Extreme Risks, Vulnerabilities and Community- Based Adaptation in India (EVA)

A PILOT STUDY

Final Report on WP 1
Climate variability, change and extremes in Jalna

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Research partners

AFPRO Action For Food Production

CICERO Center for International Climate and Environmental Research - Oslo

NIBR Norwegian Institute for Urban and Regional Research

NIVA Norwegian Institute for Water Research

teri The Energy and Resources Institute

Extreme Risks, Vulnerabilities and Community- Based Adaptation in India (EVA): a Pilot Study

Final Report on WP 1
'Climate Variability, Change and Extremes in Jalna'

Lead Institute: TERI

Title:

Climate variability, change and extremes in Jalna

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1 Introduction

The Intergovernmental Panel on Climate Change (IPCC)[1] defines climate variability as variation in the mean state of the climate and its statistics (such as standard deviation, the occurrence of extremes etc.) on all spatial and temporal scales beyond that of individual weather events. Climate variability is not as explicitly noticeable and perceivable as weather variability because it happens over long term seasons and years. Typical climate variability is the variation of the climate from its long term (generally 30 years) average value. These long term averages are of any weather variable and are referred as the climatological normals. Climate change refers to a change in the state of the climate that can be identified e.g., by the use of statistical techniques, for instance changes in the mean and/or the variability of its properties, and that persists over an extended period, typically decades or longer.

To be able to study the changes in the climate, a time period of 30 years has been suggested as a standard requirement to assess the nature of change. These changes in future context are studied based on an analysis of climate model outputs. The model generates the results for future time periods and has a spin off time. Thus, the results of future projections and its estimations requiring at least a 20 year gap before it can be used in research and other applications.

Climate change introduces huge uncertainties in the way in which the weather is likely to play out over future time periods. The Intergovernmental Panel for Climate Change (IPCC), Fourth Assessment Report highlights with a high degree of confidence that the warming of the climate is unequivocal. This indicates not only changes in the overall climate over future time periods but also changes in the variability itself. The IPCC Special Report on Extremes indicates that the extreme events are likely to become frequent and intense over future periods (SREX, 2012). Instances of extreme cold summers and warm winters in many parts of the world are already being observed like the cold summers of 2009 in Michigan, 2010 Russia heat waves, 2009 snowfall in Emirates etc. There are also instances of extremes being observed in India, heavy precipitation events in Barmer in Rajasthan, Mumbai in 2005, Jammu and Kashmir in 2014, hailstorm in drylands of Maharashtra in 2014.

There are huge impacts of such events on both life and property. Damage to agriculture especially during sensitive stages of crop growth is known. While India is exposed in many ways to the changes in the climate, for the purpose of the study exposure in drylands and its implications on societies has been studied. India has a huge area of land under arid and semi-arid category. Also a large percentage of cultivated land, nearly 60 %, is still rainfed with a majority of people still agri dependent thus making it uniquely exposed to the risks related to climate change.

[1] Climate Variability: IPCC Glossary http://www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessglossary-a-d.html

2 Objective and Approach

The overall objective of work package 1 is to assess climate variability, change and extremes for district Jalna in the state of Maharashtra. The district lies in the Marathwada region of the state and constitutes the dryland belt. This work package captures the physical basis of exposure to extreme events using modelling tools and statistical techniques using data over a high spatial resolution of 25 * 25 km and for future time slices of 2030s, 2050s and 2070s. This has been supported by undertaking a literature review with a focus on observed and projected climate variability, change and extremes over the Indian region. Observed time series analysis of meteorological parameters has been done and trends studied. Extreme climate exposure over Jalna district has been studied via climate indices and related analysis. Outputs from this work package have been utilized in the subsequent work packages to analyse the impacts of these extremes on natural and human systems.

3 Background – Literature review on climate variability, change and extremes

The IPCC 5th assessment report (IPCC, 2013) attributes with a higher degree of certainty that most of the increase in observed global average temperatures since the mid-20th century are due to anthropogenic causes leading to an overall increase in greenhouse gas (GHG) concentrations in the atmosphere. These changes in the concentration levels of GHGs influence changes in the climate system contributing to an overall warming of the earth's surface. This includes warming of the atmosphere and oceans, change in humidity levels, evapotranspiration rates, rainfall patterns and extremes. Instrumental record of the past one and a half century reveals that the earth has already warmed by 0.74^{0}C during the last 100 years, with 12 of the last 13 years being the warmest. It is projected that the rise in temperatures by the end of the century would be in the range of 1^{o}C to 3.7^{0}C by 2100 (IPCC, 2013).

Kothawale et al., 2010 has shown that Indian annual mean temperature for the period 1901-2007 has shown a significant warming trend of 0.51^{0}C per 100 year. For the recent period 1971-2007, accelerated warming has been observed, mainly contributed by the warming in winter and post-monsoon seasons. Maximum and minimum temperatures have shown an increase by 0.71oC and 0.27oC for the period 1901-2007 (INCCA, MoEF, 2010). Even though the monsoon rainfall of the last few decades have no significant trend on an all India scale (Parthasarthy, 1984n Pant and Kumar, 1997), there are regional trends in the monsoons that have been observed in the past century (Rupa Kumar et al., 1994. Guhathakurta and Rajeevan, 2008, Krishna Kumar, 2010). Sen Roy and Balling, 2004 have reported overall increase in extreme rainfall events and their intensities during the period 1901-2000. Also in central India a study by Goswami et al., 2006 has concluded an increase in the frequency distribution of extremes during 1980-2000 as compared to 1951-1970. A study done by Krishna Kumar et.al., in 2011 indicates an overall decrease in the number of rainy days[2] in India with increase in the rainfall intensity for future time periods thus indicating higher risk of exposure to extreme events.

Although there is no universally accepted definition of drought, The Indian Met India Meteorological Department (IMD) broadly perceives droughts in three different ways: Hydrological drought – when there is marked depletion of surface water causing very low stream flow and drying of lakes, reservoirs and rivers; Agricultural drought – when inadequate soil moisture produces acute crop stress and affects productivity and Meteorological drought – a situation when the monsoon seasonal (June-September) rainfall over the area is less than 75% of its long-term average value. IMD monitors drought based on 'percentage of rainfall departure' and 'aridity anomaly index' respectively. All the figures and mention for droughts in this chapter are meteorological droughts. is defined as. Droughts have been categorized as moderate when rainfall deficiency is between 26 to 50 % and severe with deficiency exceeding 50% (IMD, 2010).

[2] Rainy days – rainfall > 2.5mm

3.1 Marathwada region: The case of district Jalna

The EVA case study site was finalised as Jalna district that lies in the Marathwada meteorological sub-division (IMD[3]) or the Aurangabad division (GoM[4]) (figure 1). Marathwada is enlisted under the frequent drought[5] prone areas[6] in the country (figure 2, district #14) in which a drought is expected to occur once in 6 to 10 years. These areas belong to sub-humid climate zone (both dry and moist). District Jalna within the Marathwada region has a semi-arid climate with average annual rainfall of 730 mm. Since the geographical location of Maharashtra give rise to different climate features over the state, IMD have classified the state into four meteorological sub-divisions which differ owing to their climate variability and topographical features. Konkan & Goa is the extreme western part elongated north south along the west coast of India and receives very high rainfall during monsoon season. The Vidarbha region is the extreme eastern parts of the state and receives mean monsoon or annual rainfall below to that of Konkan and Goa but more than the other two sub-divisions viz. Madhya Maharashtra and Marathwada which almost have similar mean rainfall with Madhya Maharashtra having slightly higher mean monsoon or annual rainfall. Table 1 shows the frequency of drought along with their probabilities for the four meteorological sub-divisions of Maharashtra for the 134 years of observational data. Marathwada and Vidarbha have the highest drought incidences and probability amongst the sub-divisions of the state. Drought in two consecutive years has been seen once in Marathwada during 1984-85. In the table the droughts have been categorized as being moderate when rainfall deficiency is between 26% to 50% and severe with deficiency exceeding 50%. Figure 2 shows the distribution of meteorological subdivisions of India on the basis of probability of drought occurrences for the period 1875-2004 wherein Marathwada (district #14) falls under the frequently drought prone area.

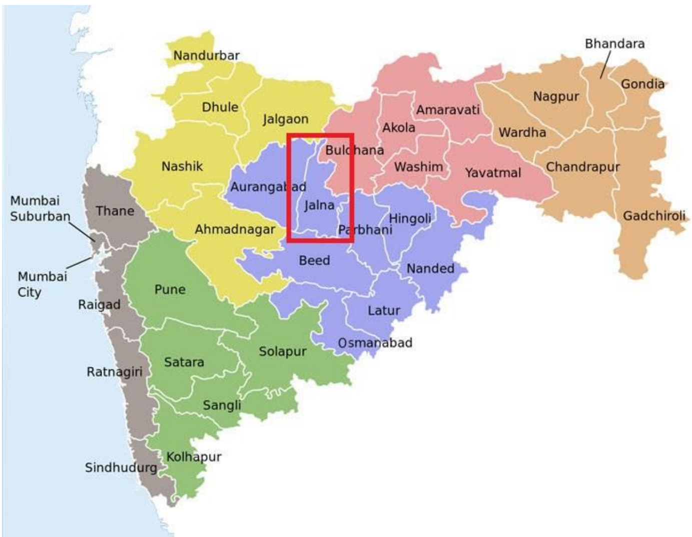

Figure 1. District map of the state of Maharashtra with Marathwada sub-division shown in blue and Jalna district boxed. *Source:* https://www.maharashtra.gov.in/1128/Districts

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[3] IMD – Indian Meteorological Department

[4] GoM – Government of Maharashtra

[5] The IMD defines drought in any area when the rainfall deficiency in that area is 26% or more of its long term normal / average.

[6] Frequent drought prone - Areas having the drought probability between 10-20%. (**IMD**)

The Indian Meteorological Department has done a spatial assessment of the occurrence of drought in the country based on rainfall data analysed for the period 1875-2004. It highlights that most of the arid parts of the country are chronically drought prone and central (including the Marathwada belt which includes Jalna district) and northern regions are frequently drought prone (Figure 2). Figure 3 shows that the district of Jalna has not been considered in the all India district wise probability analysis of moderate drought and severe drought for the period 1901-2003 due to data unavailability issues. Although its neighbouring district i.e. Aurangabad have been included and since it lies in the same sub-division, and lies within similar latitudinal belt it's assessment can be reported as a proxy for Jalna. Aurangabad is seen to have moderate drought probability between 10%-15% and severe drought probability below 5%.

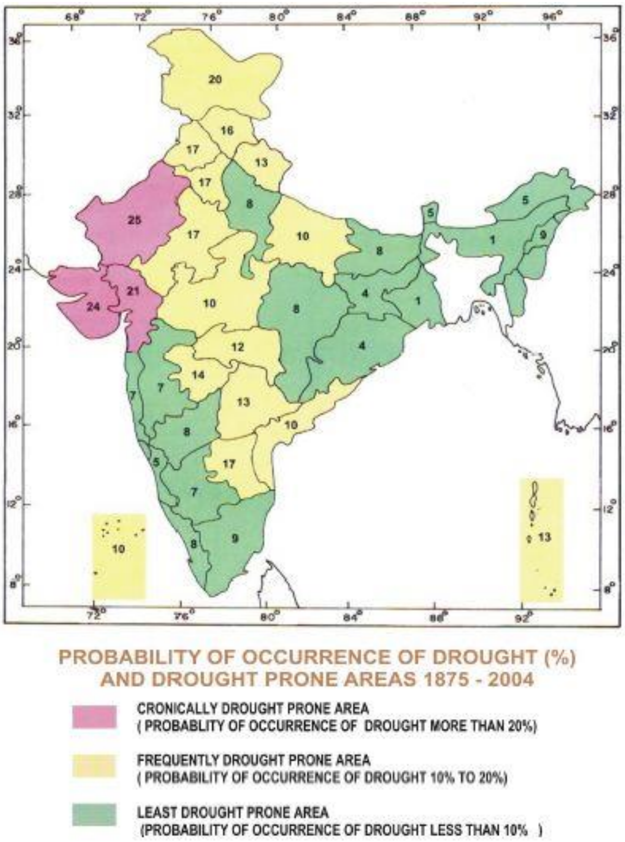


Figure 2. Probability of occurrence of drought and drought prone areas during 1875-2004.
Source: **IMD Met Monograph no. environment meteorology – 01/2010**

Table 1: Sub-division wise frequencies of drought during 1875-2009 and probability of drought years

Sub- Divisions	Moderate	Severe	Total	Drought Probability (total) %	Two consecutive years
Marathwada	17	1	18	14	1 (1984-85)
Madhya Maharasthra	7	2	9	7	0
Vidarbha	16	1	17	13	1 (1971-72)
Konkan and Goa	9	0	9	7	0

Source: IMD met monograph 21/2005 and 01/2010

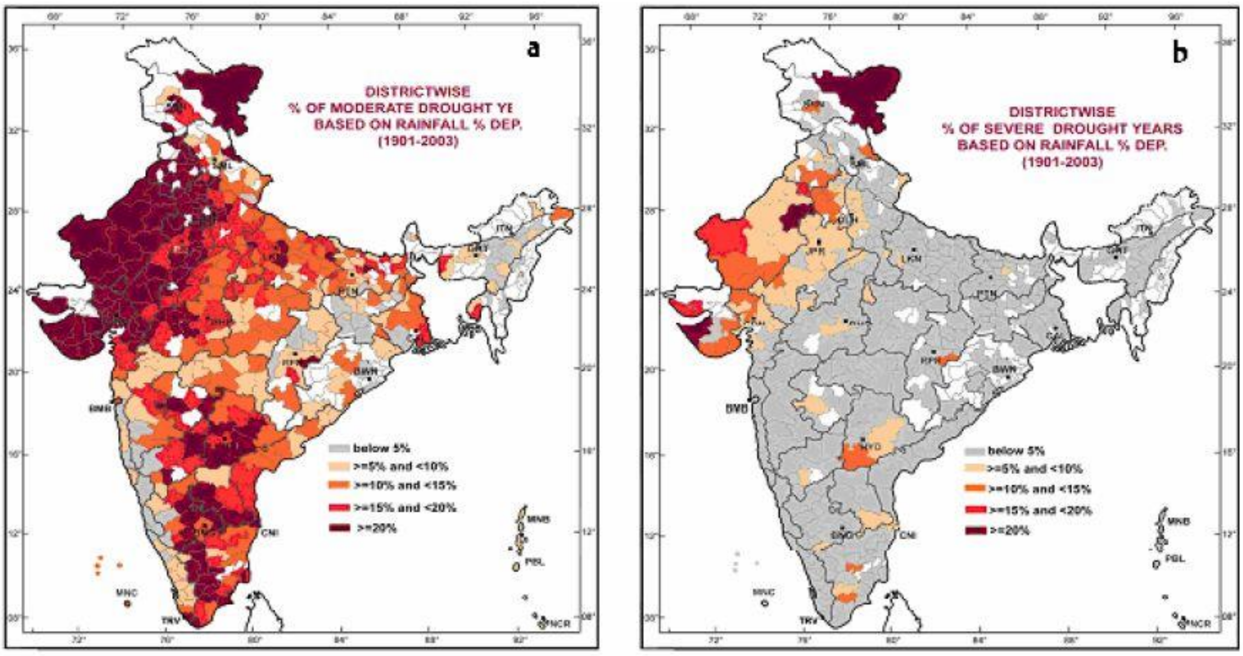


Figure 3. District-wise percentage of incidences (probability) of drought of (a) moderate intensity and (b) severe intensity during the southwest monsoon season for the period 1901-2003
Source: **IMD Met Monograph no. environment meteorology – 01/2010**

An assessment of the sub-divisional seasonal rainfall done by IMD (IMD monograph – 01/2010) for India shows a decreasing but not statistically significant trend in the rainfall for the Marathwada region for the winter and pre-monsoon season for the period of 1901-2003 (figure 4). However, the monsoon season and post-monsoon season shows an increasing trend which is statistically significant at 99% only for post-monsoon season. Specifically, the contributions in months of June and August towards the annual rainfall have increased but there is no significant trend. July contributions have decreased but not so significant trend is observed whereas the September contributions have been decreasing at 95% level significance (figure 5). This indicates the rainfall distribution over the monsoon period in the Marathwada region highlighting the trends in increase or decrease across the JJAS period, of utmost importance for any kind of crop planning and also planning for water storage.

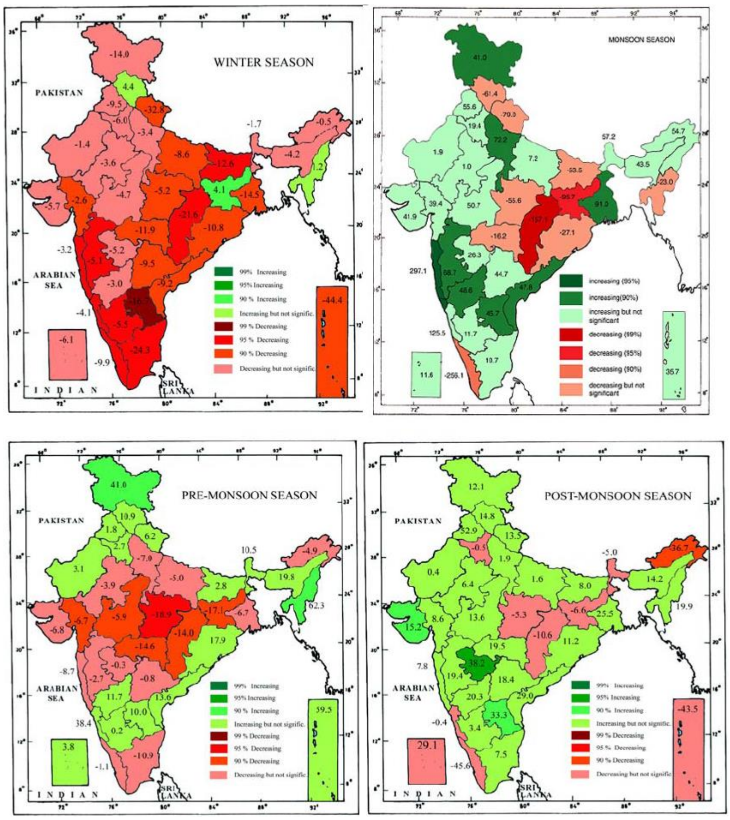


Figure 4. Trend in sub- divisional rainfall data (increase/decrease in rainfall in mm) for different seasons season (1901-2003). Different levels of significance are shaded with colours.
Source: **IMD Met Monograph no. environment meteorology – 01/2010**

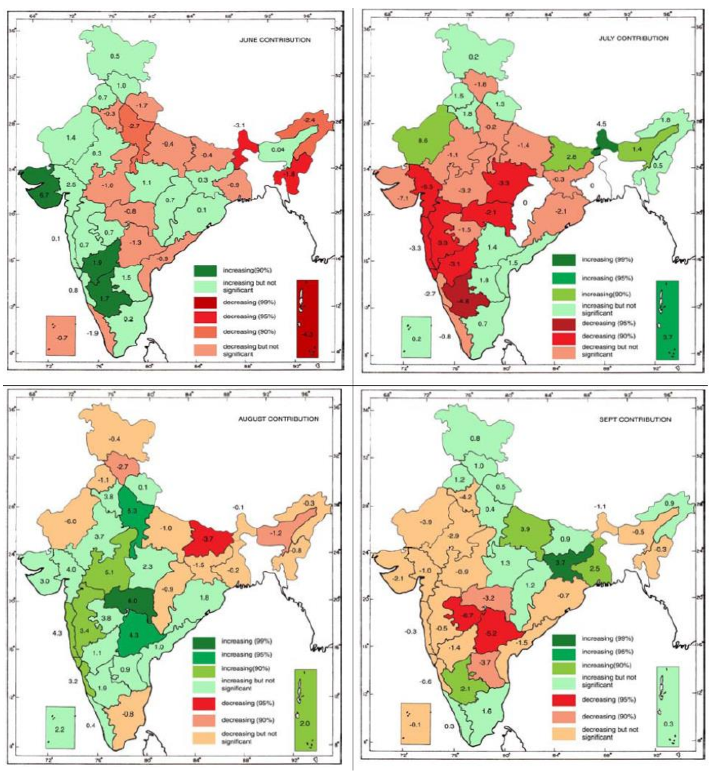


Figure 5. Trend in sub- divisional rainfall data of monsoon months (increase/Decrease in rainfall in percentage) to annual rainfall (1901-2003). Different levels of significance are shaded with colours.
Source: **IMD Met Monograph no. environment meteorology – 01/2010**

3.2 Dataset Used

The analysis carried out under this work package includes use of historical climate data and climate projections for different time periods. The observational data utilised for the same is taken from the Indian Meteorological Department, IMD gridded temperature data at a 1 degree resolution and rainfall at 0.5 degree resolution and station level data. Regional climate model outputs generated for future time periods have been used. (See annexure A for more details)

3.3 Regional Climate Model and Its Setup

To analyse the future climate for Jalna, the database has been taken from the high resolution limited area model simulations carried out over the state of Maharashtra at 0.25 degree horizontal resolution. The model used in the study is the UK Met Office regional climate model HadRM3P contained in the atmosphere only part of general circulation model HadCM37 (Jones et al., 2004). It gives a comprehensive representation of physical processes in atmosphere and on land in terms of

- dynamics – atmospheric circulations, cyclones, fronts
- radiation – effects of greenhouse gases and aerosols
- clouds – radiative effects, sulphate aerosol effects
- precipitation – convection, large-scale condensation
- land-surface – soil hydrology (4 levels), vegetation

The regional model is driven by using lateral boundary conditions from the HadCM3 perturbed atmosphere physics ensemble QUMP8 (Collins et al., 2006, Collins et al., 2010) which uses the SRES A1B[9] emissions scenario. The model has been run to simulate the baseline runs from 1970-2000 and future runs of 2030s (2020-2040), 2050s (2040-2060) and 2070s (2060-2080).

[7] HadCM3 – Hadley Center Coupled Model version 3, http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadcm3
[8] QUMP - http://www.metoffice.gov.uk/precis/qump
[9] A1B is a typical Business As Usual scenario under the A1 SRES scenario which assumes balance across all the resources. (http://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya1)

4 Methods

To establish the climate profile of the domain area of study the historical assessment of the meteorological parameters *viz*. Temperature (minimum and maximum) and JJAS precipitation have been carried out. Gridded datasets from IMD at 1 degree resolution for temperature and accumulated rainfall data from the Krishi Vigyan Kendra (KVK), Kharpudi located near Jalna city have been utilized. The time periods for both these datasets differ given the different sources used.

The 1970-2000 time period has been taken as a reference or the baseline for the regional model simulations for future time slices. The validation of the model dataset has been carried out over the entire Maharashtra domain using six different observational datasets. Data over the Jalna district has been extracted for the baseline and future time slices and spatial and temporal analysis for changes in temperature and precipitation patterns has been carried out. Analysis has been done for computing warm nights using minimum temperatures and heat index considering temperatures and humidity levels, rainfall during peak season in the months of JJAS, total rainfall and extreme rainfall both for historical periods and projections.

5 Results and Discussions

5.1 Observed Climate Variability, Change and Extremes

Temperature

The maximum and minimum temperatures for Jalna district for the period 1969 – 2005 using the IMD gridded dataset are shown in figure 6a and 6b. Though the 36 year data for maximum and minimum temperatures for Jalna does not show any significant trend over this period, the year-by-year climate variability is clearly seen in the plots.

Figure 6a

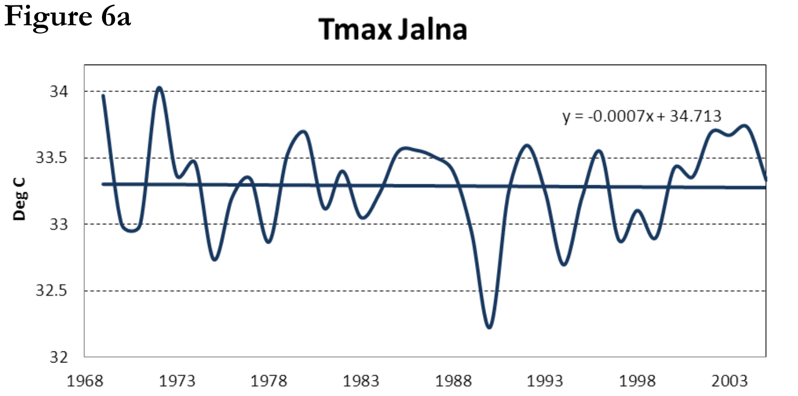


Figure 6b

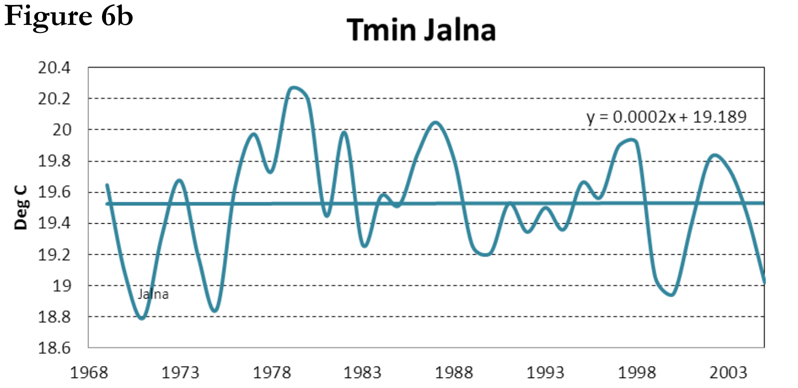


Figure 6: Time series for maximum temperature (figure 6a) and minimum temperature (figure 6b) over Jalna showing climate variability.

Rainfall

Historical data indicates great year-to year variability of rainfall in Jalna (Figure 7). However, a trend analysis of the dataset from 1985 onwards indicates a drastic decline in the overall rainfall in the region, with the year 2012 again an extreme drought year (Figure 7). Data analysed over the longer time periods indicates some drought years post 1940s.

The annual accumulated rainfall data from the KVK station from 1985-2012 shows a clear decreasing trend (figure 7) in the last two to three decades. This is in accordance with the climatology of Jalna which lies in the Marathwada sub-division which is classified as the frequent drought prone region in the state. In 2012, the station recorded barely 200 mm of accumulated yearly rainfall.

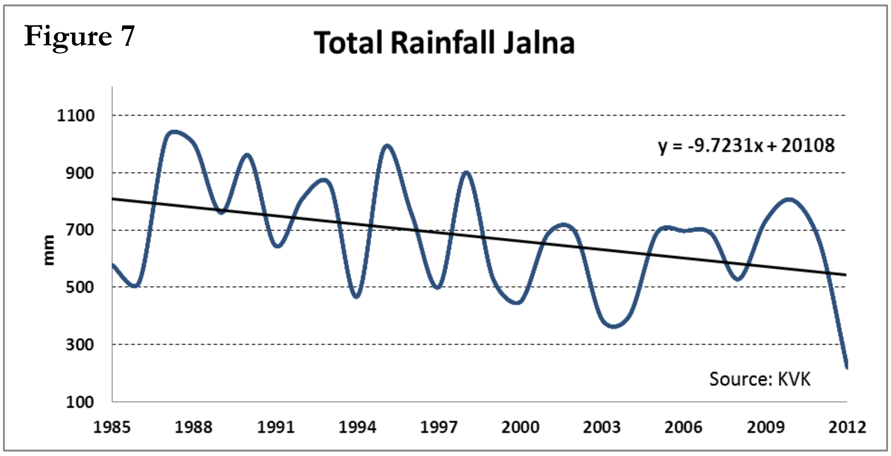


Figure 7. Annual accumulated rainfall over Jalna. ***Data Source:*** **KVK met. Station**

The recent seven year period (2004-2011) district rainfall over the monsoon months are made available by IMD on their website. The data also shows a decreasing rainfall for monsoon months (figure 8) but the seven year time period is too short to present a climatic trend analysis over the district. Hence this should be taken as purely on indicative basis.

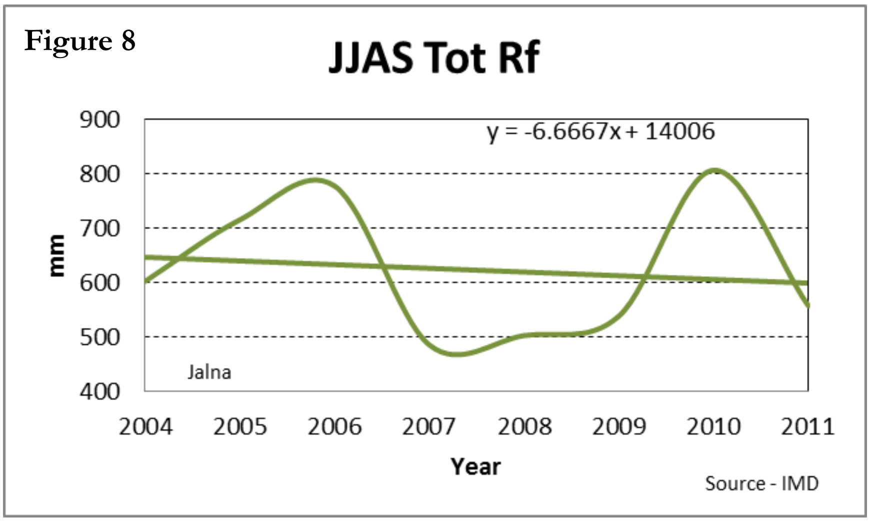


Figure 8. Accumulated rainfall for June, July, August and September over Jalna for 2004-2011. ***Data Source:*** **IMD**

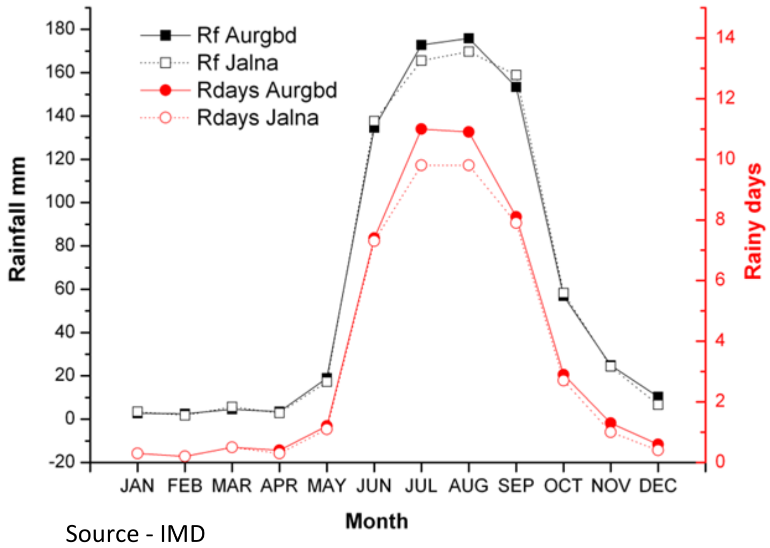


Figure 9. Cumulative rainfall normal and rainy day frequency for Aurangabad and Jalna for the period 1941 – 1990. Source: IMD

Figure 9 shows cumulative rainfall normals (see annexure A for definition of normals) and rainy days over Aurangabad and Jalna for the 50 year period 1941-1990. The rainfall over the Jalna district is mostly confined during the monsoon months of June, July, August and September. Jalna gets comparatively less rainy days in the months of July and August as compared to Aurangabad.

Apart from the rainfall analysis at Jalna district and at the KVK station, weekly rainfall datasets from Badnapur research station were also used to arrive at monthly rainfall analysis for 1984-2011 time period (figure 10). June and July rainfall (blue and red lines) in the past 27 years over Badnapur station have shown a decreasing trend for weekly rainfall amounts aggregated on a monthly scale showing that the June and July rainfall have declined over the years over Badnapur. August and September rainfall (green and purple lines respectively) shows an increasing trend.

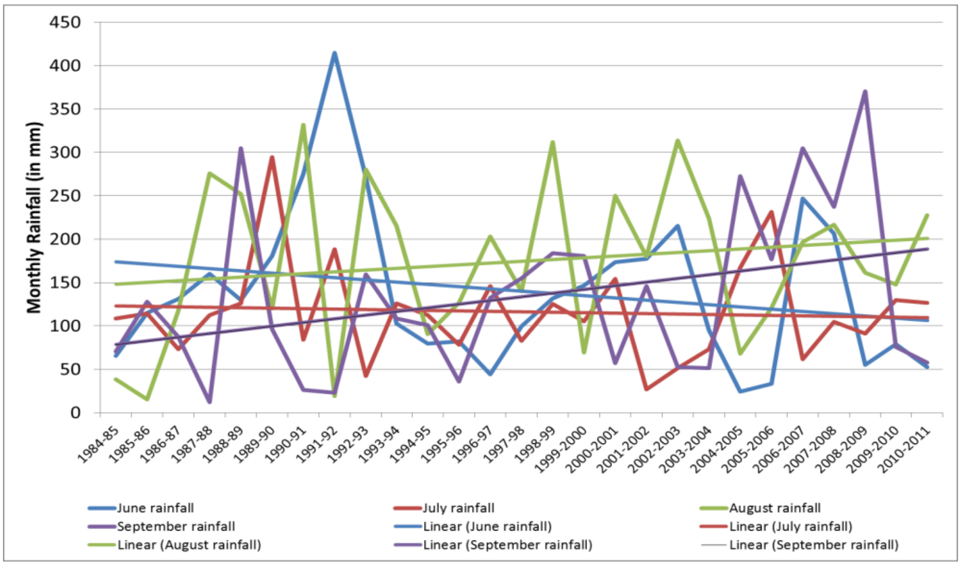


Figure 10. Cumulative rainfall for monsoon months over Badnapur station. June is blue, July is red, August is green and September is purple. *Data Source*: Research station Badnapur

Extreme rainfall events

Based on a threshold classification of rainfall received in a day some studies have defined extreme rainfall incidences. Goswami et al. (2006) and Rajeevan et al. (2008), have classified rainfall events between 5 and 100 mm/day as moderate events and rainfall events between 100 and 150 mm/day as heavy rain (HR) events, rainfall events equal or greater than 150 mm/day as very heavy rain (VHR) events. Considering this classification in the literature and using the 0.5 degree resolution gridded IMD datasets over Jalna, extreme rainfall events have been categorised in figure 11a. As seen from the figure, the VHR events have risen from 1988 onwards with around 9 incidences of VHR events in from 1988 till 2005. The trend for the intensity of these extreme events has also shown an increase in the last 30 years as seen from figure 11b. Interestingly, as the data indicates a clear decline in the overall rainfall over the region, the high intensity rainfall events are on an increase, which indicates that these events of rainfall are interspersed with long dry periods with lesser number of rainy days as well as an overall decline in the rainfall.

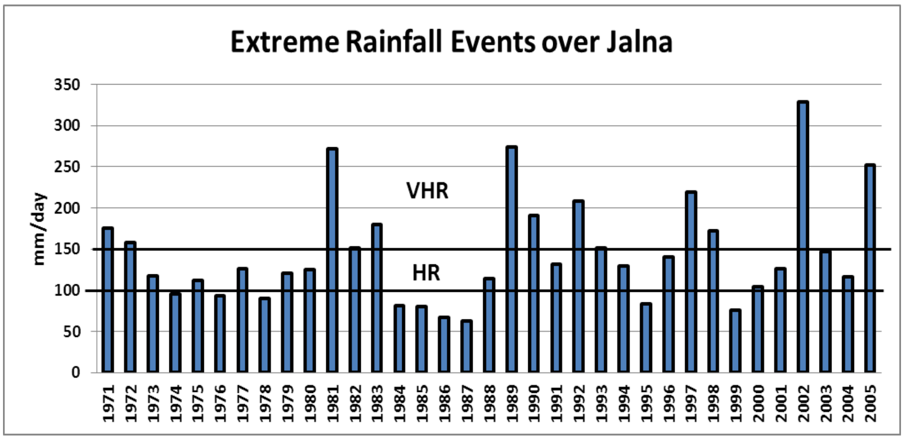


Figure 11a. **5-100mm/day: Moderate rainfall event**
100-150 mm/day: Heavy Rain event (HR)
<150mm/day: Very Heavy Rain event (VHR)

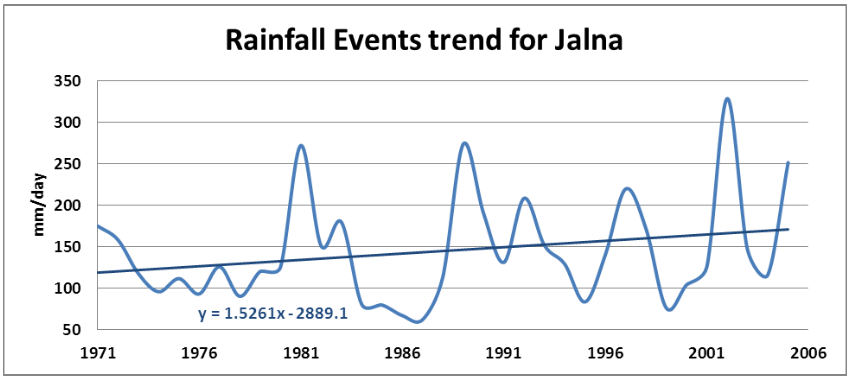


Figure 11b. Trend for the extreme rainfall events over Jalna shows an increase from 1971-2005.

5.2 Future climate variability, change and extremes

Table 2: Percentage change in precipitation and change in temperature over Jalna district for future time. The changes in temperatures and precipitation are relative to a baseline or model reference period of 1970-2000. The change for temperature is in degree Celsius and for precipitation in percentage. The range of change shown in the table are spatial range and the average is spatial or area average.

Variables	Model baseline (1970-2000)	Future Projections					
		Change in 2030s		Change in 2050s		Change in 2070s	
		Avg	Range	Avg	Range	Avg	Range
Precipitation (JJAS)	444.367	26 %	20 – 27.5 %	28 %	17.5 – 32.5%	26 %	22.5 – 30 %
Tmean (°C)	26.33	1.3	1.28 – 1.35	1.94	1.9 – 2.0	2.84	2.74 – 2.95
Tmin (°C)	19.73	1.56	1.48 – 1.6	2.29	2.2 – 2.35	3.29	3.14 – 3.38
Tmax (°C)	33.25	1.06	1.02 – 1.1	1.63	1.55 – 1.7	2.47	2.38 – 2.56

Temperature

The regional climate modelling assessment for Jalna district for future time periods indicates a warming climate. The mean temperature increase relative to baseline or the reference period for the model (1970-2000) for future time slices is projected to increase by 1.2°C to 2.9°C with 2070s (2060-2080 time period) showing the highest increase (Table 2). The increase in minimum temperature is higher than that seen for maximum temperature for all future time periods (table 2). The comparative higher increasing trend seen for minimum temperature is in accordance to many studies that have been carried out globally (IPCC, 2013) as well over Indian subcontinent (INCCA, MoEF, 2010).

Rainfall

The precipitation change in percentage from the 1970-2000 baseline for the monsoon months of June, July, August and September also shows an increase in rainfall for the future time periods (Table 2).

Extreme event analysis

Rainfall

It has been reported in many studies that the frequency and intensity of rainfall extremes are increasing over many regions over India (Goswami et al., 2006; Kothawale et al., 2010; Krishnamurthy et al., 2009; and Turner et al., 2009) and the world (IPCC, 2007 and Alexander et al., 2006). To calculate extreme rainfall events for the future, extreme wet days and extreme rain events have been analysed for the time period of 2020-2040. Extreme wet days in this study are defined by R99ptot index under the ETCCDI[10] which is a ratio of high rainfall events in future to the total rainfall in future (see Appendix B for details). Figure 12a shows the trend of such extreme wet days over Jalna. Overall there is a net increase in the nature of these events in future periods.

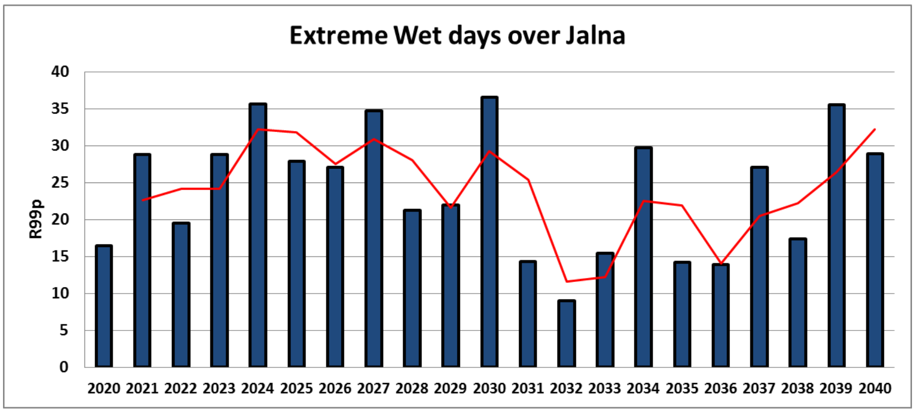
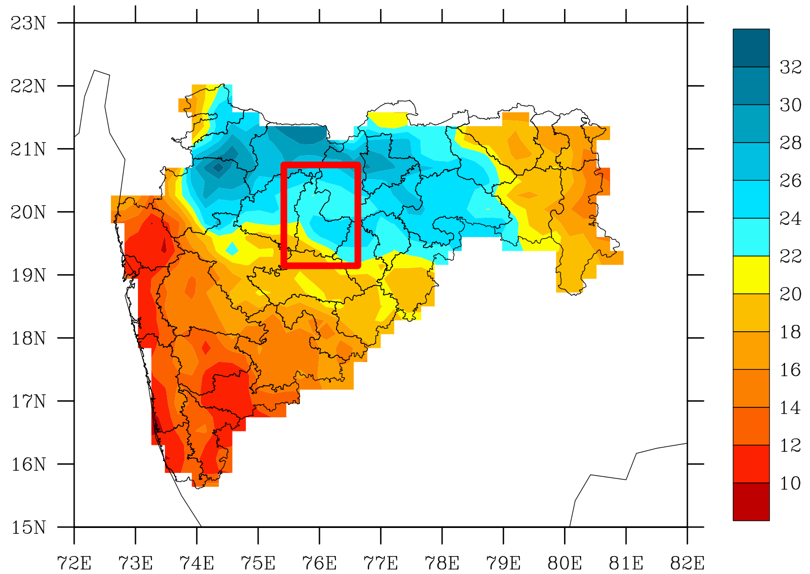


Figure 12a. Extreme wet days; R99p over Jalna for 2020-2040 time period.

On a spatial scale, the entire Marathwada region experiences an increase in extreme rainfall, in Jalna increase of extreme rainfall in 2030s is also higher than the increase seen over Konkan belt (extreme west) and over Vidarbha region (extreme eastern parts) (figure 12b). As indicated above with an increase in the extreme rainfall with not much in the number of rainy days there are likely to more interspersed dry periods.



[10] ETCCDI – Expert Team on Climate Change Detection and Indices url - http://etccdi.pacificclimate.org/

Figure 12b. Spatial plot of extreme wet days; R99p over Jalna for 2020-2040 time period. Jalna district is shown in red box.

Figure 13 shows the trends of extreme rainfall events for the 2020-2080 time period. As seen from the figure, the 2030s (2020-2040) time period shows an increasing trend of such extreme rainfall events. A slight decline in the occurrence of such events is seen for 2050s though this is still above the baseline and then again an increase by 2070s.

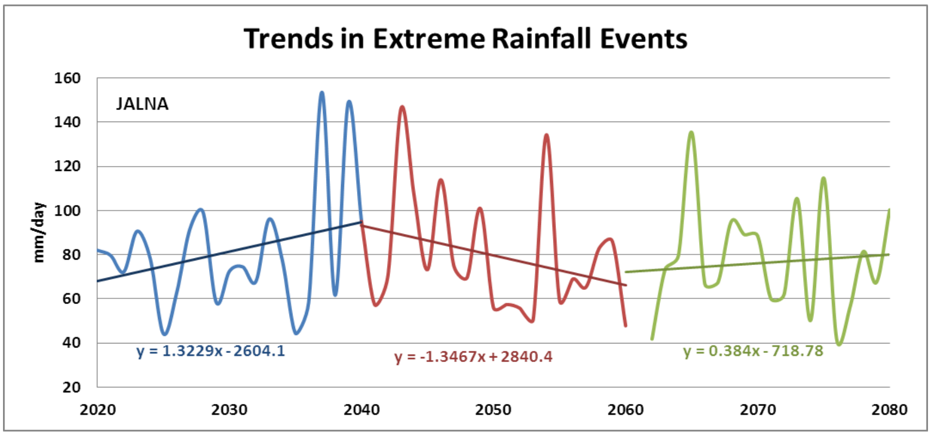


Figure 12c. Trends in extreme rainfall events over Jalna for 2020-2080 time period.

Temperature

To assess and analyse extremes in temperatures, a warm night index also called as Tn90p index under ETCCDI was developed (see Appendix B for details). Figure 13 shows the warm night index over Jalna with a clear indication towards increase in warm nights over the region. This is in accordance with the minimum temperature increase over the region. This correlation and trend is also valid in global context as studied by Tabaldi et al., 2006 and Morak et al., 2011.

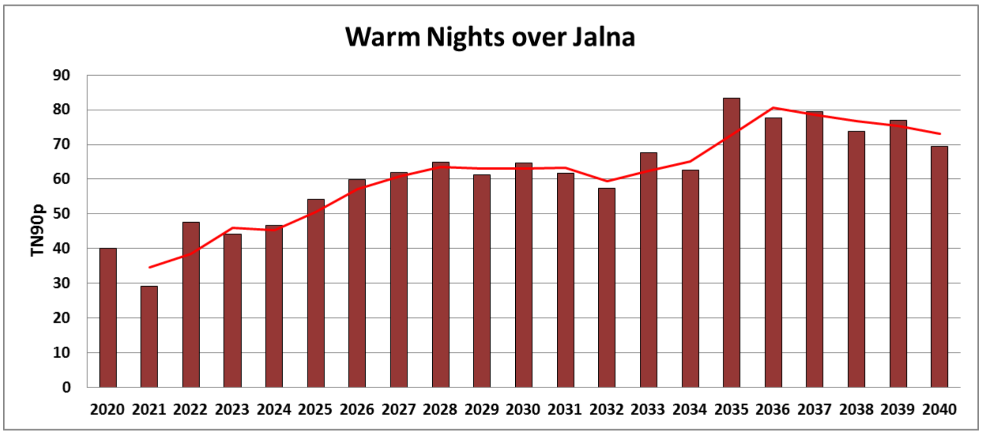


Figure 13. Trends in warm night (Tn90p) over Jalna for 2020-2040 time period.

Spatially the increase in percentage of warm nights seen over Jalna is higher than the increase seen over Vidarbha and less as compared to the Konkan region (Figure 14) for the 2030s time period. The influence of night temperatures over vegetation and crops varies from affects in the growth development and resultant productivity and has been well documented (Burbott and Loomis, 1967, Kliewer and Torres, 1972, Turnbull et al., 2002, Peng et al., 2004) and many studies have indicated that an increase of warm nights may lead to heat wave conditions and also hot days (IPCC, 2007, Alexander et. al., 2006).

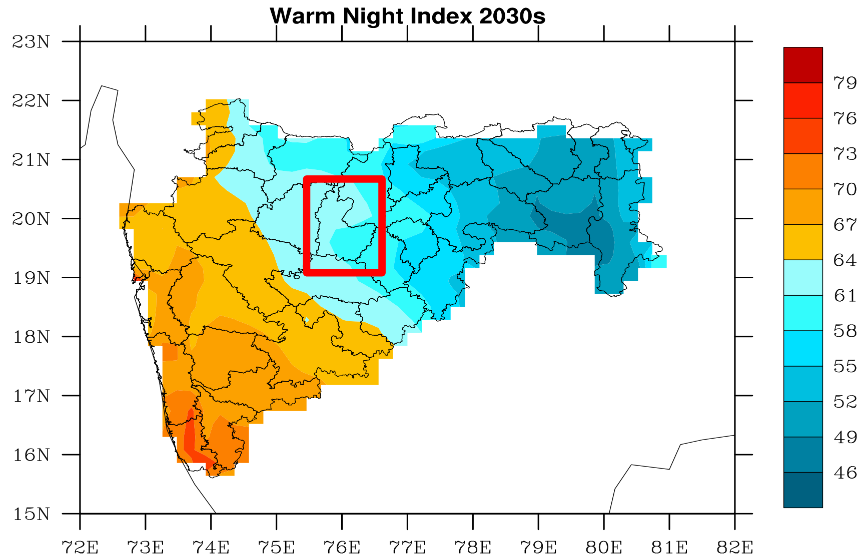


Figure 14. Percentage of increase in warm nights (tn90p) over Jalna as compared to other regions of Maharasthra. Jalna district is shown in red box.

In order to understand the temperature and moisture variability over the given region, a temperature humidity index i.e., a Heat Index was developed using method proposed by Steadman, 1979 (see Appendix B for details). Studies over the Indian sub-continent have also made use of this index to calculate human perceived equivalent temperatures and analysed their trends (Zahid, 2010, Rakib & Abedin, 2012, and Rakib, 2013). Relative to the baseline of 1970-2000, the time period of 2020-2040 shows an overall increase in the heat index values over the district of Jalna in future (figure 15). Steadman, 1979 and Rothfusz, 1990 have enlisted possible heat disorders associated with corresponding values of heat index which includes fatigue, muscle cramps, heat exhaustion, heat or sun stroke.

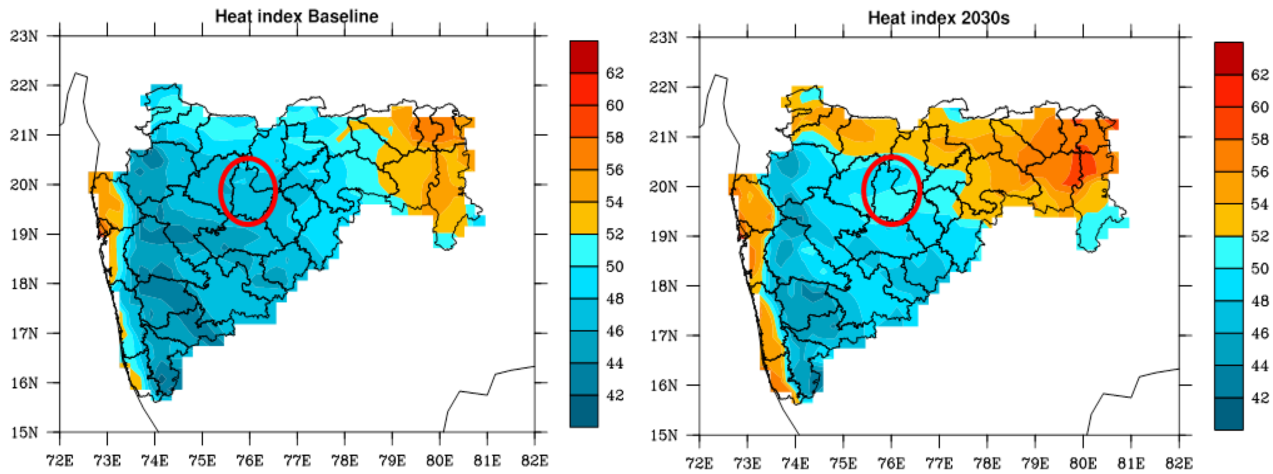


Figure 15. Heat index spatial analysis for baseline (left) and 2030s (right). The district of Jalna (encircled) shows higher values for 2030s as compared to baseline which shows an increase of temperature extreme.

6 Conclusions

Considering the recent studies around the world and the scale of the present study area, it is advised to use a multi modal ensemble study and a much higher resolution to arrive at probabilistic climate projections. An ensemble mode was followed for developing the state-wide projections. Hence, to arrive at best estimates of future climate over Jalna district, the present modelling experiment has been optimally designed.

Climate data analysis over Jalna indicates a warming climate in the 21st century with both increases in maximum and minimum temperatures including an increase in the extremes. The temperature rise and trend for extremes indicates an increase in heat stress which may have impacts towards crops and human health.

Decline in overall rainfall including the monsoon period and increase in extreme rainfall over the past few decades indicates a fall in the number of rainy days and greater interspersed dry periods. Increase in rainfall has been projected over all time periods in future. However these increases are quite small and likely to be in the range of 70-140 mm over the period of 2020 to 2040s. The same period would experience extreme rainfall conditions indicating that most rainfall will be spread out over few rainy days and the region is in future also likely to experience both forms of extremes – heavy/ very heavy rainfall events as well as dry spells.

The high or extreme rainfall events show an increase for the future time periods although the trend of this increase is projected to be variable for the different future time slots with the recent future (2030s) showing a higher rate of increase than the mid future (2050s). We can conclude that since the contribution of high rainfall (99th percentile) events towards the total rainfall of future shows an increase, it provides favourable conditions for dry spells by limiting the rainfall over lesser number of days in a season.

7 Limitation

It may be noted that all the studies involving modelling assessments are probabilistic in nature and provide us an indication on how the climate given the past conditions might evolve in future for a particular region.

The degree of certainty depends on many factors like input data and the boundary forcings used, the parameter being modelled, the type of models used, resolution and domain utilized. The modeling projections used in this study has been simulated over the state of Maharashtra at 0.25^{o} horizontal resolution and the data has been post processed and extracted over the Jalna district for this study. Though the resolutions are finer than the resolution of data from GCMs at a 150- 200 km resolution, the horizontal resolution of the models still inhibits the granular information that is needed for a district wide analysis.

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9 Appendix A

A.1 IMD datasets for recent years 2004-2011:

The Indian Meteorological Department (IMD) has made the rainfall data for the past few years available at a monthly level, for each district of the country on their website – www.imd.gov.in

A.2 IMD daily gridded products:

National Climate Centre (NCC), India Meteorological Department, Pune has brought out high resolution daily gridded rainfall & temperature data sets for the Indian region. The data are interpolated using quality controlled station data. The data is available on payment basis details of which are on IMD website. The temperature is available at 1 degree horizontal resolution (Srivastava, Rajeevan and Khirsagar, 2008) and rainfall data used in this study is at 0.5 degree horizontal resolution (Rajeevan and Bhate, 2008)

A.3 District Level Daily Climatological Normals (IMD, 2010):

Daily normals of 7 meteorological parameters, viz. rainfall, maximum temperature, minimum temperature, mean temperature, relative humidity, total cloud amount and wind speed have been prepared for 524 districts using 50 years of data (1941- 1990) and normals of other parameters have been prepared for 445 districts using 30 years of data (1971-2000). The basic data have been quality controlled before calculating district wise normals. The data is available on payment basis details of which are on IMD website.

10 Appendix B

B.1 Extreme Rainfall Index Calculation following the definition of ETCCDI:

High rainfall events in future are calculated as all rainfall events that are more than 99th percentile of baseline or reference period. R99p extreme rainfall index is calculated by considering the baseline data and calculating the 99th percentile of rainfall at every grid for the JJA time period. This dataset is considered as a reference for calculating the future rainfall extremes compared to baseline. Rainfall of future > Rainfall of 99p for baseline is considered at every grid and the index then calculates the ratio of R99p for future/ sum of total precipitation for future. Thus providing extremely wet day proportion of rainfall in future compared to baseline (Karl 1999; Alexander 2006; IPCC 2007)

B.2 Warm nights index calculation following the definition of ETCCDI:

Warm nights index also called as Tn90p by ETCCDI (IPCC 2007; Alexander et al., 2006) is calculated using minimum temperature (Tmin). First the 90th percentile of minimum temperature (Tmin) for the baseline data is calculated. Then all values of Tmin of future > 90p of Tmin baseline is calculated which provides the percentage increase in warm nights over different grid points when compared to the baseline of the same dataset.

B.3 Heat Index:

We have also defined the Heat Index following the NOAA definition (Steadman 1979), for assessing the human comfort due to variability in temperature and humidity in a given region.