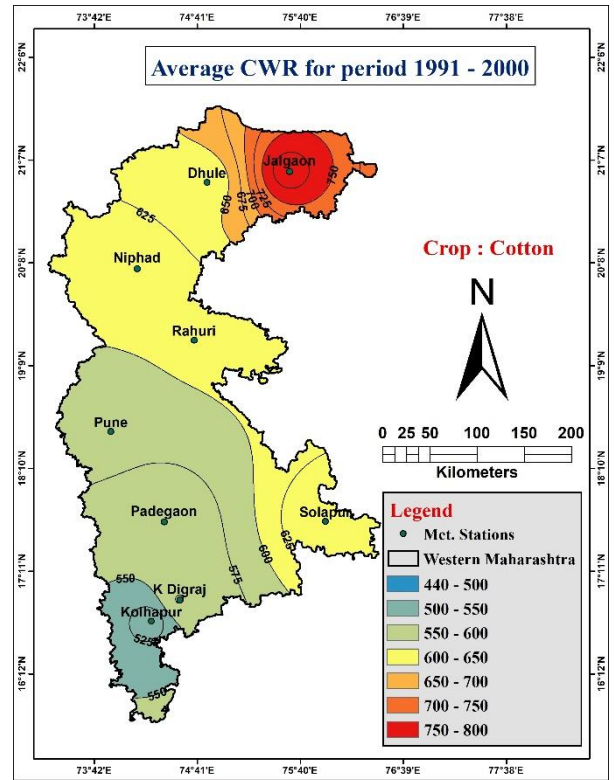
The map of 2000s decade, showed considerable close spatial distribution pattern and relative decrease in CWR as compared to 1990s decade. The average CWR for 2000s decade observed considerable lower values i.e. 440 to 700 mm (Fig. 4.12(c)). The minimum value of CWR (440 to 500 mm) were obtained at part of Kolhapur station followed by Padegaon, K. Digraj and Niphad station, while maximum value (650 to 700 mm) obtained at part of Jalgaon station.

The spatial map of 2010s decade were shown similar distribution pattern of CWR as a spatial map of 2000s decade and also obtained similar range of CWR values over study area i.e. 440 to 650 mm (Fig. 4.12 (d)). The lower values (440 to 500 mm) were depicted for part of Kolhapur and Padegaon station. Similar to 1990s decade, the values of CWR increases from southern part of study area (Kolhapur region) towards north-east (Jalgaon region) of study area. The spatial analysis of average CWR for the decade 2010s observed tremendous decrease in water requirement with maximum area of analysis representing water requirement below 550 mm. The southern part of the study area contributed lower values for all three periods i.e. 1990s, 2000s and 2010s. Based on the results it was revealed that there was relatively decrease in CWR of cotton with successive decades over Western Maharashtra.

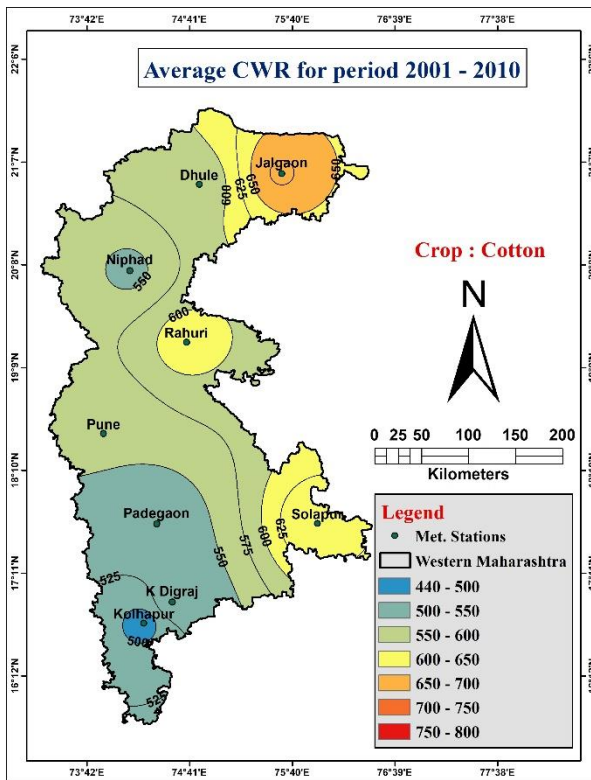
These maps can be used for irrigation planning and management involved in developing the crop planning, agricultural operations and supplemental irrigation and storages in reservoirs for Western Maharashtra.



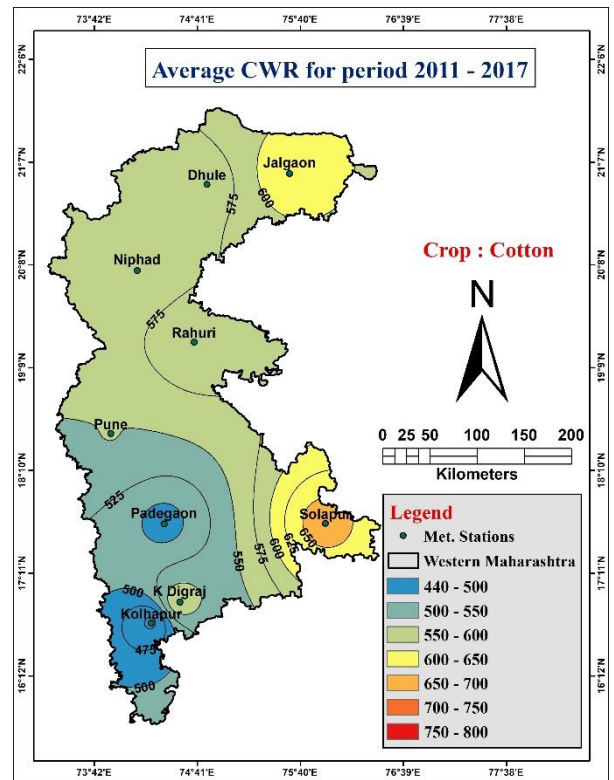
(a)



(b)



(c)



(d)

Fig. 4.12 Spatial patterns in crop water requirement of cotton for four decadal periods (a) 1981 – 1990; (b) 1991 – 2000; (c) 2001–2010; (d) 2011–2017

4.2.2 Rabi onion

The results of average decadal crop water requirement of *rabi* onion at selected stations were presented in Table 4.7. The resulted range of average crop water requirement as 373 to 495 mm, 315 to 478 mm, 318 to 422 mm, and 308 to 381 mm were observed in 1980s, 1990s, 2000s and 2010s decades respectively, over study area. The maximum average crop water requirement of 495.8, 478.6, and 422.5 mm for the decades 1980s, 1990s and 2000s respectively were observed for Jalgaon station, whereas the highest crop water requirement of 381.8 mm was observed for the decade 2010s at Solapur station. The minimum average crop water requirement of 373.1 mm for 1980s decade was observed for Pune station, 308.74 mm for 2010s decade was observed for Dhule station and 315.5, 318.4 mm for remaining 1990s, 2000s decades, sequentially were reported for Padegaon station.

Table 4.7 Periodic changes in crop water requirement of *rabi* onion over Western Maharashtra

Stations	Crop water requirement (mm)				CWR of <i>rabi</i> onion increase or decrease, %		
	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2017	(1981-1990) to (1991-2000)	(1991-2000) to (2001-2010)	(2001-2010) to (2011-2017)
Dhule	375.39	335.80	322.06	308.74	-10.55	-4.09	-4.14
Jalgaon	495.80	478.62	422.51	357.01	-3.46	-11.72	-15.50
Pune	373.11	367.24	344.55	327.98	-1.57	-6.18	-4.81
Rahuri	390.38	321.80	337.03	313.69	-17.57	4.73	-6.92
Solapur	448.51	394.79	388.67	381.82	-11.98	-1.55	-1.76
Niphad	382.00	359.10	321.53	323.91	-5.99	-10.46	0.74
Kolhapur	NA	401.51	382.00	334.80	NA	-4.86	-12.36
Padegaon	NA	315.59	318.35	310.07	NA	0.88	-2.60
K. Digraj	NA	354.80	368.97	364.95	NA	4.00	-1.09

(*NA- Not available due to unavailability of data)

The values of percent change of CWR of *rabi* onion i.e. either increase or decrease with respect to different decades were presented in Table 4.7 and Fig. 4.13. It was observed that there was decrease in CWR of *rabi* onion with respect to decades sequentially for all stations, except Rahuri, Padegaon and K. Digraj for the decades 1990s to 2000s; and Niphad6 station for the decades 2000s to 2010s showed increase in CWR of *rabi* onion (Fig. 4.13). In between the 1980s and 1990s decades, the maximum decrease (-17.57 %) in CWR of *rabi* onion was observed for Rahuri station whereas, the lowest decrease (-1.57 %) was observed for Pune station. In between 1990s and 2000s decade all stations observed decrease in CWR of *rabi* onion, except Rahuri (4.73 %), Padegaon (0.88 %) and K. Digraj (4.0 %) showed increase in CWR. Jalgaon reported a higher decrease (-11.72 %) followed by Niphad (-10.46 %) whereas, Solapur station resembled minimum reduction (-1.55 %) in CWR. In 2000s and 2010s decade, all stations showed a decrease in CWR in the range i.e. -1.09

% to -15.50 %, except Niphad (0.74 %) observed increase in CWR. The highest decrease was noted for Jalgaon (-15.50 %) whereas, K. Digraj recorded the lowest decrease (-1.09 %) in CWR. Ingle *et al.* (2018) observed an increase in rainfall in Jalgaon from (1901 – 2015) which is relevant for the decrease in CWR.

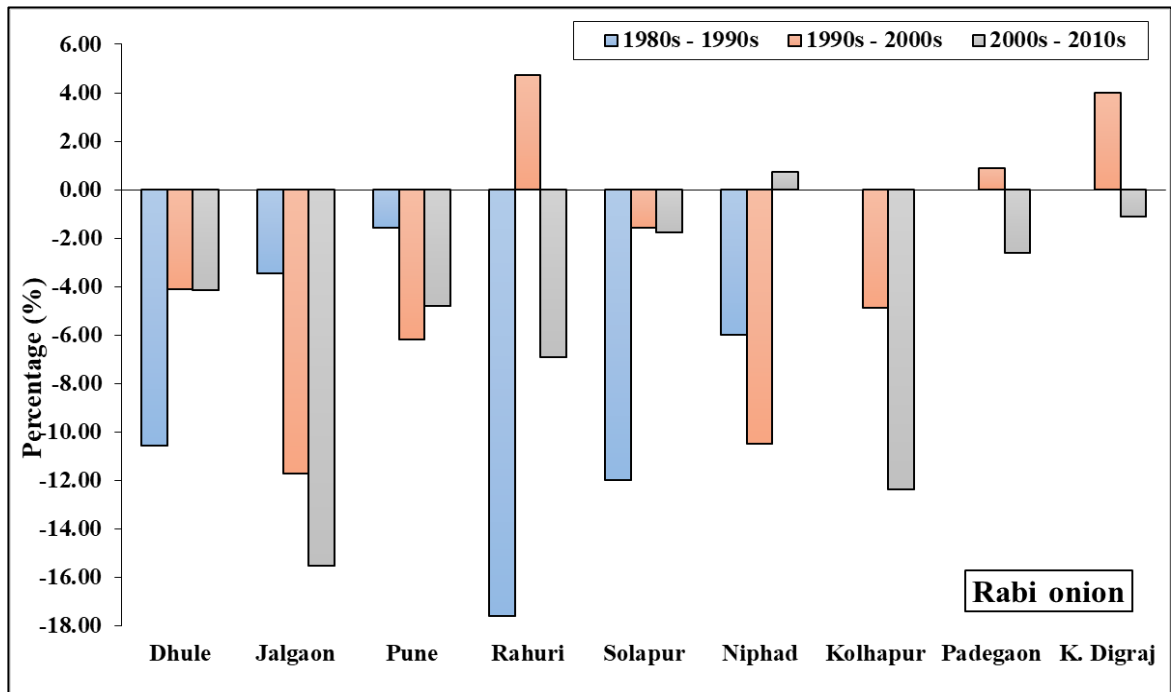


Fig. 4.13 Percentage variation in decadal water requirement of *rabi* onion

The resultant spatial maps of 1980s, 1990s, 2000s and 2010s decades for average CWR values of *rabi* onion were depicted in Fig. 4.14. The spatial analysis for 1980s decade showed average crop water requirement 360 to 500 mm over study area. The higher values in CWR was observed in northeast and the southeast corner of the region, and the low ones were spread over the west (Pune station), north (Dhule station) and middle part of the region (Fig. 4.14 (a)).

The average CWR values for 1990s decadal period varied from 300 to 480 mm over study area i.e. Western Maharashtra. The maximum contributed area had CWR in the range as 300 to 340 mm at the central part. The maximum value of CWR (420 to 480 mm) obtained at adjoining part of Jalgaon station, while minimum value of CWR (300 to 320 mm) obtained over Dhule, Rahuri and Padegaon station (Fig. 4.14 (b)).

The spatial map of 2000s decade showed average CWR values varied from 320 to 420 mm. The minimum value of CWR (320 to 340 mm) obtained over Padegaon station and north-east region of study area. The maximum value (400 to 420 mm) obtained at north-east part (Jalgaon station) and were considerably lower than values examined for previous 1990s decade (Fig. 4.14(c)).

The spatial pattern for 2010s decade were shown in Fig. 4.14(d). The average range of CWR (440 to 650 mm) values was observed over study area. Similar to 1990s decade, the lower value (300 to 320 mm) were depicted over Dhule, Rahuri and Padegaon station. The spatial analysis for 2010s

decade observed tremendous decrease in crop water requirement with maximum area of analysis representing water requirement below 340 mm. The central and northern part of the study area contributed lower values for three periods i.e. 1990s, 2000s and 2010s.

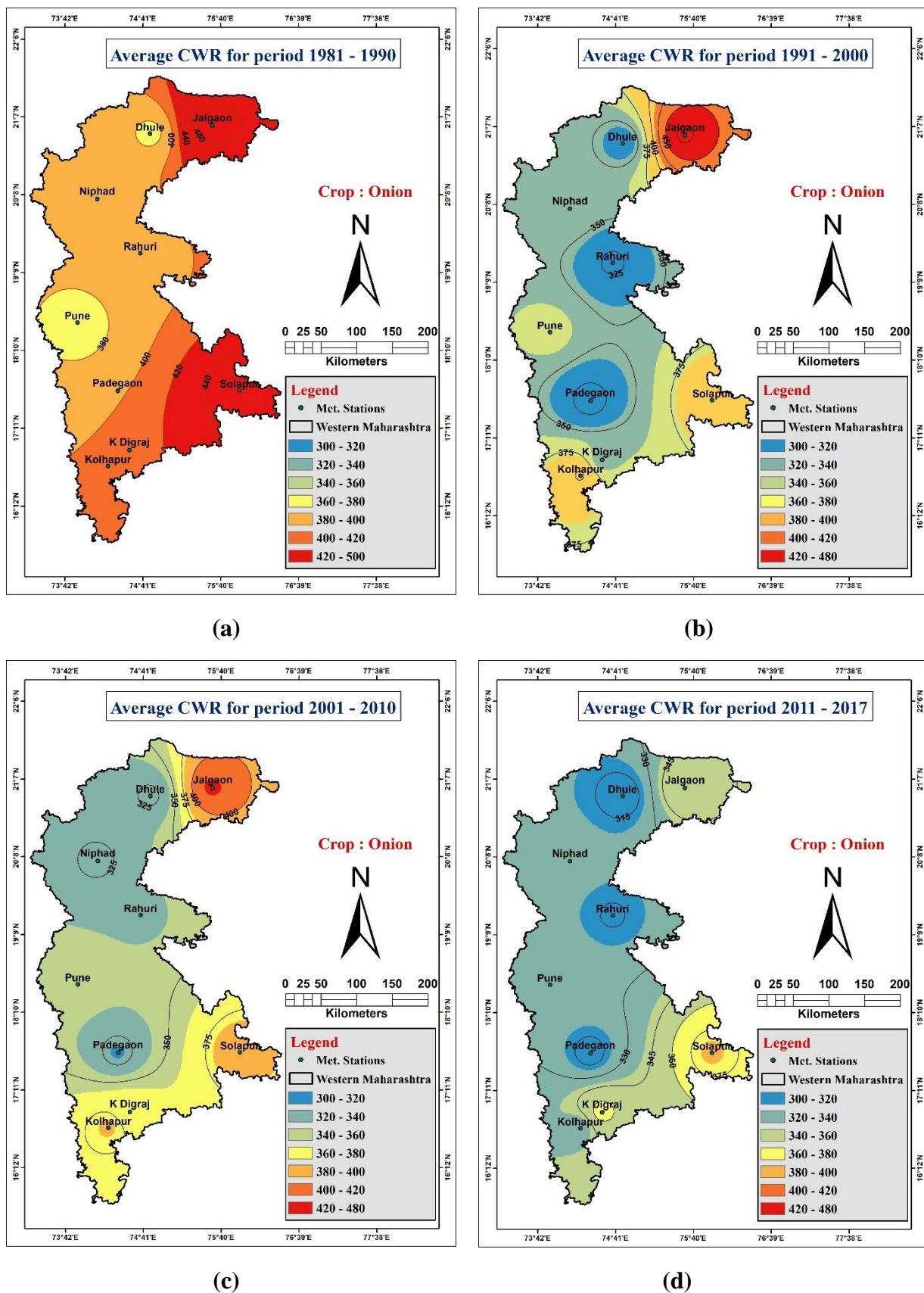


Fig. 4.14 Spatial patterns in crop water requirement of *rabi* onion for four decadal periods (a) 1981–1990; (b) 1991 – 2000; (c) 2001–2010; and (d) 2011–2017

4.2.3 Soybean

The results of average decadal crop water requirement of soybean at selected stations were presented in Table 4.8. The maximum average crop water requirement of 456.03 and 445.99 mm for 1980s and 1990s decades respectively were observed for Jalgaon station, whereas the highest crop water requirement of 394.6 and 406 mm for 2000s and 2010s decades respectively was observed for Solapur station. The minimum average crop water requirement of 357.1 mm for 1980s decade was observed for Pune station and 303.6, 293 and 268.9 mm for remaining 1990s, 2000s, 2010s decades, respectively were reported for Kolhapur station. The resulted range of average crop water requirement as 357 to 456 mm, 303 to 446 mm, 293 to 394 mm, and 269 to 406 mm were observed in 1980s, 1990s, 2000s and 2010s decades sequentially, over study area i.e. Western Maharashtra.

Table 4.8 Periodic changes in crop water requirement of soybean over Western Maharashtra

Stations	Crop water requirement (mm)				CWR of soybean increase or decrease, %		
	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2017	(1981-1990) to (1991-2000)	(1991-2000) to (2001-2010)	(2001-2010) to (2011-2017)
Dhule	386.88	376.08	342.82	335.54	-2.79	-8.85	-2.12
Jalgaon	456.03	445.99	376.53	345.22	-2.20	-15.57	-8.31
Pune	357.12	346.31	328.23	323.83	-3.03	-5.22	-1.34
Rahuri	422.80	372.16	373.90	365.64	-11.98	0.47	-2.21
Solapur	414.07	394.30	394.64	406.04	-4.77	0.09	2.89
Niphad	375.30	357.82	318.79	329.18	-4.66	-10.91	3.26
Kolhapur	NA	303.63	293.03	268.97	NA	-3.49	-8.21
Padegaon	NA	346.12	326.59	301.44	NA	-5.64	-7.70
K. Digraj	NA	355.43	330.62	352.21	NA	-6.98	6.53

(*NA- Not available due to unavailability of data)

The values of percent change of CWR of soybean i.e. either increase or decrease with respect to different decades were presented in Table 4.8 and Fig. 4.15. The decrease in CWR of soybean with respect to decades sequentially was observed for all stations, except Rahuri for the decades 1990s to 2000s and Solapur, Niphad and K. Digraj for the decades 2000s to 2010s showed increase in CWR of soybean (Fig. 4.15). In between the 1980s and 1990s decades, the maximum decrease (-11.98 %) in CWR of soybean was observed for Rahuri station whereas the lowest decrease (-2.20 %) was observed for Jalgaon station. For the decades 1990s and 2000s, all stations showed a decrease in CWR of soybean in the range i.e. -3.49 % to -15.57 %, except Rahuri (0.47 %) and Solapur (0.09 %) showed increase in CWR. Jalgaon showed a higher decrease (-15.57 %) followed by Niphad (-10.91 %) and Dhule (-8.85 %) whereas, Kolhapur station resembled minimum reduction (-3.49 %) in CWR. In between 2000s and 2010s decade, all stations observed decrease in CWR of soybean, except Solapur (2.89 %), Niphad (3.26 %) and K. Digraj (6.53 %) observed

increase in CWR. The highest decrease was showed for Jalgaon (-8.31 %) followed by Kolhapur (-8.21 %) whereas, Pune recorded the lowest decrease (-1.34 %) in CWR of soybean.

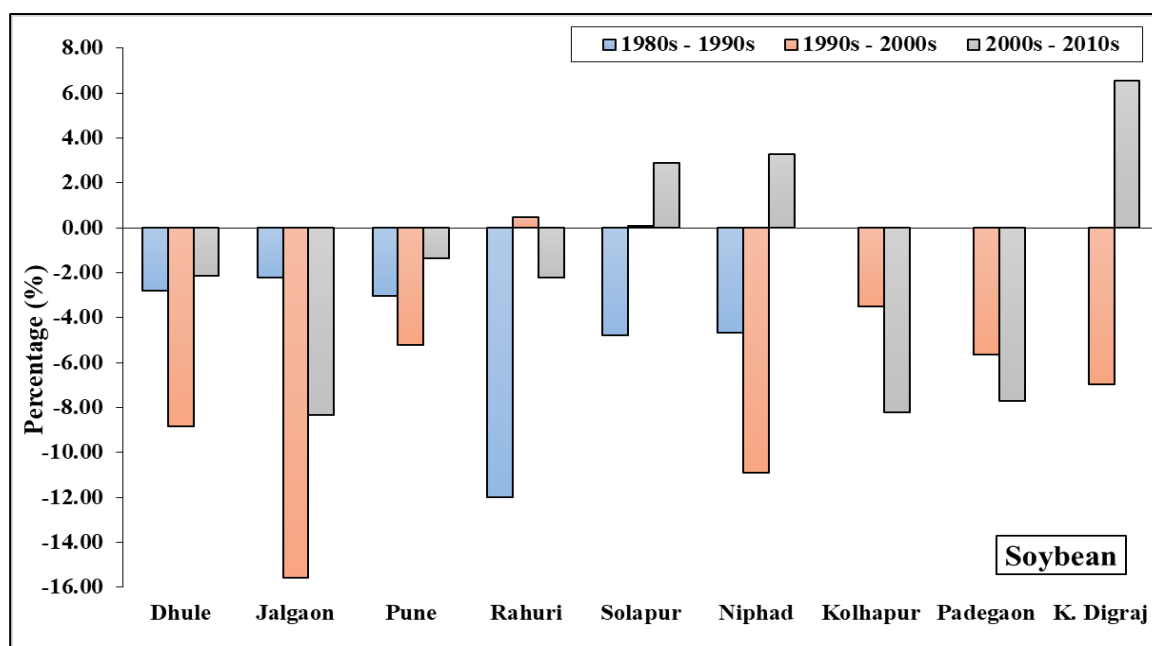
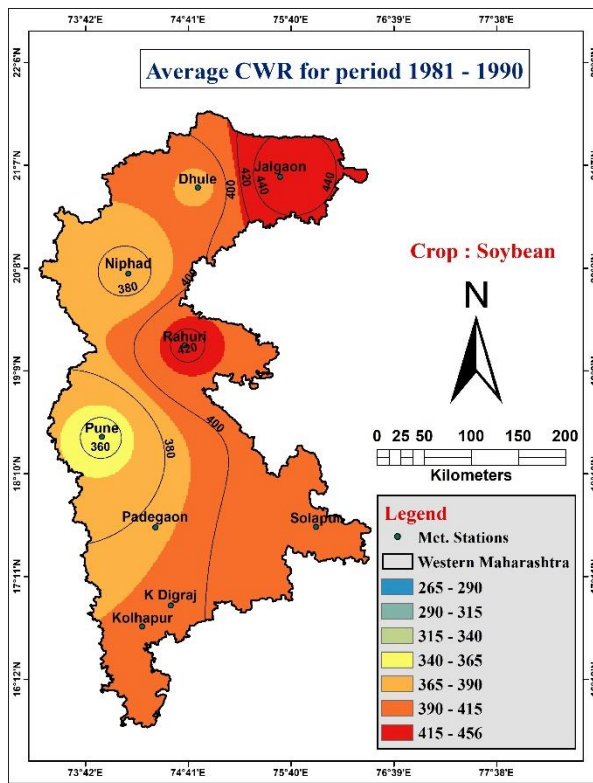


Fig. 4.15 Percentage variation in decadal water requirement of soybean

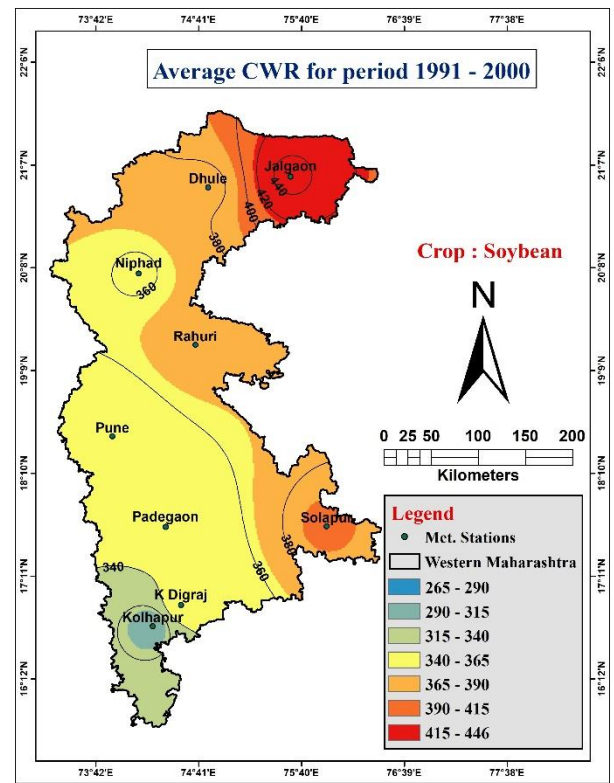
The resultant spatial maps of 1980s, 1990s, 2000s and 2010s decades for average CWR values of soybean were depicted in Fig. 4.16. The spatial map of 1980s decade showed average CWR in the range as 340 – 465 mm. The maximum value of CWR (415 to 446 mm) obtained for Jalgaon and Rahuri station, while minimum value of CWR (340 to 365 mm) obtained at Pune station (Fig. 4.16 (a)). The average CWR values for 1990s decadal period varied from 290 to 446 mm over study area i.e. Western Maharashtra. The maximum contributed area had CWR in the range as 340 to 390 mm at the central part. The maximum value of CWR (415 to 446 mm) obtained for Jalgaon station, while minimum value of CWR (290 to 315 mm) obtained over Kolhapur station (Fig. 4.16 (b)). The values of CWR increases from southern part (Kolhapur region) of the study area (Kolhapur region) towards north-east (Jalgaon region).

The spatial map of 2000s decade showed average CWR values varied from 290 to 415 mm. The minimum value of CWR (320 to 340 mm) obtained over southern part of study area. The southern and northern part of study area had CWR varied from 290 to 340 mm. The maximum contributed part of study area had CWR in the range as 315 – 365 mm. The maximum value (390 to 415 mm) obtained over south-west part (Solapur station) of study area (Fig. 4.16 (c)).

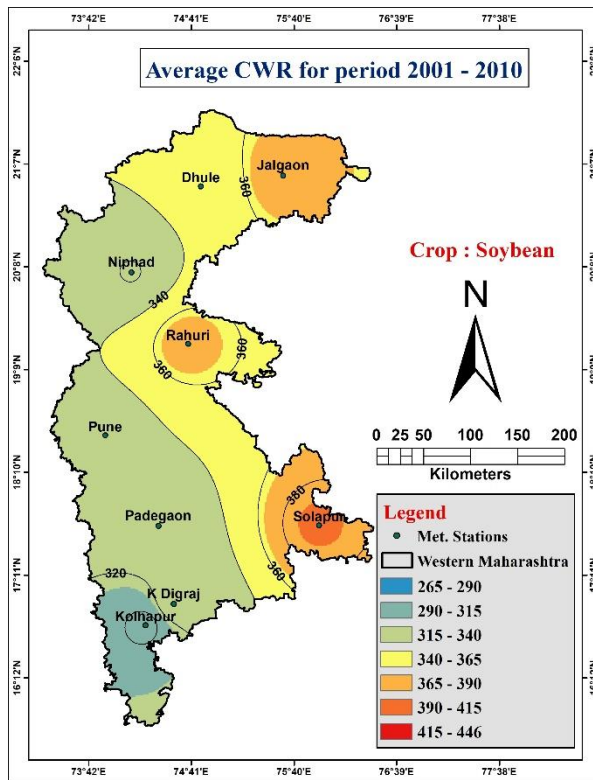
The spatial map of 2010s decade observed average CWR over study area i.e. 265 to 415 mm (Fig. 4.16 (d)). The lower values (265 to 290 mm) was depicted for southern part (Kolhapur station). The maximum area of analysis represented crop water requirement below 365 mm. The decreasing trend in water requirement was observed from the southeast (Kolhapur station) to southwest (Solapur station). The southern part of the study area contributed lower values for all three periods i.e. 1990s, 2000s and 2010s decade.



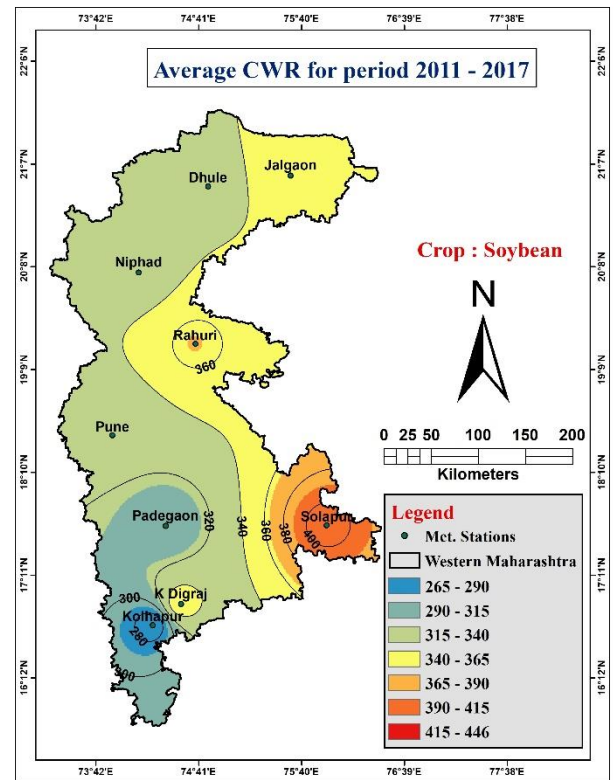
(a)



(b)



(c)



(d)

Fig. 4.16 Spatial patterns in crop water requirement of soybean for four decadal periods (a) 1981–1990; (b) 1991 – 2000; (c) 2001–2010; and (d) 2011–2017

4.2.4 *Suru* sugarcane

The results of average decadal crop water requirement of *suru* sugarcane at selected stations were presented in Table 4.9. The resulted range of average crop water requirement as 1429 to 2032 mm, 1271 to 1939 mm, 1236 to 1692 mm, and 1125 to 1508 mm were observed in 1980s, 1990s, 2000s and 2010s decades respectively, over study area. The maximum average crop water requirement of 2032.2, 1939, and 1692.8 mm for the decades 1980s, 1990s and 2000s respectively were observed for Jalgaon station, whereas the highest crop water requirement of 1508.2 mm was observed for the decade 2010s at Solapur station. The minimum average crop water requirement of 1429.56 mm for 1980s decade was observed for Pune station, 1125.6 mm for 2010s decade was observed for Kolhapur station and; 1271 and 1236.6 mm for remaining 1990s and 2000s decades, sequentially were reported for Padegaon station.

Table 4.9 Periodic changes in crop water requirement of *suru* sugarcane over Western Maharashtra

Stations	Crop water requirement (mm)				CWR of sugarcane increase or decrease, %		
	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2017	(1981-1990) to (1991-2000)	(1991-2000) to (2001-2010)	(2001-2010) to (2011-2017)
Dhule	1585.51	1465.14	1377.87	1311.18	-7.59	-5.96	-4.84
Jalgaon	2032.25	1939.03	1692.85	1493.94	-4.59	-12.70	-11.75
Pune	1429.56	1389.58	1325.84	1301.22	-2.80	-4.59	-1.86
Rahuri	1562.37	1335.15	1381.63	1312.94	-14.54	3.48	-4.97
Solapur	1644.09	1516.13	1495.23	1508.21	-7.78	-1.38	0.87
Niphad	1532.09	1425.42	1288.28	1303.04	-6.96	-9.62	1.15
Kolhapur	NA	1354.52	1272.52	1125.66	NA	-6.05	-11.54
Padegaon	NA	1271.09	1236.68	1130.27	NA	-2.71	-8.60
K. Digraj	NA	1330.91	1298.17	1315.56	NA	-2.46	1.34

(*NA- Not available due to unavailability of data)

The values of percent change of CWR of *suru* sugarcane i.e. either increase or decrease with respect to different decades were presented in Table 4.9 and Fig. 4.17. Similar to cotton, *rabi* onion and soybean it was observed that there was decrease in CWR of *suru* sugarcane with respect to decades sequentially for all stations, except Rahuri station for the decades 1990s to 2000s; and Solapur, Niphad, and K. Digraj station for the decades 2000s to 2010s showed increase in CWR of *suru* sugarcane (Fig. 4.17). In between the 1980s and 1990s decades, the maximum decrease (-14.54 %) in CWR of *suru* sugarcane was observed for Rahuri station whereas the lowest decrease (-2.80 %) was observed for Pune station. In between 1990s and 2000s decade all stations observed decrease in CWR of *suru* sugarcane, except Rahuri (3.48 %) showed increase in CWR. Jalgaon reported a higher decrease (-12.70 %) whereas, Solapur station resembled minimum reduction (-1.38 %) in CWR. For the decades 2000s and 2010s, all stations showed a decrease in CWR of *suru*

sugarcane in the range i.e. -1.86 % to -11.75 %, except Solapur (0.87 %), Niphad (1.15 %), and K. Digraj (1.34 %) observed increase in CWR. The highest decrease was noted for Jalgaon (-11.75 %) followed by Kolhapur (-11.54 %), whereas Pune station recorded the lowest decrease (-1.86 %) in CWR of *suru* sugarcane.

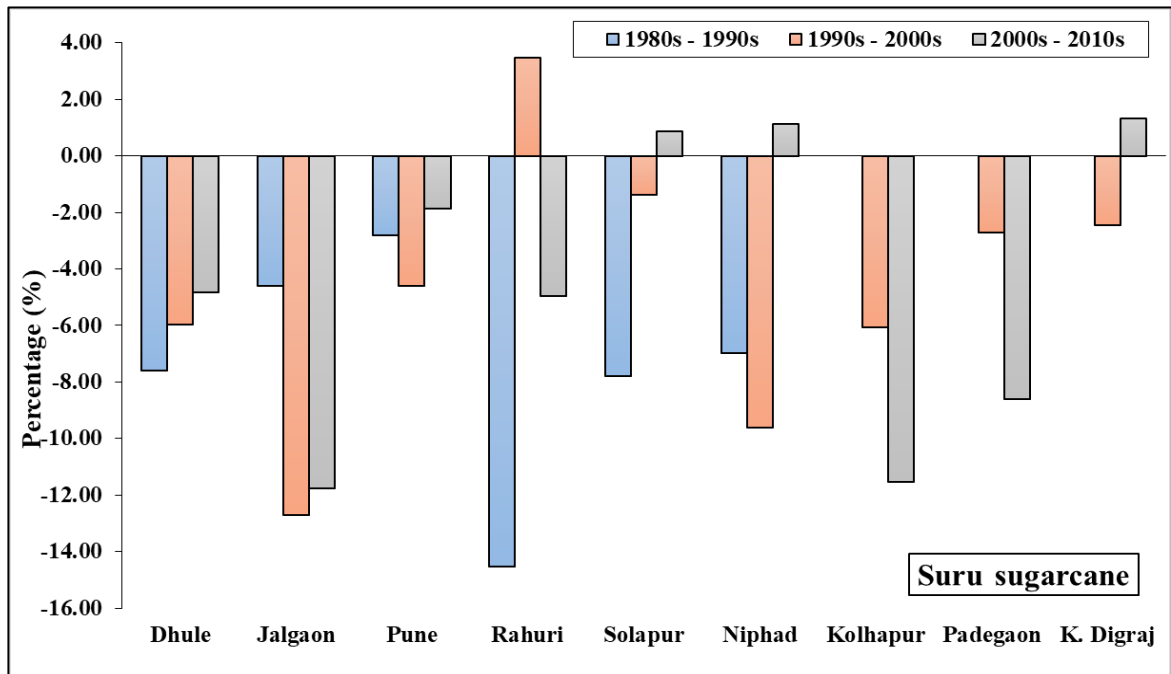


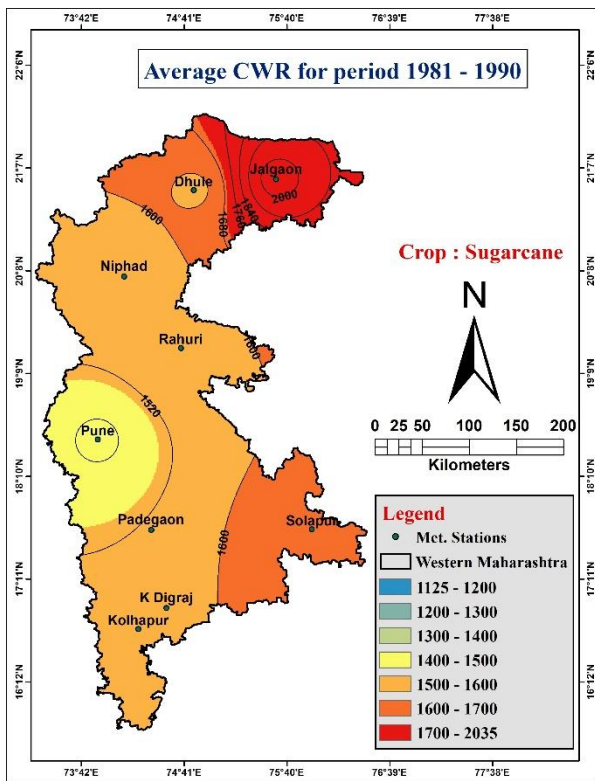
Fig. 4.17 Percentage variation in decadal water requirement of *suru* sugarcane

The spatial distribution map of 1980s decade noted average crop water requirement (1400 to 2035 mm) over study area. The high increment was spotted in the northeast corner (Jalgaon station) of the region and the low ones was spread at the west (Pune station) of the region (Fig. 4.18 (a)).

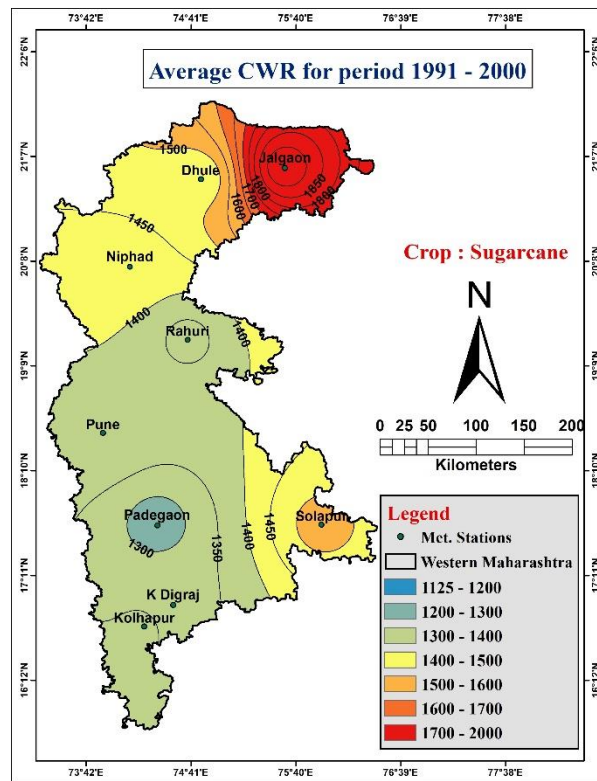
The average CWR values varied from 1200 to 2000 mm for 1990s decadal period over study area i.e. Western Maharashtra. The maximum value of CWR (1700 to 2000 mm) obtained at adjoining part of Jalgaon station, while minimum value of CWR (1200 to 1300 mm) obtained at Padegaon station. The spatial pattern revealed 85% of the total geographical area having CRW (1300 – 1500 mm) excluded the whole Jalgaon district extended from south to central part (Fig. 4.18 (b)).

The spatial map of 2000s decade showed average CWR values varied from 1200 to 1700 mm. The minimum value of CWR (1200 to 1300 mm) obtained over south (Padegaon, Kolhapur and K. Digraj station) and north-east (Niphad station) of the study area. The maximum value (1500 to 1600 mm) obtained at north-east part (Jalgaon station) and were considerably lower than values examined for previous 1990s decade (Fig. 4.18(c)).

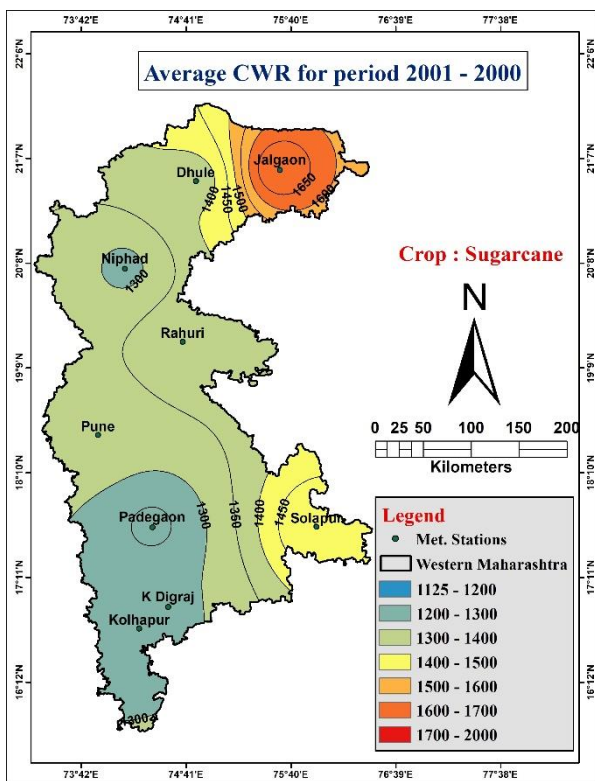
The spatial map of 2010s decade resembled similar distribution pattern in CWR as 2000s decade with slightly lower values. The 2010s decade observed an ample drop in crop water requirements in the south and west parts of the study area as compared to previous 1990s and 2000s decade (Fig. 4.18 (d)). In the entire analysis for four decades, major variation were mostly observed in the south (Padegaon, K. Digraj and Kolhapur station) and in north-east (Jalgaon station).



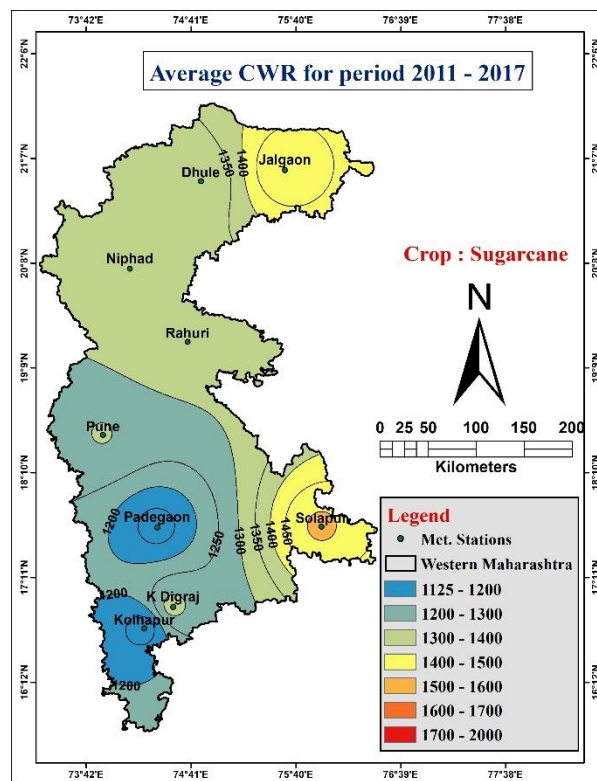
(a)



(b)



(c)



(d)

Fig. 4.18 Spatial patterns in crop water requirement of *suru* sugarcane for four decadal periods (a) 1981–1990; (b) 1991 – 2000; (c) 2001–2010; and (d) 2011–2017

4.3 Estimation of Future Crop Water Requirement

The Statistical Downscaling Model (SDSM) is used to project different climatic parameters such as temperature, relative humidity, rainfall, evapotranspiration etc. In the present study, reference evapotranspiration (ET_0) was downscaled and projected using the SDSM. The daily ET_0 was calculated using Penman Monteith equation as discussed in section 3.5.1. The output of daily ET_0 was used for projecting future ET_0 during different time periods. The projected ET_0 in combination to crop coefficient (K_c) was used to calculate CWR for future periods and further variation in crop water requirement was analyzed using observed data. Three stations *viz.*, Pune, Rahuri, and Solapur were considered for projecting ET_0 due to the availability of daily meteorological data i.e. T_{max} , T_{min} , RH_{max} , RH_{min} , WS, and BSS for generating daily ET_0 . The SDSM was used to project future ET_0 for three periods 2030s, 2050s, and 2080s based on base climate data. The results of the analysis were presented separately for Pune, Rahuri, and Solapur stations. The performance of SDSM model predictions was studied using observed and predicted values of ET_0 during the same period.

4.3.1 Selection of Predictors

Selecting a predictor was an important step in the downscaling process. It is an iterative procedure consisting of a rough screening of the possible settings and predictors, which is repeated until an objective function is optimized (Wilby and Harris, 2006). The variables with the highest correlation were selected using the screen variable tool in the SDSM. Initially, all the predictors from historical records were correlated with the observed data of reference evapotranspiration. The predictors with the highest correlation were chosen with minimum or zero p-value and maximum partial r value. The correlation statistics and p-values were used to explain the strength of the relationship between the predictor–predictand and also multi co-linearity among selected predictors. The selected number of predictors varied from three to four. To have better prediction results, all the correlations with a p-value (≤ 0) were selected. The predictors along with partial r value selected for reference evapotranspiration (ET_0) are represented in Table 4.10.

Table 4.10 Selected predictors with partial r values for reference evapotranspiration (ET_0)

Sr. No.	Predictors	Meteorological stations with partial r values					
		Pune		Rahuri		Solapur	
1	nceptempas	✓	0.494	✓	0.362	✓	0.337
2	ncepp_zhas			✓	0.260	✓	0.245
3	ncepp_uas	✓	0.185	✓	0.243		
4	ncepp5_uas	✓	0.244				
5	ncepp8_uas					✓	0.101
6	ncepp8_vas			✓	0.124	✓	0.056

Suo *et al.* (2019) examined partial r values for temperature in the range as 0.27 to 0.77. Similar results of partial r values for temperature and precipitation were also observed by Mahmood and Babel, (2013). The highest correlation values represent a higher degree of association and smaller p-values describe a better chance for an association between variables. The selection of predictors was done as discussed in section 3.8.3. Considering all 26 predictors, only six predictors (nceptempas, ncepp_zhas, ncepp_uas, ncepp5_uas, ncepp8_uas, and ncepp8_vas) were selected as they were strongly correlated with observed (ET_0) in the analysis (Table 4.10). For all three weather stations nceptempas (temperature at 2m height) was super predictor and common to all three stations with highest partial r value compared to others predictors. Similar super predictor i.e. nceptempas in downscaling of ET_0 for 9 stations in Beijing region was also examined by Guo *et al.* (2018).

4.3.2 Calibration and Validation of Model

The Calibrate Model operation takes a user-specified predictand along with a set of predictor variables, and computes the parameters of multiple regression equations via an optimization algorithm (ordinary least squares). Prior to future scenario construction, the results of the observed data of reference evapotranspiration (ET_0) was correlated with the modeled data during the calibration and validation. As explained in the section 3, the statistical parameters like coefficients of determination (R^2), nash-sutcliffe coefficient (E_{ns}), root mean square error (RSME), mean absolute percentage error (MAPE), mean absolute deviation (MAD), standard error mean ($SE-\mu$), mean (μ), and standard deviation (SD) were used for the evaluation of the model. In the present study, a monthly model of SDSM was selected in which model parameters were derived for each month. In the downscaling process of ET_0 unconditional sub-model was chosen. The statistical criteria for best fit model for downscaling ET_0 during calibration period were presented in Table 4.11. All measured statistical values were fairly resembling the statistics of observed data for reference evapotranspiration (ET_0). For the calibration of model 70% of data set and for the validation 30% of data sets had been used. The time period for calibration and validation of model for individual stations (Pune, Rahuri and Solapur) had been presented in Table 4.11 and 4.12.

4.3.2.1 Calibration of model

The statistical performance for best fit model for downscaling ET_0 during calibration period for Pune, Rahuri and Solapur station were shown in Table 4.11. It was observed that SDSM model showed best values of all performance measures as higher values for R^2 and E_{ns} and lower value for RMSE and MAPE. The MAD values showed that there was consistently less variation among observed and downscaled data ranged from 1.2 to 1.6 mm. It was observed that the values of performance measures as R^2 and E_{ns} were more than 0.71, 0.68, 0.60 for Pune, Rahuri, and Solapur station. Whereas, the values of RMSE were varied from 0.90 to 0.92 for Pune, 1.000 to 1.003 for

Rahuri and 1.31 to 1.32 mm for Solapur station. It was also observed that value of MAPE was less than 16.12, 15.93, and 18.33 % for Pune, Rahuri, and Solapur station sequentially during calibration. The mean, standard deviation and standard error mean suggested observed and modelled data had almost similar mean, lesser deviation and less error between observed and predicted values respectively.

Table 4.11 Statistical criteria for best fit model for downscaling ET_0 during calibration

Pune (1970-1990)									
Model	Data type	R²	<i>E_{ns}</i>	RMSE	MAPE	μ	S.D.	SE-μ	MAD
HadCM3	OBS	-				4.583	1.39	0.016	1.38
	NCEP	0.71	0.713	0.92	16.10	4.575	1.05	0.012	1.21
	H3A2	0.72	0.719	0.91	16.12	4.584	1.07	0.012	1.22
	H3B2	0.72	0.721	0.90	16.09	4.574	1.06	0.012	1.23
Rahuri (1975 – 1990)									
Model	Data type	R²	<i>E_{ns}</i>	RMSE	MAPE	μ	S.D.	SE-μ	MAD
HadCM3	OBS	-				5.087	1.47	0.019	1.44
	NCEP	0.69	0.685	1.000	15.86	5.073	1.10	0.014	1.23
	H3A2	0.68	0.683	1.003	15.93	5.080	1.12	0.015	1.24
	H3B2	0.68	0.683	1.002	15.84	5.078	1.13	0.015	1.24
Solapur (1968- 1989)									
Model	Data type	R²	<i>E_{ns}</i>	RMSE	MAPE	μ	S.D.	SE-μ	MAD
HadCM3	OBS	-				5.709	1.73	0.019	1.61
	NCEP	0.60	0.603	1.32	18.33	5.689	1.27	0.014	1.39
	H3A2	0.61	0.609	1.31	18.19	5.690	1.25	0.014	1.39
	H3B2	0.61	0.609	1.31	18.16	5.694	1.27	0.014	1.38

4.3.2.2 Validation of model

Similarly, the results of statistical performance for best fit model for downscaling ET_0 during validation period for Pune, Rahuri and Solapur station were showed in Table 4.12. For Rahuri station, considering NCEP data the value of the R^2 in calibration period was 0.69 and it was enhanced to 0.71 in validation stage, similar kind of enhancement also occurred in E_{ns} i.e. 0.685 to 0.71 for Rahuri station. It was also observed that there was reduction in the values of RMSE and MAPE during validation of model from 1.0 to 0.78 and 15.86 to 14.48 respectively for NCEP data at Rahuri station. This indicated that NCEP data showed slightly increase in performance in

validation period than calibration period, however it also showed close difference in enhancement and reduction of each performance measures during calibration and validation period of SDSM model. Similar kind of close difference for each performance measures were occurred during calibration and validation period of remaining data of HadCM3 i.e. H3A2 and H3B2 scenario for Rahuri and Solapur stations. Overall, the performance suggested that HadCM3 model can be an acceptable approach for accurate projection of ET_0 values. Based on the results of Tables 4.11 and 4.12, the derived predictor–predictand relationships were considered valid and quite satisfactory for three stations. Guo *et al.* (2018) observed that the value of R^2 and E_{ns} ranged from 0.61 to 0.78 during calibration and validation of downscaled ET_0 in China. Similar values of R^2 were also observed by Saraf and Regulwar, (2016) during calibration of observed and modelled temperature for Godavari basin, Maharashtra.

Table 4.12 Statistical criteria for best fit model for downscaling ET_0 during validation

Pune (1991-2000)									
Model	Data type	R^2	E_{ns}	RMSE	MAPE	μ	S.D.	SE-μ	MAD
HadCM3	OBS	-				4.452	1.62	0.027	1.30
	NCEP	0.70	0.698	0.89	15.96	4.442	1.38	0.023	1.15
	H3A2	0.70	0.698	0.89	15.78	4.434	1.39	0.023	1.16
	H3B2	0.70	0.701	0.88	15.68	4.442	1.40	0.023	1.16
Rahuri (1991 – 2000)									
Variable	Data type	R^2	E_{ns}	RMSE	MAPE	μ	S.D.	SE-μ	MAD
ET_0	OBS	-				4.221	1.44	0.024	1.17
	NCEP	0.71	0.71	0.78	14.48	4.201	1.22	0.020	0.98
	H3A2	0.70	0.70	0.79	14.51	4.211	1.23	0.020	0.99
	H3B2	0.71	0.71	0.78	14.37	4.196	1.24	0.020	1.00
Solapur (1990- 2000)									
Variable	Data type	R^2	E_{ns}	RMSE	MAPE	μ	S.D.	SE-μ	MAD
ET_0	OBS	-				4.850	1.67	0.026	1.35
	NCEP	0.62	0.61	1.11	18.51	4.842	1.37	0.022	1.14
	H3A2	0.62	0.61	1.12	18.56	4.849	1.36	0.021	1.15
	H3B2	0.61	0.61	1.10	18.43	4.836	1.36	0.021	1.15

4.3.3 Projected Changes in ET_0 for Future Climate Scenarios

Considering the period from 1961 to 2000 widely used in impact studies worldwide as a reference period, the changes in mean monthly ET_0 across the stations in the three future periods, i.e. 2030s, 2050s, and 2080s under the H3A2 and H3B2 scenarios were carried out. Moreover, the changes of mean monthly ET_0 in the three selected stations under all scenarios would present noticeable differences in different months.

4.3.3.1 Future projections and percent change in ET_0 for Pune station

The changes in ET_0 for future 2030s, 2050s, and 2080s relative to the base period (1970–2000) under H3A2 and H3B2 scenarios for Pune stations were presented in Fig. 4.19. The figure represents general monthly changes observed in modelled ET_0 . It was seen that the changes in ET_0 projected under both scenarios were quite different in magnitude (amount), but identical in pattern. The maximum mean monthly ET_0 (7.43 mm) for base period was observed in May whereas, minimum ET_0 (3.08 mm) was observed in December. Projected ET_0 presented an increasing trend in the entire period from 2015 to 2095 under both scenarios during 2030s, 2050s, and 2080s (Fig. 4.19). The maximum projected ET_0 would be in May followed by April during 2030s, 2050s and 2080s whereas, minimum projected ET_0 would be in December followed by August (Table 4.13 and Fig. 4.19).

Table 4.13 Mean monthly downscaled ET_0 for Pune station

Months	Obs (1970- 2000)	2030s (2015- 2045)		2050s (2035-2065)		2080s (2065- 2095)	
		H3A2	H3B2	H3A2	H3B2	H3A2	H3B2
Jan	3.27	3.33	3.32	3.34	3.35	3.35	3.41
Feb	4.29	4.36	4.34	4.40	4.38	4.44	4.46
Mar	5.52	5.62	5.64	5.70	5.67	5.77	5.74
Apr	6.81	6.93	6.95	7.12	6.96	7.25	7.07
May	7.43	7.60	7.55	7.76	7.69	7.90	7.62
Jun	5.55	5.27	5.35	5.29	5.29	5.45	5.41
Jul	3.79	3.86	3.87	3.88	3.87	3.94	3.88
Aug	3.54	3.40	3.32	3.25	3.26	3.41	3.30
Sep	3.91	3.86	3.90	3.91	3.92	3.90	3.99
Oct	3.91	3.91	3.92	4.04	3.92	3.91	4.05
Nov	3.48	3.49	3.55	3.69	3.57	3.63	3.62
Dec	3.08	3.18	3.17	3.27	3.28	3.37	3.29
Min	3.08	3.18	3.17	3.25	3.26	3.35	3.29
Max	7.43	7.60	7.55	7.76	7.70	7.90	7.62
Mean	4.55	4.57	4.58	4.64	4.60	4.69	4.65

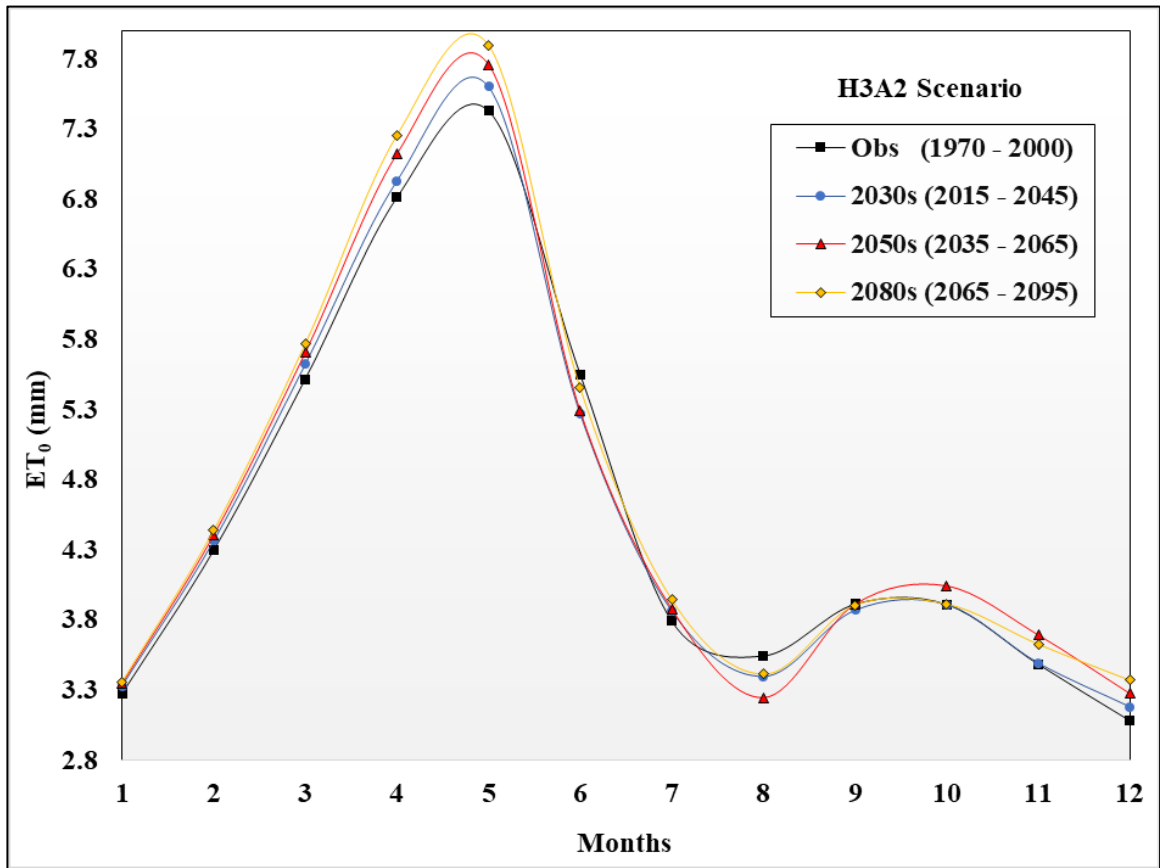
The mean annual ET_0 for Pune station during base/observed period is 4.55 mm, and ET_0 would increase by 0.42, 1.93, and 3.09 % under the H3A2 scenario, and 0.56, 1.05, and 2.25 % under the H3B2 scenario during the periods of 2030s, 2050s and 2080s respectively (Table 4.14).

Table 4.14 Percentage changes in ET_0 as compared to base period for Pune station

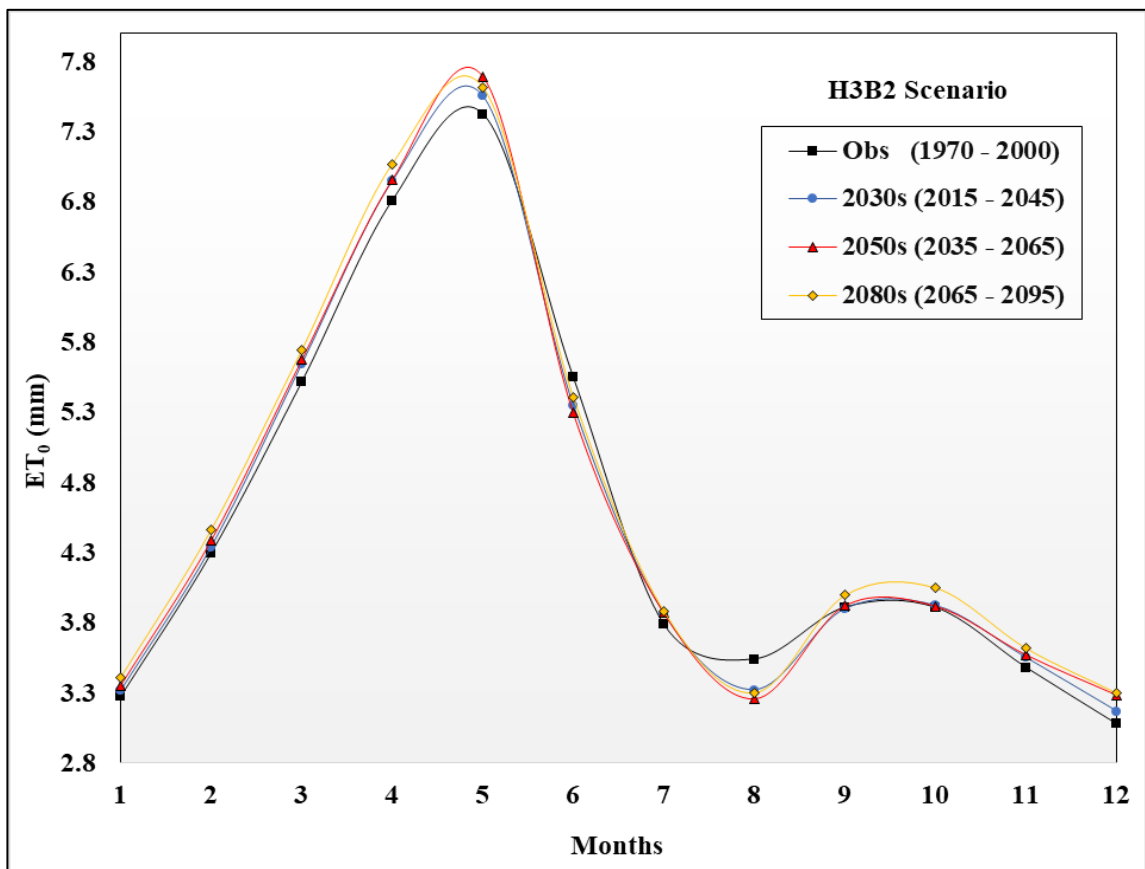
Months	H3A2			H3B2		
	2030s	2050s	2080s	2030s	2050s	2080s
Jan	1.65	2.10	2.42	1.29	2.30	3.91
Feb	1.53	2.45	3.19	1.05	2.04	3.71
Mar	1.87	3.30	4.34	2.25	2.75	3.93
Apr	1.70	4.36	6.12	1.98	2.10	3.67
May	2.26	4.26	5.93	1.69	3.46	2.49
Jun	-5.34	-4.92	-1.76	-3.70	-4.85	-2.62
Jul	1.91	2.26	3.94	2.03	2.03	2.40
Aug	-4.29	-9.15	-3.81	-6.58	-8.78	-7.36
Sep	-1.10	0.03	-0.17	-0.26	0.22	2.07
Oct	-0.02	3.28	0.09	0.37	0.20	3.40
Nov	0.28	5.68	3.96	2.00	2.48	3.74
Dec	3.15	5.91	8.57	2.88	6.21	6.60
Mean Annual	0.42	1.93	3.09	0.56	1.05	2.25

The highest increment in ET_0 as compared to observed period in 2030s, 2050s and 2080s would be observed in December while, highest decrease in ET_0 relative to observed period would be noted in August followed by June. The 2050s and 2080s period would observe increment in average value of ET_0 for all months except June and August under both scenarios. The maximum decrease in mean monthly ET_0 for the 2050s would be observe in August i.e. -9.15 % under H3A2 scenario and -8.78 % under H3B2 scenario. While in the 2080s, ET_0 in the month of August would be moderated by -3.81 and -7.36 % under H3A2 and H3B2 scenarios respectively (Table 4.14 and Fig. 4.20). The maximum increase in ET_0 as compared to base period during 2030s, 2050s and 2080s would be observed in December i.e. 3.15, 5.91, and 8.57 % under H3A2 scenario, whereas 2.88, 6.21, and 6.60 % under H3B2 scenario respectively (Table 4.14).

Doria *et al.* (2016) found that the projected ET_0 tended to increase under H3A2, H3B2, C3A1B, and C3A2 scenarios in annual scale and almost all seasonal scales, except in winter during the 2020s with decreases only by 1.1% and 0.9% for the C3A2 and C3A1B scenarios respectively. The increasing rate of ET_0 was also reported by Rehana and Mujumdar (2013) in the southern part of India that also conforms to the present study.

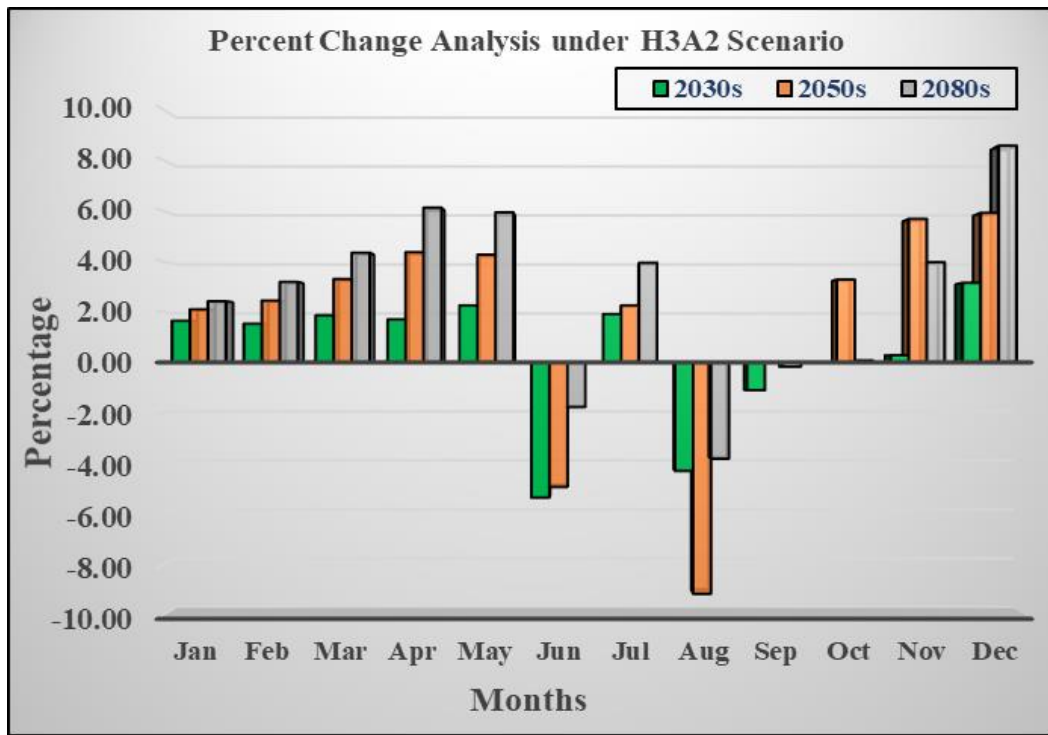


(a)

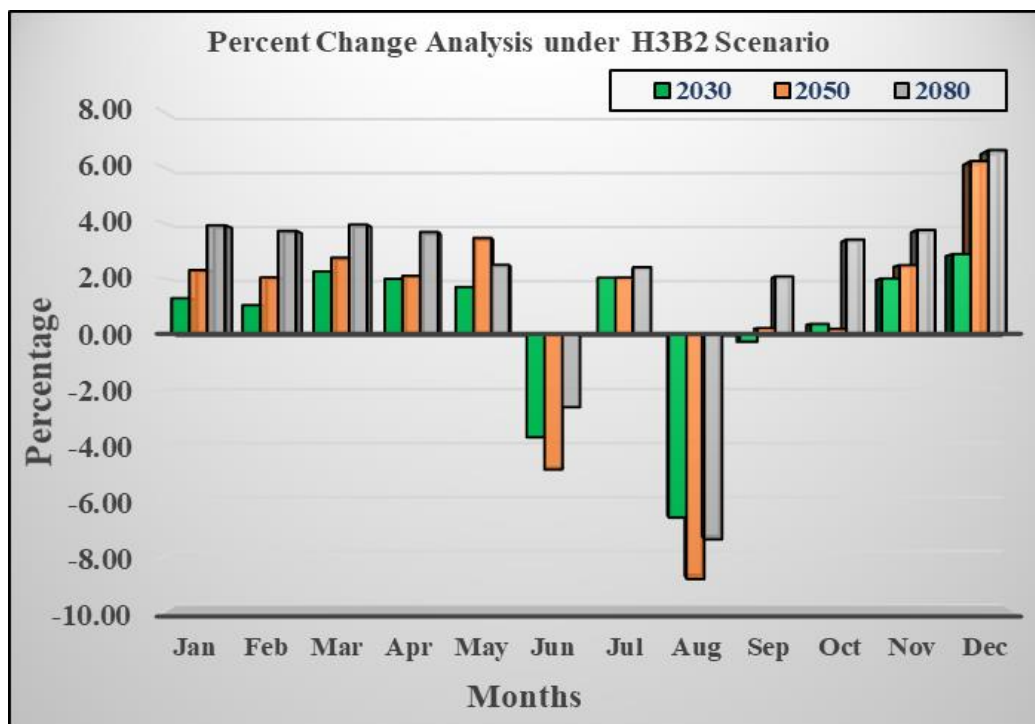


(b)

Fig. 4.19 Mean monthly downscaled ET_0 under (a) H3A2 and (b) H3B2 scenario for Pune station



(a)



(b)

Fig. 4.20 Percent changes in ET_0 under (a) H3A2 and (b) H3B2 scenario for Pune station

Overall, it was revealed that all months during three future period's viz., 2030s, 2050s and 2080s showed increments in ET_0 as compared to base period, except June, August, and September month showed relative decrease in ET_0 . The ET_0 would increase during summer, pre-monsoon and winter season, while it could decrease during monsoon season for Pune station. The higher decrease in ET_0 as compared to base period amongst all month would be observed in August followed by June month.

4.3.3.2 Future projections and percent change in ET_0 for Rahuri station

The ET_0 advanced constantly over three periods at Rahuri station, and the maximum increasing rate in contrast to the baseline period was computed for the 2080s period. The mean monthly downscaled ET_0 under H3A2 and H3B2 scenario were presented in Table 4.15. The maximum and minimum mean monthly ET_0 during base period was observed in the month of May i.e. 7.54 mm and December i.e. 2.98 mm respectively. The maximum projected ET_0 under H3A2 and H3B2 scenario during 2030s, 2050s and 2080s would be observe in May followed by April month whereas, minimum projected ET_0 would be observe in December followed by November month (Table 4.15 and Fig. 4.21).

Table 4.15 Mean monthly downscaled ET_0 for Rahuri station

Months	Obs (1975–2000)	2030s (2017- 2043)		2050s (2037-2063)		2080s (2067- 2093)	
		H3A2	H3B2	H3A2	H3B2	H3A2	H3B2
Jan	3.40	3.44	3.48	3.51	3.45	3.57	3.48
Feb	4.26	4.35	4.38	4.41	4.37	4.60	4.65
Mar	5.51	5.47	5.53	5.50	5.51	5.46	5.78
Apr	6.56	6.78	6.64	6.76	6.76	7.49	6.80
May	7.54	7.62	7.51	7.59	7.56	7.78	7.80
Jun	5.97	5.98	6.00	6.12	6.02	6.13	6.20
Jul	4.51	4.54	4.56	4.60	4.60	4.83	4.67
Aug	4.25	4.12	4.05	4.06	4.00	4.01	4.03
Sep	3.97	4.05	3.95	3.79	3.76	3.81	3.72
Oct	4.01	4.12	4.22	4.10	4.32	4.08	4.09
Nov	3.38	3.56	3.45	3.42	3.41	3.43	3.42
Dec	2.98	2.98	3.01	3.16	3.21	3.22	3.16
Min	2.98	2.98	3.01	3.16	3.21	3.22	3.16
Max	7.54	7.62	7.51	7.59	7.56	7.78	7.80
Mean	4.70	4.75	4.73	4.75	4.75	4.87	4.82

It was also observed that the mean annual ET_0 for Rahuri station during observed period was 4.70 mm, and ET_0 would increase by 1.19%, 1.20%, and 3.52 % under the H3A2 scenario whereas, 0.77%, 1.11%, and 2.52% under the H3B2 scenario during the periods of 2030s, 2050s, and 2080s respectively (Table 4.16). The percent change in ET_0 during future period i.e. 2030s, 2050s and 2080s as compared to base period for Rahuri station were shown in Fig. 4.22. It would be observed that during 2030s, 2050s, and 2080s period the mean monthly ET_0 as compared to base period would increase for all months except March, August and September under H3A2 scenario and; August and September under H3B2 scenario.

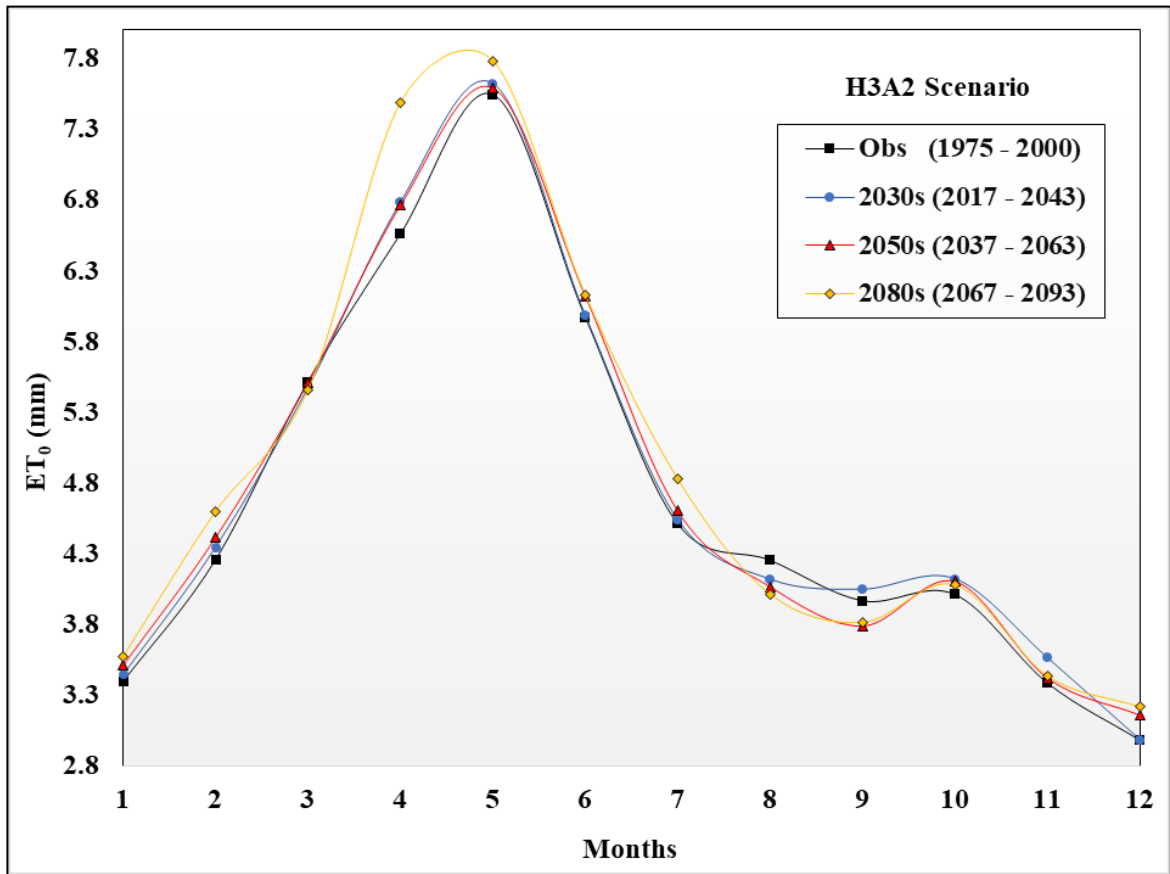
Table 4.16 Percentage changes in ET₀ as compared to base period for Rahuri station

Months	H3A2			H3B2		
	2030s	2050s	2080s	2030s	2050s	2080s
Jan	1.39	3.25	4.95	2.34	1.67	2.53
Feb	2.05	3.52	7.40	2.87	2.51	8.52
Mar	-0.77	-0.18	-1.09	0.23	-0.17	4.52
Apr	3.32	2.96	12.39	1.22	3.01	3.54
May	1.03	0.59	3.06	-0.50	0.24	3.26
Jun	0.21	2.42	2.57	0.51	0.90	3.67
Jul	0.67	1.97	6.58	1.10	1.97	3.41
Aug	-3.24	-4.62	-5.96	-4.91	-6.40	-5.59
Sep	2.05	-4.73	-4.00	-0.29	-5.58	-6.49
Oct	2.71	2.23	1.67	4.92	7.23	1.88
Nov	5.04	1.02	1.45	1.97	0.81	1.12
Dec	0.16	5.59	7.32	0.90	7.18	5.80
Mean Annual	1.19	1.20	3.52	0.77	1.11	2.52

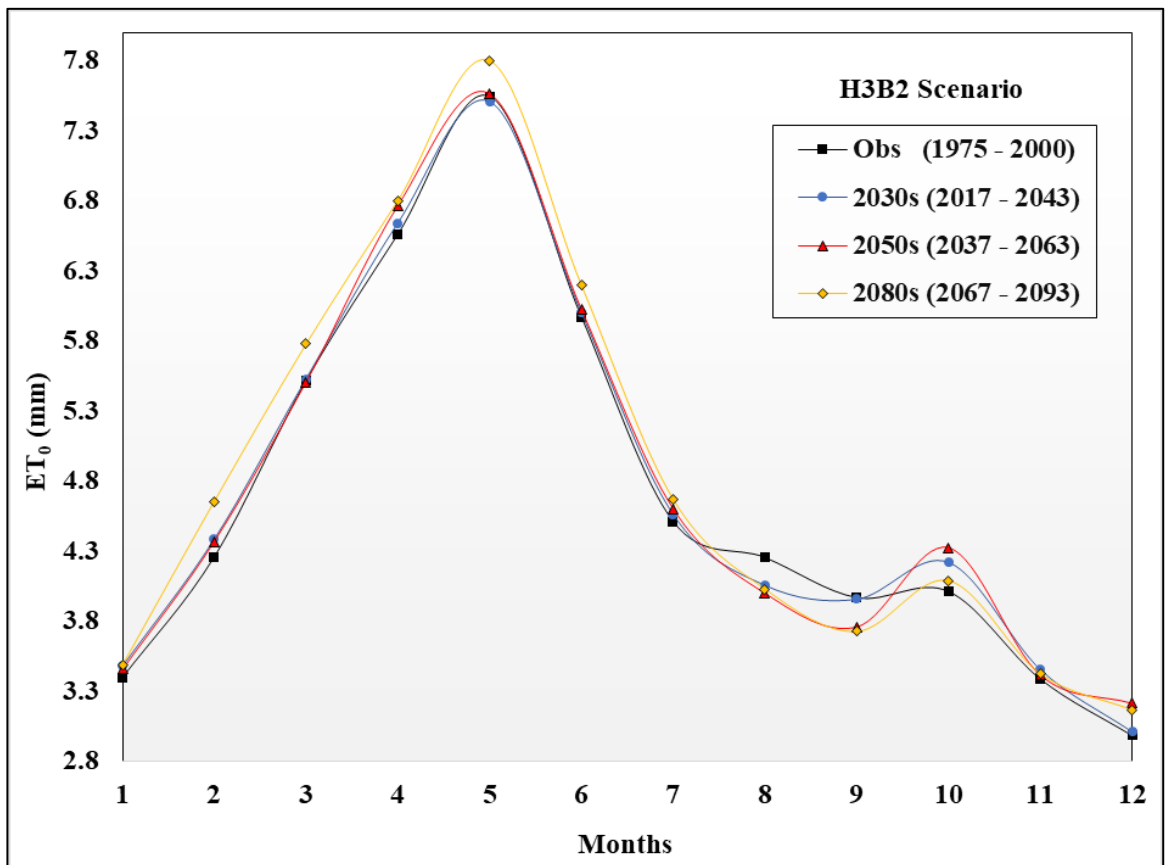
It would be observed that in 2030s as compared to base period, ET₀ would increase for all months except March (-0.77 %) and August (-3.24 %) under H3A2 scenario, whereas all months except May (-0.50 %), August (-4.91 %), and September (-0.29 %) would observe increase in mean monthly ET₀ under H3B2 scenario. Similarly in 2050, all months would observe increase in ET₀ as compared to base period, except March (-0.18 %), August (-4.62 %), and September (-4.73 %) under H3A2 scenario; and March (-0.71 %), August (-6.40 %), and September (-5.58 %) under H3B2 scenario. Lastly, in 2080s period similar variation would be observe with increase in mean monthly ET₀ for all months, except March (-1.09 %), August (-5.96 %), and September (-4.00 %) under H3A2 scenario; and all months expect August (-5.59 %) and September (-6.49 %) under H3B2 scenario would observe increase in ET₀ (Table 4.16 and Fig. 4.22).

The maximum increase in mean monthly ET₀ as compared to base period in 2030s would be observe in November (5.04 %) under H3A2 scenario and October (4.92 %) under H3B2 scenario. Similarly, the maximum increase in ET₀ as compared to base period in 2050s would be observed in December (5.59 %) under H3A2 scenario and October (7.23 %) under H3B2 scenario. The same during 2080s period would be observed in May i.e. 12.39 % under H3A2 and in February i.e. 8.52 % under H3B2 scenario (Table 4.16 and Fig. 4.22).

Kundu *et al.* (2016) observed increase in projected ET₀ with fluctuation of both increase and decrease in ET₀ during different decades with highest rise projected in period 2091–2099, particularly in the winter season from November to January.

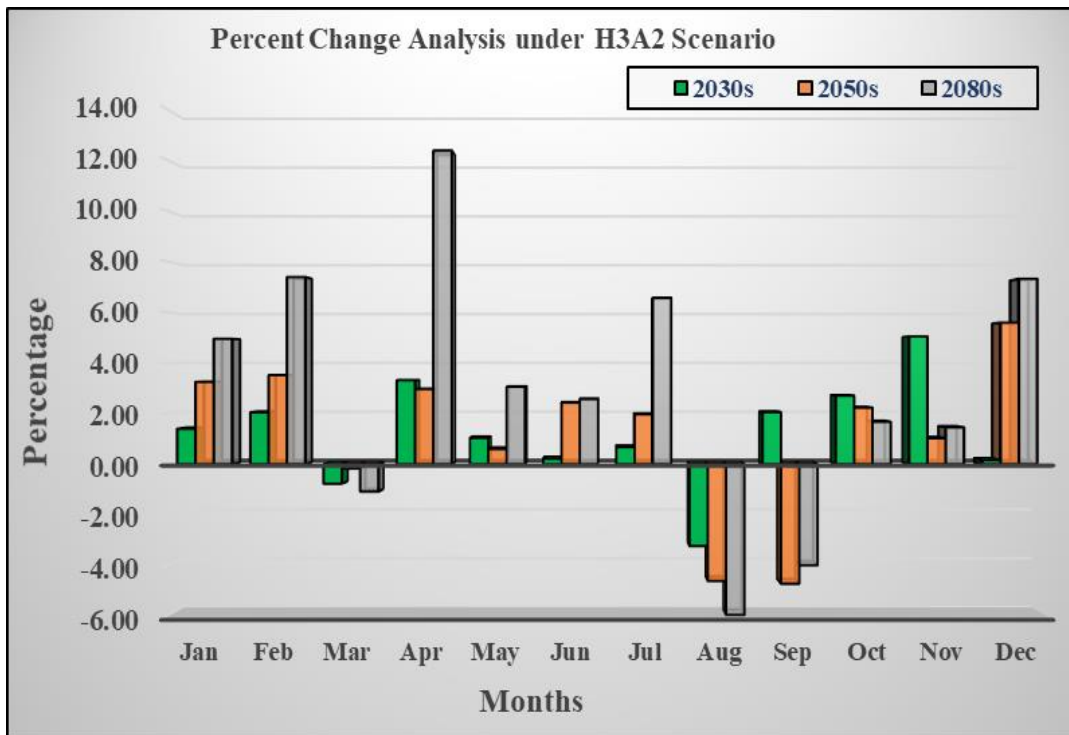


(a)

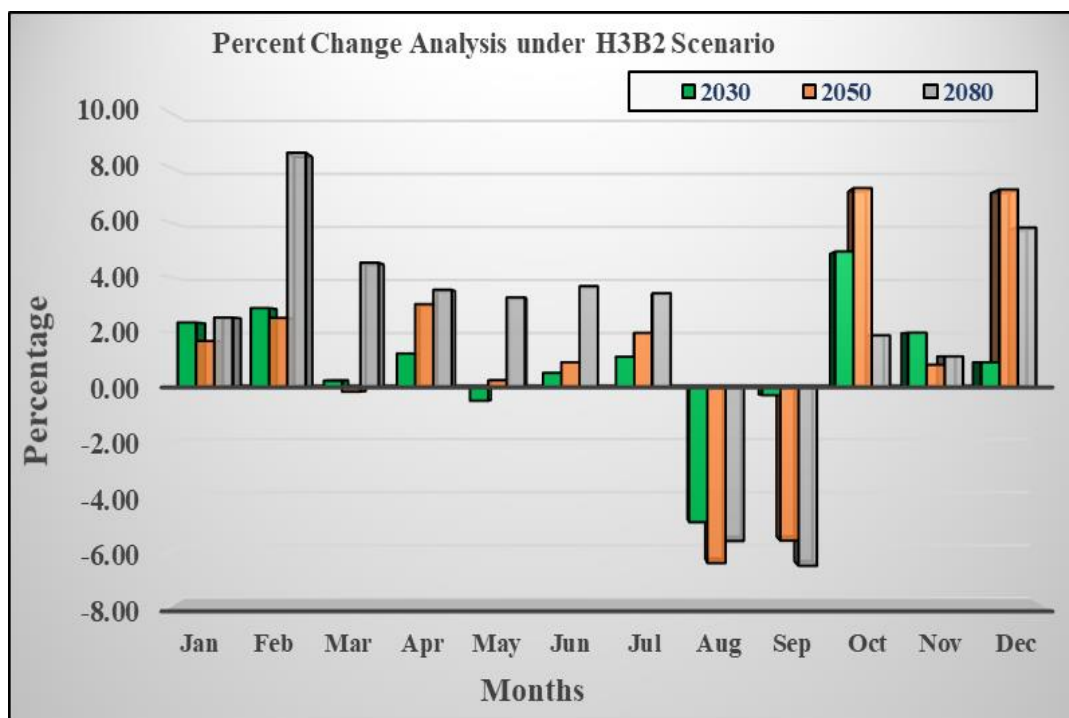


(b)

Fig. 4.21 Mean monthly downscaled ET_0 under (a) H3A2 and (b) H3B2 scenario for Rahuri station



(a)



(b)

Fig. 4.22 Percent changes in ET_0 under (a) H3A2 and (b) H3B2 scenario for Rahuri station

Overall, it was analysed that maximum and minimum values in mean monthly ET_0 would be observed in the month of May and December respectively, under both scenarios during 2030s, 2050s and 2080s. Considering both scenarios it was examined that, the ET_0 in future period would increase for all month except August and September as compared to the present condition. In all three future periods, ET_0 would be drastically reduced in the month of August followed by September.

4.3.3.3 Future projection and percent change in ET_0 for Solapur station

Solapur station had higher mean monthly ET_0 values for all months as compared to Rahuri and Pune station. The ET_0 indicated a rise in different periods under both H3A2 and H3B2 scenarios. The mean annual ET_0 for observed/base period (1968 to 2000) is 5.41 mm and the periods i.e. 2030s, 2050s, and 2080s could have similar ET_0 as the base period with the highest increment in ET_0 observe in 2080s (Table 4.17).

The maximum and minimum mean monthly ET_0 during base period was observed in month of May i.e. 8.25 mm and Dec i.e. 3.90 mm respectively. The maximum projected ET_0 under both scenario during 2030s, 2050s and 2080s would be observed in May followed by April whereas, the minimum projected ET_0 would be observed in December followed by November month (Table 4.17 and Fig. 4.23).

Table 4.17 Mean monthly downscaled ET_0 for Solapur station

Months	Obs (1968 - 2000)	2030s (2014- 2046)		2050s (2034 -2066)		2080s (2064- 2096)	
		H3A2	H3B2	H3A2	H3B2	H3A2	H3B2
Jan	4.49	4.40	4.41	4.47	4.56	4.66	4.77
Feb	5.71	5.82	5.85	5.85	5.88	5.92	5.99
Mar	6.77	6.87	6.89	6.96	6.95	7.03	7.00
Apr	8.00	8.14	8.14	8.27	8.22	8.47	8.31
May	8.25	8.84	8.69	8.62	8.74	8.53	8.52
Jun	5.84	5.75	5.80	5.70	5.79	5.71	5.73
Jul	4.72	4.99	5.02	5.05	5.12	5.15	5.09
Aug	4.37	4.35	4.35	4.50	4.46	4.42	4.69
Sep	4.44	4.39	4.32	4.26	4.31	4.11	4.17
Oct	4.37	4.37	4.38	4.34	4.37	4.32	4.30
Nov	4.06	4.18	4.18	4.32	4.31	4.28	4.46
Dec	3.90	4.00	3.91	3.91	3.88	4.15	3.99
Min	3.90	4.00	3.91	3.91	3.88	4.11	3.99
Max	8.25	8.84	8.69	8.62	8.74	8.53	8.52
Mean	5.41	5.51	5.49	5.52	5.55	5.56	5.58

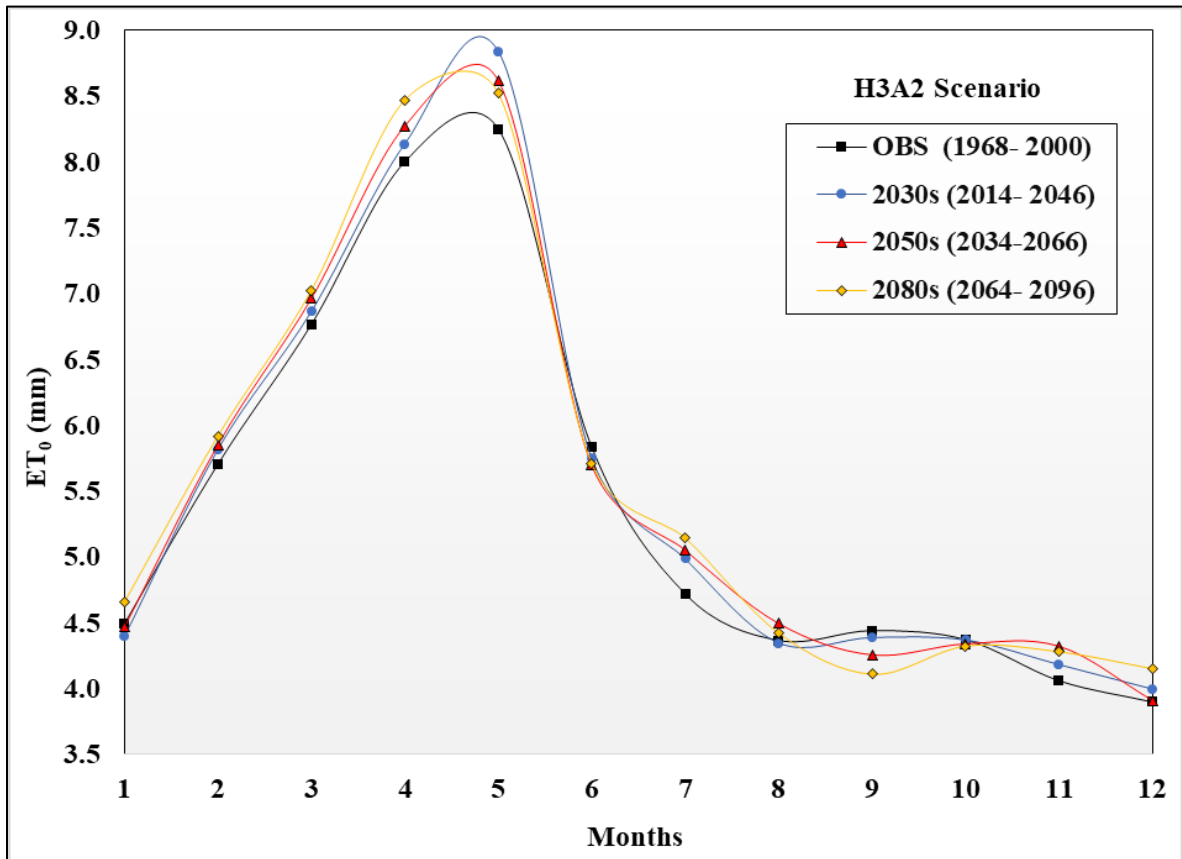
The mean annual ET_0 for Solapur station during observed period is 5.41 mm, and ET_0 would increase by 1.76, 2.01, and 2.73 % under the H3A2 scenario; and 1.54, 2.52, and 3.13 % under the H3B2 scenario during the periods of 2030s, 2050s, and 2080s respectively (Table 4.18). The increment in mean monthly ET_0 as compared to base period during 2030s, 2050s and 2080s would be observed for all months except January, June, September and October under H3A2 scenario; and January, June, September, October and December under H3B2 scenario (Fig. 4.24).

Table 4.18 Percentage changes in ET₀ as compared to base period for Solapur station

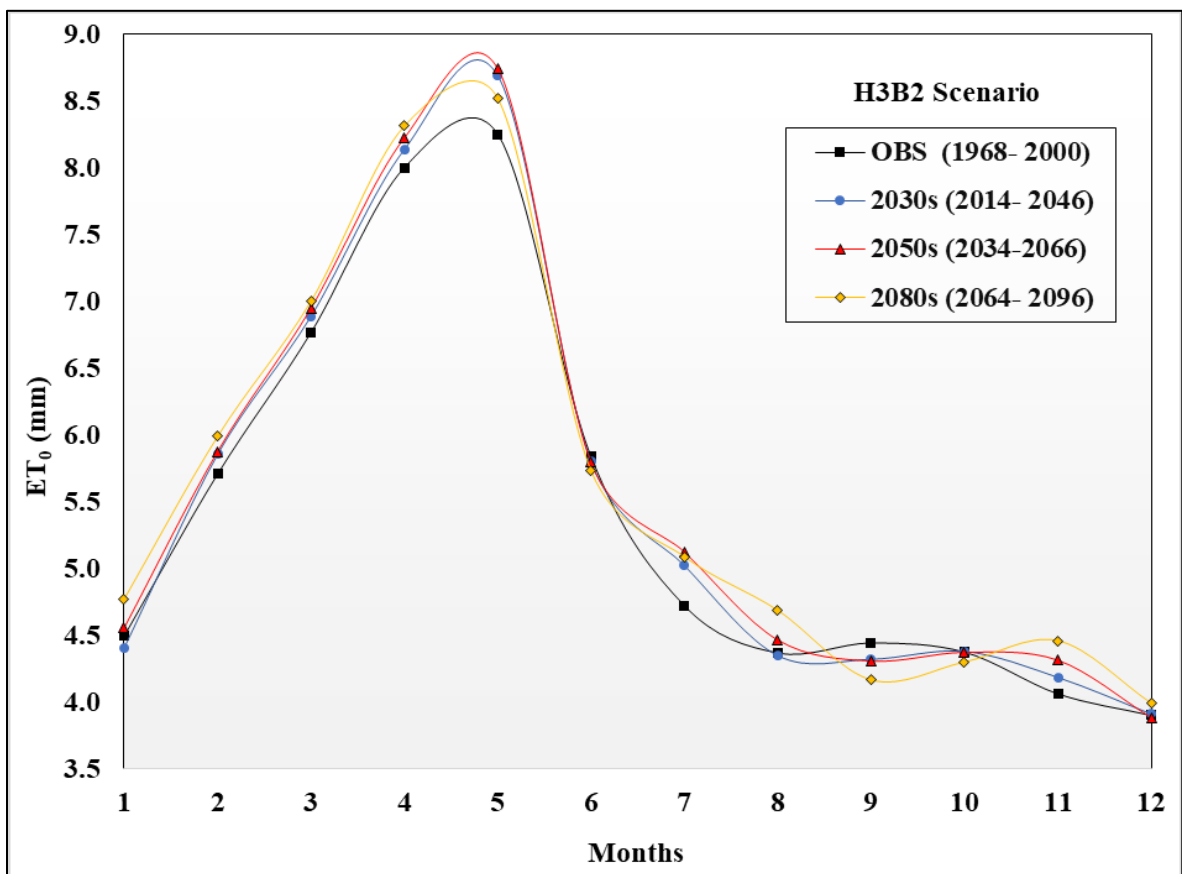
Months	H3A2			H3B2		
	2030s	2050s	2080s	2030s	2050s	2080s
Jan	-2.20	-0.59	3.53	-2.03	1.34	5.80
Feb	1.92	2.51	3.60	2.51	2.89	4.71
Mar	1.45	2.83	3.69	1.76	2.62	3.34
Apr	1.68	3.29	5.53	1.67	2.70	3.74
May	6.67	4.27	3.20	5.05	5.62	3.16
Jun	-1.52	-2.46	-2.21	-0.65	-0.75	-1.83
Jul	5.34	6.57	8.25	6.00	7.86	7.22
Aug	-0.43	2.85	1.25	-0.47	2.17	6.81
Sep	-1.19	-4.35	-8.09	-2.82	-3.14	-6.62
Oct	-0.06	-0.75	-1.14	0.13	-0.04	-1.71
Nov	2.93	6.07	5.15	2.94	5.83	8.93
Dec	2.46	0.30	6.09	0.26	-0.43	2.29
Mean Annual	1.76	2.01	2.73	1.54	2.52	3.13

The percent change in mean monthly ET₀ during future period i.e. 2030s, 2050s and 2080s as compared to base period for Solapur station were presented in Table 4.18 and Fig. 4.24. It would be observed that in 2030s as compared to base period, ET₀ would increase for all months except January (-2.20 %), June (-1.52 %), August (-0.43 %), September (-1.19 %), and October (-0.06 %) under H3A2 scenario, whereas all months except January (-2.03 %), June (-0.65 %), August (-0.47 %), and September (-2.82 %) under H3B2 scenario. In 2050, similar increase in mean monthly ET₀ as compared to base period would be observed for all months except January (-0.59 %), June (-2.46 %), September (-4.35 %), and October (-0.75 %) under H3A2 scenario whereas, all month except June (-0.75 %), September (-3.14 %), and December (-0.43 %) under H3B2 scenario would observe increase in ET₀ values. During 2080s period the increase in ET₀ values would be observed for all months except June (-2.21 %), September (-8.09 %), and October (-1.14 %) under H3A2 scenario; and June (-1.83 %), September (-6.62 %), and October (-1.71 %) under H3B2 scenario.

The maximum increase in mean monthly ET₀ as compared to base period in 2030s would be observe in May i.e. 6.67 % under H3A2 scenario and July i.e. 6.00 % under H3B2 scenario. Similarly in 2050s, the maximum increase in ET₀ would be observed in the month of July i.e. 6.57 % under H3A2 scenario and 7.86 % under H3B2 scenario. The same during 2080s period would be observed in July i.e. 8.25 % under H3A2 and November i.e. 8.93 % under H3B2 scenario. The maximum increase in projected ET₀ would be observed in the summer season. Rajabi and Babakhani, (2017) also observed higher increase in projected ET₀ during hot months of the year.

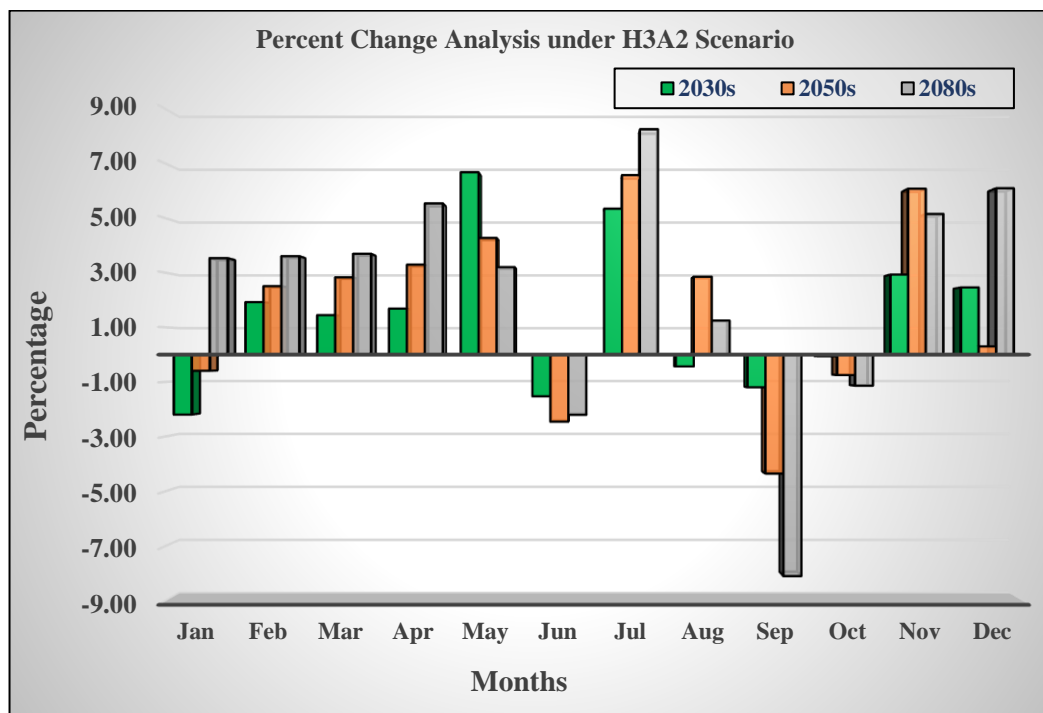


(a)

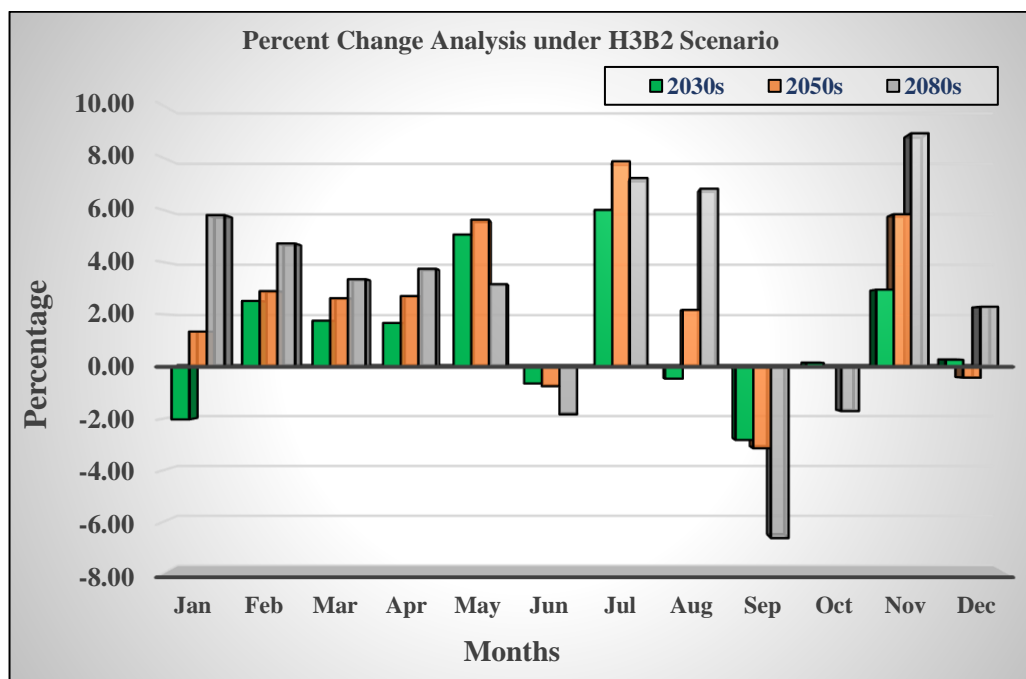


(b)

Fig. 4.23 Mean monthly downscaled ET_0 under (a)H3A2 and (b) H3B2 scenario for Solapur station



(a)



(b)

Fig. 4.24 Percent changes in ET_0 under (a) H3A2 and (b) H3B2 scenario for Solapur station

Overall, it was envisioned that there would be gradual rise in projected ET_0 during 2030s, 2050s and 2080s period for most of the months. The maximum and minimum mean monthly projected ET_0 would be observed in May and December respectively, under both scenarios i.e. H3A2 and H3B2. The projected ET_0 during 2030s, 2050s and 2080s compared to base period found decreased in June, September, and October month under both scenarios with maximum reduction in ET_0 examined in the month of September.

4.3.1 Future Crop Water Requirement (CWR)

Crop evapotranspiration (ET_c) is closely correlated with reference evapotranspiration (ET_0) and indicated the quantity of water that a type of plant needs throughout its growth season i.e. crop water requirement (CWR) in this case. Considering projected ET_0 and present K_c values, crop water requirement of cotton, *rabi* onion, soybean and *suru* sugarcane for three stations i.e. Pune, Rahuri and Solapur were estimated for 2030s, 2050s and 2080s period. Owing to the different growing periods and K_c values, the water requirements of four crops were different. Crop water requirement was calculated for three time period considering both H3A2 and H3B2 scenarios as discussed earlier.

4.3.1.1 Cotton

The predicted ET_0 in the earlier section considering both scenarios for three stations i.e. Pune, Rahuri and Solapur revealed that reference evaporation (ET_0) increased for all months except from June to September i.e. (*Kharif* Season). Therefore, it was quite obvious that water requirement of cotton would decrease or most likely to be same as that of base period. The changes in CWR during different time periods for all three stations is shown in Fig. 4.25. The detail data of estimated values of CWR of cotton under both scenarios were given in Appendix B (Table B.1 and B.2).

The base/observed period CWR of cotton for Pune station is 620.2 mm. The CWR would marginally decreased during 2030s and 2050s as compared to present condition under both scenario i.e. H3A2 and H3B2. The marginal increase CWR would be observed in 2080s over base period as 626.1 and 622.1 mm under H3A2 and H3B2 scenario, respectively for Pune station.

For Rahuri station, the base period CWR of cotton is 672.3 mm (Fig. 4.25) and it would relatively increase as 677.1 mm and 676.3 mm for 2030s and 2080s period, respectively and found relatively decrease during 2050s (667.8 mm) under H3A2 scenario. Similarly under H3B2 scenario, the CWR would marginally decrease or approximately same during all three periods i.e. 2030s, 2050s, and 2080s and found as 672.0, 667.8, and 670.8 mm respectively for Rahuri station.

The Solapur station has higher CWR value (717.6 mm) for base period as compared to Rahuri and Pune station. The CWR of cotton for Solapur station would increase during all three periods i.e. 2030s, 2050s and 2080s under both scenarios (H3A2 and H3B2) as showed in Fig. 4.25.

The percentage variations in CWR for cotton as compared to base period during 2030s, 2050s, and 2080s were shown in Fig. 4.26. It was observed that for Pune station CWR under H3A2 scenario would marginally decrease as -0.97% and -0.28 % during 2030s and 2050s, respectively; and found marginally increase during 2080s (0.95 %). Similarly, under H3B2 scenarios CWR would decrease during 2030s (-0.85 %) and 2050s (-0.97 %); and would increase in 2080s (0.31 %) as compared to base period.

For Rahuri station, CWR for cotton under H3A2 scenario would marginally increase during 2030s (0.7 %) and 2080s (0.59 %); and marginally decrease during 2050s (-0.56 %). Under H3B2 scenario for Rahuri station, observe decrease in CWR during all three period i.e. 2030s, 2050s and 2080s would be with magnitude as -0.04, -0.68, and -0.22 % respectively.

For Solapur station, the crop water requirement of cotton would increase under both scenario during all periods as compared to base period (Fig. 4.26). Under H3A2 scenario, it would increase by 1.67%, 1.70 % and 0.91% respectively during 2030s, 2050s and 2080s respectively. The increment in CWR for Solapur station under the H3B2 scenario would be 1.41, 2.48, and 2.29 % during 2030s, 2050s, and 2080s period respectively.

Doria *et al.* (2010) compared results of estimated CWR to the base period and observed an increase in crop water requirements by 3.0 % (20 mm) per season for 2020s and about 7.0 % (43 mm) per season for 2050s using both H3A2 and H3B2 scenarios.

Overall it was concluded that the crop water requirement of cotton would approximately same (less than 1% variation) during the periods 2030s, 2050s and 2080s with respect to base period for Pune and Rahuri station, whereas marginally increase (0.91 to 2.48% variation) for all periods at Solapur station.

4.3.1.2 Rabi onion

The base/observed period CWR of *rabi* onion for Pune station is 428.9 mm. The CWR would relatively increase in 2030s and found increase during 2050s and 2080s under both scenarios i.e. H3A2 and H3B2. The estimated values of CWR of *rabi* onion are 435.2, 447, and 446.8 mm under H3A2 scenario; and 436, 441.8, and 448.8 mm under H3B2 scenario during 2030s, 2050s, and 2080s respectively (Fig. 4.27). The detail data of estimated values of CWR of *rabi* onion under both scenarios were given in Appendix B (Table B.3 and B.4).

For Rahuri station, the base period CWR of *rabi* onion is same as Pune station i.e. 428.3 mm. The CWR would relatively increase in 2030s as 437.9 and 429.2 mm under H3A2 and H3B2 scenario respectively. The CWR of *rabi* onion would increase during 2050s and 2080s under both scenarios as compared to present condition.

For Solapur station, the base period CWR of *rabi* onion is 537.9 mm (Fig. 4.27). The CWR would marginally increase during 2030s and found relatively increase during 2050s under both scenario. In 2080s period, the CWR of *rabi* onion would increase as 559.1 mm by 21 mm under H3A2 and 562.1 mm by 24 mm under H3B2 sequentially.

The percentage variations in CWR for *rabi* onion during 2030s, 2050s, and 2080s as compared to base period were shown in Fig. 4.28. *Rabi* onion would have consistent increase in CWR during all three periods considering all stations under both scenarios. It was observed that for Pune station,

CWR under H3A2 scenario would marginally increase by 1.44 % during 2030s and found increase during 2050s and 2080s by 4.04 % and 4.02 % respectively. The increment in CWR for Pune station under the H3B2 scenario would be 1.64, 2.93, and 4.43 % during 2030s, 2050s and 2080s period respectively.

For Rahuri station, CWR of *rabi* onion would relatively increase during 2030s by 2.17 and 2.48 % under H3A2 and H3B2 scenario respectively. The CWR would increase by 3.24 % under H3A2 scenario and 4.01 % under H3B2 scenario during 2050s. In 2080s, the CWR of *rabi* onion would increase by 4.62 and 3.77 % under H3A2 and H3B2 scenario respectively. The reason for the increment in the CWR of *rabi* onion was due to the increasing trend in ET_0 observed during growth period i.e. November to February.

For Solapur station, CWR of *rabi* onion under H3A2 scenario would marginally increase during 2030s by 0.88 % and 2050s by 1.37 %; and found increase during 2080s by 3.8 %. Similarly under H3B2 scenario, the increment in CWR during 2030s, 2050s and 2080s would be 0.49, 1.8, and 4.3 % respectively as shown in Fig. 4.28. Zhou *et al.* (2017) found that ET_0 would increase by 4% to 7% for 2050s at HID region of China with CWR having the same trend as ET_0 , with different crops have different increase rates.

Overall it was concluded that the CWR would advance for all three stations i.e. Pune, Rahuri and Solapur during 2030s, 2050s and 2080s. The CWR would marginally increase (0.49 to 2.48 %) during 2030s, whereas 2050s and 2080s period would observed highest increment in CWR (1.80 to 4.62 %) for all three stations. This could be due to the predominant increase in the ET_0 during winter season under both scenario.

4.3.1.3 Soybean

The base/observed period CWR of soybean for Pune station is 359.2 mm. The CWR would marginally decreased during 2030s and 2050s as compared to present condition under both scenario i.e. H3A2 and H3B2. The approximately same CWR would be observe in 2080s over base period as 358.6 and 359.4 mm under H3A2 and H3B2 scenario, respectively for Pune station. The detail data of estimated values of CWR of soybean under both scenarios were given in Appendix B (Table B.5 and B.6).

For Rahuri station, the base period CWR of soybean is 396.6 mm (Fig. 4.29) and it would marginally increase as 398.1 mm during 2030s; and found relatively decrease as 390.2 and 393.5 mm during 2050s and 2080s period, respectively under H3A2 scenario. Similarly under H3B2 scenario, the CWR would marginally decrease or approximately same during all three periods i.e. 2030s, 2050s, and 2080s and found as 396, 391.9, 388.5 mm respectively for Rahuri station.

The Solapur station has higher CWR value (424.5 mm) for base period as compared to Rahuri and Pune station. The CWR of soybean for Solapur station would marginally increase or approximately

same during all three periods i.e. 2030s, 2050s and 2080s under both scenarios (H3A2 and H3B2) as showed in Fig. 4.29.

The percentage variations in CWR for soybean during 2030s, 2050s, and 2080s as compared to base period were shown in Fig. 4.30. It was observed that for Pune station CWR under H3A2 scenario CWR would marginally decrease by -1.05, -1.05, and -0.16 % during 2030s, 2050s, and 2080s respectively. Similarly, under H3B2 scenarios CWR would marginally decrease during 2030s (-1.25 %) and 2050s (-1.67 %); and found marginally increase in 2080s (0.06 %) as compared to base period.

For Rahuri station, CWR for soybean under H3A2 scenario would marginally increase during 2030s (0.37 %); and found marginally decrease during 2050s (-1.65 %) and 2080s (-0.78 %). Under H3B2 scenario for Rahuri station, observe decrease in CWR during all three period i.e. 2030s, 2050s and 2080s would be with magnitude as -0.16, -1.2, -2.09 % respectively.

For Solapur station, the crop water requirement of soybean would increase under both scenarios during all periods except in 2080s under H3A2 scenario as compared to base period (Fig. 4.30). Under H3A2 scenario, it would marginally increase during 2030s (0.77 %) and 2050s (1.03 %); and found marginally decrease in 2080s (-0.04 %). The marginal increment in CWR for Solapur station under the H3B2 scenario would be 0.52, 1.61, and 1.63 % during 2030s, 2050s, and 2080s period respectively.

Manasa and Shivapur, (2016) observed both rise and fall in CWR for future scenario when compared with base period condition with decrease in CWR during *kharif* season i.e. jowar, maize, groundnut, soybean, cotton while increase in CWR during *rabi* season i.e. sugarcane and wheat.

Overall it was concluded that the crop water requirement of soybean would marginally decrease or approximately same (-2.09 to 0.37 % variation) during 2030s, 2050s and 2080s with respect to base period for Pune and Rahuri station, whereas marginally increase or approximately same (-0.04 to 1.63 % variation) for all three periods at Solapur station.

4.3.1.4 *Suru* sugarcane

Suru sugarcane resemble highest increase in crop water requirement as compared to cotton, *rabi* onion and soybean. The base/observed period CWR of *suru* sugarcane for Pune station is 1384.6 mm. The CWR would be approximately same or marginally increase in 2030s and found increase during 2050s and 2080s under both scenarios (H3A2 and H3B2). The highest increment in CWR of *suru* sugarcane would be observe during 2080s with estimated CWR values as 1421.4 and 1410.8 mm under H3A2 and H3B2 scenario respectively. The detail data of estimated values of CWR of *suru* sugarcane under both scenarios were given in Appendix B (Table B.7 and B.8).

For Rahuri station, similar increasing trend in CWR of *suru* sugarcane would be observed for all three periods. The base period CWR of *suru* sugarcane is 1443.5 mm (Fig. 4.31). The CWR would relatively increase in 2030s as 1460.6 and 1452.8 mm under H3A2 and H3B2 scenario respectively. The CWR of *suru* sugarcane would increase during 2050s and 2080s under both scenarios as compared to present condition. The 2080s period could observe an increase as 1484.6 mm by 41.1 mm under H3A2 and 1468.4 mm by 24.8 mm under H3B2 scenario respectively as compared to base period.

For Solapur station, the base period CWR of *suru* sugarcane is 1631.6 mm (Fig. 4.31). The CWR would increase during 2030s, 2050s and 2080s under both scenarios. In 2080s period, the CWR of *rabi* onion would increase as 1669.3 mm by 37.7 mm under H3A2 and 1679.6 mm by 48.3 mm under H3B2 respectively.

The percentage variations in CWR as compared to base period for *suru* sugarcane during 2030s, 2050s, and 2080s were shown in Fig. 4.32. *Suru* sugarcane would have consistent increase in crop water requirement during all three periods considering all stations under both scenarios. It was observed that for Pune station, CWR under H3A2 scenario would marginally increase as 0.05 % and 1.56 % during 2030s and 2050s respectively; and found relatively increase by 2.6 % during 2080. The increment in CWR would be 0.23, 0.6, and 1.86 % during 2030s, 2050s and 2080s period respectively for Pune station under the H3B2 scenario.

For Rahuri station, CWR of *suru* sugarcane would marginally increase during 2030s by 1.17 and 0.64 % under H3A2 and H3B2 scenario respectively. The CWR also found marginal increase as 0.83 % under H3A2 scenario and 0.88 % under H3B2 scenario in 2050s. In 2080s, the CWR of *suru* sugarcane would relatively increase by 2.77 and 1.69 % under H3A2 and H3B2 scenario respectively.

For Solapur station, CWR of *suru* sugarcane under H3A2 scenario would relatively increase during 2030s (1.66 %) and 2050s (1.83 %); and increase during 2080s (2.26 %). Similarly under H3B2 scenario, the increment in CWR during 2030s, 2050s and 2080s would be 1.37, 2.37, and 2.86 % respectively.

Overall it was concluded that the CWR would advance for all three stations i.e. Pune, Rahuri and Solapur during 2030s, 2050s and 2080s. The CWR would marginally increase or approximately same (0.05 to 2.37 % variation) during 2030s and 2050, whereas it would relatively increase (1.69 to 2.86 % variation) in 2080s period for all three stations.

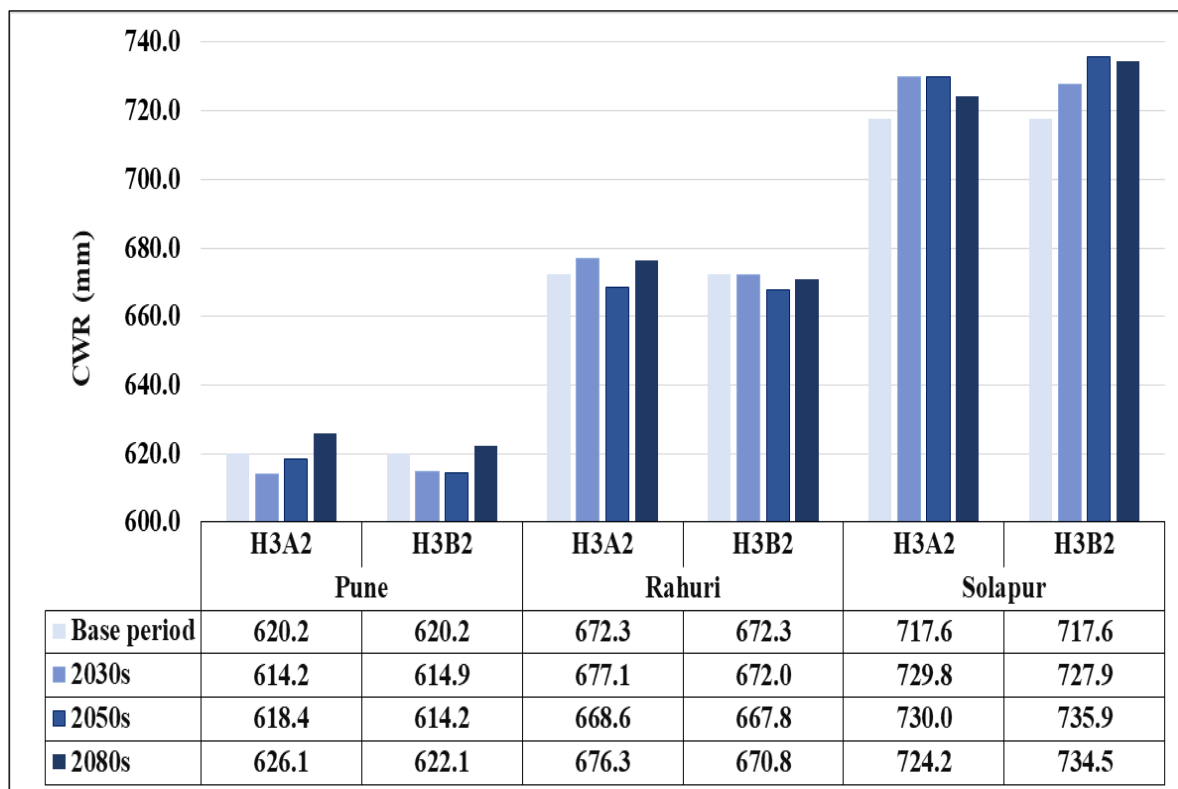


Fig. 4.25 CWR of cotton during different time period at different stations

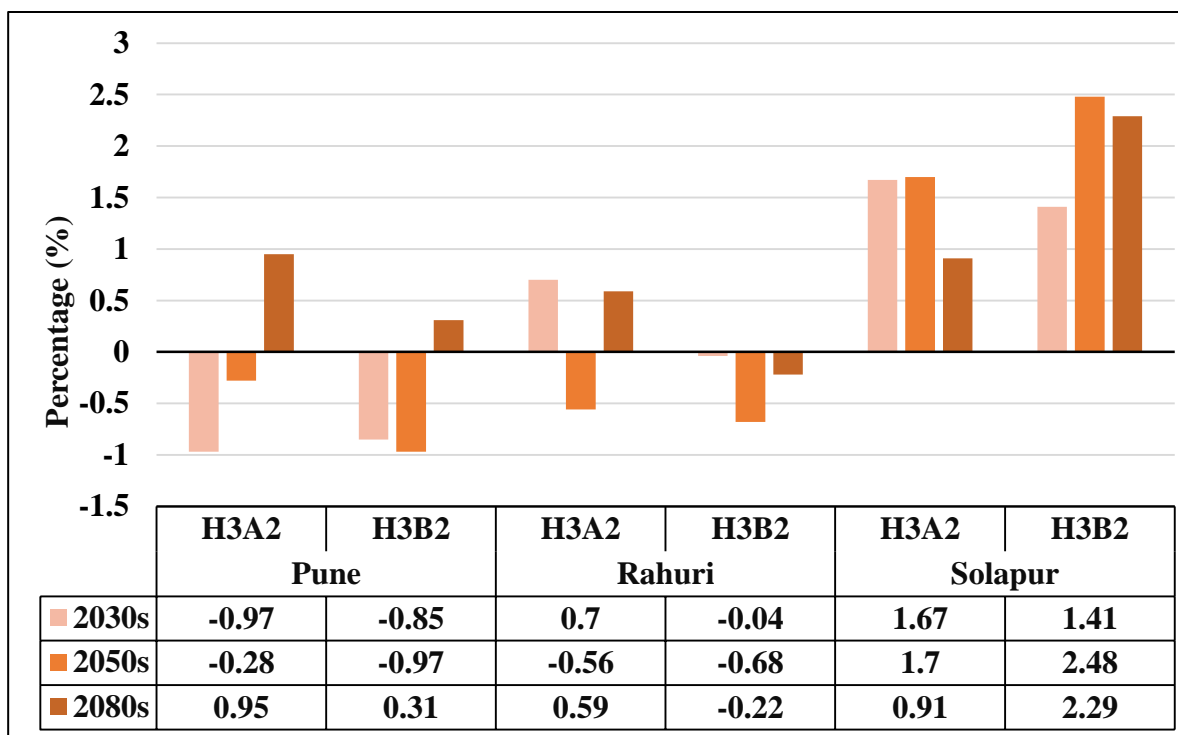


Fig. 4.26 Percentage changes in CWR of cotton during different time period at different stations as compared to base period

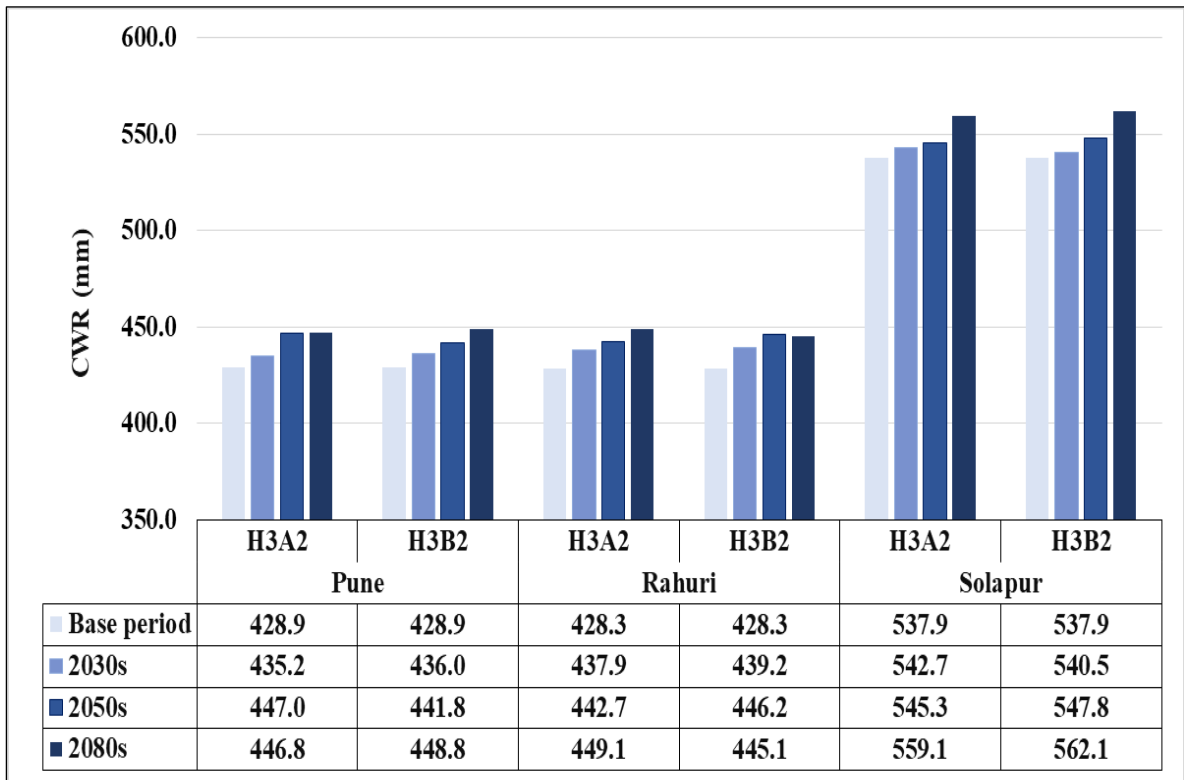


Fig. 4.27 CWR of rabi onion during different time period at different stations

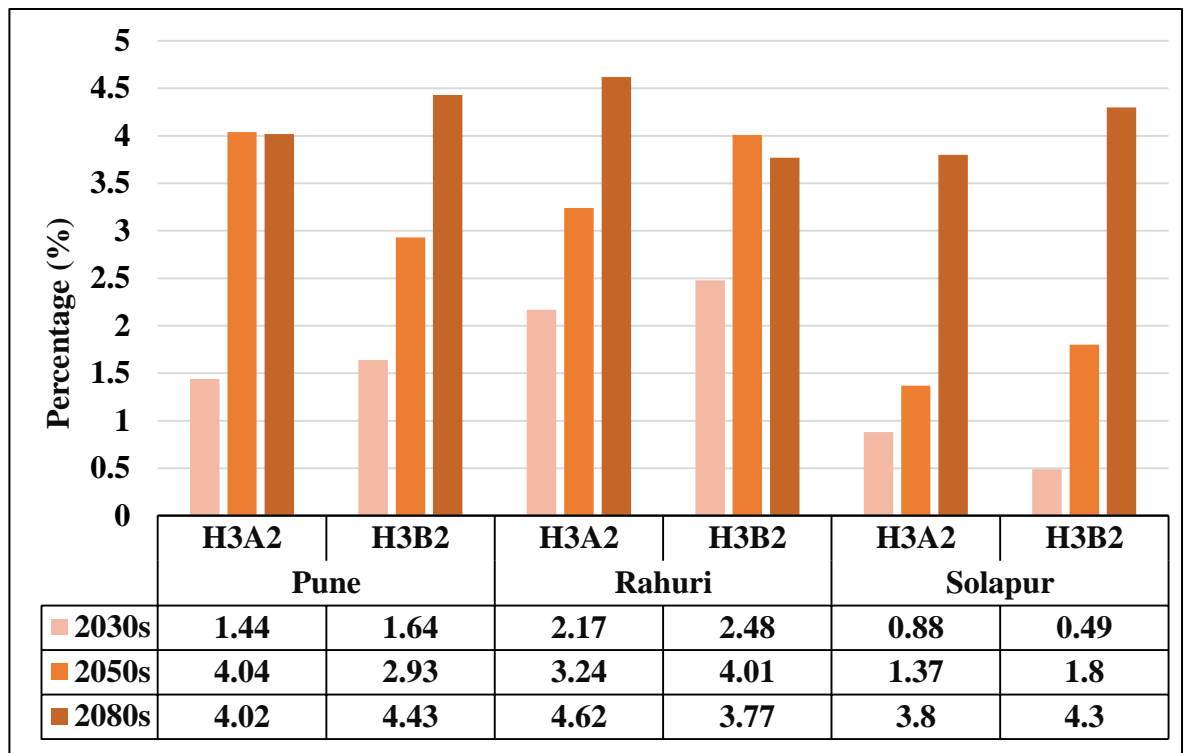


Fig. 4.28 Percentage changes in CWR of rabi onion during different time period at different stations as compared to base period

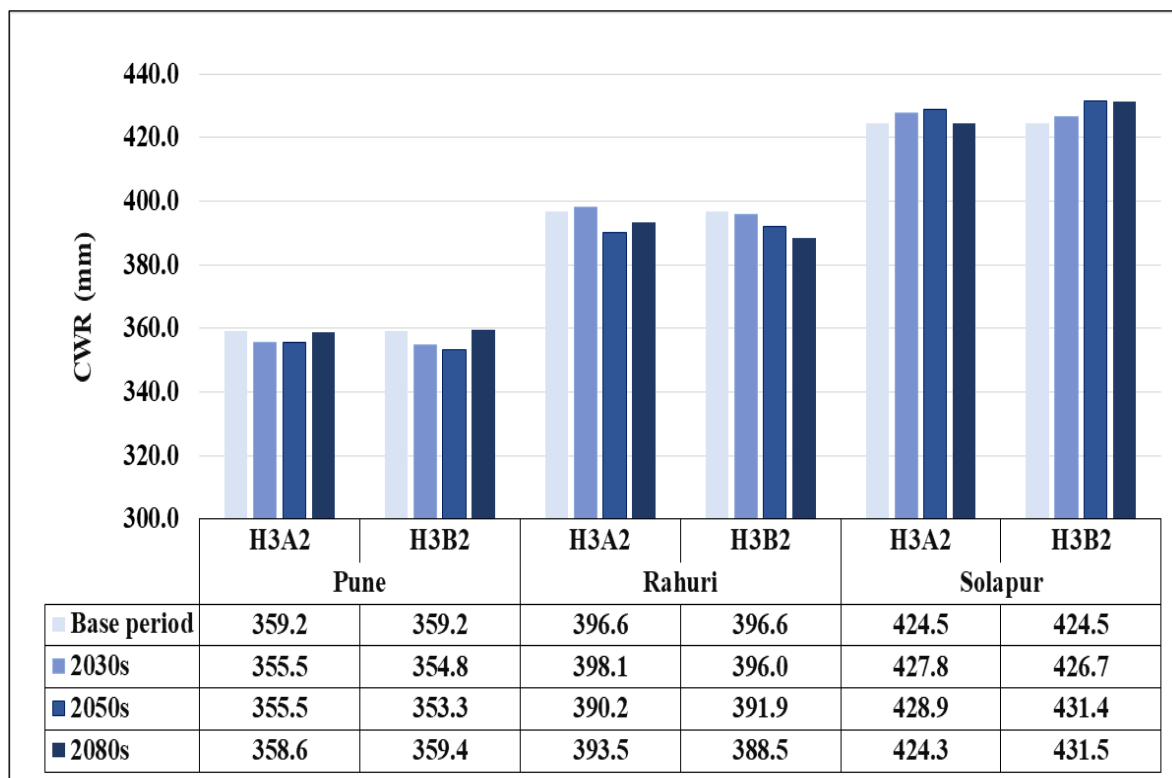


Fig. 4.29 CWR of soybean during different time period at different stations

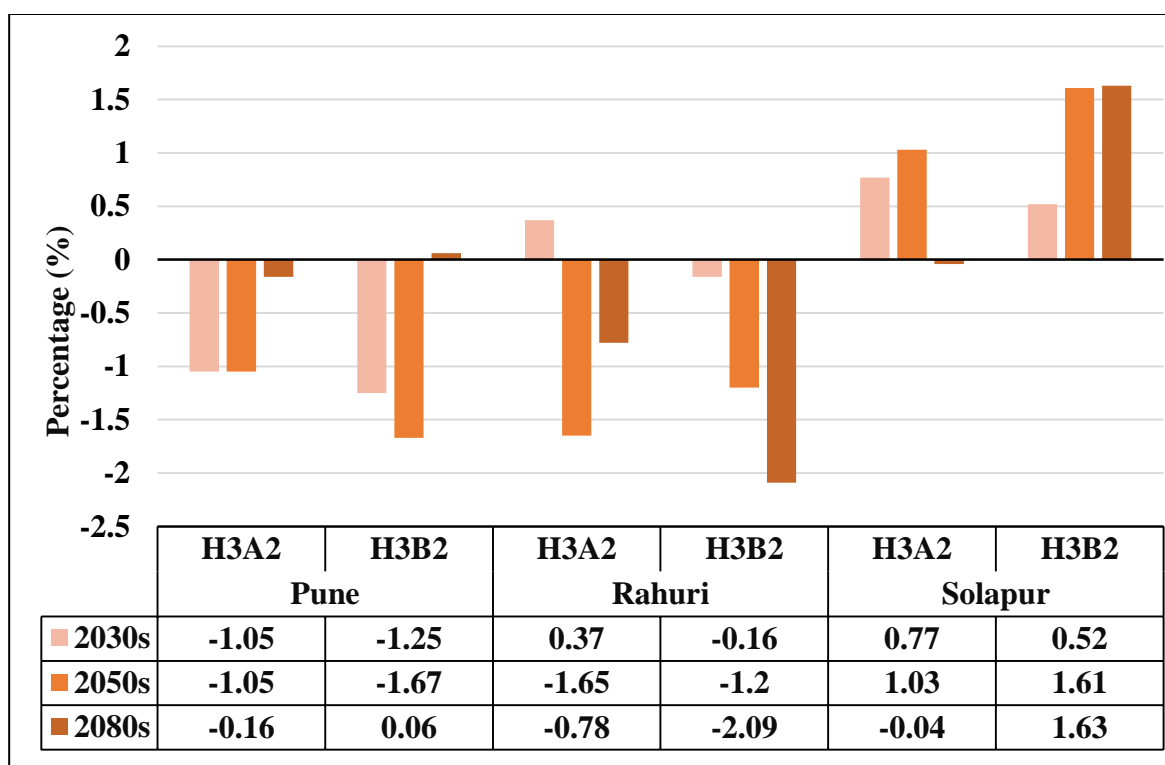


Fig. 4.30 Percentage changes in CWR of soybean during different time period at different stations as compared to base period

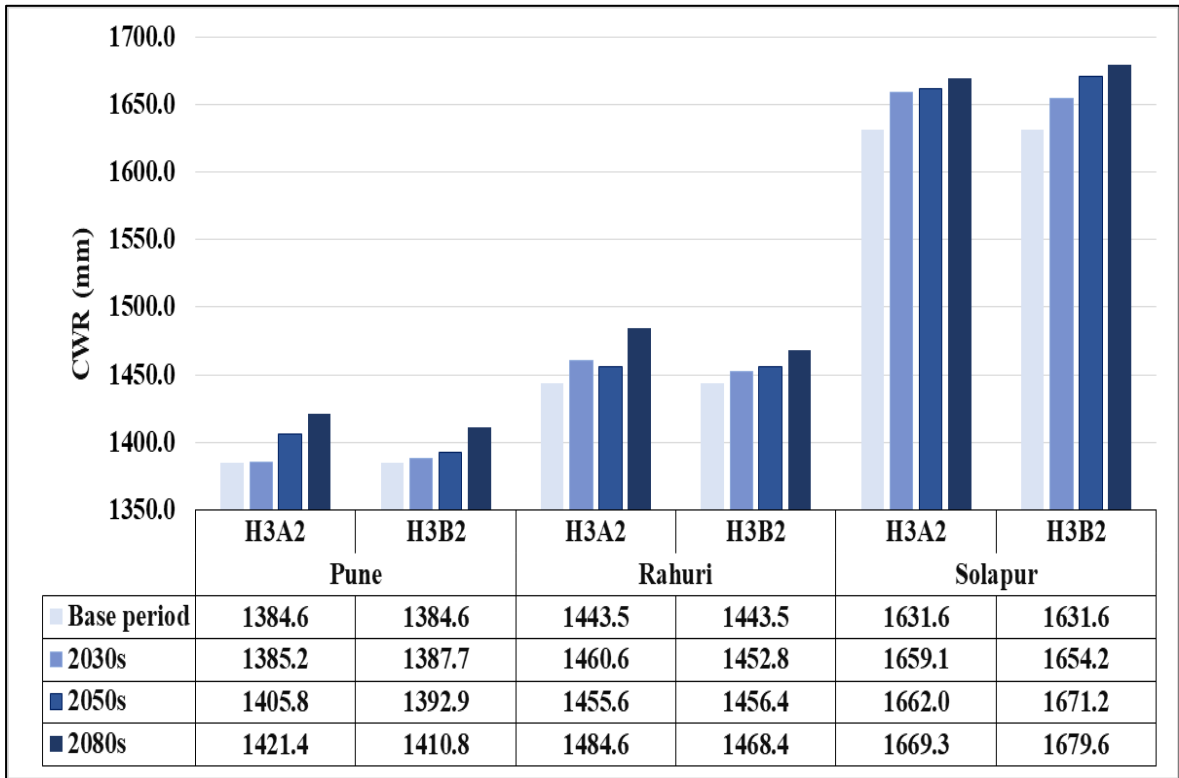


Fig. 4.31 CWR of *suru* sugarcane during different time period at different stations

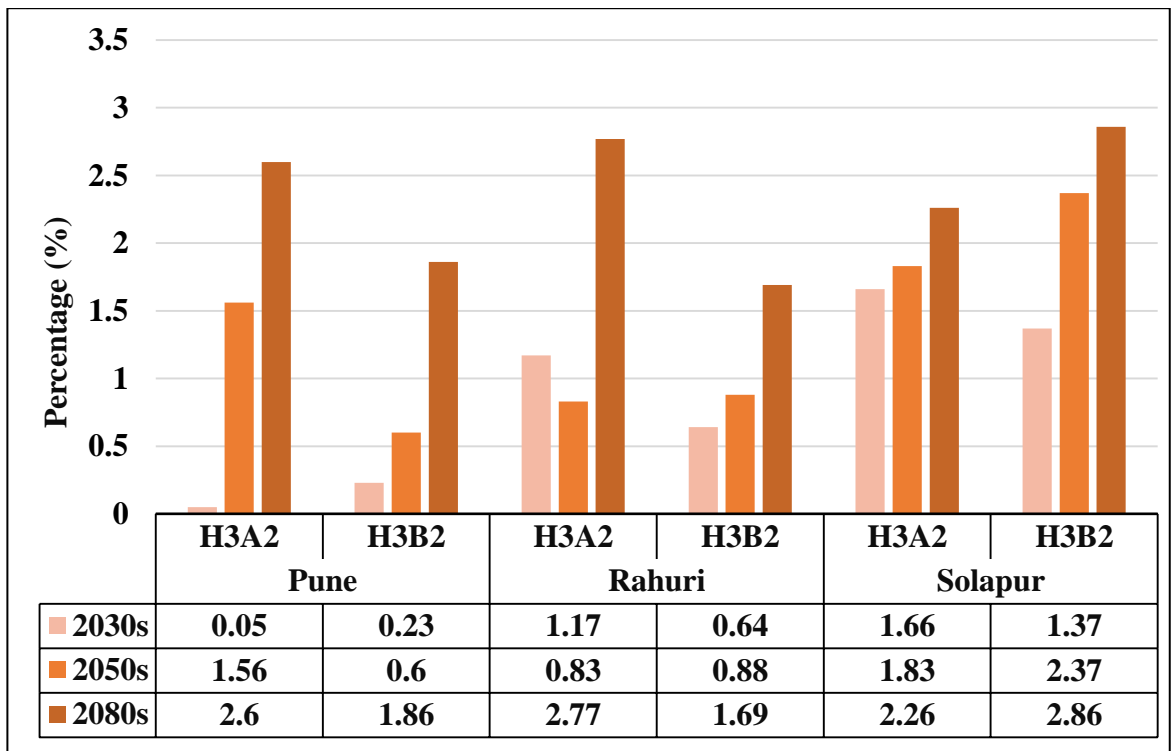


Fig. 4.32 Percentage change in CWR of *suru* sugarcane during different time period at different stations as compared to base period

5. SUMMARY AND CONCLUSIONS

The crop water requirement is considered as the most important fundamental physical parameter in crop growth amongst other parameters as it also determines the environmental condition of a particular region, which affects agricultural productivity. Therefore the study entitled ‘crop water requirement in context of climate variability’ was undertaken to determine temporal as well as spatial trends in crop water requirement, determination of periodic i.e. decadal changes in CWR, and lastly estimation of future CWR at selected stations. The long term average weekly meteorological data of nine stations *viz.*, Dhule, Jalgaon, Pune, Rahuri, Niphad, Solapur, Kolhapur, Padegaon, and K. Digraj over Western Maharashtra was used for estimating reference evapotranspiration (ET_0). The ET_0 was calculated using the sole standard FAO56 Penman-Monteith method. The CWR was estimated for four main crops *viz.*, cotton, *rabi* onion, soybean and *suru* sugarcane during the entire analysis.

The calculated average weekly ET_0 in conjunction with the crop coefficient (K_c) values was further utilized to estimate crop evapotranspiration (ET_c). The water requirement was estimated considering demand side and nullifying the losses due to application and special needs as these parameters varies from place to place. The CWR was estimated for 38 years during 1980 to 2017 for Dhule, Jalgaon, Niphad Rahuri, Pune and Solapur station; 28 years during 1990 to 2017 for Kolhapur and Padegaon station; and 23 year during 1995 to 2017 for Kasbe Digraj station as per the availability of the data. The trend analysis was carried out using the non-parametric Mann Kendall test and Sen’s slope estimator method. The test compares the relative magnitude of sample data rather than the data themselves. The trend analysis in CWR was performed annually with one value corresponding to one years at 95% probability level. The decadal changes in crop water requirement was analyzed by examining percentage variation within successive decades and spatially by interpolating them using IDW interpolation technique in ArcGIS software. The Statistical Downscaling Model (SDSM) was used to downscale the reference evapotranspiration (ET_0) for three selected stations i.e. Pune, Rahuri and Solapur under two climate scenarios (H3A2 and H3B2) of HadCM3 model. The downscaling of ET_0 was very important to study the impact of the future climate on ecological and water resource management. The predictors of the model were screened and selected based on the R^2 , E_{ns} , RMSE, MAD, MAPE, and p-values. The study found an appreciable correlation between the modelled and observed results during both calibration and validation periods. The projected CWR for cotton, *rabi* onion, soybean and *suru* sugarcane were estimated using downscaled ET_0 values and present crop coefficient values. The results obtained are summarized below;

5.1 Summary

5.1.1 Estimation of CWR

The average CWR for cotton, *rabi* onion, soybean, and *suru* sugarcane were estimated and presented in Table 5.1.

Table 5.1 Average CWR for cotton, *rabi* onion, soybean, and *suru* sugarcane

Sr. No.	Station	Data Period	Crop water requirement (mm)			
			Cotton	<i>Rabi</i> onion	Soybean	<i>Suru</i> sugarcane
1.	Dhule	1980 - 2017	618.1	338.6	362.9	1448.6
2.	Jalgaon	1980 - 2017	735.6	446.4	412.0	1819.2
3.	Pune	1980 - 2017	570.8	355.7	340.5	1368.1
4.	Rahuri	1980 - 2017	628.9	344.1	386.0	1409.1
5.	Solapur	1980 - 2017	662.4	406.3	402.2	1546.2
6.	Niphad	1980 - 2017	591.2	349.4	347.3	1397.7
7.	Kolhapur	1990 - 2017	488.1	377.4	291.5	1267.6
8.	Padegaon	1990 - 2017	529.0	315.0	326.9	1220.4
9.	K. Digraj	1995 - 2017	557.4	364.1	343.7	1312.0

The average CWR for soybean and *rabi* onion had almost similar range though soybean being slightly lower. The maximum CWR considering all stations was observed for Jalgaon followed by Solapur and Dhule stations. Whereas, the least values in CWR were noted for Kolhapur and Padegaon stations.

5.1.2 Trends in CWR

The results of trend analysis for CWR of cotton using the Mann-Kendall test and Sen's Slope estimator method revealed the decreasing trend in Dhule, Jalgaon, Pune, Rahuri, Niphad, Kolhapur, and Padegaon stations at 5 % significance level except for Solapur and K. Digraj with no trend. The Sen's Slope 'Q' value corresponded to the magnitude of trend for cotton ranged from -1.79 to -7.06 mm/year with the highest decrease i.e. -7.06 mm/year for Jalgaon and lowest i.e. -1.79 mm/year for Pune station. *Rabi* onion had a decreasing trend in CWR for all stations except Padegaon and K. Digraj station showed no trend. The resulted 'Z' value of *rabi* onion was minimum for Dhule (-5.61) followed by Jalgaon (-5.41) which implied a massive decrease in CWR. The 'Q' values for *rabi* onion ranged between -1.53 to -4.65 mm/year. The analysis of trend variation for CWR of soybean was quite similar as of cotton for respective stations in the study period. The 'Q' values for soybean ranged from -1.04 to -4.21 mm/year. The highest and lowest decrease in CWR for soybean was observed for Jalgaon and Pune station, respectively. The result of trend analysis in CWR of *suru* sugarcane revealed significantly decreasing trend at 5 %

significance level for all station except K. Digraj station showed no trend. The magnitude of decrease in CWR for *suru* sugarcane ranged between -4.38 to -18.84 mm/year with maximum and minimum decrease observed for Jalgaon and Pune stations, respectively.

The spatial analysis of resulted 'Z' values of Mann Kendall test for cotton, *rabi* onion, soybean and *suru* sugarcane showed that 'Z' values were minimum at central part of study area, whereas they have been relatively decreased towards north side and relatively increased towards south side of study area. This particularizes there is more decreasing trends towards north part than south part of study area i.e. Western Maharashtra. Considering all crops i.e. cotton, *rabi* onion, soybean and *suru* sugarcane the severity of trend was strong for the *suru* sugarcane due to perennial crop. To support the above mentioned findings, the individual trend analysis of annual mean T_{max} , T_{min} , RH_{max} , RH_{min} , WS, and BSS for Rahuri station during 1980 – 2017 was carried out. It was observed that there was increasing trend for RH_{max} and RH_{min} whereas, decreasing trend for WS and BSS and no trend was observed in T_{max} and T_{min} at 95 % confidence level. Hence, it was concluded that decrease in CWR for Rahuri station was primarily due increase in relative humidity (RH) and decrease in wind speed (WS) and bright sunshine hours (BSS).

5.1.3 Periodic Changes in CWR

The periodic changes in CWR specified decadal variation within successive decades at each stations for cotton, *rabi* onion, soybean and *suru* sugarcane. The resulted range of average CWR of cotton were 595 to 817 mm, 512 to 786 mm, 489 to 678 mm, and 446 to 661 mm during 1980s, 1990s, 2000s and 2010s decades sequentially over study area. The value of percent change in CWR of cotton showed that there was decrease in CWR with respect to decades sequentially for all stations, except Rahuri for the decades 1990s to 2000s; and Solapur, Niphad, and K. Digraj for the decades 2000s to 2010s showed increase in CWR of cotton. The highest decrease in CWR of cotton was observed for Jalgaon (-13.76 %) during 1990s to 2000s, whereas highest increase in CWR (5.20 %) was observed for K. Digraj during 2000s to 2010s decade.

Rabi onion had resulted range of average CWR as 373 to 495 mm, 315 to 478 mm, 318 to 422 mm, and 308 to 381 mm during 1980s, 1990s, 2000s and 2010s decades respectively over study area. It was observed that there was decrease in CWR of *rabi* onion with respect to decades sequentially for all stations, except Rahuri, Padegaon and K. Digraj for the decades 1990s to 2000s; and Niphad for the decades 2000s to 2010s showed increase in CWR. The maximum decrease (-17.57 %) in CWR of *rabi* onion was observed during 1980s–1990s decade for Rahuri station, whereas the maximum increase (4.73 %) in CWR of *rabi* onion was observed and during 1990s to 2000s for Rahuri station.

Soybean had resulted range of average crop water requirement as 357 to 456 mm, 303 to 446 mm, 293 to 394 mm, and 269 to 406 mm during 1980s, 1990s, 2000s and 2010s decades sequentially

over study area. It was observed that there was decrease in CWR of soybean with respect to decades sequentially for all stations, except Rahuri for the decades 1990s to 2000s and Solapur, Niphad and K. Digraj for the decades 2000s to 2010s showed increase in CWR. The percent change in CWR showed the maximum decrease (-11.98 %) for Rahuri during 1980s to 1990s decade and maximum increase (6.53 %) in CWR for K. Digraj during 2000s to 2010s decades.

Suru sugarcane had resulted range of average CWR as 1429 to 2032 mm, 1271 to 1939 mm, 1236 to 1692 mm, and 1125 to 1508 mm during 1980s, 1990s, 2000s and 2010s decades, respectively, over study area. It was observed that there was decrease in CWR of *suru* sugarcane with respect to decades sequentially for all stations, except Rahuri station for the decades 1990s to 2000s; and Solapur, Niphad, and K. Digraj station for the decades 2000s to 2010s showed increase in CWR. The maximum decrease (-14.54 %) during 1980s to 1990s decades and increase (3.48%) in CWR during 1990s to 2000s period was observed for Rahuri station.

The maximum values of decadal average CWR for all crops was observed for Jalgaon followed by Solapur station, whereas least values of CWR was reported for Padegaon, Kolhapur and Pune station. The spatial maps of average CWR for all crops generally revealed increasing values towards the north part of study area and decreasing along central and south region of study area. The spatial maps revealed shifting of CWR from south-east to north-east as proceeded from 1990s, 2000s and 2010s decades sequentially.

5.1.4 Statistical Criteria for Best Model Fit

Selecting a predictor was an important step in the downscaling process. In the downscaling of reference evapotranspiration (ET_0), the predictors with the highest correlation were chosen with minimum or zero p-value and maximum partial r value. Considering all 26 predictors, only six predictors i.e. nceptempas, ncepp_zhas, ncepp_uas, ncepp5_uas, ncepp8_uas, and ncepp8_vas were selected as they were strongly correlated with observed (ET_0). The statistical measures were evaluated using simulated model values with observed data for the same period. It was observed that the values of performance measures as R^2 and E_{ns} were more than 0.60 while the values of RMSE and MAPE were less than 1.32 and 18.19, respectively for selected stations i.e. Pune, Rahuri and Solapur during calibration. The mean, standard deviation and standard error mean suggested that observed and modelled data had almost similar mean, lesser deviation and less error values. Similarly, good agreements were noticed in modeled and observed data during the validation period of the model.

5.1.5 Projected Changes in Reference Evapotranspiration (ET_0)

Using downscaling of ET_0 , the projected changes in ET_0 were observed at three selected stations i.e. Pune, Rahuri and Solapur. The projected changes in ET_0 for Pune station revealed that all months during three future period viz., 2030s, 2050s and 2080s showed increments in ET_0 as

compared to base period, except June, August, and Sept. month which showed relative decrease in ET_0 . The ET_0 would increase during summer, pre-monsoon and winter season whereas, it could decrease during monsoon season. The higher decrease in ET_0 as compared to base period amongst all months would be observed in August.

The changes in projected ET_0 for Rahuri station concluded that maximum and minimum mean monthly ET_0 would be observed in May and December, respectively, under both scenarios i.e. H3A2 and H3B2 during 2030s, 2050s and 2080s. It was also examined that, the ET_0 in future period would increase for all month except August and September as compared to present condition for Rahuri station. In all three future periods, ET_0 would be drastically reduced in the month of August followed by September.

For Solapur station it was envisioned that there would be gradual rise in projected ET_0 during 2030s, 2050s and 2080s period for most of the months. The maximum and minimum mean monthly projected ET_0 would be observed in May and December, respectively, under both scenarios i.e. H3A2 and H3B2. The projected ET_0 during 2030s, 2050s and 2080s compared to base period found decrease in ET_0 values in June, September, and October month under both scenarios with maximum reduction in ET_0 examined in the month of September.

5.1.6 Estimation of Future CWR

Crop evapotranspiration (ET_c) indicated the quantity of water that a type of plant needs throughout its growth season. The future CWR for selected crops were estimated using projected ET_0 values and present value of crop coefficient. It was observed that the crop water requirement of cotton would approximately same (-0.97 to 0.95 % variation) during the periods 2030s, 2050s and 2080s with respect to base period for Pune and Rahuri station, whereas marginally increase (0.91 to 2.48% variation) for all periods at Solapur station.

The CWR of *rabi* onion would advance for all three stations i.e. Pune, Rahuri and Solapur during 2030s, 2050s and 2080s. The CWR would marginally increase (0.49 to 2.48 % variation) during 2030s and 2050, whereas in 2080s period the increment in CWR would be in the range as 3.77 to 4.62 % for all three stations. This could be due to the predominant increase in the ET_0 during winter season under both scenario for all three station.

The CWR of soybean would marginally decrease or approximately same (-2.09 to 0.37 % variation) during 2030s, 2050s and 2080s with respect to base period for Pune and Rahuri station, whereas marginally increase or approximately same (-0.04 to 1.63 % variation) during all three periods for Solapur station.

The CWR of *suru* sugarcane would marginally increase or approximately same (0.05 to 2.37 % variation) during 2030s and 2050 for all three stations i.e. Pune, Rahuri and Solapur, whereas it would relatively increase (1.69 to 2.86 % variation) in 2080s period for all three stations.

5.2 Conclusions

The major findings are concluded as follows

1. The decreasing trends in CWR was observed for all crops i.e. cotton, *rabi* onion, soybean and *suru* sugarcane for all stations i.e. Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon, and K. Digraj excepts no trends in CWR showed for cotton and soybean for Solapur, *rabi* onion for Padegaon and all selected crops for K. Digraj station.
2. Spatial analysis of the trends in CWR is beneficial for planners of all sectors for planning of cotton, *rabi* onion, soybean, and *suru* sugarcane, and identifying the water requirement zones in western Maharashtra for better resource management.
3. Among decadal changes in CWR, there was decrease in CWR varied from -1.57 to -17.57 % for all stations for all crops during 1980s to 1990s decades. For the decades of 1990s to 2000s, it was observed that all stations showed decrease (-1.38 to -15.57 %) in CWR for all crops except Solapur for cotton and soybean, and Rahuri for all crops showed increase in CWR (0.47 to 4.73 %). For decades of 2000s to 2010s, it was observed that all stations showed decrease (-0.11 to -15.50 %) in CWR for all crops, except Solapur and K. Digraj for cotton, soybean and *suru* sugarcane, and Niphad for all crops showed increase in CWR (0.74 to 3.26 %).
4. The highest decrease in CWR i.e. -17.57 % was observed for *rabi* onion crop in Rahuri during decades of 1980s to 1990s. Whereas highest increase in CWR i.e. 6.53 % was observed for soybean crop in K. Digraj during decades of 2000s to 2010s.
5. The SDSM performs satisfactory in downscaling ET_0 with the values more than 0.60 for R^2 and E_{ns} and less than 1.32 and 18%, for RMSE and MAPE, respectively during both calibration and validation periods for selected stations i.e. Pune, Rahuri and Solapur.
6. The projected changes showed increase in ET_0 for all months (in summer, winter and pre-monsoon seasons) except decrease in ET_0 from June to September (monsoon season) during 2030s, 2050s, and 2080s period as compare to base period for Pune, Rahuri and Solapur stations under both H3A2 and H3B2 scenario. This particularizes decrease in projected CWR for *Kharif* season whereas increase in CWR for *rabi* and *summer* season.
7. The variation in estimated future CWR of *Kharif* crop i.e. cotton (-0.97 to 0.95 %) and soybean (-2.09 to 0.37%) showed marginal decrease or approximately same CWR for Pune and Rahuri station whereas, relative increase in CWR of cotton (0.91 to 2.48 %) and

soybean (-0.04 to 1.63 %) for Solapur station during 2030s, 2050s, and 2080s period as compare to base period under both H3A2 and H3B2 scenario.

8. The variation in estimated future CWR of *rabi* crop i.e. onion (0.49 to 4.62 %) and *perennial* crop i.e. *suru* sugarcane (0.05 to 2.86 %) showed gradual increment in CWR during 2030s, 2050s, and 2080s period as compare to base period for Pune, Rahuri and Solapur stations under both H3A2 and H3B2 scenario.

Looking at the impact of the climate variability on crop water requirement, there is a need to promote water saving technologies like drip and sprinkler irrigation systems. Also promote rain-water conservation and increase groundwater recharge in the Western Maharashtra region to minimize the risk of yield reduction and enhance maximum water availability in the study area due to climatic variability.

The finding of this study can be used for leading better irrigation water management and planning, also contingent crop planning during drought periods. In addition to this, it will be useful for designing the small soil and water conservation structures, study of groundwater recharge, surface drainage structures etc.

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7. APPENDICES

Appendix –A

Table A.1 Crop water requirement data (mm) of cotton for western Maharashtra

Year	Dhule	Jalgaon	Pune	Rahuri	Solapur	Niphad	Kolhapur	Padegaon	K. Digraj
1980	673.2	787.6	576.2	641.4	661.3	597.6	NA	NA	NA
1981	633.1	778.5	622.1	750.1	654.1	636.4	NA	NA	NA
1982	689.2	834.9	620.1	783.0	633.7	675.6	NA	NA	NA
1983	647.4	753.6	585.3	676.0	684.4	588.4	NA	NA	NA
1984	678.5	798.9	566.9	723.3	716.7	643.7	NA	NA	NA
1985	711.1	887.4	611.1	732.2	742.6	661.3	NA	NA	NA
1986	715.5	866.2	633.0	721.1	818.8	716.8	NA	NA	NA
1987	697.1	865.3	639.7	695.0	684.9	712.5	NA	NA	NA
1988	612.7	773.2	590.6	612.0	641.1	641.0	NA	NA	NA
1989	640.2	863.6	569.9	639.6	693.0	637.8	NA	NA	NA
1990	623.1	783.3	530.5	591.0	618.9	566.8	522.3	505.5	NA
1991	689.1	840.6	563.7	614.1	671.2	622.2	479.2	533.1	NA
1992	663.3	924.4	629.6	616.8	677.5	632.1	529.7	581.1	NA
1993	668.3	865.9	573.2	606.0	619.2	572.0	507.5	547.7	NA
1994	565.5	687.8	514.7	596.8	679.9	526.6	480.2	512.9	NA
1995	709.8	851.3	626.8	664.2	707.8	722.0	551.5	582.1	624.6
1996	650.0	778.6	564.2	580.9	681.7	638.7	532.1	555.7	605.7

1997	616.9	790.2	619.0	622.5	729.0	646.3	545.4	625.3	550.7
1998	611.3	713.2	560.7	562.9	591.2	604.0	496.1	543.4	559.7
1999	572.5	678.6	547.1	545.3	558.2	544.1	481.9	509.2	531.0
2000	609.1	734.6	588.8	613.7	577.6	563.0	515.5	584.4	583.2
2001	560.1	709.6	536.5	613.9	649.5	540.7	476.0	540.0	589.4
2002	619.0	725.7	581.4	586.5	687.3	579.5	521.0	588.0	549.6
2003	549.9	638.7	575.1	695.0	724.1	494.6	520.0	589.8	540.5
2004	607.1	720.0	570.7	621.0	642.7	558.8	497.4	537.8	545.5
2005	618.0	709.2	522.3	604.9	597.9	527.6	496.4	513.3	513.9
2006	562.5	628.1	517.1	570.0	648.1	480.2	491.0	497.1	499.7
2007	584.1	629.7	553.4	586.9	624.8	531.0	487.0	507.2	496.2
2008	571.4	659.8	543.9	637.1	674.0	548.5	481.1	527.3	527.6
2009	623.2	703.8	565.8	627.0	663.8	619.3	474.4	504.9	555.8
2010	551.0	658.7	541.4	592.3	586.2	558.7	455.3	488.7	576.5
2011	565.2	648.3	514.8	608.2	623.5	541.7	456.8	473.5	541.6
2012	553.2	586.9	567.0	622.4	693.9	562.4	452.0	525.6	550.6
2013	554.4	560.1	520.8	588.6	607.5	479.5	432.2	473.0	550.6
2014	618.6	657.1	575.6	628.9	656.3	553.1	477.7	500.9	607.2
2015	614.4	682.0	594.1	618.0	750.0	634.4	458.2	503.2	617.1
2016	525.5	573.0	528.4	523.1	607.4	547.4	411.0	468.6	528.6
2017	532.6	605.0	550.5	586.9	692.5	561.8	438.2	493.1	576.9
Average	618.1	735.6	570.8	628.9	662.4	591.3	488.1	529.0	557.5

Table A.2 Crop water requirement data (mm) of *rabi* onion for western Maharashtra

Year	Dhule	Jalgaon	Pune	Rahuri	Solapur	Niphad	Kolhapur	Padegaon	K. Digraj
1980	394.2	475.3	371.9	416.4	419.4	387.4	NA	NA	NA
1981	353.2	452.4	372.4	409.5	428.7	376.2	NA	NA	NA
1982	400.1	530.4	323.3	420.2	476.3	366.4	NA	NA	NA
1983	375.7	455.3	359.8	375.3	457.4	360.1	NA	NA	NA
1984	397.0	462.4	363.8	400.6	486.1	374.7	NA	NA	NA
1985	402.1	469.9	368.4	409.1	466.4	394.7	NA	NA	NA
1986	385.1	500.7	397.8	386.4	475.1	436.5	NA	NA	NA
1987	350.0	482.6	365.3	376.5	401.9	376.7	NA	NA	NA
1988	360.3	563.1	412.7	379.7	445.2	366.1	NA	NA	NA
1989	365.8	545.6	391.5	378.2	453.6	388.6	NA	NA	NA
1990	346.0	516.2	377.4	342.1	423.4	374.6	388.3	311.7	NA
1991	363.0	558.9	383.7	347.9	453.1	385.4	403.5	314.2	NA
1992	346.4	532.6	377.1	331.7	454.7	369.8	361.0	313.4	NA
1993	340.7	491.3	343.9	299.9	379.8	342.4	439.8	300.4	NA
1994	328.4	480.1	388.9	319.4	369.8	358.4	363.1	303.2	NA
1995	364.2	460.4	364.9	345.5	419.5	388.3	414.0	318.2	353.9
1996	343.1	461.8	361.2	315.7	366.6	398.0	414.8	305.8	351.7
1997	323.0	421.6	348.4	314.0	385.2	352.9	379.7	330.8	352.4
1998	322.4	442.4	365.2	304.0	369.6	325.8	393.6	327.9	350.6
1999	294.8	475.6	389.7	303.4	377.6	309.2	428.9	311.4	353.9

2000	331.9	461.7	349.4	336.5	371.9	360.7	416.7	330.6	366.3
2001	299.7	442.1	314.6	318.8	361.3	333.8	402.9	332.3	367.2
2002	349.4	476.2	369.4	347.6	405.1	318.5	394.4	343.5	361.8
2003	332.4	422.3	372.0	376.4	420.7	329.8	402.0	319.2	360.8
2004	369.9	447.2	371.9	332.8	419.3	318.0	393.1	315.1	401.6
2005	324.5	440.6	329.1	334.7	382.7	313.6	390.0	311.5	389.6
2006	300.1	405.5	346.5	327.6	386.4	284.4	394.7	323.2	356.4
2007	305.9	414.0	359.2	330.8	393.4	354.3	382.4	310.1	357.4
2008	316.5	408.8	327.6	344.4	391.1	302.5	375.9	308.9	375.6
2009	311.4	367.7	331.9	328.6	356.9	340.5	341.1	316.4	354.8
2010	310.9	400.7	323.3	328.5	369.8	320.1	343.6	303.5	364.5
2011	325.4	424.5	342.8	337.9	385.4	330.2	374.6	311.4	382.4
2012	318.3	444.2	339.5	354.4	392.7	318.7	379.9	305.1	365.4
2013	307.9	383.3	309.0	356.1	374.7	331.3	346.7	296.2	361.6
2014	294.1	316.1	309.9	277.7	377.6	340.0	318.9	277.8	349.2
2015	315.9	295.3	341.9	284.4	413.6	316.6	291.5	324.0	372.3
2016	308.5	283.2	326.1	277.8	343.1	312.9	319.4	324.3	364.5
2017	291.0	352.5	326.7	307.5	385.6	317.7	312.6	331.7	359.3
Average	338.7	446.4	355.7	344.2	406.3	349.4	377.4	315.1	364.1

(*NA – Not available due to unavailability of data)

Table A.3 Crop water requirement data (mm) of soybean for western Maharashtra

Year	Dhule	Jalgaon	Pune	Rahuri	Solapur	Niphad	Kolhapur	Padegaon	K. Digraj
1980	405.4	465.9	344.0	391.8	406.7	349.3	NA	NA	NA
1981	330.2	403.3	378.3	453.6	391.0	356.7	NA	NA	NA
1982	413.6	483.0	389.6	503.6	392.8	411.5	NA	NA	NA
1983	366.5	388.2	333.7	402.6	398.7	338.3	NA	NA	NA
1984	384.8	441.2	333.4	441.6	419.0	356.9	NA	NA	NA
1985	420.5	502.2	369.7	455.8	452.9	388.3	NA	NA	NA
1986	432.0	501.3	387.1	450.3	519.7	431.0	NA	NA	NA
1987	414.8	514.2	399.6	428.3	413.0	425.3	NA	NA	NA
1988	344.3	414.5	337.6	360.0	358.0	364.0	NA	NA	NA
1989	372.0	468.7	339.5	387.2	411.5	374.5	NA	NA	NA
1990	371.6	433.9	315.8	375.9	391.6	332.4	313.4	318.3	NA
1991	420.0	479.4	333.7	388.4	408.3	365.8	278.9	327.0	NA
1992	379.8	508.9	371.5	378.0	405.0	360.9	305.1	361.9	NA
1993	397.1	478.2	338.5	375.0	370.9	340.2	294.4	337.6	NA
1994	321.8	375.6	299.8	368.5	425.1	296.7	290.2	318.5	NA
1995	424.7	494.5	374.4	406.8	420.4	431.9	322.7	360.6	384.3
1996	377.1	433.4	334.3	347.8	406.4	364.5	313.6	340.0	373.2
1997	363.4	451.6	380.9	388.7	455.8	381.9	327.0	395.5	339.9
1998	347.4	385.2	328.9	335.6	350.3	342.8	286.1	325.0	344.6
1999	348.2	396.6	333.9	341.7	345.2	346.1	295.9	321.8	323.8

2000	381.3	456.5	367.4	391.2	355.6	347.4	322.5	373.4	366.8
2001	338.1	424.8	323.0	382.8	395.8	332.4	287.3	338.2	371.0
2002	360.7	390.7	352.0	372.9	422.9	339.2	313.5	372.8	339.3
2003	313.4	343.5	340.7	421.0	438.9	285.6	309.6	368.7	330.4
2004	355.3	411.5	350.4	387.7	399.6	335.8	303.9	342.8	335.4
2005	360.1	392.5	301.5	361.1	351.4	296.6	293.8	308.9	305.0
2006	321.9	341.3	302.9	344.0	401.8	278.1	291.2	301.2	305.2
2007	348.4	350.9	330.1	359.1	383.3	312.3	292.4	306.0	302.6
2008	341.0	360.6	324.1	384.5	402.1	319.2	287.3	328.8	315.8
2009	369.1	384.9	332.6	371.3	404.4	362.9	278.1	301.6	340.9
2010	320.1	364.6	325.0	354.6	346.3	325.8	273.1	297.0	360.4
2011	327.6	356.8	311.5	369.8	375.3	316.7	277.0	293.9	329.5
2012	316.5	306.8	332.3	375.0	421.8	318.8	257.0	318.6	338.3
2013	337.9	328.1	320.7	360.3	373.9	293.7	266.8	300.2	341.5
2014	368.3	367.7	339.9	376.4	387.0	330.3	284.4	314.9	376.5
2015	383.8	414.7	357.0	393.6	486.8	391.6	274.7	309.9	389.5
2016	300.8	308.8	291.0	320.3	365.8	318.9	250.1	277.6	322.3
2017	313.9	333.7	314.4	364.1	431.7	334.2	272.7	295.0	367.9
Average	363.0	412.1	340.5	386.1	402.3	347.3	291.5	327.0	343.7

*NA – Not available due to unavailability of data

Table A.4 Crop water requirement data (mm) of *suru* sugarcane for western Maharashtra

Year	Dhule	Jalgaon	Pune	Rahuri	Solapur	Niphad	Kolhapur	Padegaon	K. Digraj
1980	1646.9	1966.8	1401.9	1549.1	1534.1	1464.9	NA	NA	NA
1981	1588.3	1956.5	1451.1	1693.2	1548.0	1545.3	NA	NA	NA
1982	1583.9	2016.9	1409.4	1698.4	1590.4	1504.9	NA	NA	NA
1983	1565.4	1994.6	1428.7	1574.4	1694.4	1442.1	NA	NA	NA
1984	1641.2	1942.3	1383.1	1632.1	1761.0	1552.4	NA	NA	NA
1985	1666.9	2078.5	1428.2	1631.1	1719.2	1554.8	NA	NA	NA
1986	1676.9	2114.0	1523.5	1591.4	1859.2	1717.8	NA	NA	NA
1987	1590.4	2021.9	1486.9	1536.9	1631.6	1601.1	NA	NA	NA
1988	1506.4	2033.2	1466.8	1457.7	1604.0	1543.4	NA	NA	NA
1989	1509.6	2171.0	1401.2	1465.8	1645.6	1505.5	NA	NA	NA
1990	1464.7	2059.2	1344.4	1356.1	1497.5	1420.9	1342.8	1181.9	NA
1991	1534.9	2094.7	1392.7	1365.6	1605.4	1491.6	1282.2	1238.6	NA
1992	1535.5	2271.7	1477.8	1383.3	1640.6	1488.0	1368.6	1293.3	NA
1993	1539.3	2133.9	1369.4	1323.5	1513.3	1415.3	1402.8	1243.7	NA
1994	1406.9	1807.0	1327.3	1337.7	1456.0	1355.7	1278.9	1200.6	NA
1995	1560.8	1939.8	1425.1	1424.0	1621.4	1584.6	1408.3	1284.3	1412.7
1996	1523.8	1946.9	1383.5	1336.5	1562.8	1542.7	1415.5	1265.3	1390.8
1997	1418.4	1830.5	1399.3	1326.2	1561.4	1500.7	1365.9	1349.5	1304.1
1998	1435.4	1802.7	1368.5	1278.3	1453.9	1395.2	1338.6	1308.0	1300.7
1999	1332.2	1775.7	1373.5	1223.0	1359.2	1233.3	1326.1	1203.5	1246.0

2000	1364.3	1787.2	1378.7	1353.4	1387.4	1247.1	1358.2	1324.0	1331.2
2001	1324.0	1775.4	1312.5	1359.3	1441.3	1287.0	1299.8	1271.6	1341.0
2002	1442.9	1839.1	1373.7	1261.6	1531.3	1349.4	1350.6	1329.6	1306.9
2003	1367.7	1684.1	1398.5	1553.4	1644.4	1223.1	1347.5	1312.6	1291.5
2004	1444.9	1772.4	1373.0	1386.5	1539.0	1290.5	1301.8	1216.6	1335.1
2005	1408.6	1726.8	1277.5	1370.9	1438.5	1217.0	1282.4	1204.2	1293.8
2006	1359.2	1628.3	1286.8	1322.3	1468.6	1170.4	1281.7	1189.4	1224.2
2007	1346.5	1609.5	1338.5	1339.5	1459.8	1280.7	1263.9	1225.0	1233.8
2008	1335.5	1636.8	1296.1	1414.3	1530.0	1294.5	1233.1	1233.7	1292.5
2009	1418.4	1636.4	1309.7	1428.1	1489.6	1424.6	1201.1	1207.0	1331.7
2010	1331.1	1619.8	1292.1	1380.4	1409.9	1345.7	1163.5	1177.0	1331.2
2011	1354.4	1655.2	1257.7	1381.6	1467.8	1300.6	1187.2	1095.1	1305.6
2012	1327.7	1518.0	1345.4	1375.2	1544.6	1336.7	1211.3	1178.6	1301.3
2013	1289.1	1478.5	1253.0	1390.3	1448.8	1192.4	1138.0	1096.1	1307.3
2014	1351.8	1530.9	1326.5	1367.9	1487.2	1280.5	1173.0	1099.7	1349.9
2015	1344.7	1484.0	1334.4	1266.9	1641.2	1403.9	1070.5	1149.2	1363.8
2016	1260.6	1354.9	1280.3	1146.6	1426.1	1306.4	1053.9	1119.1	1286.4
2017	1249.9	1436.3	1311.2	1262.0	1541.8	1300.8	1045.8	1174.1	1294.7
Average	1448.7	1819.2	1368.1	1409.1	1546.2	1397.7	1267.6	1220.4	1312.0

*NA – Not available due to unavailability of data

Appendix B

1). Cotton

Table B.1 Estimation of future CWR of cotton under H3A2 scenario

Pune station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	7.43	7.60	7.76	7.90	0.38	2.80	2.87	2.93	2.98
Jun	5.55	5.27	5.29	5.45	0.51	2.85	2.71	2.72	2.80
Jul	3.79	3.86	3.88	3.94	0.94	3.58	3.65	3.66	3.73
Aug	3.54	3.40	3.25	3.41	1.02	3.61	3.46	3.31	3.48
Sep	3.91	3.87	3.91	3.90	1.02	3.98	3.94	3.98	3.98
Oct	3.91	3.91	4.04	3.91	0.61	2.38	2.38	2.46	2.38
Nov	3.48	3.49	3.69	3.63	0.42	1.47	1.47	1.56	1.53
Total						20.67	20.47	20.61	20.87
CWR (Total * 30 days)						620.16	614.22	618.40	626.09
Rahuri station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	7.54	7.62	7.59	7.78	0.38	2.85	2.87	2.86	2.93
Jun	5.97	5.98	6.12	6.13	0.51	3.07	3.07	3.14	3.15
Jul	4.51	4.54	4.60	4.83	0.94	4.26	4.29	4.35	4.56
Aug	4.25	4.12	4.06	4.01	1.02	4.33	4.19	4.14	4.09
Sep	3.97	4.05	3.79	3.81	1.02	4.04	4.12	3.86	3.88
Oct	4.01	4.12	4.10	4.08	0.61	2.44	2.51	2.50	2.49
Nov	3.38	3.56	3.42	3.43	0.42	1.43	1.50	1.44	1.45
Total						22.41	22.57	22.29	22.54
CWR (Total * 30 days)						672.33	677.05	668.59	676.34
Solapur station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	8.25	8.84	8.62	8.52	0.38	3.11	3.33	3.25	3.21
Jun	5.84	5.75	5.70	5.71	0.51	3.00	2.95	2.93	2.93
Jul	4.72	4.99	5.05	5.15	0.94	4.46	4.71	4.77	4.86
Aug	4.37	4.35	4.50	4.42	1.02	4.45	4.43	4.58	4.50
Sep	4.44	4.39	4.26	4.11	1.02	4.52	4.47	4.34	4.19
Oct	4.37	4.37	4.34	4.32	0.61	2.67	2.66	2.65	2.64
Nov	4.06	4.18	4.32	4.28	0.42	1.71	1.76	1.82	1.80
Total						23.92	24.33	24.33	24.14
CWR (Total * 30 days)						717.61	729.81	730.02	724.21

Table B.2 Estimation of future CWR of cotton under H3B2 scenario

Pune station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	7.43	7.60	7.76	7.90	0.38	2.80	2.87	2.93	2.98
Jun	5.55	5.27	5.29	5.45	0.51	2.85	2.71	2.72	2.80
Jul	3.79	3.86	3.88	3.94	0.94	3.58	3.65	3.66	3.73
Aug	3.54	3.40	3.25	3.41	1.02	3.61	3.46	3.31	3.48
Sep	3.91	3.87	3.91	3.90	1.02	3.98	3.94	3.98	3.98
Oct	3.91	3.91	4.04	3.91	0.61	2.38	2.38	2.46	2.38
Nov	3.48	3.49	3.69	3.63	0.42	1.47	1.47	1.56	1.53
Total						20.67	20.47	20.61	20.87
CWR (Total * 30 days)						620.16	614.22	618.40	626.09
Rahuri station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	7.54	7.51	7.56	7.80	0.38	2.85	2.83	2.85	2.94
Jun	5.97	6.00	6.02	6.20	0.51	3.07	3.08	3.09	3.18
Jul	4.51	4.56	4.60	4.67	0.94	4.26	4.31	4.35	4.41
Aug	4.25	4.05	4.00	4.03	1.02	4.33	4.13	4.07	4.10
Sep	3.97	3.95	3.76	3.72	1.02	4.04	4.03	3.83	3.79
Oct	4.01	4.22	4.32	4.09	0.61	2.44	2.57	2.63	2.49
Nov	3.38	3.45	3.41	3.42	0.42	1.43	1.46	1.44	1.44
Total						22.41	22.40	22.26	22.36
CWR (Total * 30 days)						672.33	672.02	667.78	670.83
Solapur station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	8.25	8.69	8.74	8.52	0.38	3.11	3.28	3.30	3.21
Jun	5.84	5.80	5.79	5.73	0.51	3.00	2.98	2.98	2.94
Jul	4.72	5.02	5.12	5.09	0.94	4.46	4.74	4.84	4.81
Aug	4.37	4.35	4.46	4.69	1.02	4.45	4.43	4.55	4.77
Sep	4.44	4.32	4.31	4.17	1.02	4.52	4.40	4.39	4.24
Oct	4.37	4.38	4.37	4.30	0.61	2.67	2.67	2.66	2.62
Nov	4.06	4.18	4.31	4.46	0.42	1.71	1.76	1.82	1.88
Total						23.92	24.26	24.53	24.48
CWR (Total * 30 days)						717.61	727.86	735.88	734.45

2). *Rabi* OnionTable B.3 Estimation of future CWR of *rabi* onion under H3A2 scenario

Pune station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Oct	3.91	3.91	4.04	3.91	0.65	2.52	2.52	2.61	2.52
Nov	3.48	3.49	3.69	3.63	0.83	2.90	2.91	3.07	3.02
Dec	3.08	3.18	3.27	3.37	1.14	3.50	3.61	3.72	3.83
Jan	3.27	3.33	3.34	3.36	1.06	3.47	3.52	3.54	3.55
Feb	4.29	4.36	4.40	4.44	0.44	1.91	1.94	1.96	1.97
Total						14.30	14.51	14.90	14.89
CWR (Total * 30 days)						428.89	435.17	446.96	446.84
Rahuri station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Oct	4.01	4.12	4.10	4.08	0.65	2.59	2.66	2.65	2.63
Nov	3.38	3.56	3.42	3.43	0.83	2.82	2.97	2.85	2.86
Dec	2.98	2.98	3.16	3.22	1.14	3.38	3.39	3.58	3.65
Jan	3.40	3.44	3.51	3.57	1.06	3.60	3.65	3.72	3.78
Feb	4.26	4.34	4.41	4.60	0.44	1.89	1.93	1.96	2.04
Total						14.28	14.60	14.76	14.97
CWR (Total * 30 days)						428.33	437.85	442.68	449.07
Solapur station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Oct	4.37	4.37	4.34	4.32	0.65	2.82	2.82	2.80	2.79
Nov	4.06	4.18	4.32	4.28	0.83	3.38	3.48	3.60	3.56
Dec	3.90	4.00	3.91	4.15	1.14	4.43	4.54	4.44	4.72
Jan	4.49	4.40	4.47	4.66	1.06	4.76	4.66	4.73	4.93
Feb	5.71	5.82	5.85	5.92	0.44	2.54	2.59	2.60	2.63
Total						17.93	18.09	18.18	18.64
CWR (Total * 30 days)						537.89	542.67	545.33	559.12

Table B.4 Estimation of future CWR of *rabi* onion under H3B2 scenario

Pune station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Oct	3.91	3.92	3.92	4.05	0.65	2.52	2.53	2.53	2.61
Nov	3.48	3.55	3.57	3.62	0.83	2.90	2.96	2.97	3.01
Dec	3.08	3.17	3.28	3.30	1.14	3.50	3.60	3.73	3.74
Jan	3.27	3.32	3.35	3.41	1.06	3.47	3.51	3.55	3.61
Feb	4.29	4.34	4.38	4.46	0.44	1.91	1.93	1.95	1.98
Total						14.30	14.53	14.73	14.96
CWR (Total * 30 days)						428.89	436.02	441.84	448.79
Rahuri station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Oct	4.01	4.22	4.32	4.09	0.65	2.59	2.72	2.79	2.64
Nov	3.38	3.45	3.41	3.42	0.83	2.82	2.87	2.84	2.85
Dec	2.98	3.01	3.21	3.16	1.14	3.38	3.41	3.65	3.59
Jan	3.40	3.48	3.45	3.48	1.06	3.60	3.68	3.66	3.69
Feb	4.26	4.38	4.37	4.65	0.44	1.89	1.95	1.94	2.07
Total						14.28	14.64	14.87	14.84
CWR (Total * 30 days)						428.33	439.24	446.22	445.11
Solapur station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Oct	4.37	4.38	4.37	4.30	0.65	2.82	2.83	2.82	2.77
Nov	4.06	4.18	4.31	4.46	0.83	3.38	3.48	3.59	3.71
Dec	3.90	3.91	3.88	3.99	1.14	4.43	4.44	4.41	4.53
Jan	4.49	4.41	4.56	4.77	1.06	4.76	4.66	4.82	5.05
Feb	5.71	5.85	5.88	5.99	0.44	2.54	2.60	2.61	2.66
Total						17.93	18.02	18.26	18.74
CWR (Total * 30 days)						537.89	540.55	547.77	562.07

Table B.5 Estimation of future CWR of soybean under H3A2 scenario

Pune station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	3.79	3.86	3.88	3.94	0.66	2.52	2.57	2.58	2.62
June	3.54	3.40	3.25	3.41	0.92	3.25	3.12	2.98	3.13
July	3.91	3.87	3.91	3.90	0.92	3.59	3.55	3.59	3.58
Aug	3.91	3.91	4.04	3.91	0.67	2.62	2.62	2.71	2.62
Total						11.97	11.85	11.85	11.95
CWR (Total * 30 days)						359.21	355.48	355.47	358.62
Rahuri station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	4.51	4.54	4.60	4.83	0.66	3.00	3.02	3.06	3.21
June	4.25	4.12	4.06	4.01	0.92	3.90	3.78	3.73	3.68
July	3.97	4.05	3.79	3.81	0.92	3.64	3.71	3.47	3.50
Aug	4.01	4.12	4.10	4.08	0.67	2.69	2.76	2.75	2.73
Total						13.22	13.27	13.01	13.12
CWR (Total * 30 days)						396.61	398.07	390.16	393.53
Solapur station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	4.72	4.99	5.05	5.15	0.66	3.14	3.32	3.36	3.42
June	4.37	4.35	4.50	4.42	0.92	4.01	3.99	4.12	4.06
July	4.44	4.39	4.26	4.11	0.92	4.07	4.03	3.90	3.77
Aug	4.37	4.37	4.34	4.32	0.67	2.93	2.93	2.91	2.90
Total						14.15	14.26	14.30	14.14
CWR (Total * 30 days)						424.46	427.75	428.85	424.30

Table B.6 Estimation of future CWR of soybean under H3B2 scenario

Pune station									
Mean monthly ET₀ (mm/day)					Mean monthly Kc	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	3.79	3.87	3.87	3.88	0.66	2.52	2.57	2.57	2.58
June	3.54	3.32	3.26	3.30	0.92	3.25	3.05	2.99	3.03
July	3.91	3.90	3.92	3.99	0.92	3.59	3.58	3.60	3.66
Aug	3.91	3.92	3.92	4.05	0.67	2.62	2.63	2.62	2.71
Total						11.97	11.83	11.78	11.98
CWR (Total * 30 days)						359.21	354.76	353.30	359.42
Rahuri station									
Mean monthly ET₀ (mm/day)					Mean monthly Kc	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	4.51	4.56	4.60	4.67	0.66	3.00	3.03	3.06	3.10
June	4.25	4.05	4.00	4.03	0.92	3.90	3.72	3.67	3.69
July	3.97	3.95	3.76	3.72	0.92	3.64	3.63	3.44	3.42
Aug	4.01	4.22	4.32	4.09	0.67	2.69	2.83	2.90	2.74
Total						13.22	13.20	13.06	12.95
CWR (Total * 30 days)						396.61	395.98	391.89	388.47
Solapur station									
Mean monthly ET₀ (mm/day)					Mean monthly Kc	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
May	4.72	5.02	5.12	5.09	0.66	3.14	3.34	3.41	3.38
June	4.37	4.35	4.46	4.69	0.92	4.01	3.99	4.09	4.30
July	4.44	4.32	4.31	4.17	0.92	4.07	3.96	3.95	3.82
Aug	4.37	4.38	4.37	4.30	0.67	2.93	2.93	2.93	2.88
Total						14.15	14.22	14.38	14.38
CWR (Total * 30 days)						424.46	426.67	431.39	431.49

Table B.7 Estimation of future CWR of *suru* sugarcane under H3A2 scenario

Pune station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Jan	3.27	3.33	3.34	3.36	0.66	2.17	2.20	2.21	2.22
Feb	4.29	4.36	4.40	4.44	0.41	1.76	1.79	1.81	1.82
Mar	5.52	5.62	5.70	5.77	0.51	2.80	2.85	2.89	2.92
April	6.81	6.93	7.12	7.25	0.64	4.33	4.41	4.53	4.62
May	7.43	7.60	7.76	7.90	0.78	5.79	5.93	6.05	6.16
Jun	5.55	5.27	5.29	5.45	0.92	5.12	4.86	4.88	5.03
Jul	3.79	3.86	3.88	3.94	1.05	3.97	4.05	4.06	4.13
Aug	3.54	3.40	3.25	3.41	1.19	4.22	4.05	3.87	4.07
Sep	3.91	3.87	3.91	3.90	1.19	4.66	4.61	4.66	4.65
Oct	3.91	3.91	4.04	3.91	1.18	4.62	4.62	4.78	4.62
Nov	3.48	3.49	3.69	3.63	1.10	3.83	3.84	4.06	3.99
Dec	3.08	3.18	3.27	3.37	0.94	2.88	2.98	3.06	3.15
Total						46.15	46.17	46.86	47.38
CWR (Total * 30 days)						1384.55	1385.23	1405.82	1421.45
Rahuri station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Jan	3.40	3.44	3.51	3.57	0.66	2.25	2.28	2.32	2.36
Feb	4.26	4.34	4.41	4.60	0.41	1.75	1.78	1.81	1.88
Mar	5.51	5.47	5.50	5.46	0.51	2.80	2.77	2.79	2.77
April	6.56	6.78	6.76	7.49	0.64	4.17	4.32	4.30	4.76
May	7.54	7.62	7.59	7.78	0.78	5.88	5.95	5.92	6.07
Jun	5.97	5.98	6.12	6.13	0.92	5.51	5.52	5.64	5.65
Jul	4.51	4.54	4.60	4.83	1.05	4.72	4.75	4.82	5.06
Aug	4.25	4.12	4.06	4.01	1.19	5.07	4.91	4.84	4.78
Sep	3.97	4.05	3.79	3.81	1.19	4.73	4.82	4.51	4.54
Oct	4.01	4.12	4.10	4.08	1.18	4.74	4.87	4.85	4.82
Nov	3.38	3.56	3.42	3.43	1.10	3.72	3.92	3.76	3.78
Dec	2.98	2.98	3.16	3.22	0.94	2.79	2.79	2.95	3.01
Total						48.12	48.69	48.52	49.49
CWR (Total * 30 days)						1443.53	1460.59	1455.60	1484.58
Solapur station									
Mean monthly ET ₀ (mm/day)					Mean monthly K _c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Jan	4.49	4.40	4.47	4.66	0.66	2.97	2.91	2.96	3.08
Feb	5.71	5.82	5.85	5.92	0.41	2.34	2.39	2.40	2.43
Mar	6.77	6.87	6.96	7.03	0.51	3.43	3.48	3.53	3.56
April	8.00	8.14	8.27	8.47	0.64	5.09	5.18	5.27	5.39

May	8.25	8.84	8.62	8.52	0.78	6.44	6.90	6.72	6.65
Jun	5.84	5.75	5.70	5.71	0.92	5.38	5.30	5.25	5.27
Jul	4.72	4.99	5.05	5.15	1.05	4.95	5.22	5.29	5.39
Aug	4.37	4.35	4.50	4.42	1.19	5.21	5.18	5.36	5.27
Sep	4.44	4.39	4.26	4.11	1.19	5.29	5.23	5.07	4.90
Oct	4.37	4.37	4.34	4.32	1.18	5.17	5.16	5.13	5.11
Nov	4.06	4.18	4.32	4.28	1.10	4.47	4.60	4.76	4.71
Dec	3.90	4.00	3.91	4.15	0.94	3.65	3.74	3.66	3.88
Total						54.39	55.30	55.40	55.64
CWR (Total * 30 days)						1631.57	1659.07	1662.03	1669.31

Table B.8 Estimation of future CWR of *suru* sugarcane under H3B2 scenario

Pune station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Jan	3.27	3.32	3.35	3.41	0.66	2.17	2.19	2.22	2.25
Feb	4.29	4.34	4.38	4.46	0.41	1.76	1.78	1.80	1.83
Mar	5.52	5.64	5.67	5.74	0.51	2.80	2.86	2.88	2.91
April	6.81	6.95	6.96	7.07	0.64	4.33	4.42	4.43	4.50
May	7.43	7.55	7.69	7.62	0.78	5.79	5.89	6.00	5.94
Jun	5.55	5.35	5.29	5.41	0.92	5.12	4.93	4.88	4.99
Jul	3.79	3.87	3.87	3.88	1.05	3.97	4.05	4.05	4.07
Aug	3.54	3.32	3.26	3.30	1.19	4.22	3.96	3.88	3.93
Sep	3.91	3.90	3.92	3.99	1.19	4.66	4.65	4.67	4.76
Oct	3.91	3.92	3.92	4.05	1.18	4.62	4.64	4.63	4.78
Nov	3.48	3.55	3.57	3.62	1.10	3.83	3.91	3.93	3.98
Dec	3.08	3.17	3.28	3.30	0.94	2.88	2.97	3.07	3.09
Total						46.15	46.26	46.43	47.03
CWR (Total * 30 days)						1384.55	1387.74	1392.93	1410.79
Rahuri station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Jan	3.40	3.48	3.45	3.48	0.66	2.25	2.30	2.28	2.30
Feb	4.26	4.38	4.37	4.65	0.41	1.75	1.80	1.79	1.91
Mar	5.51	5.53	5.50	5.78	0.51	2.80	2.80	2.79	2.93
April	6.56	6.64	6.76	6.80	0.64	4.17	4.23	4.30	4.33
May	7.54	7.51	7.56	7.80	0.78	5.88	5.86	5.90	6.08
Jun	5.97	6.00	6.02	6.20	0.92	5.51	5.53	5.55	5.71
Jul	4.51	4.56	4.60	4.67	1.05	4.72	4.78	4.82	4.89
Aug	4.25	4.05	4.00	4.03	1.19	5.07	4.83	4.76	4.80
Sep	3.97	3.95	3.76	3.72	1.19	4.73	4.71	4.48	4.44
Oct	4.01	4.22	4.32	4.09	1.18	4.74	4.98	5.11	4.83

Nov	3.38	3.45	3.41	3.42	1.10	3.72	3.80	3.76	3.77
Dec	2.98	3.01	3.21	3.16	0.94	2.79	2.81	3.00	2.96
Total						48.12	48.43	48.55	48.95
CWR (Total * 30 days)						1443.53	1452.82	1456.35	1468.37
Solapur station									
Mean monthly ET₀ (mm/day)					Mean monthly K_c	Mean Monthly CWR (mm/day)			
Months	Obs	2030s	2050s	2080s		Obs	2030s	2050s	2080s
Jan	4.49	4.41	4.56	4.77	0.66	2.97	2.91	3.01	3.16
Feb	5.71	5.85	5.88	5.99	0.41	2.34	2.40	2.41	2.46
Mar	6.77	6.89	6.95	7.00	0.51	3.43	3.49	3.52	3.55
April	8.00	8.14	8.22	8.31	0.64	5.09	5.18	5.23	5.29
May	8.25	8.69	8.74	8.52	0.78	6.44	6.78	6.82	6.65
Jun	5.84	5.80	5.79	5.73	0.92	5.38	5.35	5.34	5.29
Jul	4.72	5.02	5.12	5.09	1.05	4.95	5.26	5.37	5.33
Aug	4.37	4.35	4.46	4.69	1.19	5.21	5.18	5.32	5.59
Sep	4.44	4.32	4.31	4.17	1.19	5.29	5.15	5.13	4.97
Oct	4.37	4.38	4.37	4.30	1.18	5.17	5.17	5.17	5.08
Nov	4.06	4.18	4.31	4.46	1.10	4.47	4.61	4.75	4.91
Dec	3.90	3.91	3.88	3.99	0.94	3.65	3.66	3.63	3.73
Total						54.39	55.14	55.71	55.99
CWR (Total * 30 days)						1631.57	1654.22	1671.21	1679.61

Appendix C

Snapshots of process involved in downscaling of 'reference evapotranspiration (ET₀)' in SDSM.

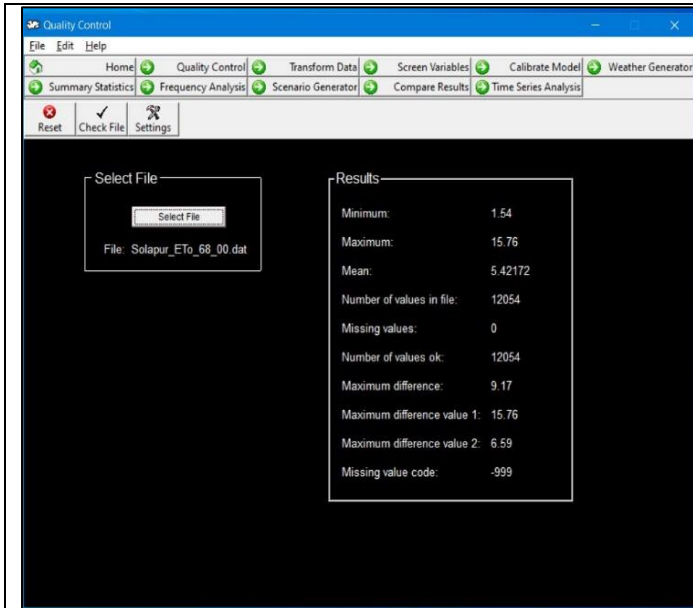


Plate C. 1 Quality control

Pre-checking data is done to analyze maximum, minimum, missing values, etc. of observed data

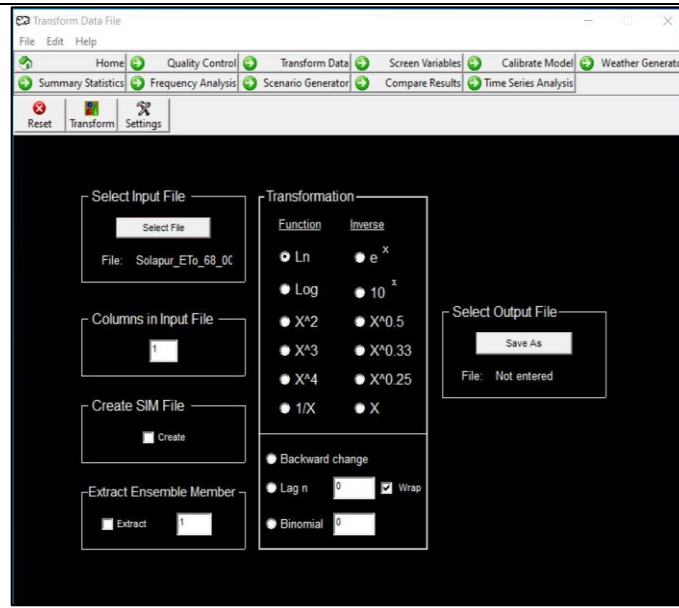


Plate C. 2 Data transformation

Data transformation to ln, log, exponential function, etc. is done in data transformation window.

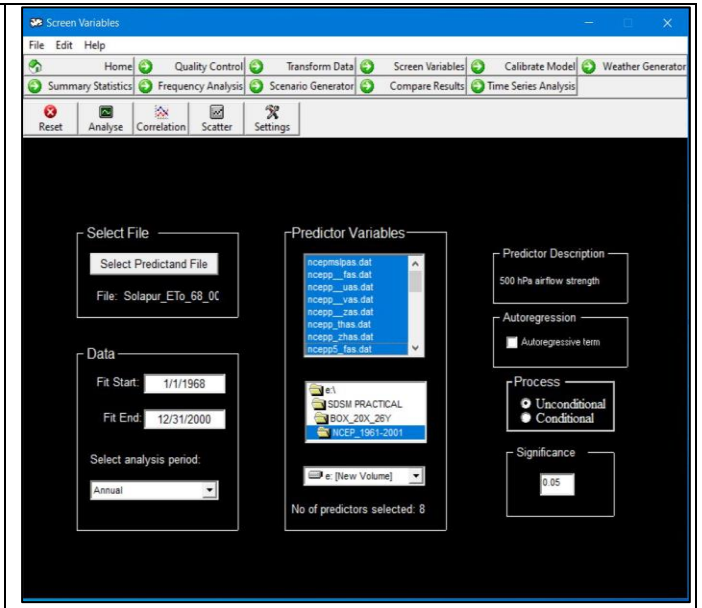


Plate C. 3 Screening of variables

Analyzing physical link between observed and model data as well selection of predictors are done in screen variable window.

Screen Variable

- P values - Minimum or Zero
- Partial r values - Maximum

PARTIAL CORRELATIONS WITH pune_70_00.dat

	Partial r	P value
nceptmslpas.dat	-0.139	0.0000
nceptp_fas.dat	0.035	0.0005
nceptp_uas.dat	0.138	0.0000
nceptp_vas.dat	-0.095	0.0000
nceptp_zas.dat	0.058	0.0000
nceptp_thas.dat	-0.030	0.0030
nceptp_zhas.dat	0.062	0.0000
nceptp5_fas.dat	-0.182	0.0000
nceptp5_uas.dat	0.119	0.0000
nceptp5_vas.dat	0.062	0.0000
nceptp5_zas.dat	-0.071	0.0000

PARTIAL CORRELATIONS WITH pune_70_00.dat

	Partial r	P value
nceptp500as.dat	0.205	0.0000
nceptp5thas.dat	-0.122	0.0000
nceptp5zhas.dat	-0.136	0.0000
nceptp8_fas.dat	-0.015	0.1478
nceptp8_uas.dat	0.084	0.0000
nceptp8_vas.dat	0.077	0.0000
nceptp8_zas.dat	-0.213	0.0000
nceptp850as.dat	-0.185	0.0000
nceptp8thas.dat	-0.070	0.0000
nceptp8zhas.dat	0.121	0.0000
nceptp500as.dat	-0.182	0.0000

PARTIAL CORRELATIONS WITH pune_70_00.dat

	Partial r	P value
nceptp_uas.dat	0.185	0.0000
nceptp5_uas.dat	0.244	0.0000
nceptp500as.dat	-0.033	0.0014
nceptp8zhas.dat	-0.034	0.0007
nceptp8humas.dat	-0.248	0.0000
nceptmpas.dat	0.494	0.0000

Selected parameter are:

- nceptp_uas = 0.138
- nceptp5_uas = 0.119

Selected parameter are:

- nceptp500as = 0.205
- nceptp8zhas = 0.121

Final selected parameter are:

- nceptmpas = 0.205
- nceptp5_uas = 0.121
- nceptp_uas = 0.138

	Partial r	P value
nceptp850as.dat	-0.358	0.0000
nceptp8humas.dat	0.154	0.0000
nceptp8shumas.dat	-0.128	0.0000
nceptp8mpas.dat	0.449	0.0000

Selected parameter are:

- nceptmpas = 0.449
- nceptp8humas = 0.154

Plate C. 4 Screening and selection of Predictors based on partial r values

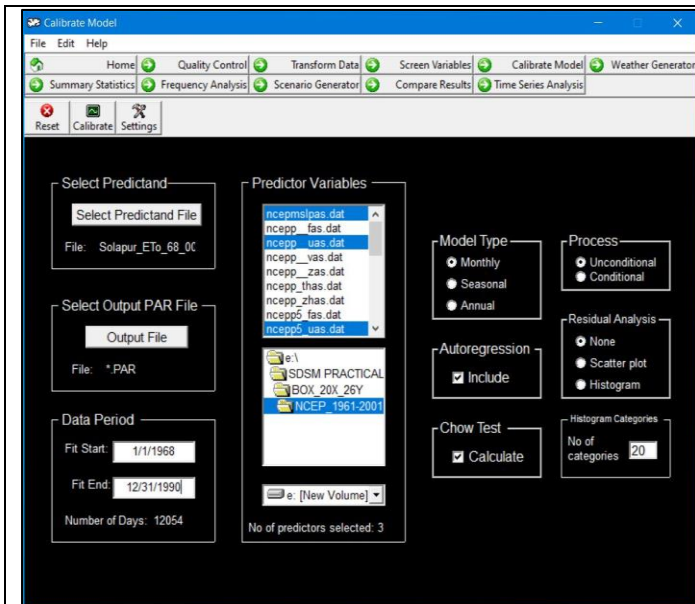


Plate C. 5 Calibration of Model

Building a model based on predictant – predictor data for downscaling

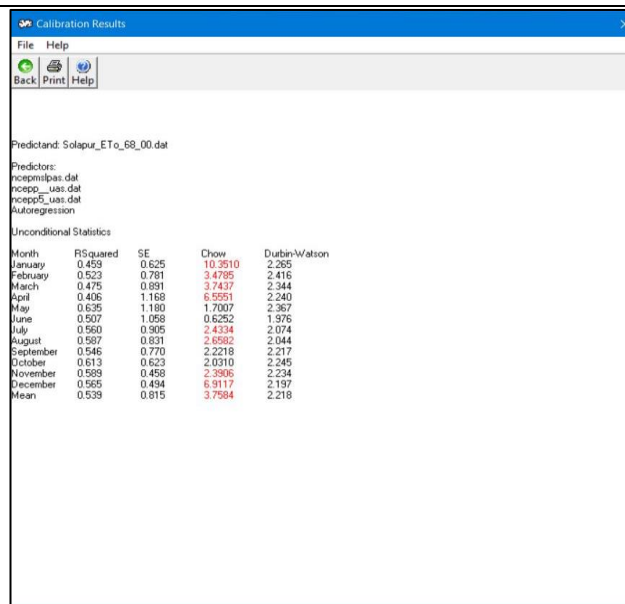


Plate C.6 Generated (.PAR) file

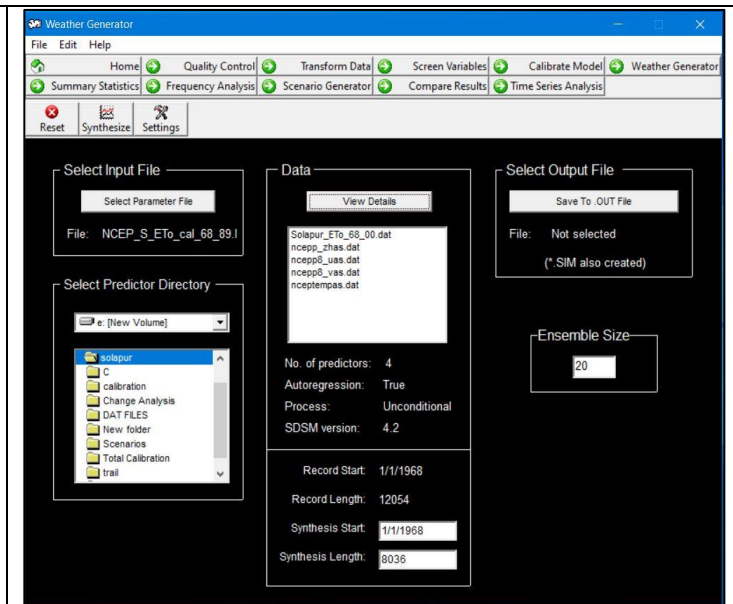


Plate C.7 Weather generation

Downscaling for observed period using NCEP and GCM data for statistical performance analysis. If statistical parameters i.e. (R^2 , E_{ns} , MAPE, RMSE, MAD, etc.) are not valid, again screening is done with different predictors.

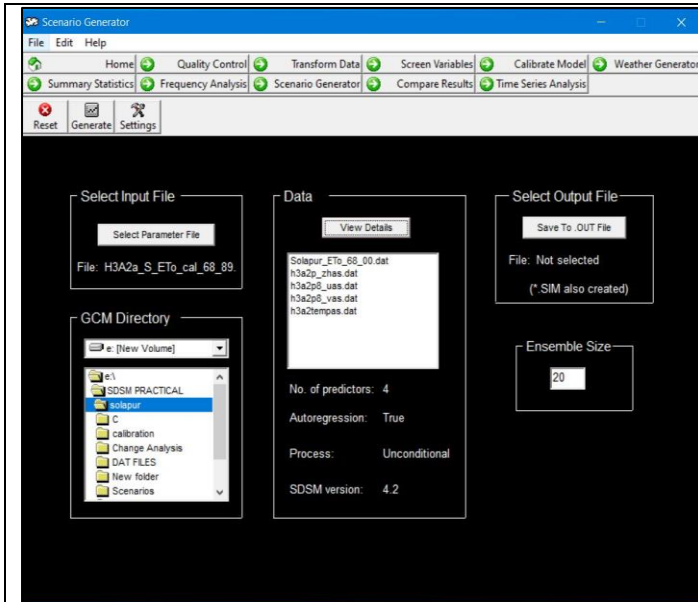


Plate C.8 Generation of future scenario.

If the statistical parameters are valid and acceptable the selected predictors are used for further downscaling else the process is repeated again unless getting the appropriate predictors.

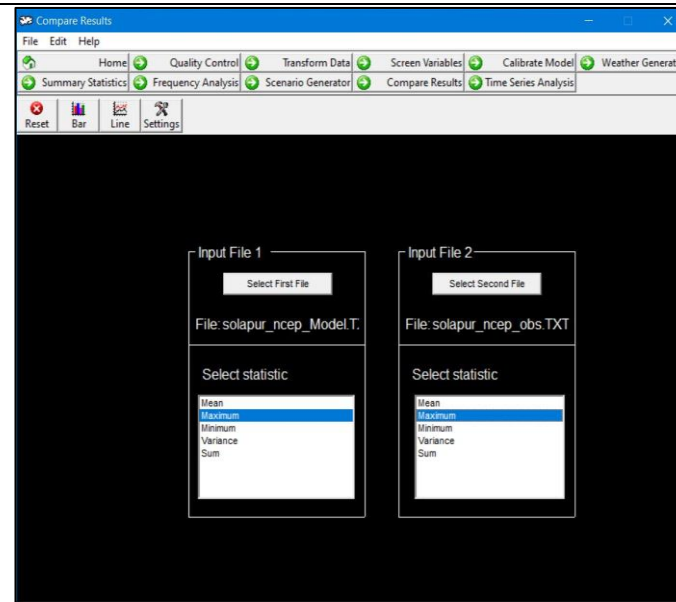


Plate C.9 Results comparison window

Comparison between two time periods.

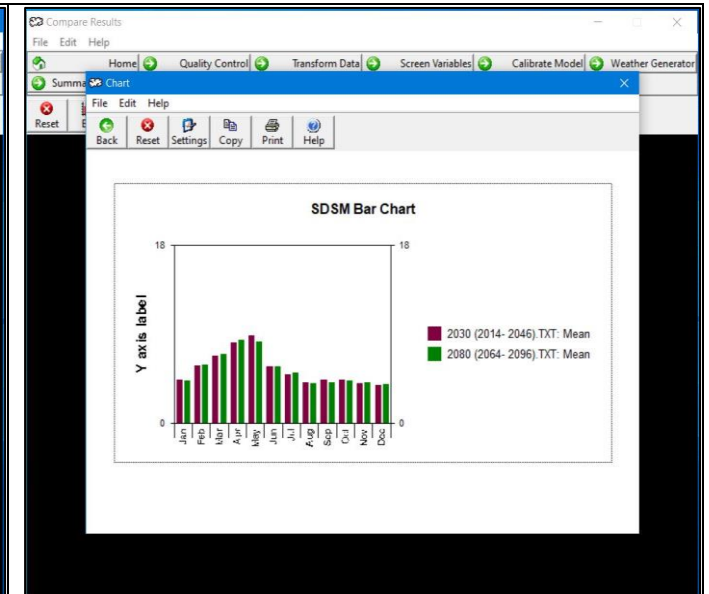


Plate C.10 Comparison between two time period

Ex. The comparison between downscaled ET_0 of Solapur for 2030s and 2050s period. These graphs are further exported in excel.

8. VITAE

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