CE499

Socio-economic Vulnerability Assessment of Climate Change in India

SUBMITTED BY **-**
PRANJALI ANIL BORSE (17110111)
ADVISOR ***- PROF. UDIT BHATIA***

Abstract

Based on the observed datasets and simulations of 5 CMIP5 models in combination with socio-economic data, the spatial distribution of the vulnerability to climate change in India is estimated for the past term with period (1970 - 2001) and (1981-2015) and projected under the RCP8.5 for the near term period (2006–2036), medium-term period (2037–2076) respectively. The results show the vulnerability of the rural region of each district in each state. From the observed datasets, past precipitation extremities i.e. 30-year return levels and 100 return levels of 1-day, 2-day, 3- days and 5-day cumulative rainfall are calculated and under the RCP8.5 greenhouse gas emissions scenario, future precipitation extremities and hence exposure index is estimated by calculating the volatility ratio.

Compared with the baseline period, the return levels turned out to be increasing with time, although the volatility ratio change is small as both 30-year and 100-year return levels tend to increase. Due to the unavailability of the year-wise consistent socio-economic data and the linear approach followed for the estimation of vulnerability and independency assumed amongst the indicators for determining the weight coefficients, uncertainty still exists in the assessment however the results give the idea about the vulnerability associated with each region relative to another region and are able to highlight the areas with high vulnerability in the states for different time periods.

Introduction

Intergovernmental Panel on Climate Change defines **vulnerability** as the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the magnitude, and rate of climate variation to which system is exposed, its sensitivity, and its adaptive capacity.
Nowadays, India is experiencing abrupt climate change and the current management system is facing problems in coping up with it due to lack of enough resources (adaptability) which gives a huge contribution in increasing the vulnerability of the sensitive regions which are prone to the events happening due to climate change like extreme precipitation events (flooding). In order to reduce the impact of these events, it is necessary to analyse the data and assess the degree of susceptibility of a region to the event and thereby develop the framework which can help reduce the impact or reduce the intensity of an event.

Three components of vulnerability

Exposure -

Exposure means people, assets, and socioeconomic groups are subjected to stressors like warming, flooding. They may be repeatedly subjected to such events over a period .

Sensitivity -

Sensitivity refers to the extent to which communities and people are impacted by climate change.

Adaptive Capacity -

Adaptive capacity refers to the extent to which the community and people are capable of coping up with the impact due to climate change. The more is the adaptive capacity, lesser is the vulnerability

In this research, the analysis of climate data along with the analysis of socio-economic factors which contribute in maximising or minimising the impact on the region gives a clear idea about where there is need of planning mitigation strategies at the earliest and where there is the need of implementing effective adaptive measures. Lot of research work has been done on the risk assessment of the different regions which includes hazard analysis and vulnerability analysis and deal separately with climate and socio-economic parameters. In this research, both the climate and socio-economic parameters are combined to give the single figure called vulnerability index. Vulnerability assessment for different future periods- near term period and midterm period and past period is done. Future vulnerability is assessed using simulated results of 5 models of precipitation under RCP 8.5 carbon emission scenario. According to Mishra, V. et. al. (2018), for Indian regions, the RCP 8.5 scenario suits best to study the extreme precipitation events in the future as present emission scenarios are already either following or very close to the RCP 8.5. In 2012, IPCC published the Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC, 2012), in which comprehensive analysis on the frequency of occurrence, the intensity, the vulnerability, and the degree of exposure to extreme events and corresponding disaster risks are presented which helped in forming the framework in the research. This study analysed the past and future climate data to calculate the exposure index from using volatility ratio and combined with the socio-economic data to conduct a preliminary assessment of future and past vulnerability. This study also accounts for the temperature data analysis by calculating the difference in temperature between the future and past period. It will provide the reference for developing the mitigation strategies and implementing the adaptive measure wherever needed and help in efficient management.

Data and Methodology

This research uses two types of data for analysis - 1) Climate data 2) Socio-economic data.

Climate data -

a) Observed IMD data for precipitation b) Projected data using the models for precipitation

Observed data is used to calculate the precipitation extremes in the period 1951 to 2015 and projected data is used for future analysis i.e. to project future precipitation extremes in period 2006-2036 and 2037-2076. Models used - 1) BNUESM 2) CESM 3) MirocESM 4) NorESM 5) MPIESM under the RCP 8.5 Carbon emission scenario. 1 day, 2 days, 3 days and 5 days maximum 30-year return level and 100-year return levels are the precipitation extremes taken into account for the calculation. Both past and future analysis are done following a similar procedure. Return levels are calculated by applying the generalised extreme value theorem(GEV). Mean return levels are then calculated for each district using Inverse distance weighted average method. Volatility ratio is calculated by taking 100-year to 30-year return level ratio and then it is used to calculate the index using the following formula :

$$\text{Index (I)} = \frac{(V.R.)i - (V.R.)min}{(V.R.)max - (V.R.)min}$$

Where $(V.R.)_i$ = Volatility ratio of district i in the state.

$(V.R.)_{min}$ = Minimum volatility ratio among all districts in the state.
$(V.R.)_{max}$ = Maximum volatility ratio among all districts in the state.

After calculating the separate indices for volatility ratio of each day return levels, exposure index is calculated by summing up these indices with equal weight coefficients assigned to them in such a way that these coefficients add up to 1.

$$\textbf{Exposure index (E)} = 0.25 \times I_1 + 0.25 \times I_2 + 0.25 \times I_3 + 0.25 \times I_5$$

The reason behind as equal weights is because all the indices are independent of each other as the events occur independently.

c) Temperature data - Simulated data for past and future using models under RCP 8.5 carbon emission scenario. Models used - 1) GFDLESM 2) NorESM
3) MPIESM 4) BNUESM. The absolute difference between the temperature in past(1981-2005, averaged over time) and future(2006-2030) is taken in order to highlight the changes in temperature from past and then relative temperature index is calculated.

Socio-economic data -

Socio-economic data is obtained from the socio-economic caste Census 2011 website as well as a census of India website.
The data can be obtained from here for all the states -
https://secc.gov.in/statewiseDistrictEmploymentAndIncomeReport
http://censusindia.gov.in/2011census/dchb/DCHB.html
https://data.gov.in/

Factors which contribute towards the sensitivity of a region -

1) Population - Total population, tribal population, infants population
   Individual population indices are calculated using the established formula same as that of used in calculating volatility index.
   Overall population index is then calculated using the formula as follows:

$$\text{Pindex} = \left(\frac{i+t}{T}\right) \times \text{TPI} + \left(0.5 - \frac{t}{T}\right) \times \left(\frac{f}{t} \times \text{TRPI} + \left(1 - \frac{f}{t}\right) \times \text{FTRPI}\right) + \left(0.5 - \frac{i}{T}\right) \times \text{INFI}$$

Where i = Infant population in a district
t = Tribal population in a district
f = Female tribal population
T = Total population in a district
TPI = Total population index
TRPI = Tribal population index
FTRPI = Female tribal population index
INFI = Infant population index

Here, weights are assigned to each subindex such that they satisfy the statement -

a) Population is more vulnerable if the total tribal and infants population is grater than 50% of the total population.
b) Population is more vulnerable if female tribal population exceeds 50% of the total tribal population.

2) Agricultural parameter - Unirrigated area
3) Educational parameter - Illiteracy

Sensitivity index is calculated by summing these indices with appropriate weights assigned to them as follows:

$$\mathbf{S = 0.33 \times Pindex + 0.33 \times Unirrindex + 0.33 \times Illitindex}$$

<u>Factors which contribute toward the adaptive capacity of a region -</u>

1) Economic factors - Income, employment (workers)
   Available data consists of a population of main and marginal workers using which employment index can be calculated as
   if the population of main workers is greater than that of marginal workers, then
   $$\text{Windex} = \frac{m}{m+mr} \times \text{mworkindex} + \frac{mr}{m+mr} \times \text{mrworkindex}$$
   Else,
   $$\text{Windex} = \frac{mr}{m+mr} \times \text{mworkindex} + \frac{m}{m+mr} \times \text{mrworkindex}$$

   Where m = Population of main workers
   mr = population of marginal workers
   mworkindex = Index calculated for population of main workers
   mrworkindex = Index calculated for population of marginal workers
   Here, weights to the subindices are assigned such that they satisfy the following statements:
   a) Main workers work for all the seasons and hence have continuous source of income whereas marginal workers work for a particular season after which their source of income is not defined. Hence, bigger weight should be assigned to main workers if their population is more than marginal workers and lesser weight should be assigned if their population is less as main workers contribute more towards increasing the adaptive capacity.
2) Agricultural data - Irrigated land, agriculture workers, agriculture with electricity supply

   Agriculture index is calculated as follows:
   $$\text{Agri-index} = 0.33 \times \text{agriworkindex} + 0.33 \times \text{powerindex} + 0.33 \times \text{irrindex}$$

3) Health facilities - Hospitals and doctors
   Available data for doctors consists of population of subsidised and private doctors from which the index for total population of doctors is calculated as :
   If the population of subsidised doctors is greater than that of private doctors, then

$$\text{drindex} = \frac{sdr}{sdr+pdr} \times \text{sdrindex} + \frac{pdr}{sdr+pdr} \times \text{pdrindex}$$

Else,

$$\text{drindex} = \frac{pdr}{sdr+pdr} \times \text{sdrindex} + \frac{sdr}{sdr+pdr} \times \text{pdrindex}$$

Where pdr = private doctors' population
sdr = Subsidised doctors' population
sdrindex = index calculated for Subsidised doctors' population
pdrindex = index calculated for private doctors' population

Here, weights are assigned to the subindices such that they satisfy the statement:

a) Subsidised doctors provide the facility at a lower rate and assured treatment as they are supported by the government whereas private doctors charge huge fees for the checkup making it unfavourable for the rural people to visit them. Hence subsidised doctors should be assigned with the higher weight if their population is higher than private doctors.

Therefore, health index is calculated by combining both the health facilities with equal weights assigned to them.

$$\text{Hindex} = 0.5 \times \text{drindex} + 0.5 \times \text{hospindex}$$

4) Educational data - Literacy

Therefore, combining all these factors with equal weights assigned gives adaptive capacity of a region as

$$\mathbf{A = 0.2 \times agriindex + 0.2 \times Hindex + 0.2 \times Windex + 0.2 \times litindex}$$

VULNERABILITY -

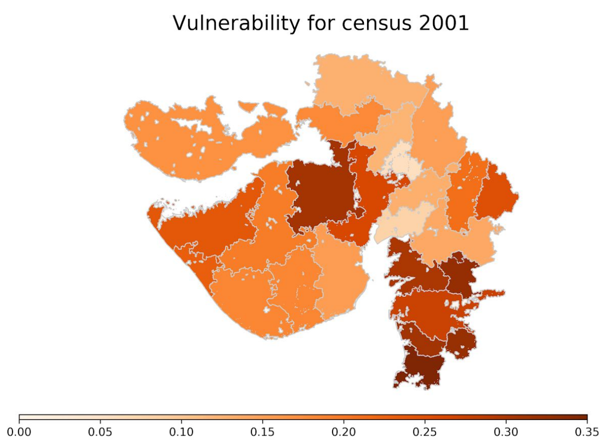
The vulnerability which in this study is considered to be the linear combination of the three components Exposure, Adaptability and Sensitivity is calculated by combining the three components with equal weights assigned. Linearity is assumed as it is the most simplest way to convey the results without any fallacy according to Occam Razor's principle although uncertainty exists. Here, adaptability is the component which has a negative effect on the vulnerability i.e. vulnerability decreases as the adaptability increases and vice-versa. Hence it is given (-) sign while combining with the other two components.

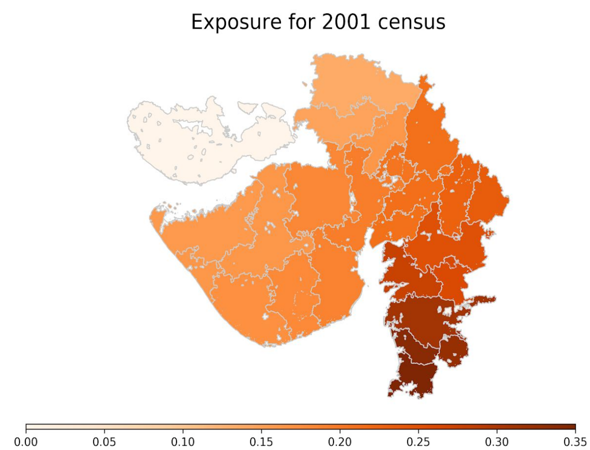
Therefore,

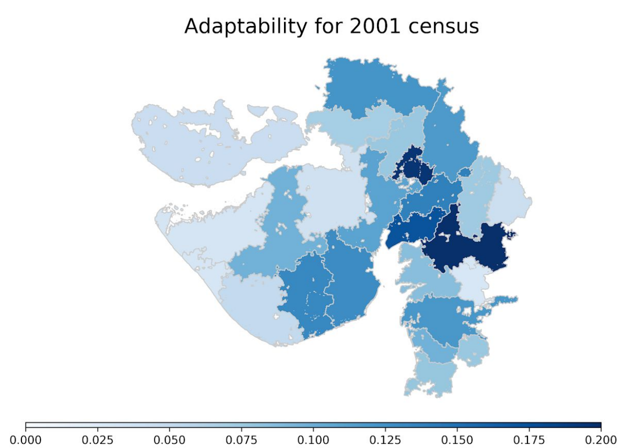
$$V = 0.33 \times E + 0.33 \times S - (0.33 \times A)$$

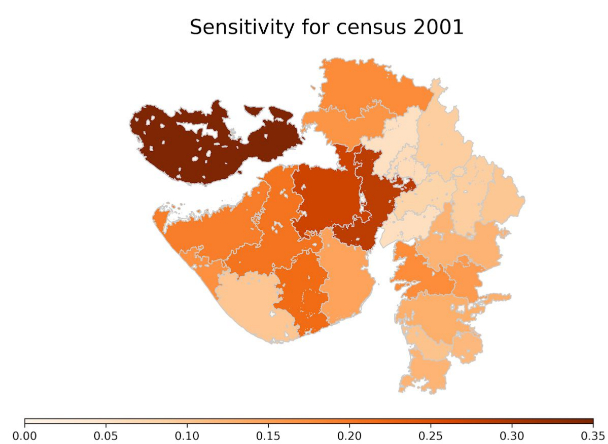
RESULTS -

- **GUJARAT -**
    - **Results for census 2001 socio-economic data analysis and 1970-2001 exposure period -**



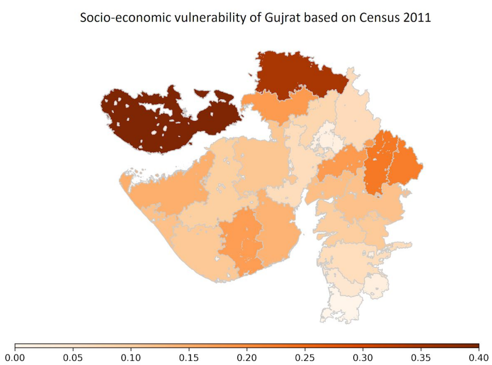


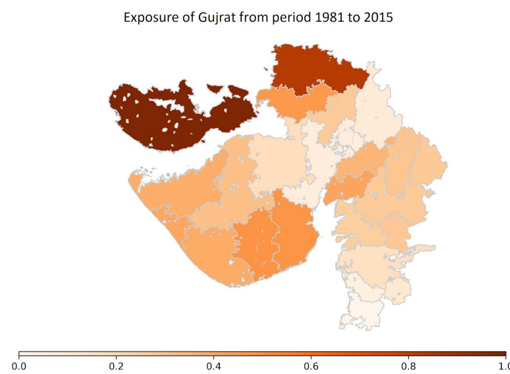


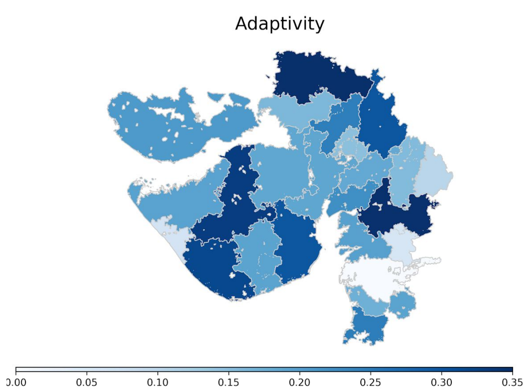


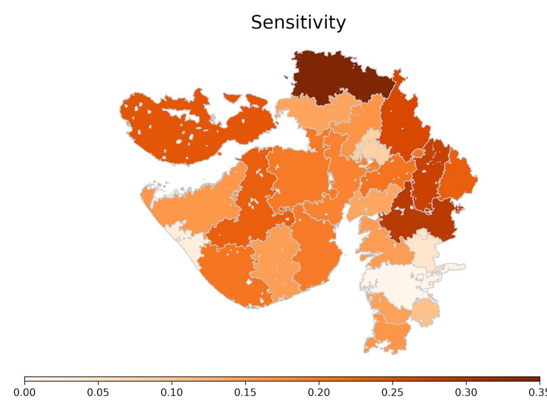
As can be seen from the above maps, exposure in Kucch area is minimum of all the districts in Gujrat whereas its sensitivity is highest and adaptive capacity is considerably low. So, vulnerability map gives the vulnerability of all the regions after combining the three components. South-east coastal regions are highly vulnerable as the exposure in that region is high and adaptive capacity is low.

- **Results for census 2011 socio-economic data analysis and 1981-2015 exposure period -**



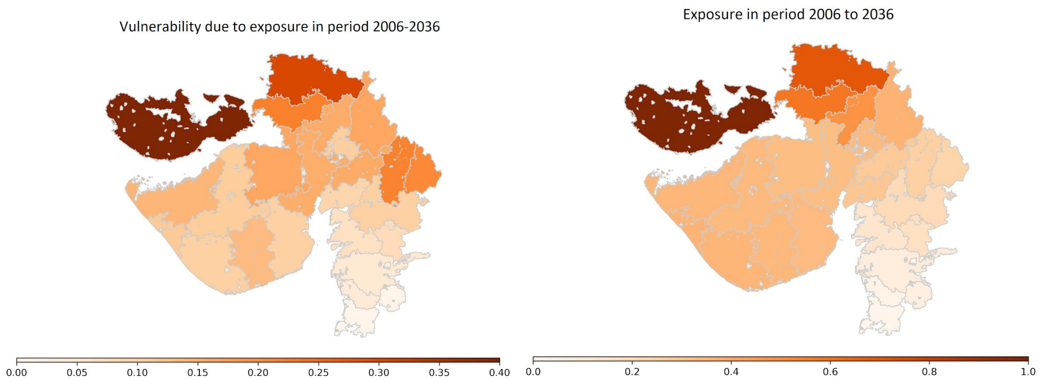






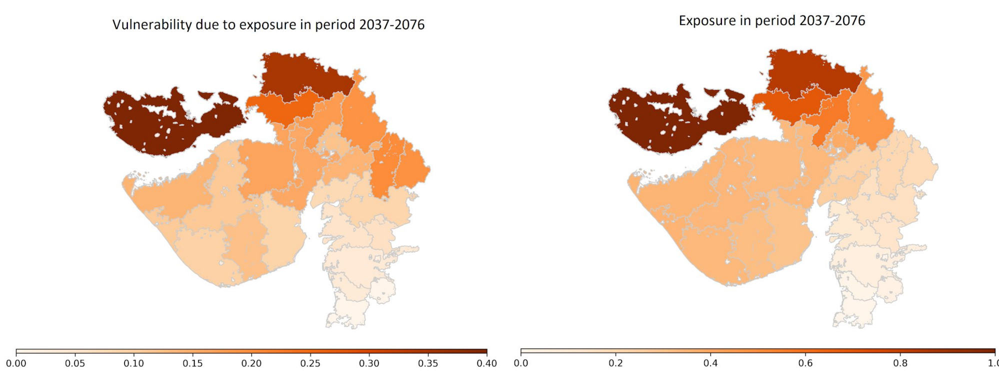
From the analysis of the above maps, it can be concluded that the volatility ratio is high during this period in kucchh as it is having maximum exposure and from the vulnerability map, it can also be concluded that exposure is the major factor in contribution in Kucchh district as vulnerability is also high there though it has significant adaptability. Hence, the major inference drawn from the analysis in this period is that Kucchh is the most vulnerable district in Gujrat with highest exposure.

- **Vulnerability in the future period with near term period(2006-2036) precipitation data analysis and constant socio-economic parameters of Census 2011 -**



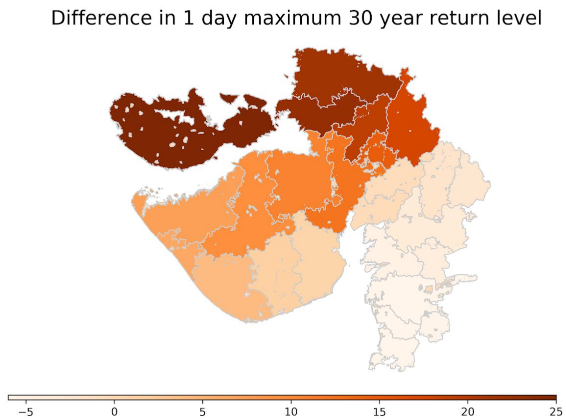
From the exposure map, it can be concluded that volatility ratio has changed more or less in same amount for all the districts if compared to past analysis such that exposure of Kucchh is still high for this particular period and hence its vulnerability as socio-economic parameters are not changed.

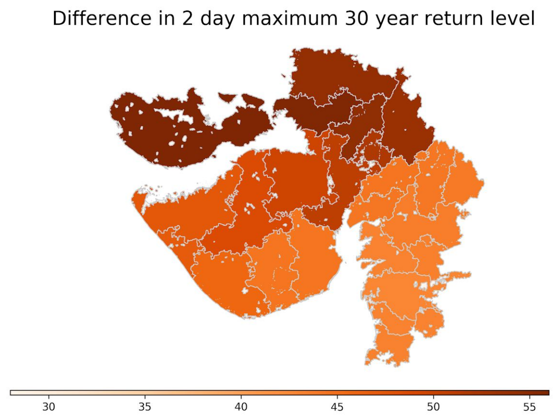
- **Vulnerability in the future period with near term period(2037-2076) precipitation data analysis and constant socio-economic parameters of Census 2011 -**

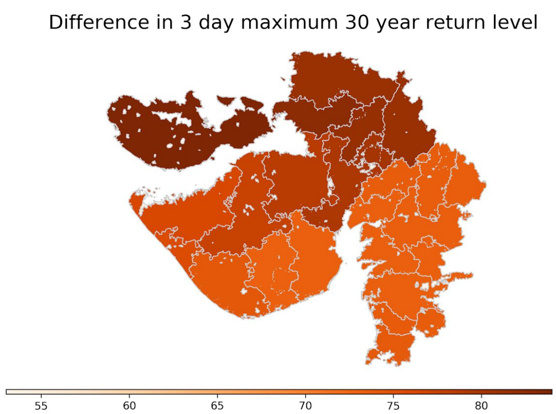


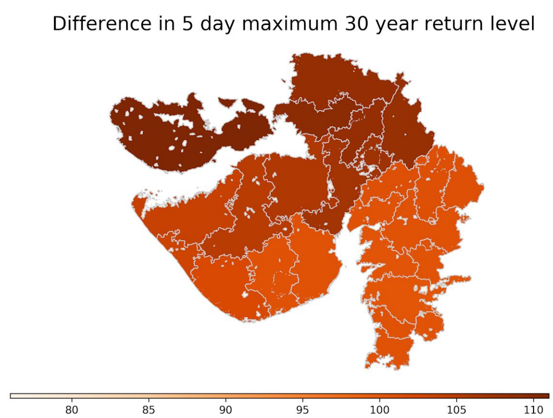
From this and previous analysis, it can be concluded that in any period of time the volatility ratio of each region is changing with same amount for each region keeping Vulnerability of Kucchh high in any period. Hence there is a serious need of designing the infrastructure in Kucchh very carefully taking into account the high volatility ratio and increasing magnitudes of the return levels with time to lessen the structural sensitivity of this area and hence ensuring the safety of people living there.

- **DIFFERENCE IN PRECIPITATION EXTREMES**
    - <u>Absolute Difference in 30-year return levels between period (2037-2080) and (1981-2015)</u>



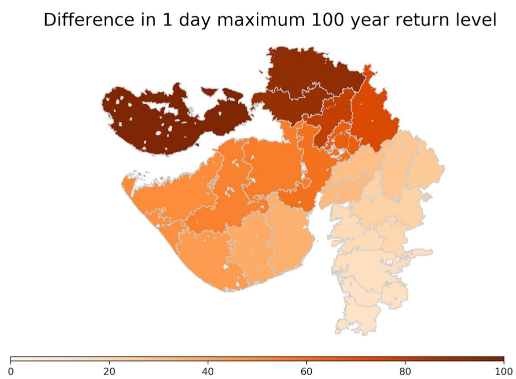


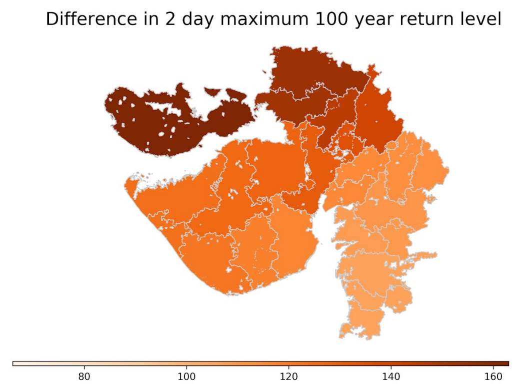


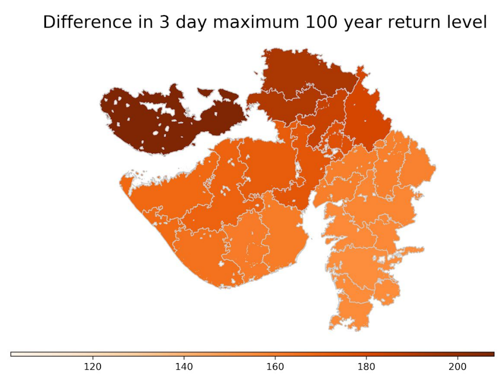


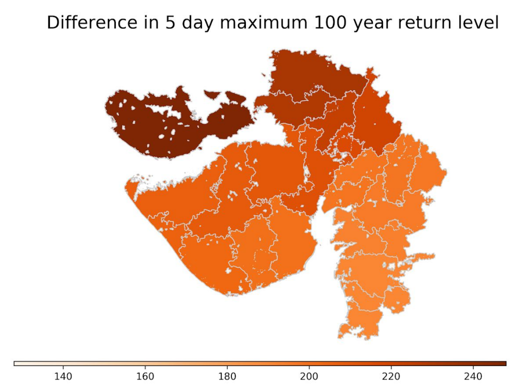
From these four maps, it is evident that the precipitation extremes (30-year return levels) have changed most significantly in the northern part of the Gujrat state and the change has the highest magnitude in Kucchh district which is the evidence for the high exposure in the vulnerability assessment.

- <u>Absolute Difference in 100-year return levels between period (2037-2080) and (1981-2015)</u>

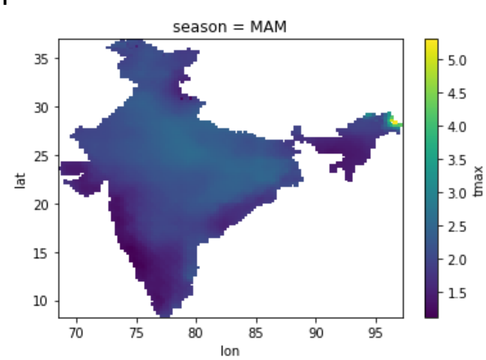


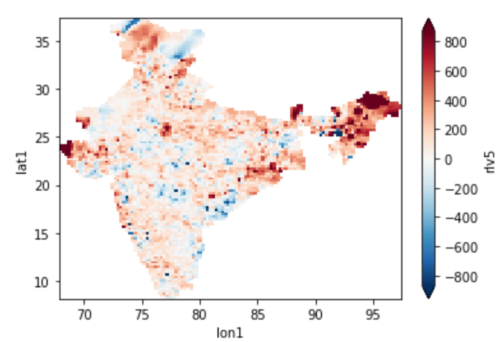






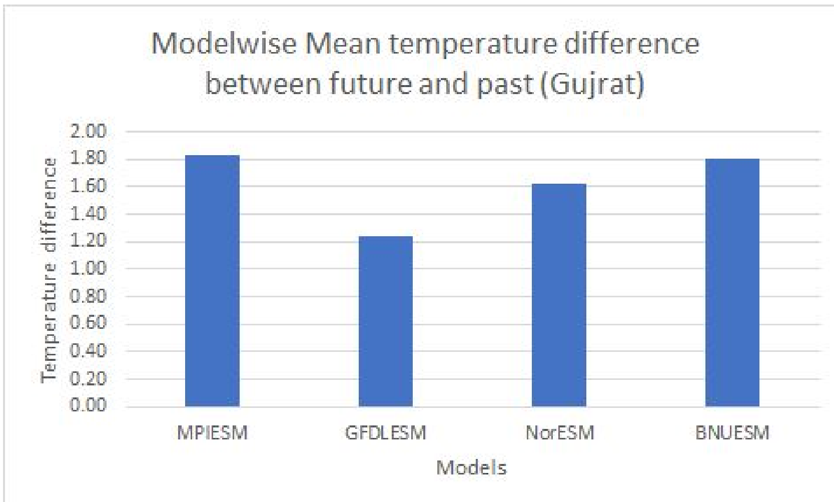
- **Temperature data analysis and its relation with precipitation data-**
  The temperature difference between future period 2006-2100 and the past period 1981-2005 for India





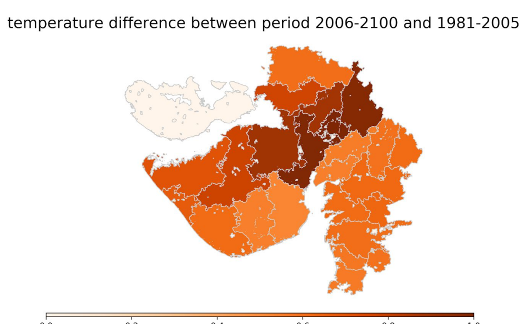
Temperature difference **Difference in 100-year return level**

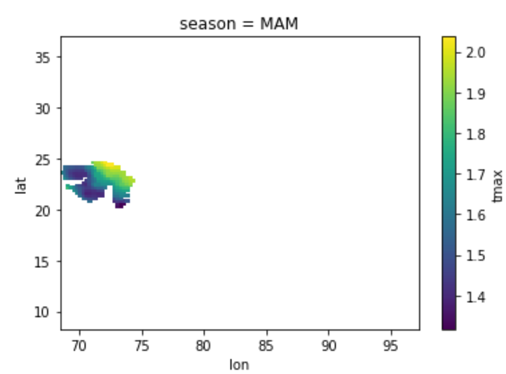
Temperature and precipitation can be related by the Clausius clapeyron's relationship according to which the saturation vapour pressure increases as the temperature increases and hence the moisture holding capacity also increases which can be the reason for incresed magnitudes of the precipitation extremes. From the above map of temperature difference, it is clear that on an average, 2-degree Celcius of temperature increase is projected in future and hence due to this warming, the precipitation extremes can be expected to rise in magnitude though there many uncertainties associated with it like, in the mountainous region, in India, its Himalayan region where the uncertainty is very much in both the projected temperature and precipitations. As in that area, orographic precipitation is dominant which is pretty unpredictable as weather can change instantly and sudden pour may occur at any time hence, accounting for it is not a trivial task and involves many uncertainties.



Above histogram shows the average temperature difference in Gujrat state according to the 4 models under RCP 8.5 scenario. So, based on these models, the average temperature difference is computed which is shown in the following map district wise:

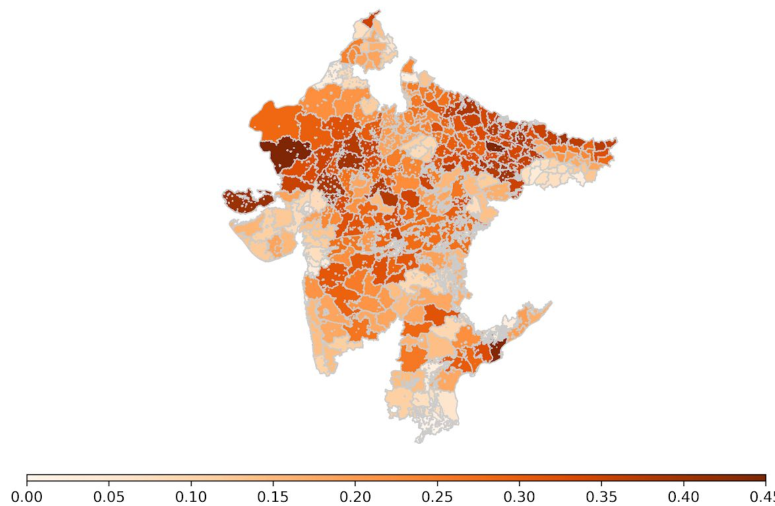
Relative temperature difference in districts **Absolute temperature difference**



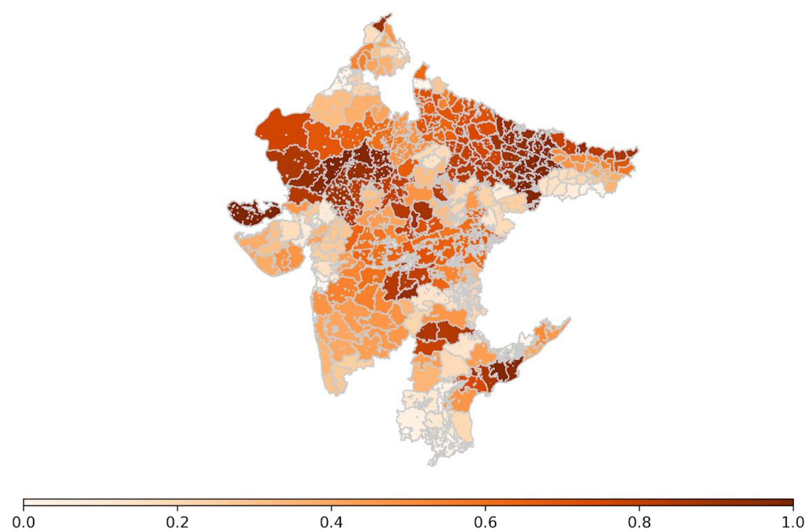


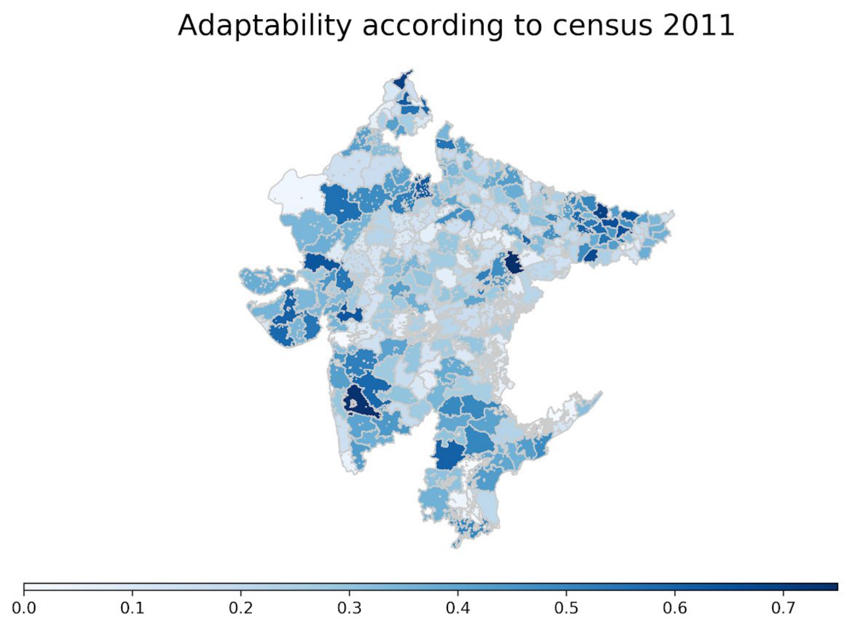
- **The vulnerability of assessment of nine states in India including Gujrat -**
    - **Assessment for Period 1981 - 2015 with socio-economic indicators data of Census 2011 -**

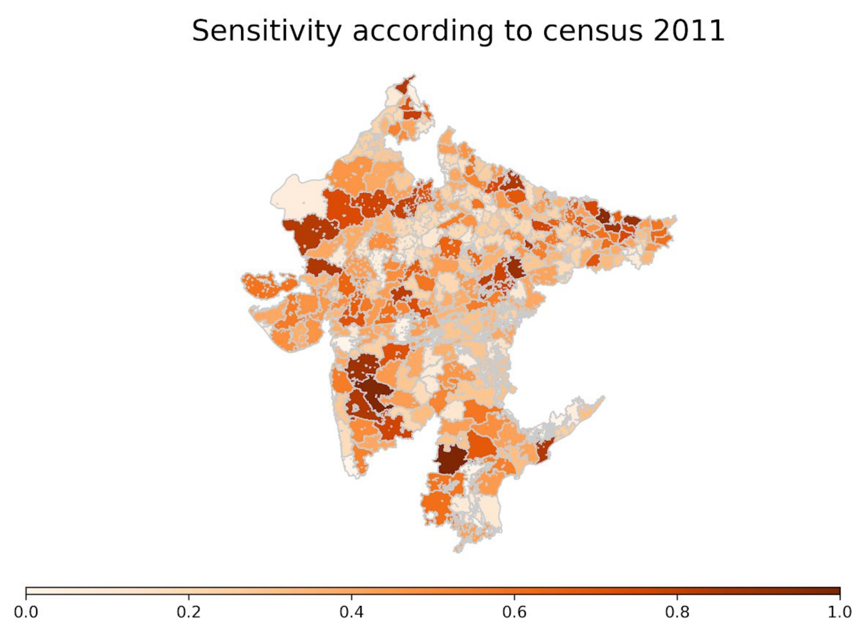
Vulnerability in period 1981-2015



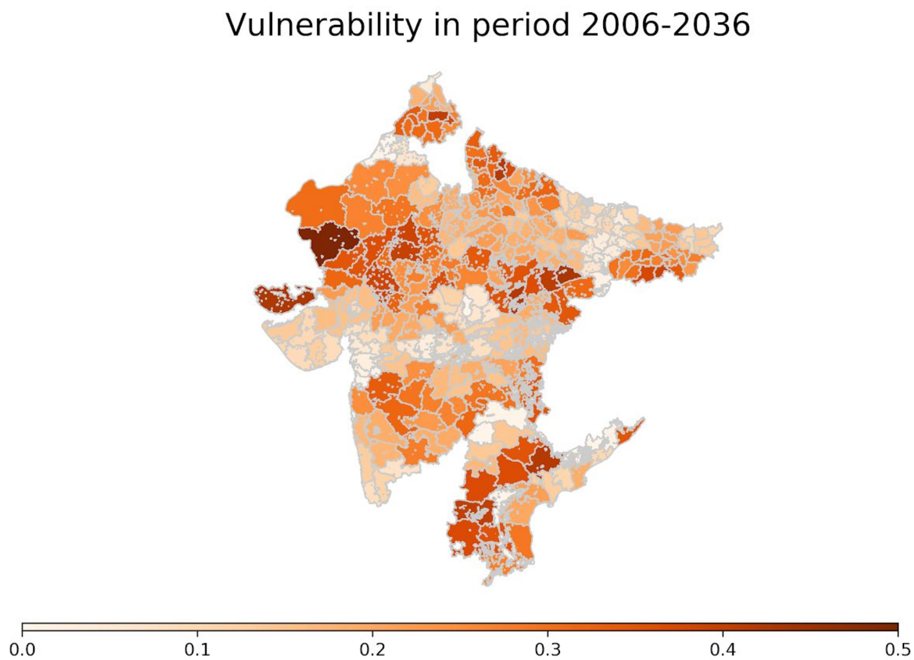
Exposure in period 1981-2015

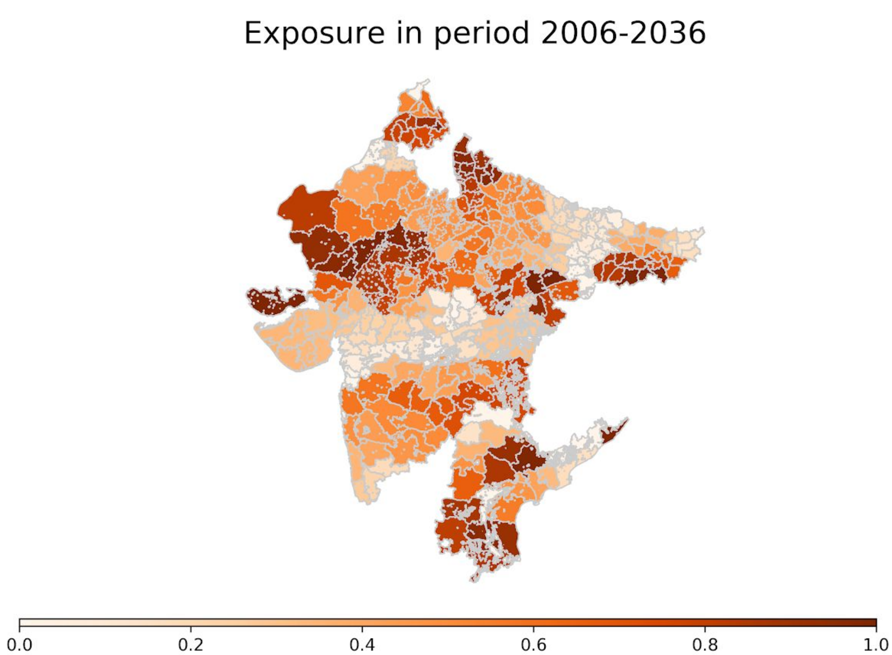



Adaptability according to census 2011
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

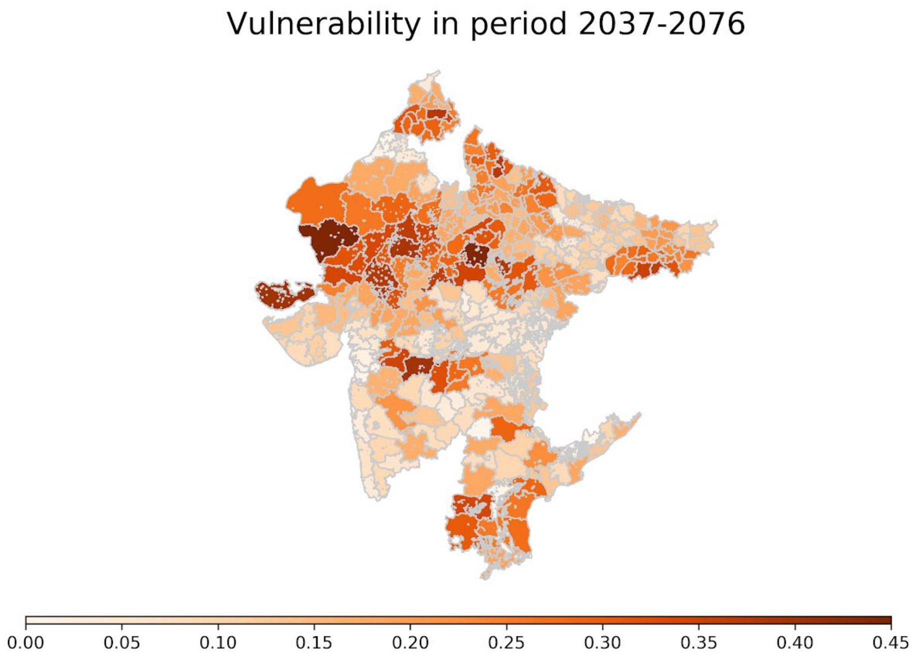

Sensitivity according to census 2011
0.0
0.2
0.4
0.6
0.8
1.0

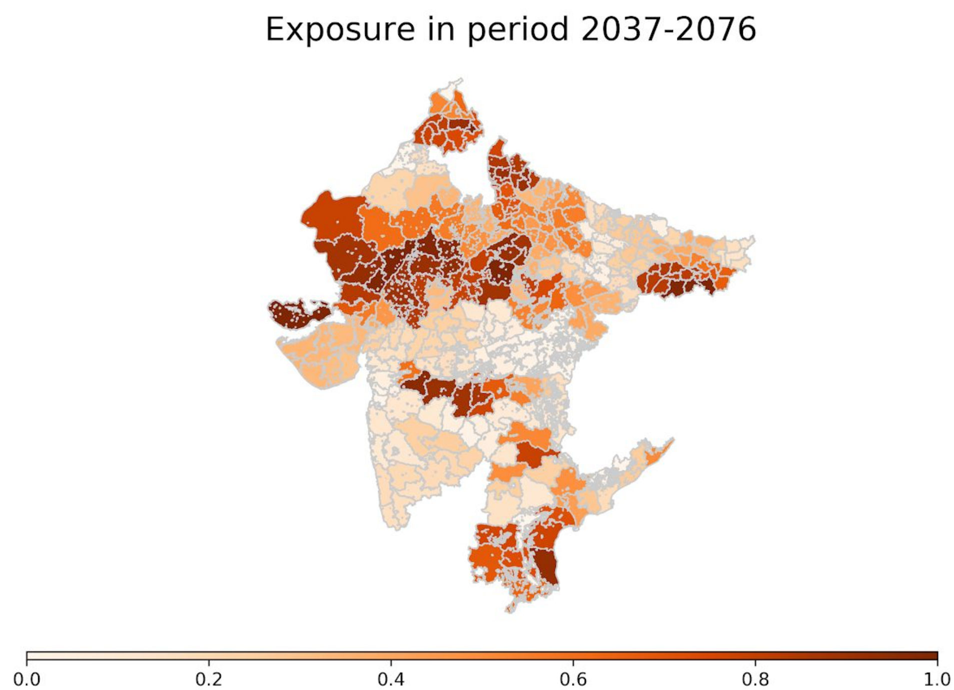
- **Assessment for Period 2006-2036 with socio-economic indicators data of Census 2011 -**





- **Assessment for Period 2037-2076 with socio-economic indicators data of Census 2011 -**





These figures give an idea about the vulnerability and exposure in each district of each state and highlight the highly susceptible areas. Same approach is followed for doing the analysis of each of the state. Here exposure only accounts for the precipitation extremes and the analysis using temperature data for all the states is the extension of this research work.

- **LIMITATIONS OF THE STUDY -**
  - Lack of year wise and future Socio- economic data availability.
  - Unknown relationships between exposure, adaptability and sensitivity.
  - According to Census 2011, some states have increased the number of districts than that according to Census 2001, hence comparison is sometimes not consistent due to lack of data.

- **REFERENCES -**

1. Pachauri, R. K., & Reisinger, A et. al, 2007. IPCC fourth assessment report. *IPCC, Geneva*, *2007*.
2. Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. et, al,2014. *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). Ipcc.
3. Boston, G. et. al, 2016. Climate Ready Boston Final Report. *City of Boston*.
4. Field, C. B., Barros, V., Stocker, T. F., & Dahe, Q. (Eds.). (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change*. Cambridge University Press.
5. Mukherjee, S., Aadhar, S., Stone, D., & Mishra, V. et. al,2018. Increase in extreme precipitation events under anthropogenic warming in India. *Weather and climate extremes*, *20*, 45-53.