Development of micro level grid data of rainfall and temperature in Odisha over different time scale

A
Thesis submitted to the
Orissa University of Agriculture and Technology
in Partial fulfilment of the Requirement for the degree of

Master of Science in Agriculture
(Agricultural meteorology)

By

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02AM/16

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BHUBANESWAR-751003, ODISHA

2018

ACKNOWLEDGEMENT

Towards, the end of this great voyage, in the quest for knowledge and wisdom, which marks the beginning of a new horizon, it gives me an insurmountable pleasure to mention all of them who planted and nurtured the spirit of faith and hope in accomplishing this task. I extend my acknowledge with gratitude and respect to the following

First of all, I owe an immeasurable debt of gratitude to ***Dr. K. K. Singh*** *Scientist G and Head Agro-Met Services Cell, IMD New Delhi a person with height of human relationship, kindness and patience, for being the Chairman of my research.*

I avail this opportunity to express sincere regards and thanks to the members of my advisory committee ***Dr. S. Pasupalak,*** *Hon'ble Vice Chancellor, Orissa University of Agriculture and Technology, Bhubaneswar,* ***Dr. B. S. Rath,*** *Professor and Head, Department of Agricultural Meteorology***,** *College of Agriculture, OUAT and* ***Dr.Anupama Baliarsingh,*** *Principal Agrometeorlogist, Department of Agricultural Meteorology***,** *College of Agriculture, OUAT for their painstaking effort, invariable support and encouragement during every odds in a friendly manner. It was indeed a great pleasure and privilege working with them.*

I am indebted to all my teachers, ***Dr. A. K. B. Mohapatra,*** *Associate Professor, Department of Agricultural Meteorology, College of Agriculture, OUAT***, Mr. S Pradhan,** *Professor and Head, Department of Bioinformatics for being the lighthouses in this hard journey.*

I shall be indebted to Mr. Ganesh and Mr. Nitesh who guided me and supported throughout my research and preparation of the Manuscript. My diction is too poor to translate into words the gratitude I have for these senior friends.

I remain indebted to my beloved parents Mother Smt. Seethi Bai Anand Naik and father Shri Anand Naik, brother Nethra Naik, Sister Sheela, Sister in aw Laxmi, uncle Rama Naik and Aunt. Shanti Bai who molded me with love and care during times of distress and challenges. Without their help this research work would not have been possible. I extend my extreme thanks to my entire family for their patience, scarifies, understanding, endurance, sustained encouragement and helping me in my each step.

I am deeply grateful to my seniors at Department of Agricultural Meteorology, Mr. Ashutsh Nanda, SRF, FASAL, Mr. G. Panigrahi, SRF, NICRA, Mr. Rakesh Kumar Swain, *DEO, NICRA, Mr. B. Jena, DEO, NICRA, Mr. Satyanarayanan Mohanty, Met Observer, GKMS, Mr. Jayaram Biswal, Staff, Department of Agricultural Meteorology, College of Agriculture, OUAT for their help and support throughout my post-graduation.*

My sincere thanks as to all my fellow classmates DJ, Padmanab, Manjari, Snigda, Sunitha, Sarkar, Deepa, Tapan, Sujatha Sharma, Dileep, Sekhar, D Shakthi, Jai Shankar and juniors SR Tripathy, Khilendhar and Praveen, for their valuable support during my PG study at OUAT.

I also thank to my seniors, classmates and juniors from Kannada Balaga Dod Punith Sir,Chik Punith Sir, Yogesh Sir, Minchu Sir, Manju Sir, Veeresh Sir, Chiru Madam, Kiran Sir, Yogi Sir (Ento) and outgone seniors, Anna Sir, Hemanth Sir, Ramachari Sir, Dude Sir, Sangeetha Mam, Abhilash Sir (Vet) and my classmates Child Chetu, Gopi, Veg Pooja, Ento Pooja, Anita U and my Juniors Dumm Manja (Aduge Manja), Gym Ummi, OH Sachya, Kari Marya, Kiccha Bro (Uday TV),TH Ashoka, PK Ramanji, Joshi, MG Naveena, LMC Saya for their tremendous support and for standing by me throughout my stay at OUAT.

I am thankful to Indian Council of Agricultural Research (ICAR), for providing NTS Scholarship for my M. Sc. Programme.

I am thankful to the staff of IMD, New Delhi and State Relief Commissioner, Department of Revenue and Disaster Management, Government of Odisha` for their kind cooperation in collection of data for my research work.

Last but not least, I express my heartfelt thanks to Ranjith Bhai (SM Printers) for neat and timely preparation and DTP work of the Thesis.

At last I would gratify Lord Jagannath, Lord Hanuman, Lord Bheemisati Thitharaja and Lord Sevalal for their choicest blessings.

……………any omission in this small manuscript does not mean lack of gratitude.

Place: Bhubaneswar **(Jagadeesha Naika)**

Date: JUNE 2018 **Adm. No. 02AM/16**

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ABBREVIATIONS

Abbreviations/Symbols	Description
cm	Centimeter
mm	Milliliter
m	Meter
Km	Kilometer
^{0}C	Degree Celsius
e.g.	For example
et al.	Co-workers
Fig.	Figure
i.e.	That is
Viz.	Such as
IDW	Inverse Distance Weightage
IMD	India Meteorological Department
SRC	Special Relief Commissioner
T MAX	Maximum temperature
T MIN	Minimum temperature
GIS	Geological Information System
Etc.	Et cetxtra
GTS	Global tele communication system
%	Per cent age
RF	Rainfall

ABSTRACT

Climate change has been the global phenomenon affecting the mankind. The ill effect of climate change necessitated the research and development in various aspects of global climate change. The present study is an attempt to prepare a grid data at the micro level (block level) to supplement the agrometeorological research and development. However, very few studies have been made on a micro-scale (block level) for the states in general and Odisha in particular. Hence, the present study was carried out to determine the trend of the extreme rainfall events during 1994-2017. The study was carried out with different interpolation techniques such as Inverse Distance Weightage (IDW) for rainfall and temperature analysis, Kriging for rainfall and Spline for temperature using geographical information system (GIS) technology to create micro level gridded datasets from the point data. The analysis exhibited that IDW technique is best for rainfall and Spline technique gives good result for temperature. The analysis revealed that the southern region (Malkanagiri, Koraput, Raygada, Nabrangpur and Kalahandi) of the state receives maximum rainfall during the monsoonal months as compared to other regions of the state. In case of temperature, the western region (Jharsuguda, Sambalpur, Deogarh, Baragarh, Sonepur, Bolangir, Nuapada) of the Odisha appears to have high Tmax values as compared to the rest part of the state. Block level daily rainfall data were used in identifying the extreme rainfall events while district-level aggregation was used in per cent extreme events and frequency of extreme events per year in three categories viz; Heavy (64.5-124.5 mm per day rainfall), Very Heavy (124.5-224.5 mm per day rainfall) and Extremely Heavy rainfall (≥244.5 mm per day rainfall) as per the criteria given by IMD. The state on an average received one extremely heavy rainfall, eight very heavy rainfall and forty heavy rainfall events in a year. Maximum percentage of extremely heavy rainfall occurred in Sambalpur (5.95 %), very heavy rainfall in Puri (22.86 %) and heavy rainfall in Sundergarh (84.66 %). A record of one-day rainfall event clearly indicated that Thuamal Rampur block of Kalahandi district experienced extremely heavy rainfall (700 mm) on 3rd June 2006.

1. INTRODUCTION

Climate change has been global phenomenon affecting the mankind. The ill effect of climate change necessitated the research and development in various accepts of global climate change many disciplines (biogeography, hydrology, forest management, agriculture, ecology and others) use spatial information about climatological data as a basis for understanding the processes they study. Though there are some useful local models (Blennow and Persson, 1998) to predict climatological variability, our aim is to develop a grid data of rainfall and temperature over a relatively large area. Nevertheless, available information is usually limited to the meteorological stations and, therefore, to discrete points in space. This makes it necessary to use interpolation techniques to map the corresponding meteorological variables.

The study on climate variability assumes a greater significance in this regard. The long term weather events, their occurrence and the predictions are the crux of the research study which are to be carried out. The present study is an attempt to prepare a grid data at micro level (block level) to supplement the agro meteorological research and development.

Over the decade's numerous approaches to interpolation have been developed (Biau et al. 1999), and range from simple linear interpolation to more sophisticated approaches. However, with a few exceptions (e.g., Hulme 1992, 1994; Osborn and Hulme 1997), most interpolation schemes provide an estimate of the observations at new *point* locations, subject to a variable set of assumptions underlying the interpolation procedure, which remains at odds with the objective of determining area averages. While some interpolation schemes have been developed for daily datasets (Piper and Stewart 1996), more often the interpolation is undertaken on time-averaged values (monthly, annual, etc.). This simplifies the task (as the spatial variability in daily atmospheric forcing is largely averaged out) but fails to address the key needs of end users for higher temporal resolution data. Osborn and Hulme (1997), developed seasonal area-averaged precipitation data using an estimate of the variance as a function of the number of observations in the grid box and the correlation decay length of the observing stations (a function of the correlation between pairs of stations and the separation distance between the stations). From this, they derived a standard deviation for the grid box. They also describe a method for estimating rain day frequency. With the spread of computers, more automatic interpolation procedures were proposed and implemented. Interpolation procedures can be simple mathematical models (inverse distance weighting, trend surface analysis, Thiessen polygons etc.), or more complex models (geostatistical methods, such as kriging and thin plate splines). Nonetheless, in most cases, those models do not take into account geographical information, although there are more sophisticated methods that incorporate this kind of information, such as co-kriging and elevation-detrended kriging techniques.

Gridded daily temperature observations are required for empirical analyses of global extremes, to validate the performance of climate models used to make future predictions of extreme events, as well as for other environmental modeling applications that require evenly spaced temperature data as input. However, no clear guideline exists for selecting the optimal method for spatial interpolation of meteorological variables. In general the geostatistical (kriging) and inverse distance weighted (IDW) methods are preferable for seasonal and daily rainfall interpolation over Thiessen polygons, polynomial interpolation, or other deterministic methods. An earlier study by Szcze´sniak and Piniewski (2015) showed that kriging interpolation of precipitation for several mesoscale basins in Poland outperformed IDW and Thiessen polygons in skill for hydrological modeling. Indeed, kriging has recently often been used as the interpolation method for precipitation and air temperature.

Data sets of spatially irregular meteorological observations interpolated to a regular grid are important for climate analyses. Such gridded data sets have been used extensively in the past and will continue to be important for many reasons. First, such interpolated data sets allow best estimates of climate variables at locations away from observing stations, thereby allowing studies of local climate in data-sparse regions. Second, for monitoring of climate change at the regional and larger scale, we frequently utilize indices of area averages. Such indices range in scale, from those representing local regions.

Standing on the coastal belt, the weather in Odisha (Orissa) is greatly influenced by the sea. The climate of the region is tropical resulting in very high temperature in the months of April and May. On the contrary, the Eastern Ghats of the state experience an extremely cold climate. In Odisha**,** there are three major seasons - summer (March-June), Rainy Season (July-September) and the winter (October-February). Odisha (Orissa) lying just South of the Tropic of Cancer, has a tropical climate. It is warm almost throughout the year in the Western districts of Sundergarh, Sambalpur, Baragarh, Bolangir, Kalahandi and Mayurbhanj with maximum temperature hovering between 40-46°C and in winter, it is intolerably cool. In the coastal districts, the climate is equable but highly humid and damp.

The summer maximum temperature ranges between 35-40°C and the low temperatures are usually between 12-14°C. Winter is not very severe except in some areas in Koraput and Phulbani where the minimum temperature may drop to 3-4°C. The average rainfall is 150 cm, experienced as the result of south-west monsoon during July-September. The month of July is the wettest and the major rivers may get flooded. The state also experiences small rainfall from the retreating monsoon in the months of October-November. January and February are dry.

Odisha state is frequently impacted by the weather hazards and extreme rainfall is one of them. Most of the extreme rainfalls are generally associated with the cyclonic circulation forming over the land or over the Bay of Bengal. Climate model simulations (Hennessey *et al*., 1997), reports of Intergovernmental Panel on Climate Change (IPCC, 2007) and empirical evidences confirm that warmer climates, owing to increased water vapor, lead to more intense precipitation events and therefore, increases risks of floods. As most of the people of Odisha depends upon agriculture, such changes on rainfall events is more important than the changes in mean pattern of rainfall for agriculture [Guhathakurta *et al.* (2010)]. Moreover, such changes in rainfall events warrant to review and reorient the disaster management and mitigation practices. Secondly, northern parts of the state are greatly affected by flood as a result of extreme rainfall. General perception in the state is that extreme rainfall events are increasing with respect to intensity and frequency and such changes in rainfall would pose a great risk on crop production and productivity. Earlier, Rakhecha and Pisharoty (1996) studied the heavy rainfall events during the southwest monsoon season for some selected stations over the country. Stephenson *et al*. (1999), using the data for the period June to September 1986 to 89, have investigated extreme daily rainfall events and their impact on ensemble forecasts of the Indian Monsoon. K C Gouda *et al*. (2017) studied the comparative study of monsoon rainfall variability over India and the Odisha State. Rajeevan *et al.* (2008) analyzed the variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. Sen Roy and Balling (2004) studied the trends in extreme daily precipitation indices. Most of the studies on extreme rainfall were on macro-scale and all India basis. However, not much studies have been made on a micro-scale (block level) for the states in general and Odisha in particular. Hence, the present studies were carried out to determine the trend of the extreme rainfall events during 1994-2017.

The aim of the study described in the value of these data by producing a consistent series of climatic statistics that enables comparisons to be made across space and time. In order to do this, different methods have been developed, following on from those used by Lee *et al*. (2000), using geographical information system (GIS) technology to create gridded datasets from the point data. There is an increasing demand for gridded datasets of climate variables from fields such as hydrology, forestry, ecology, agriculture, climate-change research, and climate model verification. Consequently, there have been numerous attempts made at spatial interpolation, using a variety of methods. Climate data are often strongly related to topographic and geographic variables, and it is important to incorporate these factors.

In the context of above, study entitled **“Development of micro level grid data of rainfall and temperature in Odisha over different time scale”** is undertaken with following objectives:

1. Compilation of daily long term data on rainfall and temperature.
2. Development of response surfaces of Rainfall and Temperature using different interpolation techniques in GIS platform and gridded data.
3. Analysis of extreme weather events at different time scale using micro level gridded data.

2. REVIEW OF LITERATURE

A review of the past research helps in identifying the conceptual and methodological issues relevant to the study. This would enable the researcher to collect information and subject for sound reasoning and meaningful interpretation. A brief review of the earlier work related to the present study is presented in this chapter. Keeping in view, the objectives of the study, the reviews are presented under the following headings.

2.1 Construction of gridded data set

Stephen *et al*. (1996) studied global terrestrial gridded data set of the daily average and range of temperature and daily precipitation has been developed, intended for use in terrestrial biospheric modeling. Daily station data, primarily from the World Meteorological Organization global synoptic surface network of stations, have been extensively quality checked and interpolated to a 1×1 degree grid by using a nearest neighbors interpolation scheme. Monthly and annual totals of the daily precipitation data have been compared with the monthly 1987 data set produced by the Global Precipitation Climatology Centre. Comparison of the time series from individual stations with those from the gridded data set indicate that the day-to-day variation of temperature and the fraction of wet days are preserved, except in the tropics where wet days are overestimated. Station densities have been tabulated in terms of total annual net primary productivity to identify countries where increases in station data will be most effective for terrestrial biospheric modeling.

David *et al*. (2002) developed a statistical modeling technique suitable for producing mean and interannual gridded climate datasets for a topographically varying domain is undertaken. Stepwise regression models at 1.1 km resolution are generated to estimate mean winter temperature and precipitation for the Southwest United States for the years 1961–1990. Topographic predictor variables are used to explain spatial variance in the datasets. Several smaller-scale precipitation regression models are developed for comparison to the domain-wide model but do not show marked accuracy improvements. Observed values of winter temperature and precipitation from the years 1961–1999 are compared to the 30 yr modeled means, and the differences are interpolated using kriging (temperature) and inverse distance weighting (precipitation). The result is a 39year time series of maps and datasets of winter temperature and precipitation at 1 × 1 km resolution for the Southwest United States

Matthew and Daniel (2005) explained monthly or annual 5 km × 5 km gridded datasets covering the UK are generated for the 1961–2000 period, for 36 climatic parameters. As well as the usual elements of temperature, rainfall, sunshine, cloud, wind speed, and pressure, derived temperature variables. The analysis process uses geographical information system capabilities to combine multiple regression with inverse distance-weighted interpolation. Geographic and topographic factors incorporated either through normalization with regard to the 1961–90 average climate, or as independent variables in the regression. Local variations are then incorporated through the spatial interpolation of regression residuals. This gives some insight into the significance, direction, and seasonality of factors affecting different climate elements. It also gives a measure of the accuracy of the method at predicting values between station locations

Rajeevan *et al*. (2008) in this study, using 104 years (1901–2004) of high resolution daily gridded rainfall data, variability and long-term trends of extreme rainfall events over central India have been examined. The frequency of extreme rainfall events shows significant inter-annual and inter-decadal variations in addition to a statistically significant long-term trend of 6% per decade. Detailed analysis shows that inter-annual, inter-decadal and long-term trends of extreme rainfall events are modulated by the SST variations over the tropical Indian Ocean. The present study supports the hypothesis that the increasing trend of extreme rainfall events in the last five decades could be associated with the increasing trend of sea surface temperatures and surface latent heat flux over the tropical Indian Ocean.

Srivastava *et al.* (2009) analysed high resolution daily gridded temperature data set for the Indian region was developed using temperature data of 395 quality controlled stations for the period 1969–2005. A modified version of Shepard's angular distance weighting algorithm was used for interpolating the station temperature data into 1◦ latitude × 1◦ longitude grids. Using the cross-validation, errors were estimated and found less than 0.5 ◦C. The data set was also compared with another high-resolution data set and found comparable. Mean frequency of cold and heat waves, temperature anomalies associated with the monsoon breaks.

Natsuko *et al.* (2011) created a daily mean gridded temperature dataset of monsoon Asia (15°S-55°N, 60°E-155°E) for the period of 1973-2007, with a 0.50 x 0.50 degree grid. We analyzed this dataset based on station observations collected and a quality control and interpolation system developed through the activities of the Asian Precipitation – Highly Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE) project. The number of stations is up to 1.5-3 times the number of stations based on the Global Telecommunication System (GTS), which have been used to obtain other gridded temperature products. We found use of the temperature product of this study and the RH derived from the reanalysis product to be adequate for determining whether precipitation was rain or snow. Our estimated solid precipitation amount using rain/snow discrimination for late fall to early spring (October to March) is consistent with satellite observations. The combination of daily mean temperature, precipitation and rain/snow information in this high- resolution gridded format would be useful as input to river-flow models, crop models and many other situations where water resources must be estimated.

John (2013) explained Landscape-scale ecological modeling has been hindered by suitable high-resolution surface meteorological datasets. To overcome these limitations, desirable spatial attributes of gridded climate data are combined with desirable temporal attributes high-resolution (4-km) gridded dataset of surface meteorological variables required in ecological, suggesting it can serve as a suitable surrogate for landscape-scale ecological modeling across vast unmonitored areas of the United States.

Claudia *et al.* (2014) High-resolution (5×5km2) gridded daily datasets of surface air temperature (DWD/BFG-HYRAS-TAS) and relative humidity (DWD/BFG-HYRAS-HURS) are presented in this study. The data sets cover Germany and the bordering river catchments and last from 1951 to 2006. Their databases consist of daily station observations from Austria, Belgium, Czech Republic, France, Germany, Luxembourg, the Netherlands, and Switzerland. The interpolation of the measurement data to the regular grid is performed using a method based upon

Optimal Interpolation. The Rhine river catchment a summer mean temperature of 16.1 °C and relative humidity of 74% is found. In contrast, the mean temperature of heat in summer 2003 amounts to 19.9 °C with a related relative humidity of 65% in this river catchment. as a climatological reference and for bias correction of regional climate models within the German research project.

Pai *et al.* (2014) studied discusses development of a new daily gridded rainfall data set at a high spatial resolution (0.25° × 0.25°, latitude × longitude) covering a longer period of 110 years (1901-2010) For preparing the new gridded data, daily rainfall records from 6955 rain gauge stations in India were used, highest number of stations used by any studies so far for such a purpose. The gridded data set was developed after making quality control of basic rain-gauge stations. The comparison of IMD with other data sets suggested that the climatological and variability features of rainfall over India derived from IMD were comparable with the existing gridded daily rainfall data sets. In addition, the spatial rainfall distribution like heavy rainfall areas in the orographic regions of the west coast and over northeast, low rainfall in the leeward side of the Western Ghats etc. were more realistic and better presented in IMD due to its higher spatial resolution and to the higher density of rainfall stations used for its development.

Venkatraman *et al.* (2014) studied was compared TRMM-3B42V6 rainfall data over the Ganga, Brahmaputra and Meghna (GBM) domain with observed point gauge data, and assess the possibility of using them for application in real time flood forecasting as well as to serve as a comparison tool for the baseline simulation of high resolution atmospheric models aimed at flood forecasting and climate change projections. The India Meteorological Department (IMD) gridded rainfall dataset, the 47 Bangladesh gauge rainfall observations and the Tropical Rainfall Measuring Mission (TRMM) 3B42V6 satellite data are used in the present analysis. The nearest neighbour interpolation scheme is used, The Bangladesh daily gauge measured rainfall is interpolated into regular grids of 0.5° × 0.5° resolution every day from January 1988 to December 2007 and appended with the daily gridded dataset of the IMD over the Indian region. A similar resolution dataset of 0.5° × 0.5° for the TRMM-3B42V6 data from January 1998 to December 2007 is created from the original data of 0.25° × 0.25° resolution. To produce a merged rainfall product, all the gridded datasets are merged.

Tomasz *et al.* (2015) showed CHASE-PL (Climate change impact assessment for selected sectors in Poland) Forcing Data–Gridded Daily Precipitation & Temperature Dataset–5 km (CPLFD-GDPT5) consists of 1951–2013 daily minimum and maximum air temperatures and precipitation totals interpolated onto a 5 km grid based on daily meteorological observations from the Institute of Meteorology and Water Management (IMGW-PIB; Polish stations),Deutscher Wetterdienst (DWD, German and Czech stations), and European Climate Assessment and Dataset (ECAD) and National Oceanic and Atmosphere Administration–National Climatic Data Center (NOAA-NCDC) (Slovak, Ukrainian, and Belarusian stations). The main purpose of constructing this product was the need for long-term aerial precipitation and temperature data for earth-system modeling, especially hydrological modeling. The number of available meteorological stations for precipitation and temperature varies in time from about 100 for temperature and 300 for precipitation in the 1950s up to about 180 for temperature and 700 for precipitation in the 1990s. The precipitation data set was corrected for snowfall and rainfall under-catch with the Richter method. The interpolation methods were kriging with elevation as external drift for temperatures and indicator kriging combined with universal kriging for precipitation. The kriging cross-validation revealed low root-mean-squared errors expressed as a fraction of standard deviation (SD): 0.54 and 0.47 for minimum and maximum temperature respectively and 0.79 for precipitation. The correlation scores were 0.84 for minimum temperatures, 0.88 for maximum temperatures and 0.65 for precipitation.

2.2 Different Interpolation techniques

Hutchinson (1995) concluded that plate smoothing splines provide accurate, operationally straight forward and computationally efficient solutions to the problem of the spatial interpolation.of annual mean rainfall for a standard period from point data which contains many short period rainfall means. Thin plate splines, with the degree of smoothing determining by minimising generalised cross validation, can estimate this smooth function in two ways. First, the spatially correlated error structure of the data can be accommodated directly by estimating the corresponding non-diagonal error covariance matrix. Secondly, spatial correlation in the data error structure can be removed by standardising the observed short term means to standard period mean estimates using linear regression. It is shown that the incorporation of a continuous, spatially varying, dependence on appropriately scaled elevation makes a dominant contribution to surface accuracy. Incorporating dependence on aspect, as determined from a digital elevation model, makes only a marginal further improvement.

Goovaerts (1999) analyzed three multivariate geostatistical algorithms for incorporating a digital elevation model into the spatial prediction of rainfall: simple kriging with varying local means; kriging with an external drift; and colocated cokriging. The techniques are illustrated using annual and monthly rainfall observations measured at 36 climatic stations in a 5000 km2 region of Portugal. Cross-validation is used to compare the prediction performances of the three geostatistical interpolation algorithms with the straightforward linear regression of rainfall against elevation and three univariate techniques: the Thiessen polygon; ordinary kriging yields more accurate predictions than linear regression when the correlation between rainfall and elevation is moderate (less than 0.75 in the case study).

Claire *et al*. (2000) in a comparative experiment, the sequence of daily maximum and minimum temperatures for 1976 was interpolated over England and Wales to a resolution of 1 km using partial thin plate splines, ordinary kriging, trend surface, and an automatic inverse-distance-weighted method of interpolation. A ‘‘level playing field’’ for comparing the estimation accuracies was established through the incorporation of a consistent set of guiding variables in all interpolators. Differences in estimation accuracy among partial thin plate splines, ordinary kriging, and inverse distance weighting results were not significant although the performance of trend surface analysis was poorer. Best accuracies were achieved using partial thin plate splines, with jackknife cross-validation root-mean-square errors of 0.88C for an annual series of daily maximum temperatures and 1.148C for daily minimum temperatures. The results from this study suggest that sole reliance on the selection of guiding variables can be a less efficient means of achieving the required accuracies than the placing of greater reliance on empirical techniques of interpolation that can account for known autocorrelation in the temperature data.

Maureen and Jean. (2000) used a GIS-based method for constructing high-resolution (in space) maps of mean seasonal temperature and precipitation is developed for the Mediterranean Basin. Terrain variables and geographical location are used as predictors of the climate variables at all points on a grid with a 1 km resolution, Seasonal mean temperature and precipitation data, for the observation period 1952 to 1989, were assembled from 248 temperature sites and 285 precipitation sites in order to initialize the regression model. Temperature data from 36 stations and precipitation data from 35 stations were retained for model validation. Climate surfaces were constructed using the regression equations and refined by kriging the residuals from the regression model and subtracting the result from the predicted ‘observation' surface. Latitude, elevation, and distance from the sea are found to be the most effective predictors of local seasonal climate. Validation determined that regression plus kriging predicts mean seasonal temperatures with a coefficient of determination (R2), between the expected and observed values, of 0.87 (summer) and 0.97 (winter), and mean seasonal precipitation with an R2 of 0.46 (autumn) and 0.94 (summer). A simple regression model without kriging yields less accurate results in all seasons except for the temperature data in spring.

Maureen *et al*. (2000) studied a total of 21 gauges across the mountainous leeward portion of the island of O‘ahu, Hawai‘i, was used to compare rainfall interpolation methods and assess rainfall spatial variability over a 34-month monitoring period from 2005 to 2008. Traditional and geostatistical interpolation methods, including Thiessen polygon, inverse distance weighting (IDW), linear regression, ordinary kriging (OK), and simple kriging with varying local means (SKlm), were used to estimate wet and dry season rainfall. The linear regression and SKlm methods were used to incorporate. The Thiessen method produced the highest error, whereas OK produced the lowest error in all but one period. The OK method produced more accurate predictions than linear regression of rainfall against elevation when the correlation between rainfall and elevation is moderate (R < 0:82).

Miquel et al. (2000) proposed an empirical methodology for modelling and mapping the air temperature (mean maximum, mean and mean minimum) and total precipitation, all of which are monthly and annual, using geographical information systems (GIS) techniques. The method can be seen as an alternative to classical interpolation techniques when spatial information is available. The geographical area used to develop and apply this model is Catalonia (32000 km2, northeast Spain). We have developed a multiple regression analysis between these meteorological Variables Data for the dependent variables were obtained from meteorological stations, and data for the independent variables were elaborated from a 180 m resolution digital elevation model

(DEM). Multiple regression coefficients (*bn*) were used to build final maps, using digital layers for each independent variable, and applying basic GIS techniques. The results are very satisfactory in the case of mean air temperature and mean minimum air temperature, with coefficients of determination ($R2$) between 0.79 and 0.97, depending on the month; in the case of mean maximum air temperature, $R2$ ranges between 0.70 and 0.89, while in the case of precipitation, it ranges between 0.60 and 0.91.

Dimitrios (2003) reported 5 km gridded temperature and precipitation dataset was constructed for the topographically complex region of Switzerland in the European Alps. A novel interpolation method was employed that accounted for possible orographic effects at different spatial scales and allowed for regionally and seasonally varying relief-climate relationships The proposed method was found to be superior to linear regression employing elevation as the only predictor for *P*—, and better than inverse distance weighting (IDW) interpolation for September to February ΔT. It was worse than IDW interpolation for springtime ΔT and for March to September ΔP. The areal mean cross-validation errors obtained for the new method were generally close to zero. The largest cross-validation errors were generally found at regions of lower station density in south-southeast Switzerland and at elevations above ~2000 m above sea level.

Yan-hong *et al.* (2004) through Spline interpolation technique used to develop a gridded climate database for China at a resolution of 0.01° in latitude and longitude. A digital elevation model (DEM) was developed at the same resolution to improve the accuracy of interpolation based upon the general spatial dependence of climate on topography. Climate data for the period 1971–2000 from meteorological stations in China were used to develop thin-plate smoothing spline surfaces for monthly mean temperature and precipitation. A regularly gridded climate database was produced by coupling the spline surfaces with the underlying DEM. The summary statistics show interpolation errors for monthly temperatures varying within 0.42–0.83 °Cand 8–13% for monthly precipitation. These estimates are superior to results produced by methods commonly used in China. The fine-resolution spatial climate database has many potential applications in natural resource management. For example, it can be used as a baseline for climate change studies, in which potential distributions of flora and fauna can be predicted under the impact of climate change and priority areas for biodiversity conservation can be identified.

Hewitson (2004) presented to estimate daily gridded area-average precipitation from station observations. The approach explicitly recognizes that the point observations represent a mixture of synoptic forcing shared in common with surrounding stations and a response that is unique to the station. Consequently, the spatial representativity of a station is conditional on the synoptic forcing and is a function of the radial direction from the station. The conditional interpolation accommodates this in a two-stage process through conditioning the interpolation parameters as a function of the Synoptic state. First, the spatial pattern of wet/dry conditions is estimated, following which the magnitude of the precipitation is derived for those locations determined as "wet." In a test based on a high-resolution dataset for South Africa, the conditional interpolation is very effective in defining the spatial extent of the precipitation field. It then derives gridded values that are representative of the area average. In comparison, both these characteristics appear to be significantly overestimated by one of the commonly used interpolation schemes (Cressman interpolation). Overall the interpolation conditioned by the synoptic state appears to better estimate realistic gridded area-average values.

John (2006) through a gridded land-only data set representing near-surface observations of daily maximum and minimum temperatures were created to allow analysis of recent changes in climate extremes and for the evaluation of climate model simulations. Using a global dataset of quality-controlled station observations compiled by the U.S. National Climatic Data Center (NCDC), Data over consecutive 5 year periods were used to calculate percentiles which allow us to see how the distributions of daily maximum and minimum temperature have changed over time. Changes during the winter and spring periods are larger than in the other seasons, particularly with respect to increasing temperatures at the lower end of the maximum and minimum temperature distributions. Regional differences suggest that it is not possible to infer distributional changes from changes in the mean alone.

Angelo *et al.* (2007) looked into the feasibility of the MODIS Land Surface Temperature (*LST*) product as a source for calculating spatially distributed daily mean air temperature to be used as input for hydrological or environmental models. The test area is located in the Italian Alpine area. The proposed procedure solves, by empirical approaches, by correlation analyses taking into account the altitude variability and exploiting historical series. Validation was accomplished by accuracy assessment procedures both punctual and spatially distributed, the latter performed by comparison with the Inverse Distance Weighting (IDW) interpolation method. The proposed methodology produced satisfactory results as related to the objective: The daily mean air temperatures derived by *LST* showing an overall *RMSE* of 1.89°C, and slightly outperforms the interpolation method used as a comparison

Haylock (2008) presented a European land-only daily high-resolution gridded data set for precipitation and minimum, maximum, and mean surface temperature for the period 1950–2006. The gridded data are delivered on four spatial resolutions to match the grids used in previous products as well as many of the rotated pole Regional Climate Models (RCMs) first interpolating the monthly precipitation totals and monthly mean temperature using three-dimensional thin-plate splines, then interpolating the daily anomalies using indicator and universal kriging for precipitation and kriging with an external drift for temperature, then combining the monthly and daily estimates. Interpolation uncertainty is quantified by the provision of daily standard errors for every grid square. They examine the effect that interpolation has on the magnitude of the extremes in the observations by calculating areal reduction factors for daily maximum temperature and precipitation events with return periods up to 10 years.

Natsuko *et al.* (2011) analyzed the dataset based on station observations collected and a quality control and interpolation system developed through the activities of the Asian Precipitation – Highly Resolved Observational Data Integration Towards Evaluation of Water Resources The ability to discriminate between rain and snow is added to the APHRODITE daily precipitation product by using daily mean temperature and relative humidity (RH). Relative humidity is derived from a reanalysis product because RH observation data are collected insufficiently for interpolation. We found the use of the temperature product of this study and the RH derived from the reanalysis product to be adequate for determining whether precipitation was rain or snow. Our estimated solid precipitation amount using rain/snow discrimination for late fall to early spring (October to March) is consistent with satellite observations.

Mohamad *et al*. (2013) explained that Rainfall is a significant portion of hydrologic data. Rainfall records, however, are often incomplete due to several factors. In this study, the inverse distance weighting (IDW) method integrated with GIS is used to estimate the rainfall distribution in Duhok Governorate. A total of 25 rainfall stations and rainfall data between 2000 and 2010 were used, where 6 rainfall stations were used for cross-validation. In addition, the relationship between interpolation accuracy and two critical parameters of IDW (Power α value, and a radius of influence) was evaluated. Also, the rainfall distribution of Duhok Governorate was classified. As an output of this study and in most cases, the optimal parameters for IDW in interpolating rainfall data must have a radius of influence up to (15 - 60 km). However, the optimal α values varied between 1 and 5. Based on the results of this study, we concluded that the IDW is an appropriate method of spatial interpolation to predict the probable rainfall data in Duhok Governorate using α = 1 and search radius = 105 km for all the 25 rainfall stations.

2.3 Extreme weather events

Stephenson *et al*. (1998) showed that Indian summer monsoon rainfall is the net result of an ensemble of synoptic disturbances, many of which are extremely intense. Sporadic systems often bring extreme amounts of rain over only a few days, which can have sizable impacts on the estimated seasonal mean rainfall. The statistics of these outlier events are presented both for observed and model-simulated daily rainfall for the summers of 1986 to 1989. The extreme events cause the wet-day probability distribution of daily rainfall to be far from Gaussian, especially along the coastal regions of eastern and northwestern India. The gamma and Weibull distributions provide good fits to the wetday rainfall distribution, whereas the lognormal distribution is too skewed. The impact of extreme events on estimates of space and time averages can be reduced by nonlinearly transforming the daily rainfall amounts. The square root transformation is shown to improve the predictability of ensemble forecasts of the mean Indian rainfall for June 1986–89.

Mausam (2009) studied persistence/intensity/frequency of heat waves/ severe heat waves in stations at Ranchi and Daltonganj have increased in the recent years showing a positive variability. The persistence/frequency of heat waves/severe heat waves in stations Bhagalpur and Gaya have decreased in the recent years showing a negative variability. No variability in all three parameters (persistence/ intensity/frequency) in Purnea has been observed. No variability of shifting of highest maximum temperature from one region to another region has been noticed.

Rajendra (2012) in his present study, attempted to analyze various temperature time series as available, varying from large domain to small domain, *e.g*., all India temperature, east coast of India temperature etc., to understand whether years which had recorded extreme temperatures in these larger domains have any relationship with that occurred over its very smaller domain, *e.g*., Orissa from station data, of which later is a part. To understand the relation between the magnitude of heat indices and loss to total human lives it caused during respective whole periods of heat waves, different heat indices, *viz*., general heat indices, Thom's discomfort, and Webb's comfort indices have been computed during these extreme years over Orissa and Andhra Pradesh states and compared with total heat wave related human deaths over the respective states for the corresponding years.

Kamaljit *et al.* (2013) analyzed extreme events like cyclones, heavy rainfall, flood, droughts and heat waves etc. across different parts of the world on varying scale/intensity. Climate variability and occurrence of extreme weather events are the major concerns for the socio-economic wellbeing of the region. During the period March to May 2010, this study was undertaken to analyze the decadal climatology of extreme high-temperature conditions over Gujarat. The decadal analysis carried out in the study indicated that the number of moderate heat wave days and severe heat wave days are highest in the last decade as compared to earlier three decades in more than 70 percent of the stations. The show increase in moderate heat waves in the last decade (2001-2010). Various IMD Stations like Baroda, Deesa, Kandla, and Idar have recorded all-time highest temperatures in the last decade. The summer maximum temperature anomalies of five non-coastal stations of Gujarat also indicate a high positive anomaly (up to 4 °C) prevalent in the last decade and analyses the synoptic condition during the severe heat wave of May 2010.

Mehfooz *et al. (*2013) opined that rainfall results in landslides, flash flood and crop damage that have a major impact on society, the economy and the environment. During southwest monsoon season, flood mostly occurs in India due to extremely or very heavy rain that originates from environmental and synoptic conditions. An attempt has been made to identify the main synoptic reasons, which are responsible for extremely heavy rainfall events over Lower Yamuna catchment (LYC) through the analysis of the relationship between this rainfall and atmospheric systems for the period 1998-2010 based on modern observational technology and developed forecasting technique in the field of short-range prediction. The finding of this study shows that the major factor as is the arrival of Bay of Bengal low-pressure systems in this region, of course, if the ascent local conditions such as heat occur, causing the heaviest rains there. The low-pressure systems (LPS like Cyclone, depression, low-pressure area etc.) developed generally over the Bay of Bengal moved in the west to the north-westwards direction and reached over the LYC region. Also, LPS may be formed *in situ* under the influence of upper air cyclonic circulation (cycler) responsible for such events. Such system yield extremely heavy rainfall events **(**generally in the south-west sector of the system) at isolated places and heavy to very heavy rainfall at a few places and thereby caused flood situation. The possibility of occurrence of such type of rainfall would be higher if the LPS is either stagnate or slow over LYC region

Rathore *et al.* (2016) examined socio-economic impacts of the extreme weather events such as floods, droughts, heavy rainfall, cyclones, hail storm, thunderstorm, heat and cold waves have been increasing due to the large growth of population and urbanizations, which has led to greater vulnerability. A spatiotemporal analysis of these weather extremes over India will be very helpful to understand the vulnerability potential and to improve the forecast skill and use these forecasts in minimizing the adverse impacts of such weather extremes.

Pasupalak *et al*. (2017) studied extreme rainfall events are a significant cause of loss of life and livelihoods in Odisha. Objectives of the present study are to determine the trend of the extreme rainfall events during 1991-2014 and to compare the events between two periods before and after 1991. Block level daily rainfall data were used in identifying the extreme rainfall events, while district-level aggregation was used in analyzing the trend in three categories, *viz*., heavy, very heavy and extremely heavy rainfall as per criteria are given by India Meteorological Department (IMD). The state as a whole received one extremely heavy, nine very heavy, and forty heavy rainfall events in a year. When the percentage of occurrence of each category out of the total extreme events over different districts was considered, maximum % of extremely heavy rainfall occurred in Kalahandi (5.8%), very heavy rainfall in Bolangir (23.8%) and heavy rainfall in

Keonjhargarh (85.4%). Trend analysis showed that the number of extreme rainfall events increased in a few districts.

Yadav *et al.* (2017) carried out a diagnostic study to analyze and understand the causes of unusual rainfall activity over Jammu & Kashmir (J&K) State during 2nd to 5th September 2014. The careful examination of available historical rainfall data of India Meteorological Department (IMD) network reveals that many stations in the region received ever-highest 24, 48 & 72 hours cumulative rainfall during the first week of September in 2014, breaking all previous records. In result, there was flooding in most parts of the State, which has caused loss of human lives and huge loss of property. The synoptic interpretation of this unusual event carried out in the study confirms very favorable meteorological conditions, as there was a western disturbance (WD) in form of cyclonic circulation/trough in mid-tropospheric level, which remained practically stationary over north Pakistan and adjoining Jammu & Kashmir from 2nd to 5th September, 2014 and its interaction with a monsoon Low-Pressure Area (LPA) over northwest & adjoining central India during the same period.

3. MATERIALS AND METHODS

This chapter deals with the description of the study area followed by the nature and sources of data and analytical tools and techniques employed. The methodology is presented under the following major headings.

3.1. Description of the study area

3.2. Nature and sources of data

3.3. Methodology

3.4. Analytical techniques employed (software)

3.4. Definition of terms and concepts used in the study

3.1 Description of the study area

3.1.1. Odisha

This study is focused on the state of Odisha, which is located at the eastern part of India. Orissa has a total number of 30 districts which contains 314 blocks and spread over the area of 155707 km2, and are bounded between North latitudes 17˚49’ to 22˚34’ and East longitude 81˚24’ to 87˚29’. The state has a tropical climate, characterized by high temperature, high humidity, medium to high rainfall and short and mild winters. On the basis of climate type, Orissa has been divided into ten agro-climatic zones. The normal rainfall of the state is 1451.2 mm. About 75% to 80% of rainfall is received from June to September. Floods, droughts, and cyclones occur almost every year in varying intensity. With a 480 km coastline that is prone to climate-mediated cyclones and coastal erosion and water resources dependent on monsoons, Orissa is relatively more vulnerable to climate change. It is a disaster capital of India. Most of the agricultural land is affected by extreme weather events such as extreme rainfall, heat waves, cold waves, cyclones, flood, tsunami and earthquake. Data on block level has been analyzed, and we have taken initiatives to develop the extreme weather event using micro-level gridded data by using different interpolation techniques. In the present study, block wise rainfall data and districts wise temperature data used for development of micro level grid data.

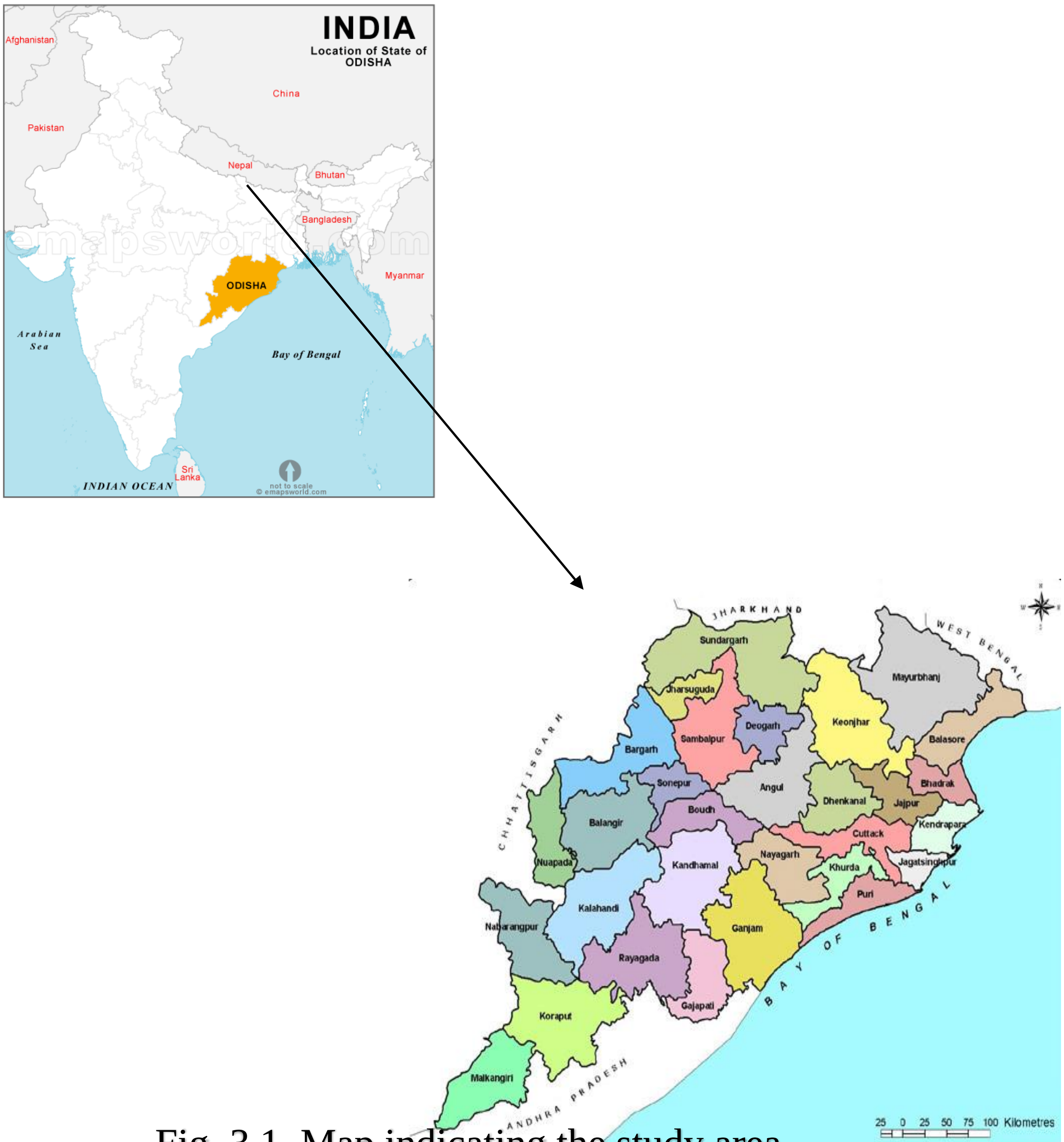


Fig. 3.1. Map indicating the study area

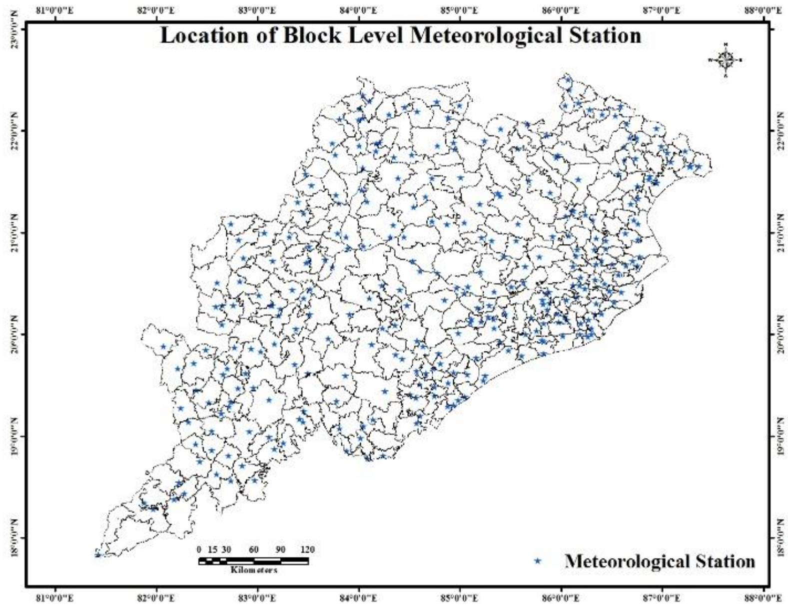


Fig. 3.1.2 spatial distribution of all blocks of Odisha state

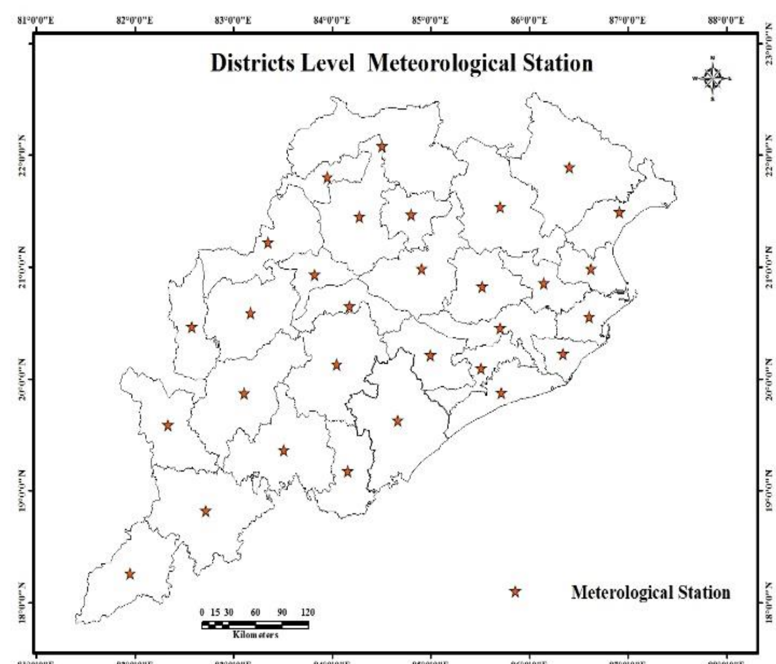


Fig. 3.1.3 spatial distribution of temperature station

3.2 Nature and Sources of data

The state has 30 districts, which are further divided into 314 revenue blocks. The data required for analysis was obtained from secondary sources, the block level rainfall data (24years; 1994-2017) and district level IMD grid data on temperature (30years; 1987-2017) were obtained from Special Relief Commissioner (SRC), Government of Odisha and IMD, New Delhi respectively. This data was further subjected to interpolation with different interpolation techniques along with estimation of extreme weather events that have taken place in the state for over two and half decades.

3.2.1 Compilation of daily long term data on rainfall and temperature

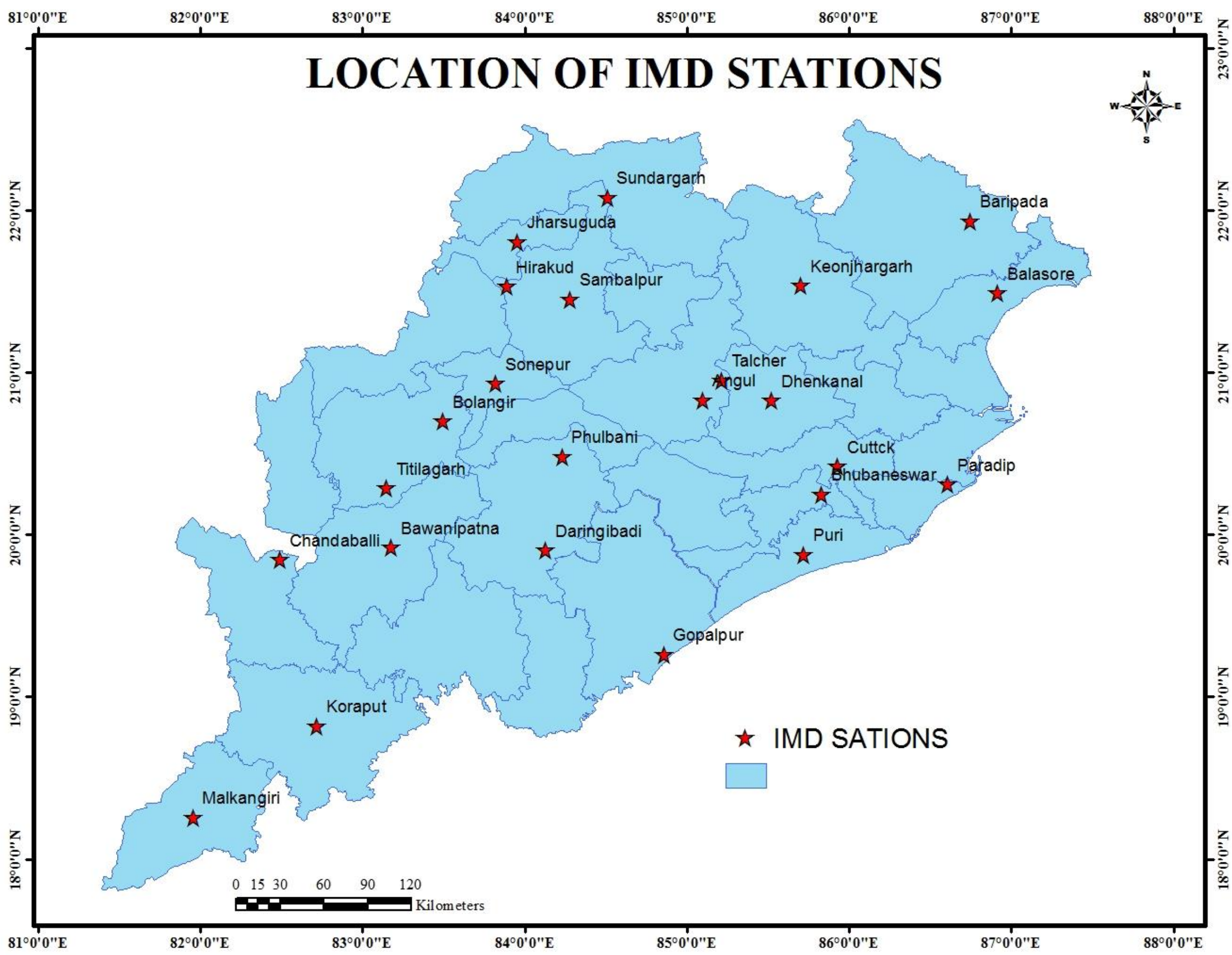
Long-term, accurate observations of atmospheric phenomena are essential for a myriad of applications, including historic and future climate assessments, resource management, and infrastructure planning. For the state of Odisha, India climate data are available with local and State agencies, and from large electronic repositories such as the National Data Centre of India Meteorological Department. The office of the Revenue Commissioner, Odisha Govt. serves as the repository for the paper records of rainfall data. The majority of the climate stations in the state have exclusively measured daily rainfall; however, some stations have also reported minimum and maximum temperature and other variables.

Data compilation

To compile a comprehensive state wide dataset, the first step is identification and acquisition of data from all relevant climate networks viz. Revenue Department of Odisha Govt. and India Meteorological Department. The data measured in Odisha networks are typically not available in open access electronic repositories. The dataset draws on observations from 314 climate stations and includes rainfall manually read stations are still in widespread use in Odisha, requiring digitization of paper records. Partly because of the need to digitize these data, a substantial lag exists between the time of observation and the time data are made publically available on electronic repositories. The office of the Revenue Commissioner, Odisha Govt. serves as the repository for the paper records of rainfall data. These data must be hand digitized from the paper records. To assure fidelity to the original written record, data are manually entered independently by two individuals and cross checked to detect entry errors.

Researchers attempting to make use of available data are faced with a series of challenges that include: (1) Identifying potential data sources; (2) Acquiring data; (3) Establishing data quality assurance and quality control (QA/QC) protocols; and (4) Implementing robust gap filling techniques. This chapter provides details on locations where data were used from, summary of the available climate data including a detailed description of the various meteorological observation networks and data accessibility.

Fig.3.1.4. Map showing location of Odisha IMD stations



3.3. Methodology

Two datasets are being used for preparing micro level gridded data

1. Block level Rainfall observed data.
2. District level Temperature GRID data.

These micro-level datasets have been used further for estimation of extreme weather events. Following procedure has been used to prepare the datasets for our analysis.

Step:

1. Block Rainfall raw data for 314 stations and District level IMD Gridded Temperature (T_{max} and T_{min}) for 30 stations are considered.
2. Datasets are prepared for model required format using MATLAB software.
3. Datasets are imported to GIS software i.e. ArcGIS for converting to micro level gridded data at (0.01^0X0.01^0).
4. Different interpolation techniques have been considered to convert these data into micro-level gridded data using ArcGIS software.
5. IDW, Kriging, Spline techniques have been considered for converting Station data to micro level gridded data.
6. After interpolation, we have done the extreme weather events analysis. For our analysis, we have considered the extreme rainfall events into three categories as per criteria of India Meteorological Department (website: IMD Monsoon Report 2014). These were

Rainfall category	one day rainfall (mm)
(a) Heavy Rainfall	64.5- 124.4
(b) Very Heavy Rainfall	124.5-244
(c) Extremely Heavy Rainfall	≥244.5

7. For extraction of the extreme events, we have considered the standard threshold values of IMD published report.
8. The result is extracted and the map has been produced corresponding to different weather events.
9. Finally, analysis has been further done based on the result output.

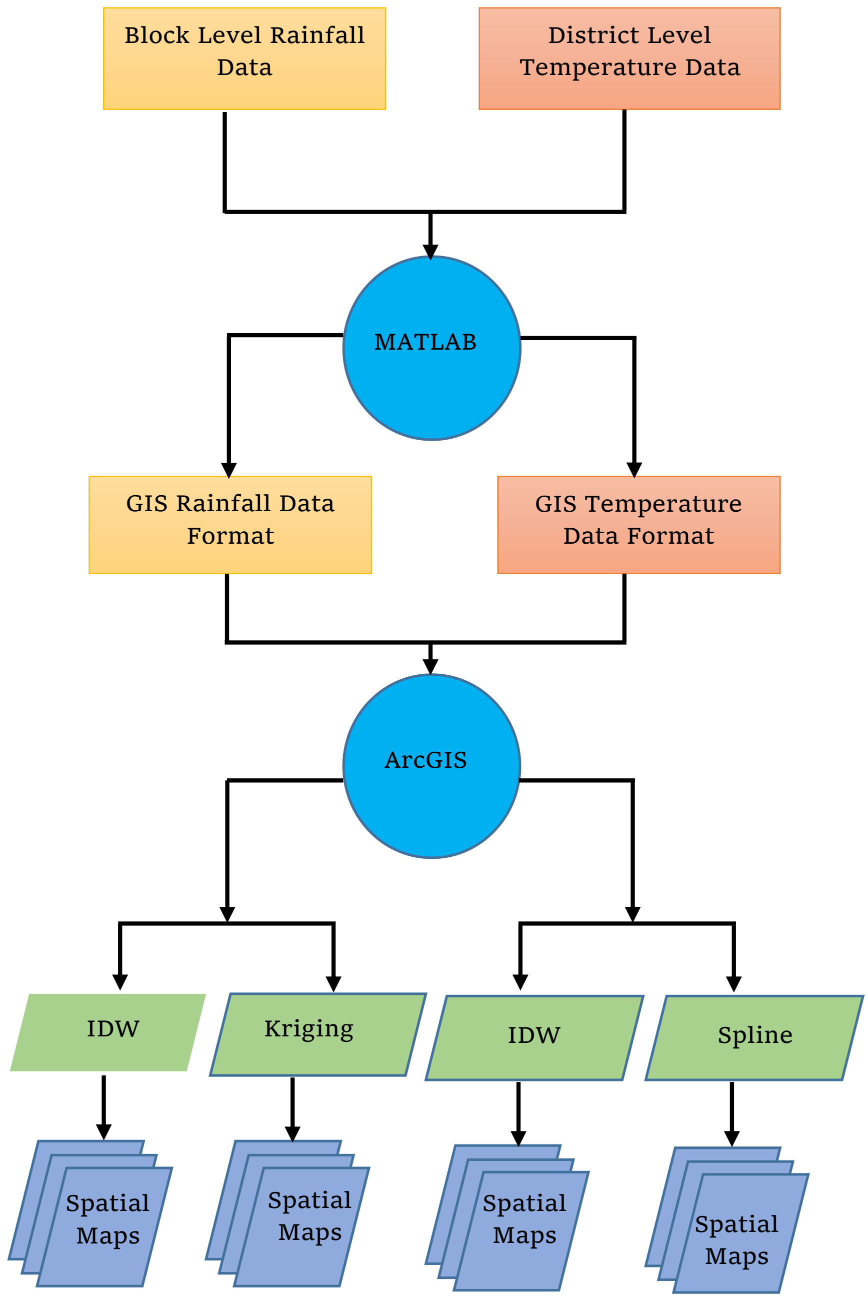


Fig. 3.3. Flowchart representation of the methodology

We have taken the approach to analyze extreme weather events using datasets at a different time interval. For extreme rainfall events, we have taken the rainfall data at the block level and Temperature data at the district level. The rainfall data is further analyzed and year wise total number of events under each category was calculated block wise and their aggregation using algebraic sum was done to get district wise events for all the 30 districts of Odisha (Pasupalak, 2015). Percent events under each category out of total of all the three categories in a year were calculated district wise. The time series data on number of category wise events were subjected to Mann- Kendall test (Kendall, 1970) for trend analysis. The trend analysis software, Weather Cock (Rao *et al*., 2015), based upon the algorithm used in RC LimDex V.1 (Zhang and Feng, 2004), was used to detect the trends of the occurrence of events. Significance tests were made at 90, 95 and 99% confidence interval. Besides the trend analysis, extreme rainfall events were compared between the two periods, before 1991 and during 1991-2014. The first period included all-time record high one-day rainfall reported by India Meteorological Department (IMD, 2002,) while the second was based on the SRC data used for trend analysis as above. For the first period only one all-time high rainfall for a district reported by IMD (2002) was considered, while for the second period, three highest rainfall events in a district were identified. Further rainfall and temperature data are being converted into spatial distribution using different interpolation techniques using ArcGIS software. We have basically used Inverse Distance Weighted (IDW), Kriging and Spline to convert the point level station data to spatially distributed data. We have taken the cell size to (0.01 X 0.01) degree which is 1 km X 1km grid size. The rainfall data is collected at the block level (314 blocks) and temperature data is taken from IMD Gridded data at the district level (30 District) and both these datasets were converted to model required format using MATLAB Software.

3.4. Analytical techniques employed (software)

3.4.1. MATLAB

The name MATLAB stands for MATrix LABoratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment.

Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research

Typical uses include:

1. Numerical computation
2. Algorithm development
3. Modeling, simulation, and prototyping
4. Data analysis, exploration, and visualization
5. Scientific and engineering graphics

3.4.2. ArcGIS

ArcGIS is a geographic information system (**GIS**) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

ArcGIS includes the following Windows desktop software:

1. Arc Reader: which allows one to view and query maps created with the other ArcGIS products;
2. ArcGIS for Desktop: which is licensed under three functionality levels:
3. ArcGIS for Desktop Basic (formerly known as ArcView): which allows one to view spatial data, create layered maps, and perform basic spatial analysis;
4. ArcGIS for Desktop Standard (formerly known as Arc Editor): which in addition to the functionality of ArcView, includes more advanced tools for manipulation of shape files and geo-data bases;
5. ArcGIS for Desktop Advanced (formerly known as Arc Info): which includes capabilities for data manipulation, editing, and analysis.

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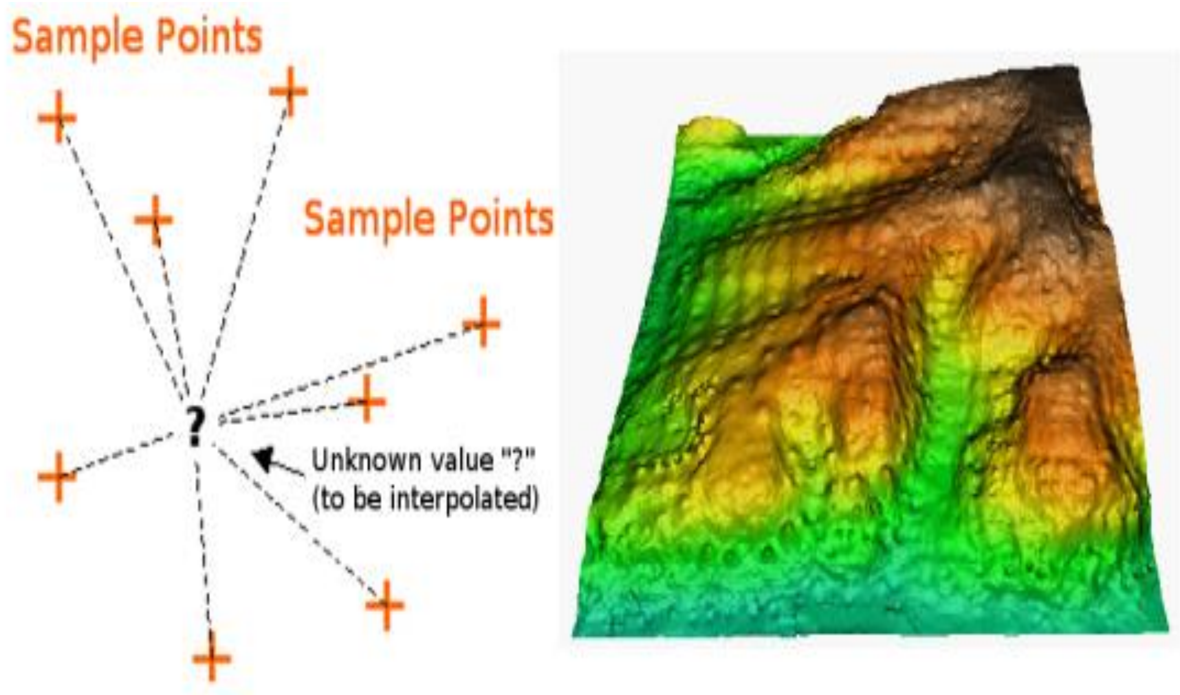
3.4.2.1 Interpolation

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, chemical concentrations, noise levels, and so on. The available interpolation methods are listed below

Interpolation techniques

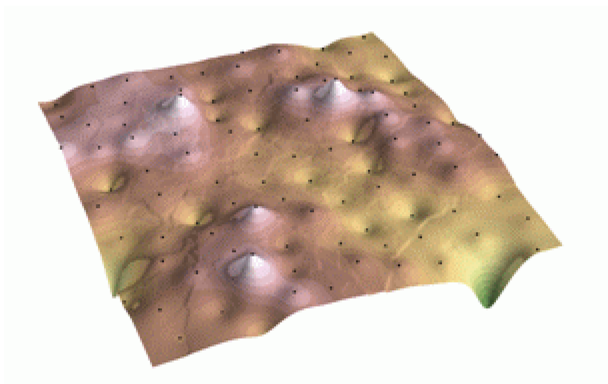
3.4.2.1.1 Inverse Distance Weighted (IDW)

The Inverse Distance Weighting interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell greater than those further away. A specified number of points, or all points within a specified radius can be used to determine the output value of each location. Use of this method assumes the variable being mapped decreases in influence with distance from its sampled location.



IDW Interpolation

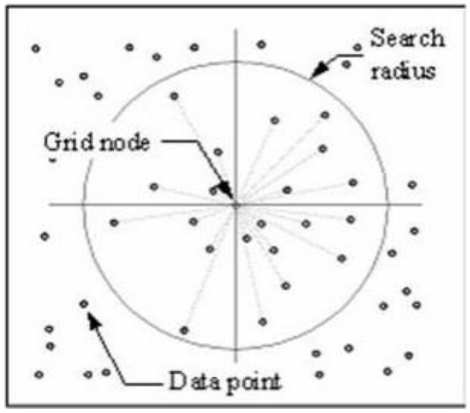
The Inverse Distance Weighting (IDW) algorithm effectively is a moving average interpolator that is usually applied to highly variable data. For certain data types, it is possible to return to the collection site and record a new value that is statistically different from the original reading but within the general trend for the area. The interpolated surface, estimated using a moving average technique, is less than the local maximum value and greater than the local minimum value.



IDW Interpolated Surface

IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. The IDW function should be used when the set of points is dense enough to capture the extent of local surface variation needed for analysis. IDW determines cell values using a linear-weighted combination set of sample points. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted.

The IDW technique calculates a value for each grid node by examining surrounding data points that lie within a user-defined search radius. Some or all of the data points can be used in the interpolation process. The node value is calculated by averaging the weighted sum of all the points. Data points that lie progressively farther from the node influence the computed value far less than those lying closer to the node.



A radius is generated around each grid node from which data points are selected to be used in the calculation. Options to control the use of IDW include power, search radius, fixed search radius, variable search radius, and barrier. The optimal power (p) value is determined by minimizing the root mean square prediction error (RMSPE).

Advantages

1. Can estimate extreme changes in terrain such as: Cliffs, Fault Lines.
2. Dense evenly space points are well interpolated (flat areas with cliffs).
3. Can increase or decrease the number of sample points to influence cell values.

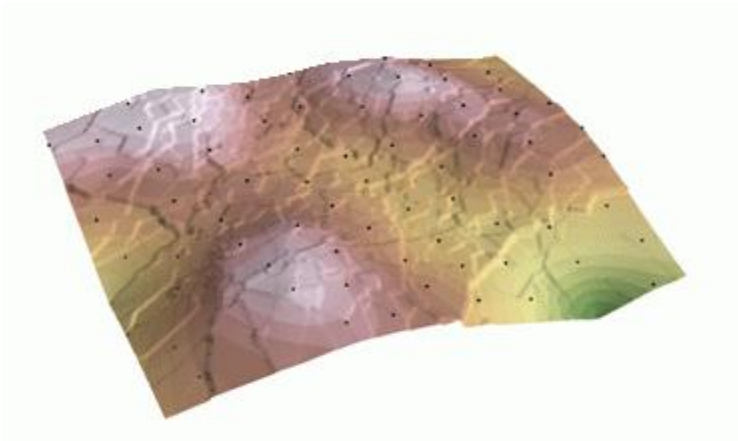
Disadvantages

1. Cannot estimate above maximum or below minimum values.
2. Not very good for peaks or mountainous areas.

3.4.2.1.2. Kriging

Kriging is a geostatistical interpolation technique that considers both the distance and the degree of variation between known data points when estimating values in unknown areas. A kriged estimate is a weighted linear combination of the known sample values around the point to be estimated.

Kriging procedure that generates an estimated surface from a scattered set of points with z-values. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology.



Kriging

The predicted values are derived from the measure of relationship in samples using the sophisticated weighted average technique. It uses a search radius that can be fixed or variable. The generated cell values can exceed value range of samples, and the surface does not pass through samples.

The kriging formula

Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

Where:

$Z(s_i)$ = the measured value at the i^{th} location

λ_i = an unknown weight for the measured value at the i^{th} location

s_0 = the prediction location

N = the number of measured values

In IDW, the weight, λ_i, depends solely on the distance to the prediction location. However, with the kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_i, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

Advantages

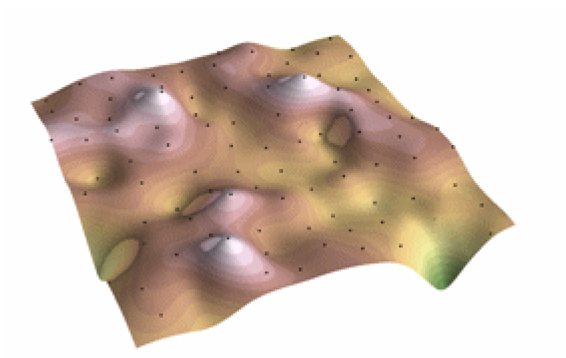
1. Directional influences can be accounted for: Soil Erosion, Siltation Flow, Lava Flow, and Winds.
2. Exceeds the minimum and maximum point values

Disadvantages

1. Does not pass through any of the point values and causes interpolated values to be higher or lower than real values

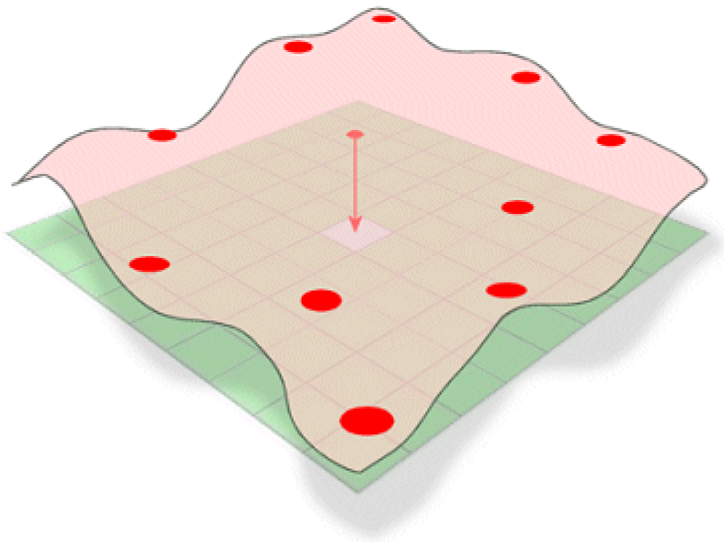
3.4.2.1.3 Spline

Spline estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points.



Spline

Conceptually, it is analogous to bending a sheet of rubber to pass through known points while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for gently varying surfaces, such as elevation, water table heights, or pollution concentrations.



The Spline method of interpolation estimates unknown values by bending a surface through known values.

Advantages

1. Useful for estimating above maximum and below minimum points.
2. Creates a smooth surface effect.

Disadvantages

1. Cliffs and fault lines are not well presented because of the smoothing effect.
2. When the sample points are close together and have extreme differences in value, Spline interpolation doesn't work as well. This is because Spline uses slope calculations (change over distance) to figure out the shape of the flexible rubber sheet

3.5. Definition of terms and concepts used in the study

3.5.1 Grid

It refers, use to define a location on a map.

3.5.2 Grid data

Is an architecture or set of services that gives individuals or groups of users the ability to access, modify and transfer extremely large amounts of geographically distributed data for research purposes

3.5.4 Compilation of data

Compilation of vital data is a process of condensing information by classifying and tabulating vital statistical data into various categories or groups with the object of producing vital statistics according to a determined tabulation programme.

3.5.4 Interpolation

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, chemical concentrations, noise levels, and so on.

3.5.5 Extreme weather

Extreme weather includes unexpected, unusual, unpredictable severe or unseasonal weather; weather at the extremes of the historical distribution—the range that has been seen in the past. Often, extreme events are based on a location's recorded weather history and defined as lying in the most unusual ten percent.

3.5.6. Heat waves

Heat waves are periods of abnormally high temperatures and heat index. Definitions of a heat wave vary because of the variation of temperatures in different geographic locations. Excessive heat is often accompanied by high levels of humidity, but can also be catastrophically dry.

3.5.7. Cold waves

A cold wave is a weather phenomenon that is distinguished by a cooling of the air. Specifically, as used by the U.S. National Weather Service, a cold wave is a rapid fall in temperature within a 24-hour period requiring substantially increased protection to agriculture, industry, commerce, and social activities.

3.5.8. Drought

Drought is a period of below-average precipitation in a given region, resulting in prolonged shortages in the water supply, whether atmospheric, surface water or ground water. A drought can last for months or years, or may be declared after as few as 15 days

4. RESULTS

In accordance with the objectives of this study, the data collected from secondary sources were analyzed using various statistical tools and techniques to draw meaningful conclusions. The major findings of the study are presented in this chapter under the following sub-heads.

4.1 compilation of daily rainfall and temperature data of the study area.

4.2 Different Interpolation techniques

4.2.1 Rainfall analysis

4.2.1. A. Rainfall by IDW

4.2.1. B Rainfall by Kriging

4.2.2 Temperature analysis

4.2.2.1. Tmax

4.2.2.1. C Tmax by IDW

4.2.2.1. D Tmax by SPLIN

4.2.2.2 Tmin

4.2.2.2. E. Tmin by IDW

4.2.2.2. F. Tmin by SPLIN

4.3 Analysis of extreme weather events in the study area.

4.3.1 Occurrence of extreme rainfall events in the study area.

4.3.2 One day extremely heavy rainfall events in the study area.

4.3.3 Extreme heavy rainfall trend in the study area

4.1 Compilation of daily rainfall and temperature data of the study area.

Data sets of spatially irregular meteorological observations interpolated to a regular grid are important for climate analyses. Such gridded data sets have been used extensively in the past and will continue to be important for many research propose. First, such interpolated data sets allow best estimates of climate variables at locations away from observing stations, thereby allowing studies of local climate in data-sparse regions. For monitoring of climate change at the regional and larger scale we frequently utilize indices of area averages. Such indices range in scale, from those representing local regions.

Daily observations were compiled for precipitation covering the time period 1994-2017. The collection of data was primarily carried out from the Special relief commissioner (SRC), at that time, this data set included about 314 stations having data over 24 years. The additional station data were gained from IMD gridded data. Further details on the data collection and raw station observations underwent a series of quality tests to identify obvious problems and remove suspicious values. This included: precipitation less than zero or greater; and more than 10 days with the same (nonzero) precipitation. Flagged observations of excessive precipitation were checked manually in regions where such amounts might occur.

In a preliminary analysis of the spatial correlation structure of the raw station data, we find out the missing values by using Matalb software and this missing values is filled with MID grid data by using R software by merging process. The merged rainfall product has been used for development of gridded data at 1×1 km grid using GIS platform. We have accumulated the rainfall data for the monsoon period and developed the gridded data for that period in raster format. This raster data can be further extracted to ASCII for further analysis.

Fig 4.1.1 shows the missing data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
161	160	0.0	0.0	6.5	0.0	0.0	0.0	0.0	13.4	0.0	5.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.2	0.0	16.6
162	161	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1.5	53.0	0.0	1.6	0.0	0.0	7.2	0.0
163	162	3.0	0.0	0.0	22.0	0.0	19.8	0.0	5.2	8.0	0.0	0.0	0.0	0.0	18.6	26.2	1.0	0.0	0.0	0.0	0.0	0.0
164	163	4.0	0.0	36.4	0.0	0.0	12.8	0.0	41.4	0.0	0.0	12.6	0.0	0.0	0.0	61.2	3.5	0.0	0.6	0.0	2.8	0.0
165	164	2.0	0.0	0.0	1.0	1.8	2.4	0.0	16.8	6.0	10.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0	3.4	0.0	33.0	0.0
166	165	2.0	0.0	0.0	26.0	2.4	2.4	0.0	53.2	0.0	5.0	42.2	0.0	0.0	5.6	0.0	0.0	0.0	1.6	5.3	27.2	0.0
167	166	15.0	0.0	0.0	1.0	13.4	0.0	0.8	0.6	0.0	37.4	69.4	0.0	0.0	0.4	2.4	0.3	0.0	23.8	0.0	11.0	0.0
168	167	42.4	0.0	6.4	0.0	0.6	0.0	19.4	12.6	0.0	0.0	0.0	0.0	0.0	1.0	18.0	0.0	9.6	31.8	0.0	0.0	0.0
169	168	4.0	0.0	0.0	0.0	0.0	9.4	18.2	0.0	31.2	0.0	0.0	0.0	0.0	15.4	7.8	0.0	0.0	6.2	0.0	22.0	0.0
170	169	0.3	0.0	6.6	3.6	0.0	11.6	7.0	0.0	0.0	3.2	0.0	0.0	0.0	21.2	24.0	0.0	63.8	5.6	40.4	0.0	0.0
171	170	7.0	0.0	0.0	1.2	0.2	0.0	1.5	2.0	0.0	27.6	0.0	0.0		0.0	25.6	0.0	0.0		0.0	0.0	1.2
172	171	44.0	15.0	0.0	8.8	0.0	13.8	0.0	11.6	0.0	54.0	0.4	0.0		0.0	2.5	0.0	0.0		13.4	0.0	2.6
173	172	10.0	7.0	0.0	0.0	0.0	8.8	26.2	0.0	0.0	14.2	0.0	0.0		0.0	9.4	0.0	0.0		0.0	17.8	9.0
174	173	1.0	0.0	49.2	0.0		13.2	0.4	0.8	0.0	0.0	0.0	0.0		10.0	0.0	0.0	0.0		9.6	5.4	0.0
175	174	0.0	18.0	117.2	8.4		3.2	5.8	0.4	14.6	8.0	0.0	0.0	12.6	8.6	3.0	0.0	0.0		16.0	34.0	0.0
176	175	0.0	15.7	18.8	0.0		0.0	0.0	16.2	8.0	1.4	0.0	26.0	0.0	11.0	3.0	0.0	0.0		13.4	9.0	0.0
177	176	0.0	0.0	0.0	0.0		0.0	0.0	0.0	17.8	1.0	0.0	4.4	0.0	3.0	7.4	12.0	44.0	1.8	1.6	22.0	0.0
178	177	1.0	0.0	0.0	8.6	0.0	0.0	2.4	0.0	0.2	2.0	0.0	0.0	0.0		1.5	0.0	1.2	0.0	0.0	11.0	34.0
179	178	17.0	0.0	0.0	47.8	3.8	0.0	9.2	0.0	0.0	0.0	0.0	5.6	0.0	3.8	17.0	0.0	6.0	0.6	0.0	9.0	0.0
180	179	4.0	48.0	0.0	35.0	3.7	0.4	1.0	0.0	0.0	25.8	0.0	53.0	0.0	0.1	5.4	0.0	0.0	0.0	0.0	0.0	0.0
181	180	0.0	1.0	0.0	0.0	0.0	6.8	26.4	23.0	0.0	4.6	0.0	59.0	0.0	20.0	4.3	3.8	0.0	9.2	0.0	0.0	0.0
182	181	17.0	0.0	1.0	0.0	20.4	0.0	7.8	22.0	0.0	0.6	0.0	0.8	2.2	18.6	0.0	0.0	16.0	1.0	0.0	0.0	0.0
183	182	0.0	0.0	7.0	0.0	72.2	0.0	0.0	19.0	0.0	0.0	18.2	0.0	7.2	0.0	0.0	6.6	0.0	0.4	0.0	1.6	38.6

Fig. 4.1.2 shows the gap filled data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
161	160	0.0	0.0	6.5	0.0	0.0	0.0	0.0	13.4	0.0	5.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.2	0.0	16.6
162	161	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1.5	53.0	0.0	1.6	0.0	0.0	7.2	0.0
163	162	3.0	0.0	0.0	22.0	0.0	19.8	0.0	5.2	8.0	0.0	0.0	0.0	0.0	18.6	26.2	1.0	0.0	0.0	0.0	0.0	0.0
164	163	4.0	0.0	36.4	0.0	0.0	12.8	0.0	41.4	0.0	0.0	12.6	0.0	0.0	0.0	61.2	3.5	0.0	0.6	0.0	2.8	0.0
165	164	2.0	0.0	0.0	1.0	1.8	2.4	0.0	16.8	6.0	10.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0	3.4	0.0	33.0	0.0
166	165	2.0	0.0	0.0	26.0	2.4	2.4	0.0	53.2	0.0	5.0	42.2	0.0	0.0	5.6	0.0	0.0	0.0	1.6	5.3	27.2	0.0
167	166	15.0	0.0	0.0	1.0	13.4	0.0	0.8	0.6	0.0	37.4	69.4	0.0	0.0	0.4	2.4	0.3	0.0	23.8	0.0	11.0	0.0
168	167	42.4	0.0	6.4	0.0	0.6	0.0	19.4	12.6	0.0	0.0	0.0	0.0	0.0	1.0	18.0	0.0	9.6	31.8	0.0	0.0	0.0
169	168	4.0	0.0	0.0	0.0	0.0	9.4	18.2	0.0	31.2	0.0	0.0	0.0	0.0	15.4	7.8	0.0	0.0	6.2	0.0	22.0	0.0
170	169	0.3	0.0	6.6	3.6	0.0	11.6	7.0	0.0	0.0	3.2	0.0	0.0	0.0	21.2	24.0	0.0	63.8	5.6	40.4	0.0	0.0
171	170	7.0	0.0	0.0	1.2	0.2	0.0	1.5	2.0	0.0	27.6	0.0	0.0	40.6	0.0	25.6	0.0	0.0	15.0	0.0	0.0	1.2
172	171	44.0	15.0	0.0	8.8	0.0	13.8	0.0	11.6	0.0	54.0	0.4	0.0	0.0	0.0	2.5	0.0	0.0	26.2	13.4	0.0	2.6
173	172	10.0	7.0	0.0	0.0	0.0	8.8	26.2	0.0	0.0	14.2	0.0	0.0	2.4	0.0	9.4	0.0	0.0	0.0	0.0	17.8	9.0
174	173	1.0	0.0	49.2	0.0	28.0	13.2	0.4	0.8	0.0	0.0	0.0	0.0	42.2	10.0	0.0	0.0	0.0	0.0	9.6	5.4	0.0
175	174	0.0	18.0	117.2	8.4	0.0	3.2	5.8	0.4	14.6	8.0	0.0	0.0	12.6	8.6	3.0	0.0	0.0	0.0	16.0	34.0	0.0
176	175	0.0	15.7	18.8	0.0	0.0	0.0	0.0	16.2	8.0	1.4	0.0	26.0	0.0	11.0	3.0	0.0	0.0	0.0	13.4	9.0	0.0
177	176	0.0	0.0	0.0	0.0	130.4	0.0	0.0	0.0	17.8	1.0	0.0	4.4	0.0	3.0	7.4	12.0	44.0	1.8	1.6	22.0	0.0
178	177	1.0	0.0	0.0	8.6	0.0	0.0	2.4	0.0	0.2	2.0	0.0	0.0	0.0	27.0	1.5	0.0	1.2	0.0	0.0	11.0	34.0
179	178	17.0	0.0	0.0	47.8	3.8	0.0	9.2	0.0	0.0	0.0	0.0	5.6	0.0	3.8	17.0	0.0	6.0	0.6	0.0	9.0	0.0
180	179	4.0	48.0	0.0	35.0	3.7	0.4	1.0	0.0	0.0	25.8	0.0	53.0	0.0	0.1	5.4	0.0	0.0	0.0	0.0	0.0	0.0
181	180	0.0	1.0	0.0	0.0	0.0	6.8	26.4	23.0	0.0	4.6	0.0	59.0	0.0	20.0	4.3	3.8	0.0	9.2	0.0	0.0	0.0
182	181	17.0	0.0	1.0	0.0	20.4	0.0	7.8	22.0	0.0	0.6	0.0	0.8	2.2	18.6	0.0	0.0	16.0	1.0	0.0	0.0	0.0
183	182	0.0	0.0	7.0	0.0	72.2	0.0	0.0	19.0	0.0	0.0	18.2	0.0	7.2	0.0	0.0	6.6	0.0	0.4	0.0	1.6	38.6

4.2.1 Seasonal (JJAS) rainfall distribution by different interpolation techniques

YEAR **IDW** **KRIGING**

1994

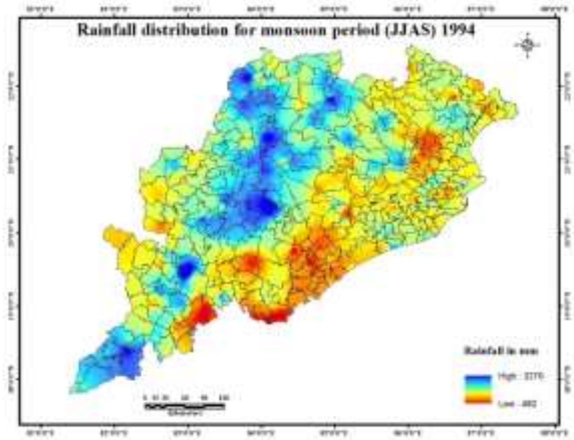


Fig. 4.2.1.A1

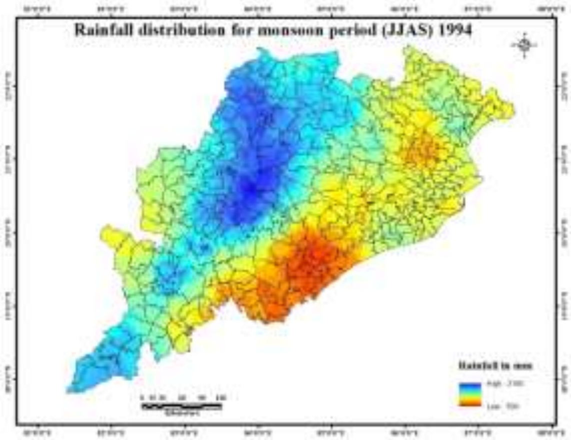


Fig. 4.2.1.B1

1995

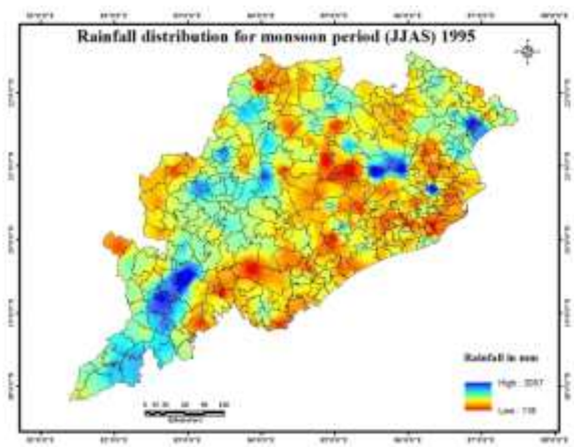


Fig. 4.2.1.A2

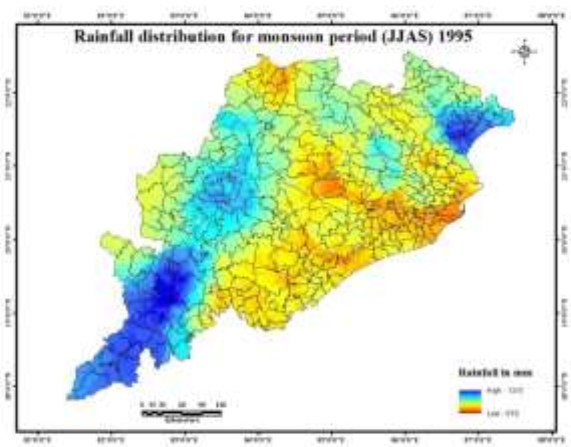


Fig. 4.2.1.B2

1996

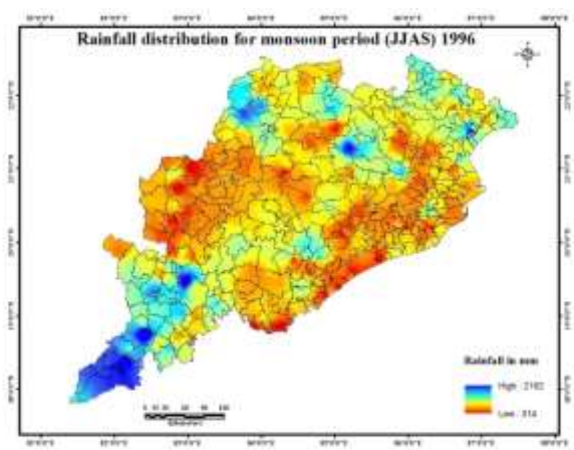


Fig. 4.2.1.A3

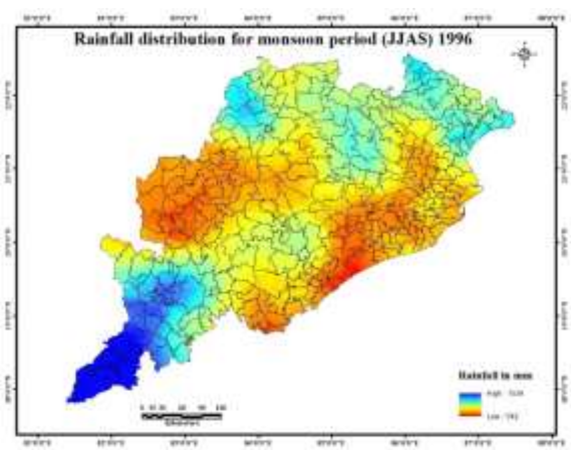
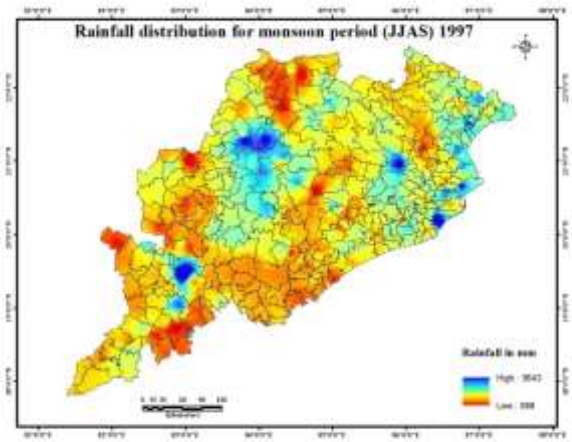
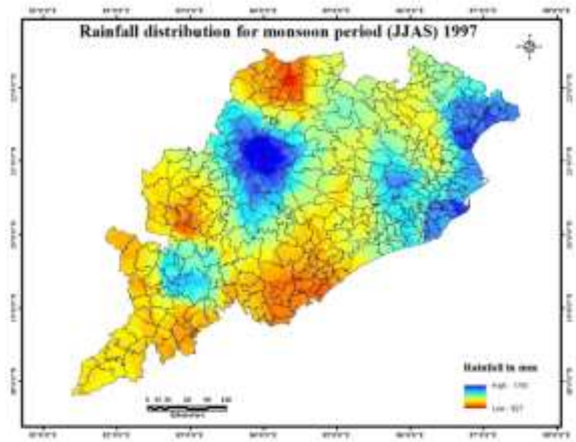
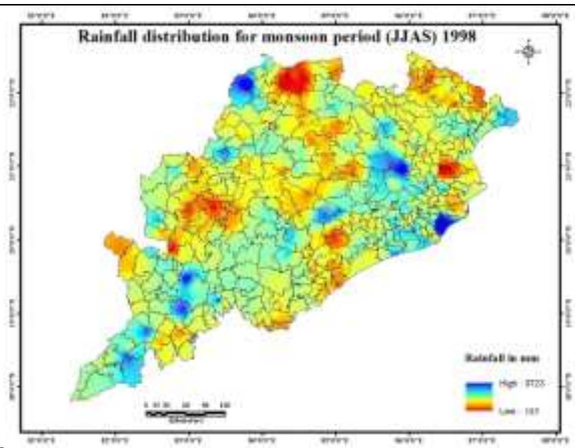
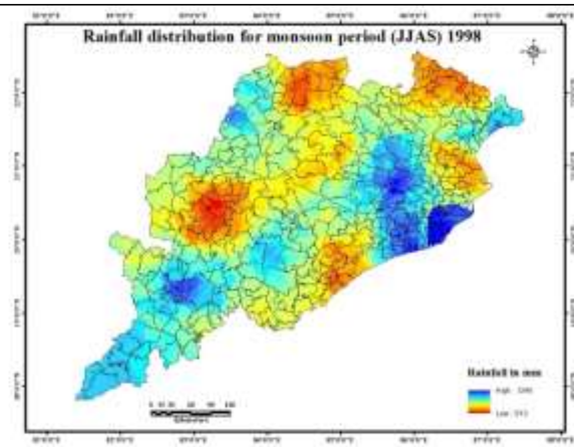
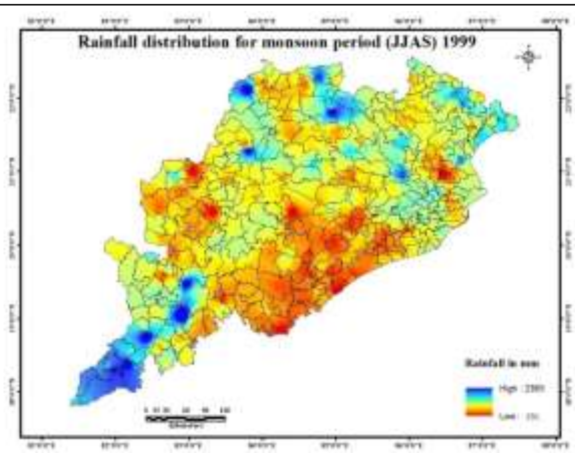
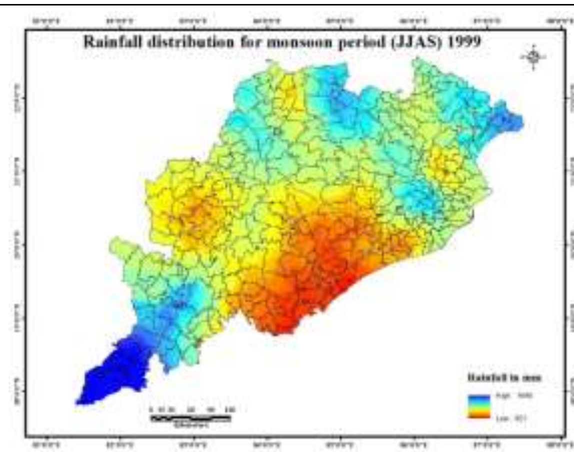


Fig. 4.2.1.B3

A review of fig 4.2.1.A1 explains the seasonal rainfall distribution for the year 1994 as estimated by IDW technique ranges from 462 mm to 3270 mm. The central region, southern region, and parts of western region experience a high and normal rainfall while coastal plains and some parts of western region experience a low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B1 which indicates that the average rainfall ranges from 700 mm to 2180 mm. It can be observed from the figure that central region, southern region and parts of western region experience a high and normal rainfall on the other hand southern part of coastal plains (Ganjam and Gajapati) and some western areas (Nuapada and Baragarh) experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of the fig 4.2.1.A2.shows the seasonal rainfall distribution for the year 1995 as estimated by IDW technique ranges from 118 mm to 2057 mm. The figure reveals that scattered areas of coastal, central and western regions (Nuapada) experienced a low and deficit rainfall while some parts of southern and western regions (Kalahandi and Bolangir) experienced a high and normal rainfall. Similarly, fig 4.2.1.B2 explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 619 mm to 1375 mm. It was observed that coastal region and some of the western regions (Sundargarh and Nuapada) experience a low and deficit rainfall. While Southern and some parts of western (Kalahandi, and Boudh) regions experience a high and normal rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 1996 as estimated by IDW technique is exhibited in fig 4.2.1.A3. Rainfall ranges from 314 mm to 2198 mm. It can be inferred that western region (Nuapada, Bolang, and Bargarh) and all the districts of coastal plains experience a low and deficit rainfall while southern and northern parts (Mayurbhanj and Keonjhar) experience a high and normal rainfall. Similarly, a perusal of fig 4.2.1.B3 indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 542 mm to 1539 mm. Figure shows that southern and northern parts of the Odisha (Mayurbhanj, Balasore, Keonjhar, and Jharsuguda) experience a high and normal rainfall while western region (Nuapada, and Bolangir) and all the districts of coastal plains experience a low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

YEAR	IDW	KRIGING
1997		
	Fig. 4.2.1.A4	Fig. 4.2.1.B4
1998		
	Fig. 4.2.1.A5	Fig. 4.2.1.B5
1999		
	Fig. 4.2.1.A6	Fig. 4.2.1.B6

A review of fig 4.2.1.A4 explains the seasonal rainfall distribution for the year 1997 as estimated by IDW technique ranges from 389 mm to 3643 mm. The western region (Bargarh, Sonepur, Boudh, and Kalahandi) and some north coastal region (Balasore, Bhadrak) experienced a high and normal rainfall while the southern, some coastal (Ganjam, Gajapati, and Puri) and western (Sundargarh, Nuapada, and Bolangir) regions of the state experience low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B4. Which indicates that the average rainfall ranges from 827mm to 1795mm. It can be observed from the figure that western part (Bargarh, Sonepur, Boudh, and Kalahandi) and some north coastal (Balasore, Bhadrak, Kendrapara, and Jagatsinghpur) part experience high and normal rainfall. While some coastal part (Ganjam, Gajapati, and Puri) and western (Sundargarh, Nuapada, and Bolangir) part of the state experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of fig 4.2.1.A5. Shows the seasonal rainfall distribution for the year 1998 as estimated by IDW technique ranges from 185 mm to 3723 mm. The figure reveals that southern region and some parts of the coastal region (Jagatsinghpur and Puri,) and western region of Jharsuguda experience high and normal rainfall. While some of the districts namely, Bolangir, Sundargarh, Mayurbanj, Bhadrak and Ganjam experience low and deficit rainfall. Similarly, fig 4.2.1.B5.explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 613 mm to 1245 mm. It was observed that southern region and some parts of the coastal region (Jagatsinghpur, Puri, Cuttack, and Dhenkanal) and western region of Jharsuguda experience high and normal rainfall. While some of the districts namely, Bolangir, Sundargarh, Mayurbanj, Bhadrak and Ganjam experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 1999 as estimated by IDW technique is exhibited in fig 4.2.1.A6. Rainfall ranges from 291 mm to 2365 mm. It can be inferred that southern region, northern region (Mayurbanj) and some parts of western region experience high and normal rainfall. While coastal districts namely Ganjam, Gajapati, Puri and western regions like Naupada and Bolangir experience low and deficit rainfall. Similarly a perusal of fig 4.2.1.B6. indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 601mm to 1648mm. The figure shows that southern region, northern region (Mayurbanj) and some

YEAR **IDW** **KRIGING**

2000

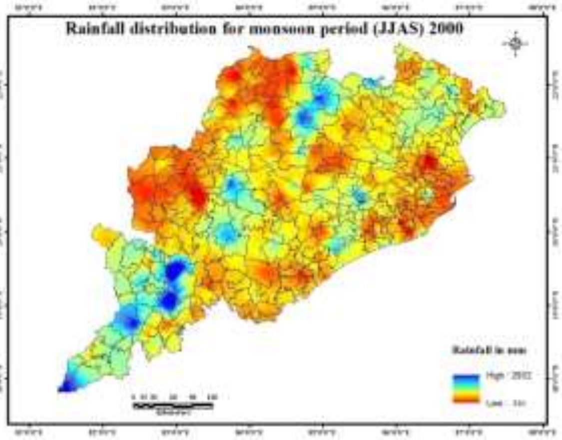


Fig. 4.2.1.A7

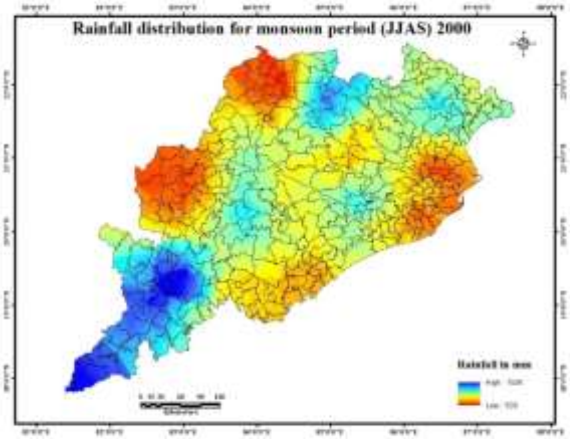


Fig. 4.2.1.B7

2001

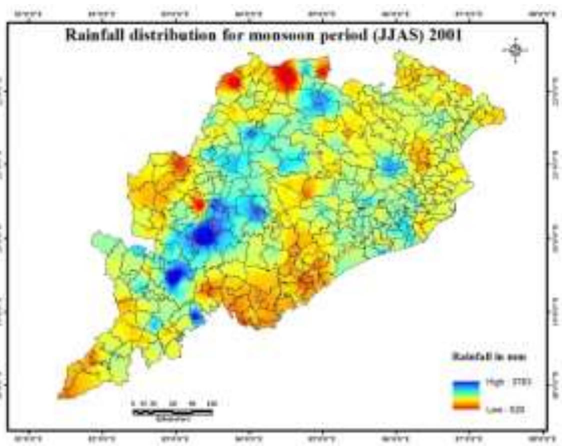


Fig. 4.2.1.A8

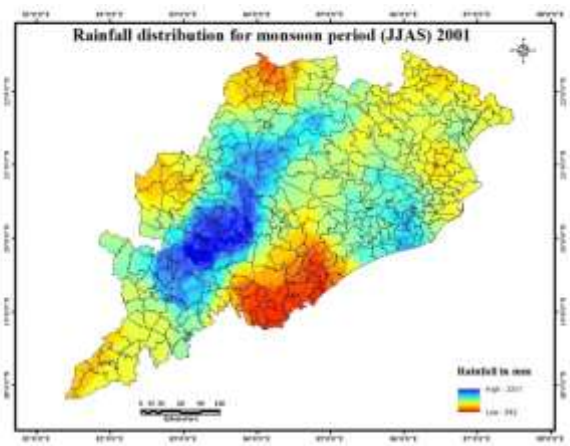


Fig. 4.2.1.B8

2002

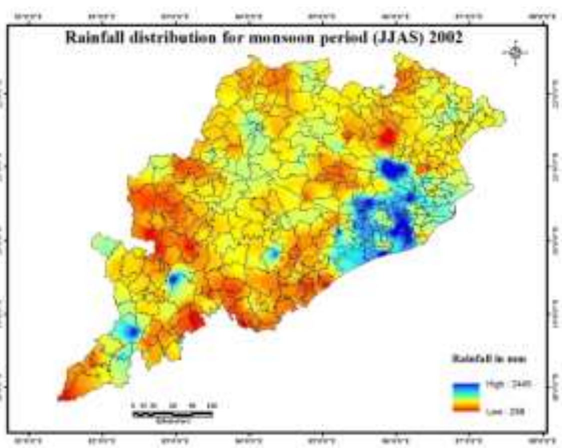


Fig. 4.2.1.A9

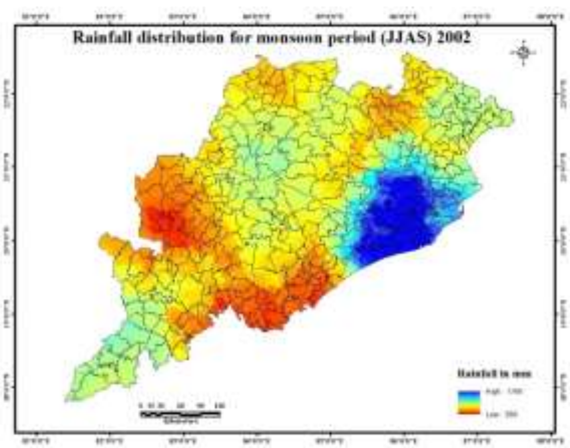


Fig. 4.2.1.B9

parts of western region experience high and normal rainfall. While coastal regions namely Ganjam, Gajapati, Puri, Nayagarh, Cuttack, Khurdha and western regions like Naupada and Bolangir experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

A review of fig 4.2.1.A7.explains the seasonal rainfall distribution for the year 2000 as estimated by IDW technique ranges from 316 mm to 2932 mm. The southern region and central region experience high and normal rainfall while all the districts of the western region and coastal region experience low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B7. Which indicates that the average rainfall ranges from 559 mm to 1528 mm. It can be observed from the figure that southern region and central (Kalahandi, Kandhamal, Sundargarh) region experience high and normal rainfall. While all the districts of the western (Naupada, Bolangir, and Jharsuguda) and coastal region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of the fig 4.2.1.A8.shows the seasonal rainfall distribution for the year 2001 as estimated by IDW technique ranges from 520 mm to 3783 mm. The figure reveals that some of the districts namely Kalahandi, Kandhamal, Boudh, Sonepur and Sambalpur and some of the coastal region experience high and normal rainfall. While Ganjam Gajpati and some of the parts of western region experience low and deficit rainfall.Similarly, fig 4.2.1.B8.explains the Seasonal Rainfall distribution as estimated by Kriging technique ranges from 842 mm to 2251 mm. It was observed that some of the districts namely Kalahandi, Kandhamal, Boudh, Sonepur and Sambalpur and some of the coastal region experience high and normal rainfall. While Ganjam Gajpati and some of the parts of western region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 2002 as estimated by IDW technique is exhibited in fig 4.2.1.A9. Rainfall distribution ranges from 258 mm to 2445 mm. It can be inferred that coastal districts namely Puri, Jagatsinghpur, and Kendrapara experience high and normal rainfall. While all other regions except some of the coastal districts experience low and deficit rainfall. Similarly a perusal of fig 4.2.1.B9. Indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall from 588 mm to 1768 mm. The figure shows that coastal districts namely Puri,

YEAR **IDW** **KRIGING**

2003

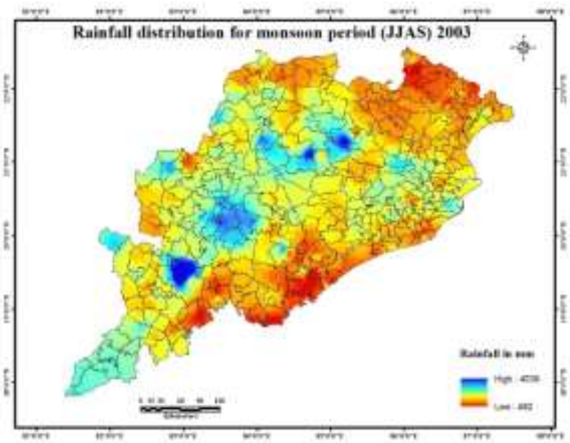


Fig. 4.2.1.A10

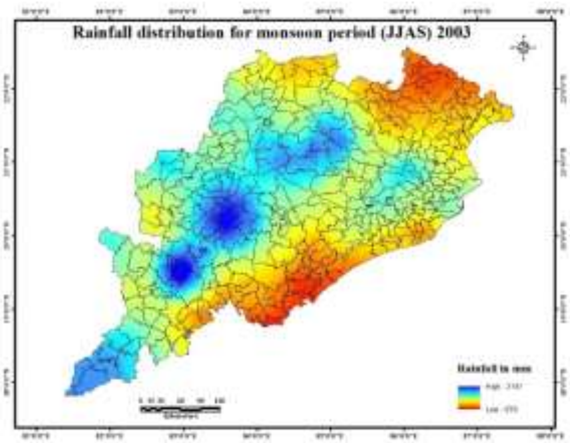


Fig. 4.2.1.B10

2004

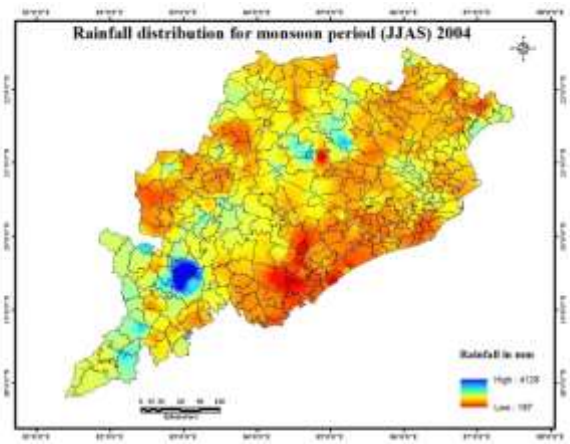


Fig. 4.2.1.A11

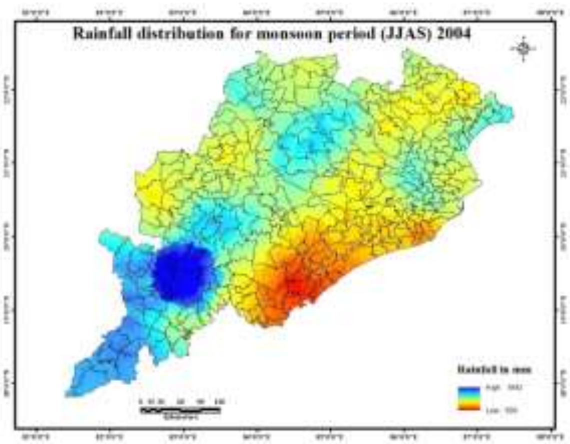


Fig. 4.2.1.B11

2005

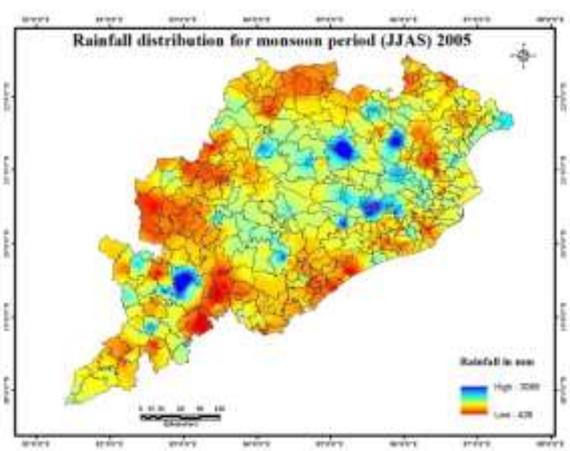


Fig. 4.2.1.A12

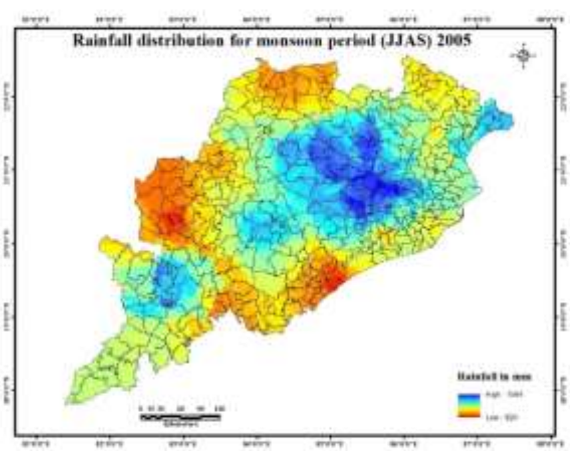


Fig. 4.2.1.B12

Jagatsinghpur, and Kendrapara, Khurda, and Cuttack experience high and normal rainfall. While all other regions except some of the coastal districts experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

A review of fig 4.2.1.A10 explains the seasonal rainfall distribution for the year 2003 as estimated by IDW technique ranges from 482 mm to 4038 mm. southern region and some of the districts viz, Kalahandi, Kandhamal, Boudh, Sonepur, and Deogarh experience high and normal rainfall. While coastal and northern (Mayurbanj and Keonjhar) region experience low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B10 which indicates that average rainfall ranges from 679 mm to 2147 mm. It can be observed from the figure that southern region, western region (Deogarh) and some of the districts viz, Kalahandi, Kandhamal, Boudh, Sonepur, and Deogarh experience high and normal rainfall. While coastal region (Ganjam, Gajapati, Puri) and northern region (Mayurbanj and Keonjhar) experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of the fig 4.2.1.A11 shows the seasonal rainfall distribution for the year 2004 as estimated by IDW technique ranges from 167 mm to 4128 mm. The figure reveals that southern regions like Kalahandi, Malkangiri, and Nabarangpur experience high and normal rainfall. While coastal region, western region and northern region of the state experience low and deficit rainfall. Similarly, fig 4.2.1.B11 explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 566 mm to 1842 mm. It was observed that southern regions like Kalahandi, Malkangiri, Nabarangpur, and Koraput experience high and normal rainfall. While coastal districts like Ganjam, Gajapati, Puri, Khurdha, and Nayagarh experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 2005 as estimated by IDW technique is exhibited in fig 4.2.1.A12. Rainfall ranges from 426 mm to 3089 mm. It can be inferred that central districts namely Dhenkanal, Angul, Deogarh, Sambalpur and Sonepur and southern region (Koraput) experience high and normal and rainfall. At the same time, all the western region and some coastal (Ganjam and Gajapati) parts experience low and deficit rainfall. Similarly, a perusal of fig 4.2.1.B12 indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 820 mm to 1594 mm. The figure shows that central districts namely Dhenkanal, Angul,

YEAR **IDW** **KRIGING**

2006

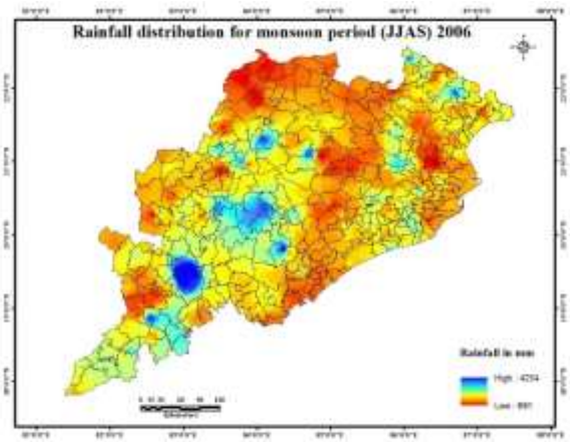


Fig. 4.2.1.A13

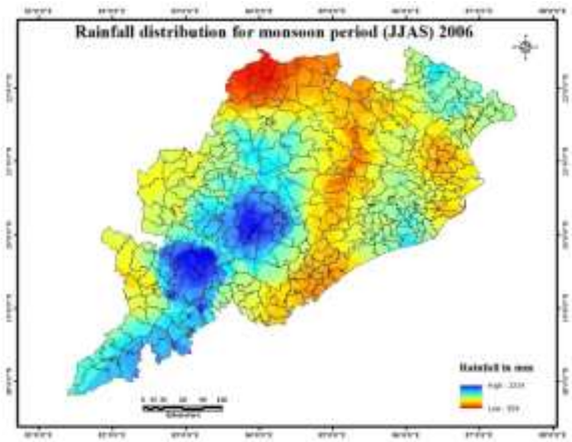


Fig. 4.2.1.B13

2007

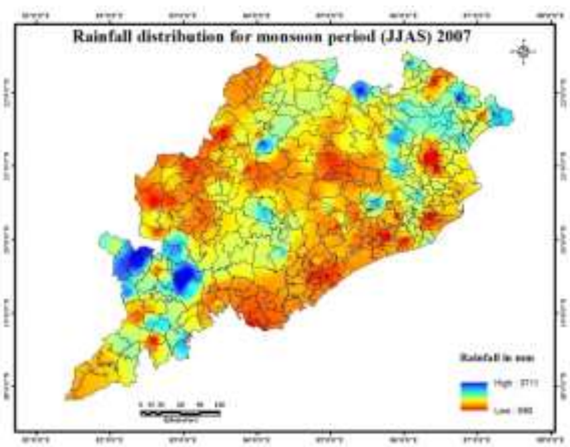


Fig. 4.2.1.A14

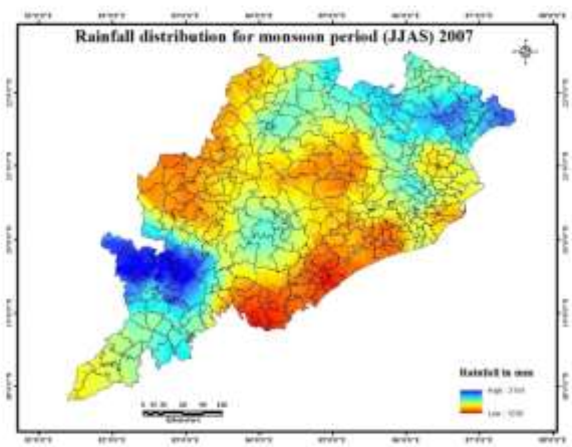


Fig. 4.2.1.B14

2008

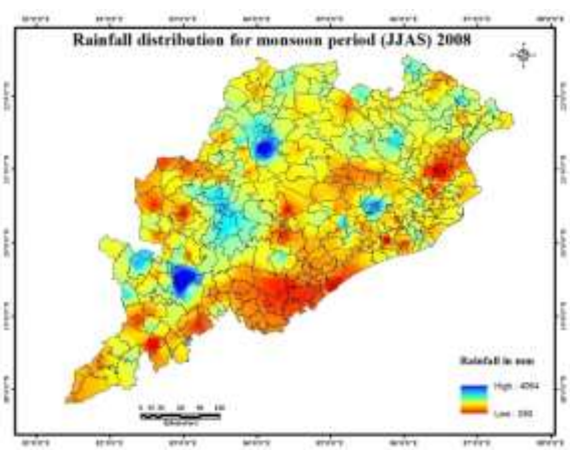


Fig. 4.2.1.A15

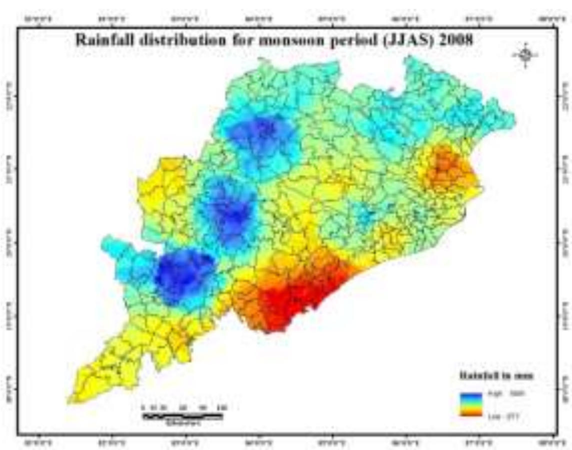


Fig. 4.2.1.B15

Deogarh, Sambalpur and Sonepur and southern region (Koraput and Nabarangapur) experience high and normal and rainfall. While all thewestern region and some coastal (Ganjam and Gajapati) parts experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

A review of fig 4.2.1.A13 explains the seasonal rainfall distribution for the year 2006 as estimated by IDW technique ranges from 691mm to 4254 mm. Some of the districts viz, Kalahandi, Kandhamal, Boudh, Sonepur and some parts of Sambalpur receives high to normal rainfall while western region, coastal region and central region of the state receive low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B13 which indicates that average rainfall ranges from 994 mm to 2234 mm. It can be observed from the figure that some of the districts viz, Kalahandi, Kandhamal, Boudh, Sonepur and some parts of Sambalpur and some southern parts receive high to normal rainfall. While western region (Sundarharh and Naupada) coastal region and some central region of the state receives low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of the fig 4.2.1.A14 shows the seasonal rainfall distribution for the year 2007 as estimated by IDW technique ranges from 590 mm to 3711mm. The figure reveals that southern regions like Nabarangpur, Koraput and some other parts of the sate like Mayurbanj, Keonjhar, and Balasore experience normal and high rainfall while coastal region and western region experience low and deficit rainfall. Similarly, fig 4.2.1.B14 explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 1036 mm to 2104 mm. It was observed that southern regions like Nabarangpur, Koraput and some other parts of the sate like Sundargarh, Mayurbanj, Keonjhar, and Balasore experience normal and high rainfall while coastal and western region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 2008 as estimated by IDW technique is exhibited in fig 4.2.1.A. Rainfall ranges from 350 mm to 4064 mm. It can be inferred that northern region and southwestern region experience normal and high rainfall while western region and coastal region (Ganjam, Gajapati, and Bhadrak) experience low and deficit rainfall. Similarly, a perusal of fig 4.2.1.B15 indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 877 mm to 1889 mm. The figure shows that northern region (Kalahandi,

YEAR	**IDW**	**KRIGING**

2009

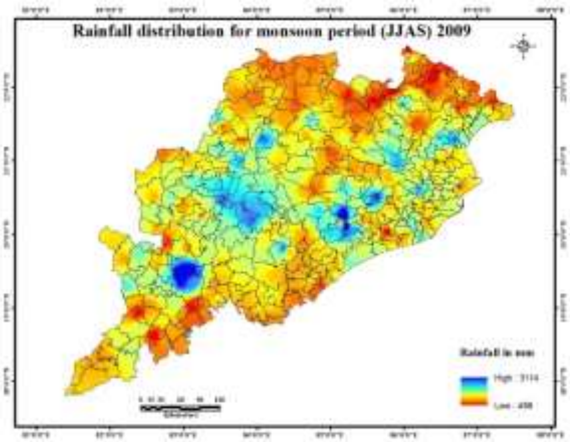


Fig. 4.2.1.A16

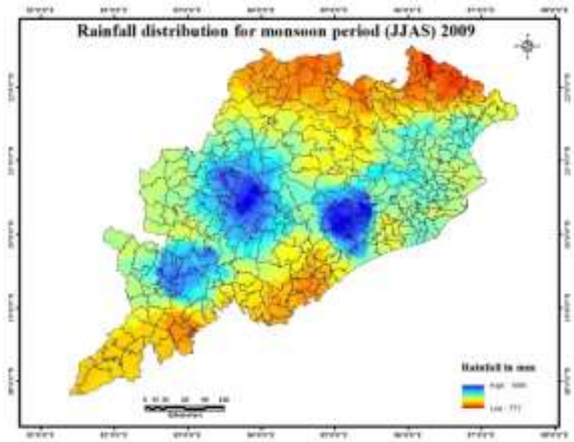


Fig. 4.2.1.B16

2010

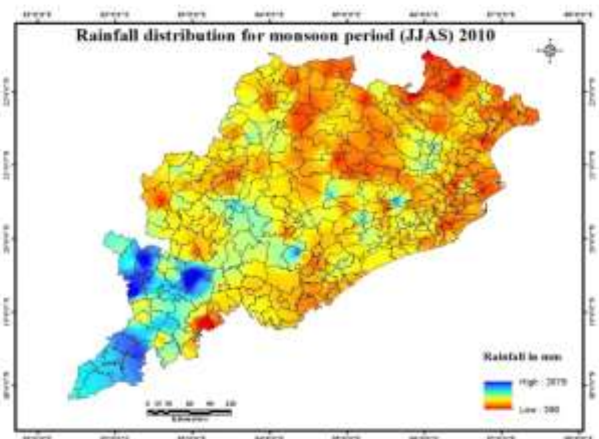


Fig. 4.2.1.A17

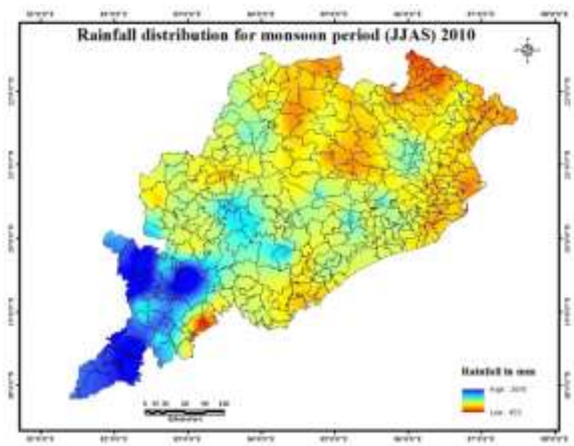


Fig. 4.2.1.B17

2011

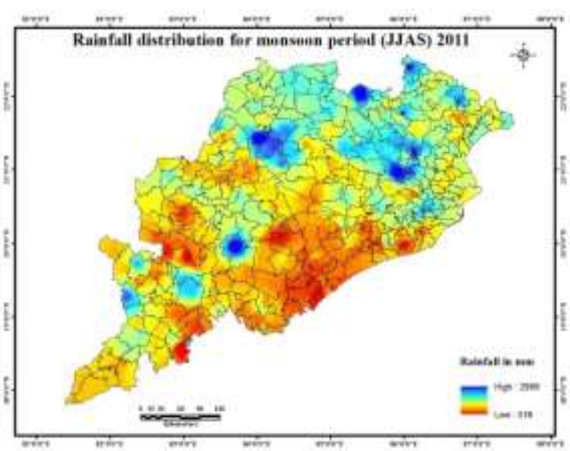


Fig. 4.2.1.A18

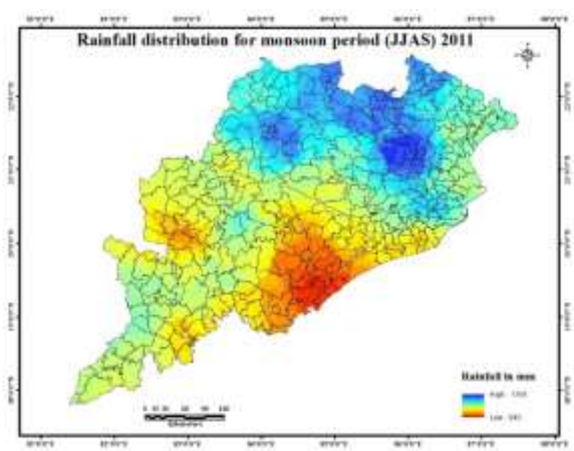


Fig. 4.2.1.B18

Boudh, Sonepur, and Sambalpur) and southwestern region experience normal and high rainfall while western region and coastal region (Ganjam, Gajapati and Bhadrak) region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state

Fig 4.2.1.A16 explains the seasonal rainfall distribution for the year 2009 as estimated by IDW technique ranges from 458 mm to 3114 mm. The central region and southern region experience normal and high rainfall while northern region (Mayurbanj), western region (Sundargarh), southern region and some parts of coastal region (Gajapati and Ganjam) experience low and deficit rainfall. Similarly, a perusal of fig 4.2.1.B16 indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 777 mm to 1698 mm. The figure shows that central region and southern region experience normal and high rainfall while northern (Mayurbanj) western (Sundargarh) southern and some parts of coastal (Gajapati and Ganjam) region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

A review of fig 4.2.1.A17 explains the seasonal rainfall distribution for the year 2010 as estimated by IDW technique ranges from 390 mm to 2678 mm. The southern region and some parts of the central region (Kandhamal) experience normal and high rainfall. At the same time, the north coastal region and western region of the state experience low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B17 which indicates that the average rainfall ranges from 453 mm to 2076 mm. It can be observed from the figure that southern region (Malkangiri, Koraput, Nabaranghpur) and some parts of central region (Kandhamal) experience normal and high rainfall while the north coastal part and western region of the state experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of the fig 4.2.1.A18 revealed that the seasonal rainfall distribution for the year 2011 as estimated by IDW technique ranges from 316 mm to 2999 mm. The figure shows the northern region and western districts like Mayurbanj, Keonjhar, Sundargarh, Jharsuguda, Deogarh, Sambalpur and Balasore experience normal and high rainfall while coastal and southern region experience low and deficit rainfall. Similarly, fig 4.2.1.B18 explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 645 mm to 1704 m. It was observed that northern region and western districts like Sundargarh, Jharsuguda, Keonjhar, Deogarh, Sambalpur,

YEAR **IDW** **KRIGING**

2012

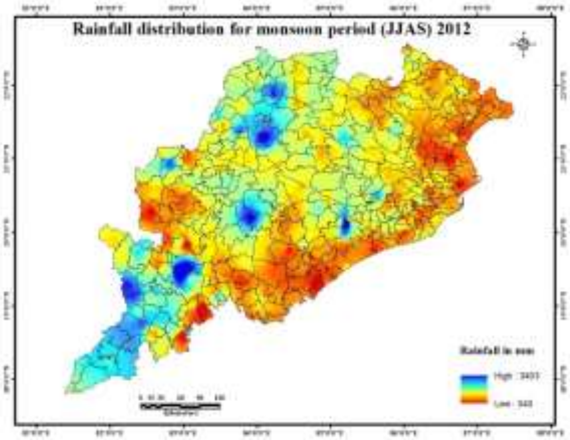


Fig. 4.2.1.A19

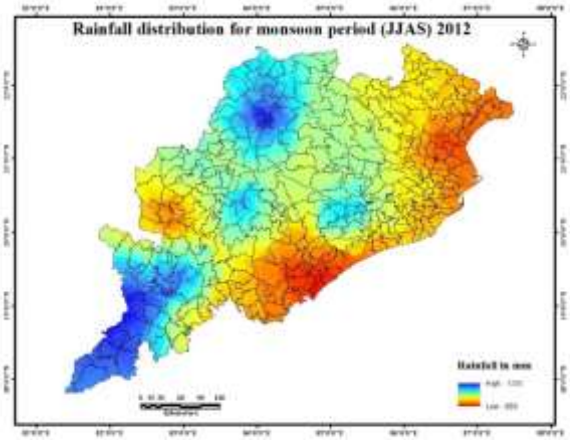


Fig. 4.2.1.B19

2013

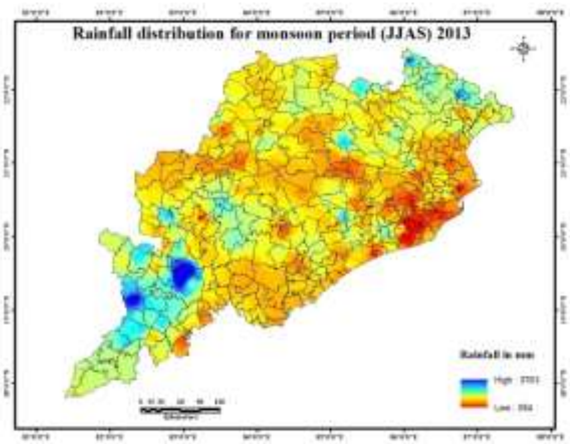


Fig. 4.2.1.A20

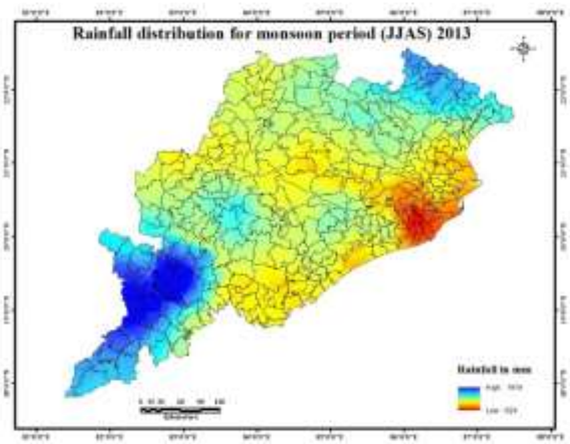


Fig. 4.2.1.B20

2014

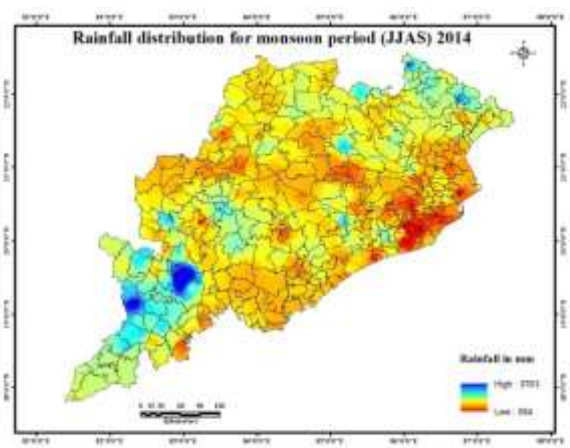


Fig. 4.2.1.A21

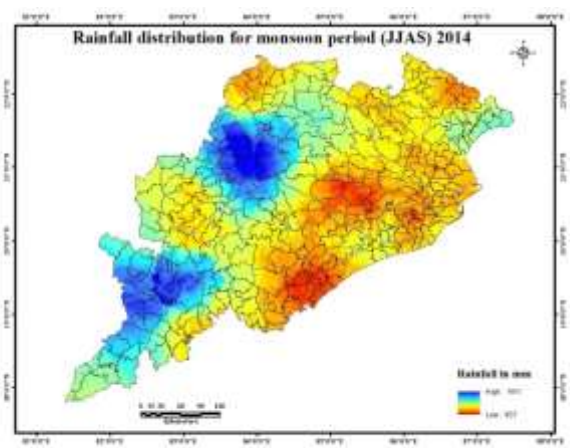


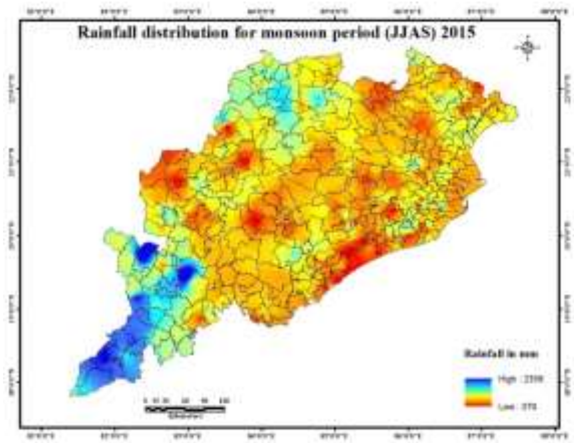
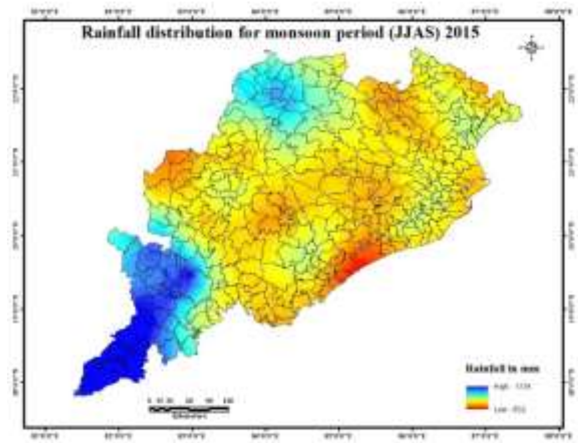
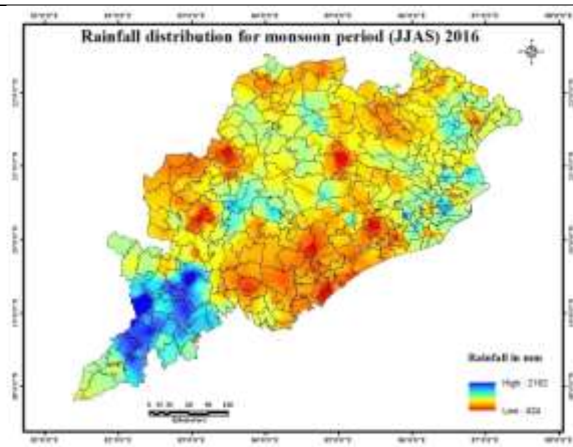
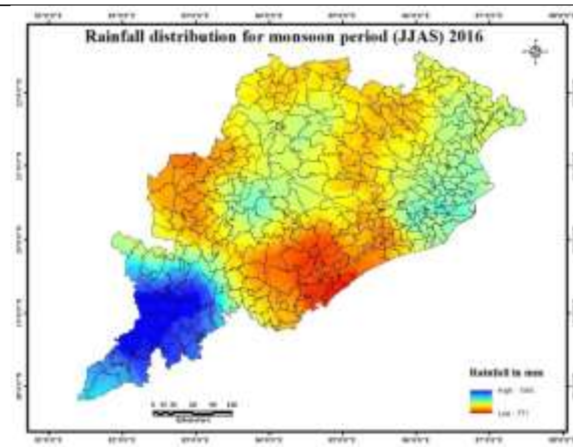
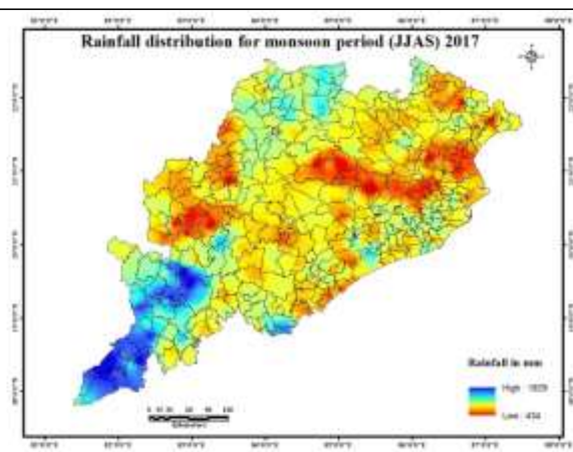
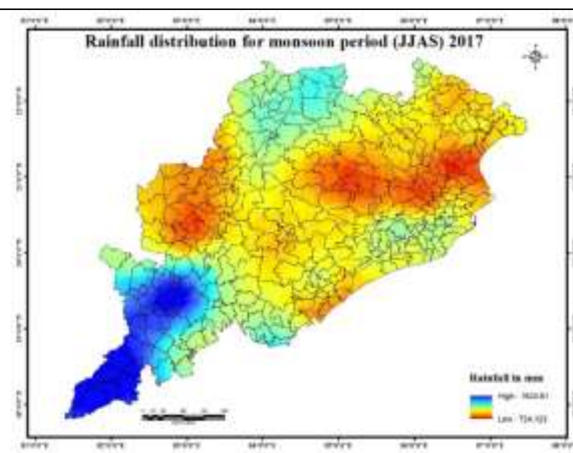
Fig. 4.2.1.B21

Mayurbanj and Balasore experience normal and high rainfall. While coastal (Ganjam) and southern region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 2012 as estimated by IDW technique is exhibited in fig 4.2.1.A19. Rainfall ranges from 343 mm to 3403 mm. It can be inferred that southern region and northern parts like Jharsuguda, Sambalpur, Sonepur and Boudh experience normal and high rainfall while all the coastal parts experience low and deficit rainfall. Similarly, a perusal of fig 4.2.1.B19 indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 689 mm to 1725 mm. The figure shows that southern region and northern parts like Sundargarh, Boudh, Sambalpur, Sonepur and Jharsuguda, experience normal and high rainfall while all the coastal parts experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

A review of fig 4.2.1.A20 explains the seasonal rainfall distribution for the year 2013 as estimated by IDW technique ranges from 354 mm to 3763 mm. The southern regions like Kalahandi, Koraput and Malkangiri experience normal and high rainfall while all the coastal and western parts experience low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B20 which indicates that the average rainfall ranges from 624 mm to 1919 mm. It can be observed from the figure that southern regions like Kalahandi, Malkangiri, Nabarangpur and Koraput, and some of the northern region like Mayurbanj experience high and normal rainfall while all the coastal regions especially Jagatsinghpur districts and western parts experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis fig 4.2.1.A21 shows the seasonal rainfall distribution for the year 2014 as estimated by IDW technique ranges from 354 mm to 3763 mm. The figure reveals that southern region and central region experience normal and high rainfall. While the coastal and western parts of the state experience low and deficit rainfall. Similarly, fig 4.2.1.B21 explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 967 mm to 1911 mm. It was observed that southern and some of the districts like Bargarh, Sambalpur, Sonepur, and Boudh receives

YEAR	IDW	KRIGING
2015		
	Fig. 4.2.1.A22	Fig. 4.2.1.B22
2016		
	Fig. 4.2.1.A23	Fig. 4.2.1.B23
2017		
	Fig. 4.2.1.A24	Fig. 4.2.1.B24

normal to high rainfall while the coastal region and western region of the state experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

Seasonal rainfall distribution for the year 2015 as estimated by IDW technique is exhibited in fig 4.2.1.A22. Rainfall ranges from 370 mm to 2358 mm. It can be inferred that southern region and western districts namely Jharsuguda and Sundargarh experience high and normal rainfall while coastal region, central region and western region (Naupada, Balangir, and Baragarh) experience low and deficit rainfall. Similarly, a perusal of fig 4.2.1.B22 indicates the seasonal rainfall distribution as estimated by Kriging technique wherein the rainfall ranges from 652 mm to 1734 mm. The figure shows that southern region and western districts of Jharsuguda and Sundargarh experience high and normal rainfall while central region, coastal region and western region (Baragarh, Balangir, and Naupada) experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

A review of fig 4.2.1.A23 explains the seasonal rainfall distribution for the year 2016 as estimated by IDW technique ranges from 424 mm to 2192 mm. The southern region and some scattered places of the state experience high and normal rainfall. At the same time, some coastal region and western region received low and deficit rainfall. Similarly, seasonal rainfall distribution as estimated by Kriging technique is being shown in fig 4.2.1.B23 which indicates that the average rainfall ranges from 771 mm to 1565 mm. It can be observed from the figure that southern region and some parts of the coastal region (Jhagatsinghpur and Bhadrak) experience high and normal rainfall. At the same time, some coastal region and western region experience low and deficit rainfall as compared to the monsoonal normal rainfall (1149 mm) of state.

An analysis of the fig 4.2.1.A24 shows the seasonal rainfall distribution for the year 2017 as estimated by IDW technique ranges from 434 mm to 1929 mm. The figure reveals that southern region and some western region (Sundargarh) experience normal and high rainfall while some parts of the western region (Naupada and Bolangir), central region and coastal plain experience low and deficit rainfall. Similarly, fig 4.2.1.A24 explains the seasonal rainfall distribution as estimated by Kriging technique ranges from 724 mm to 1624 mm. It was observed that southern region and some western region (Sundargarh) experience normal and high rainfall while some parts of the western region (Naupada and Bolangir)

Table No: 4.2.2 Mean maximum temperature for monsoon season

YEAR **IDW** **SPLINE**

1987

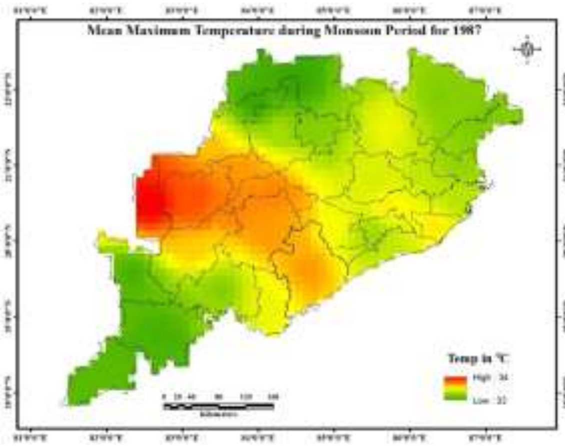


Fig. 4.2.2.1.C1

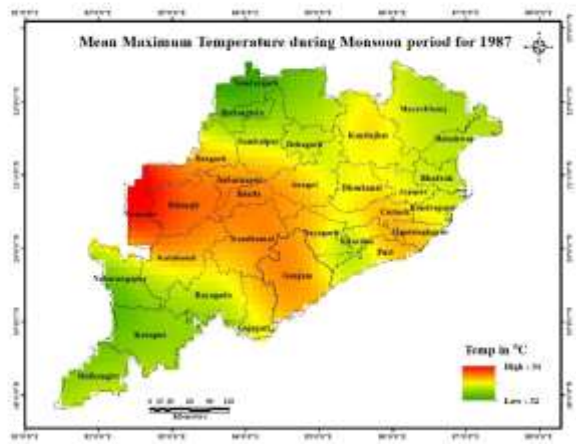


Fig. 4.2.2.1.D1

1988

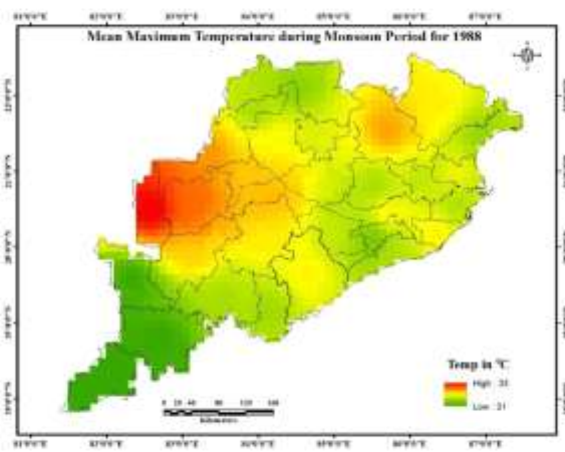


Fig. 4.2.2.1.C2

Fig. 4.2.2.1.D2

1989

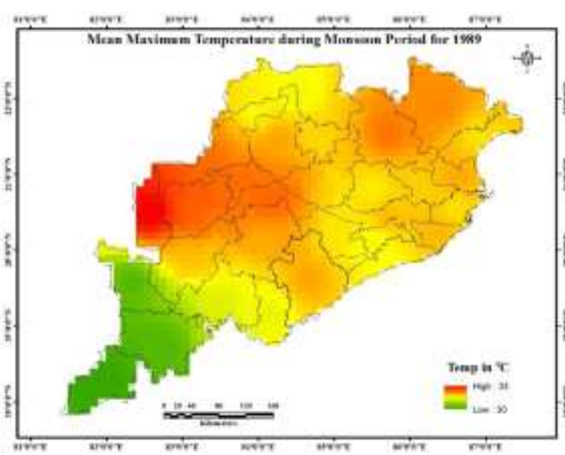


Fig. 4.2.2.1.C3

Fig. 4.2.2.1.D3

YEAR **IDW** **SPLINE**

1990

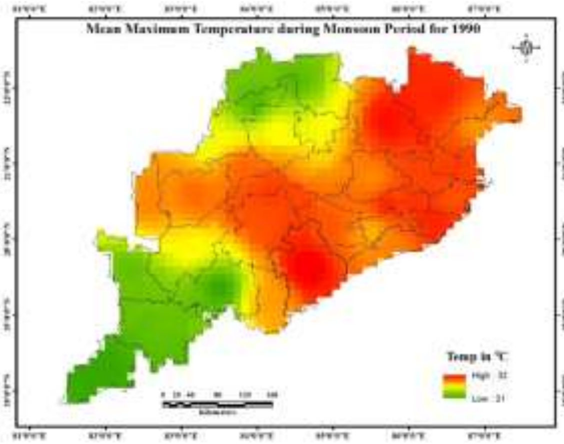


Fig. 4.2.2.1.C4

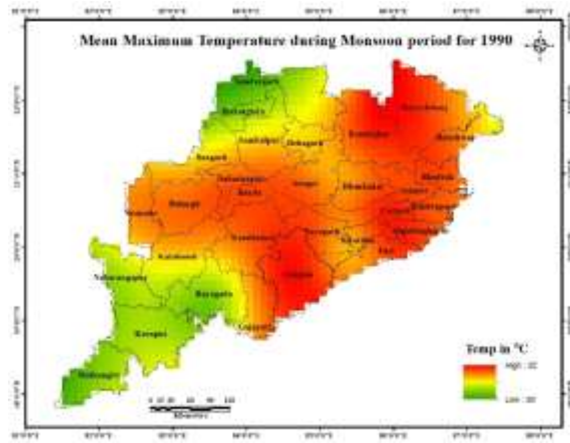


Fig. 4.2.2.1.D4

1991

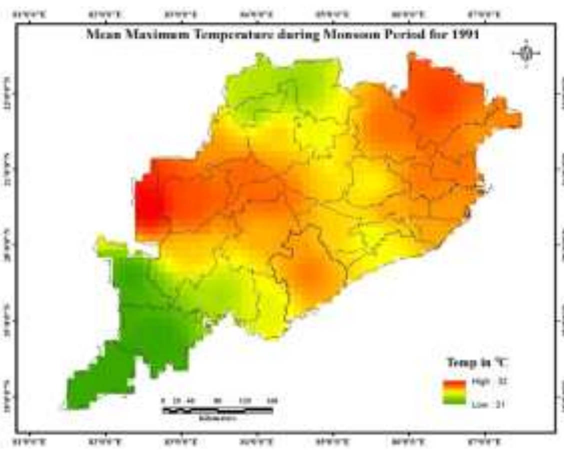


Fig. 4.2.2.1.C5

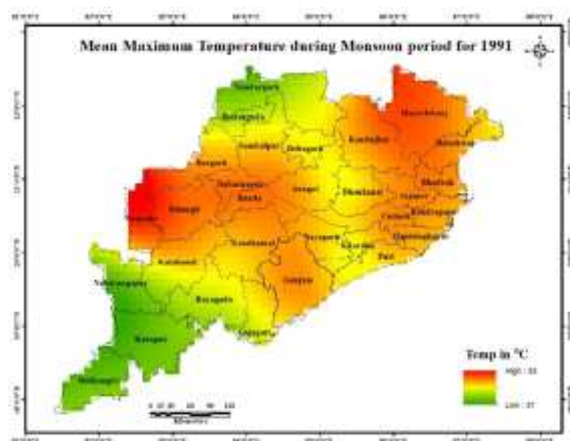


Fig. 4.2.2.1.D5

1992

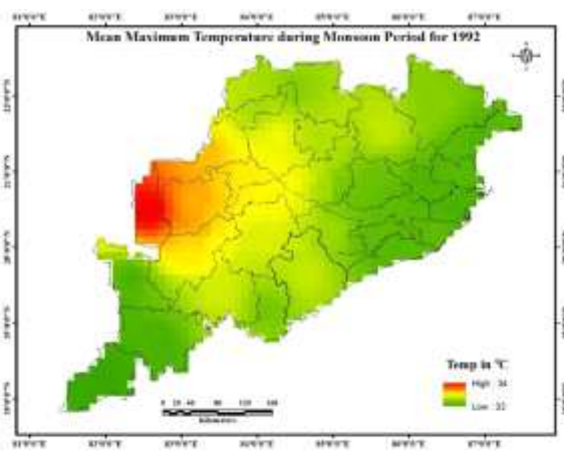


Fig. 4.2.2.1.C6

Fig. 4.2.2.1.D6

An analysis of fig.4.2.2.1.C1 and fig.4.2.2.1.D1 show the mean maximum temperature during monsoon period for the year 1987 as estimated by IDW and Spline interpolation techniques, respectively. The values range from 32-34^{0}C. Temperature was comparatively higher in the some parts of western and central regions of Odisha.

Mean maximum temperature observed during the monsoon period for the year 1988 as estimated by IDW and Spline techniques is represented in fig.4.2.2.1.C2 and fig.4.2.2.1.D2, respectively. The figures indicate that both the techniques showed the range of temperature to be 31-33^{0}C.It can be inferred that temperature was comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.1.C3 and fig.4.2.2.1.D3 show the mean maximum temperature values estimated by IDW and Spline techniques, respectively for the year 1989. The value of the temperature showed the range of 30-33^{0}C (IDW) and 31-33^{0}C (Spline). Figures reveal that temperature was comparatively higher in the central, western, north eastern, southern regions of Odisha.

An analysis of fig.4.2.2.1.C4 and fig.4.2.2.1.D4 show the mean maximum temperature during monsoon period for the year 1990. The values range from 31-32^{0}C and 30-32^{0}C as estimated by IDW and Spline interpolation techniques, respectively. Temperature was comparatively higher in the northern region, western region (Naupada and Bolangir) central region and all the coastal region of the state.

Mean maximum temperature observed during the monsoon period for the year 1991 as estimated by IDW and Spline techniques is represented in fig.4.2.2.1.C5 and fig.4.2.2.1.D5 respectively. The figures indicate values range from 31-32^{0}C (IDW) and 31-33^{0}C (Spine). Temperature was comparatively higher in western region (Nuapada and Bolangir), northern region, all coastal region and central region of the state.

A review of fig.4.2.2.1.C6 and fig.4.2.2.1.D6 shows the mean maximum temperature during monsoon period for the year 1992 as estimated by IDW and Spline techniques, the values range from 32-34^{0}C and 31-34^{0}C respectively. Figures reveal that temperature was comparatively higher in the western (Nuapada) region of the state.

YEAR **IDW** **SPLINE**

1993

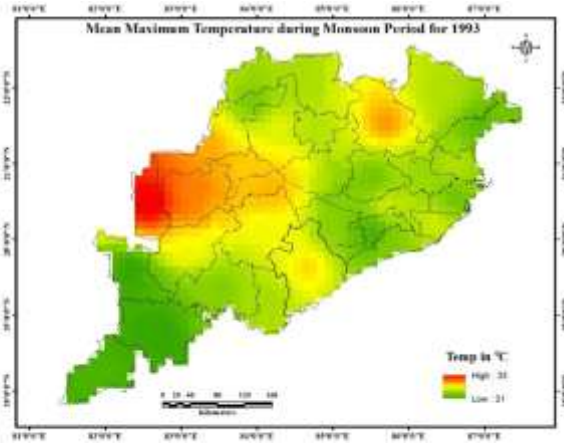


Fig. 4.2.2.1.C7

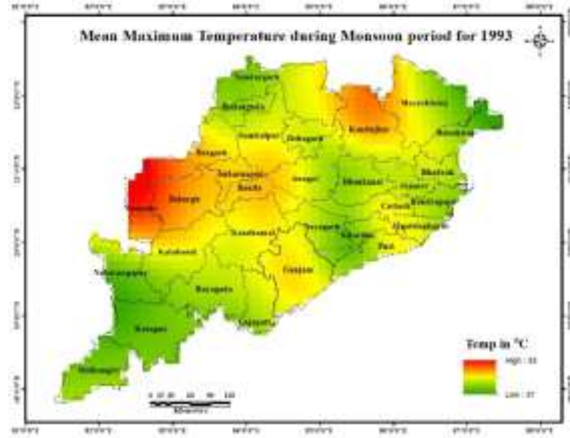


Fig. 4.2.2.1.D7

1994

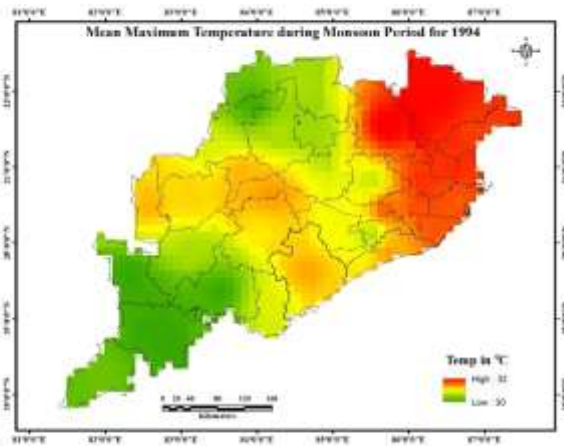


Fig. 4.2.2.1.C8

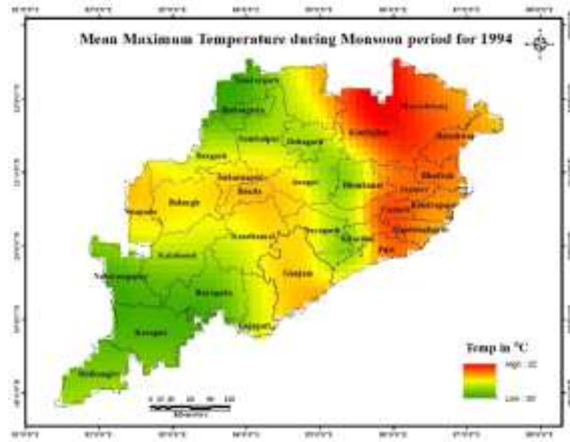


Fig. 4.2.2.1.D8

1995

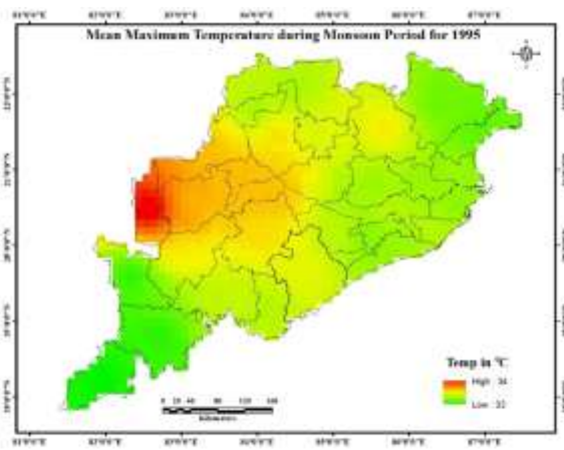


Fig. 4.2.2.1.C9

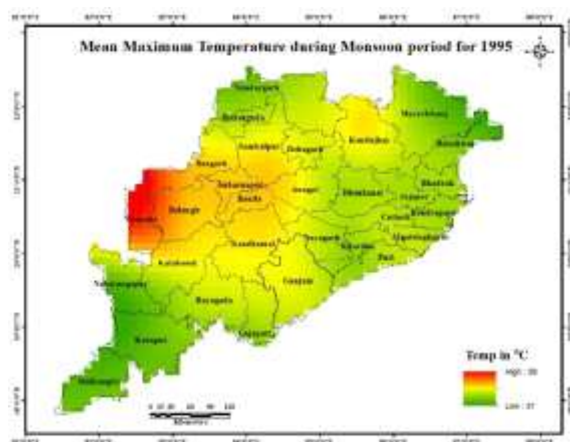


Fig. 4.2.2.1.D9

YEAR	IDW	SPLINE

1996

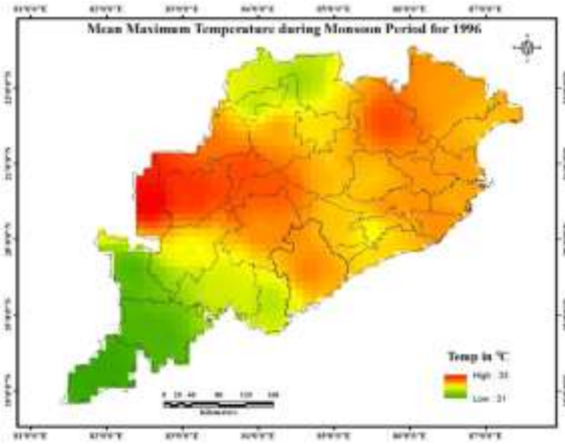


Fig. 4.2.2.1.C10

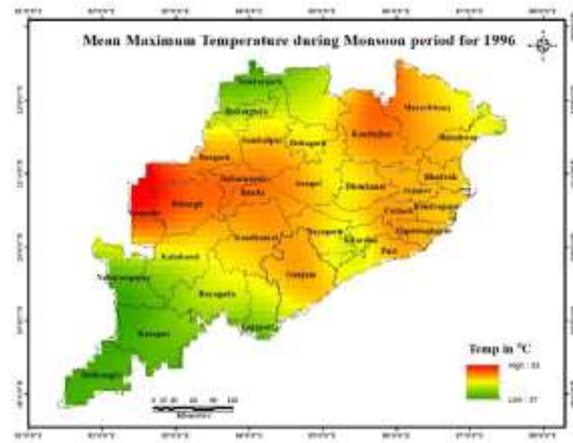


Fig. 4.2.2.1.D10

1997

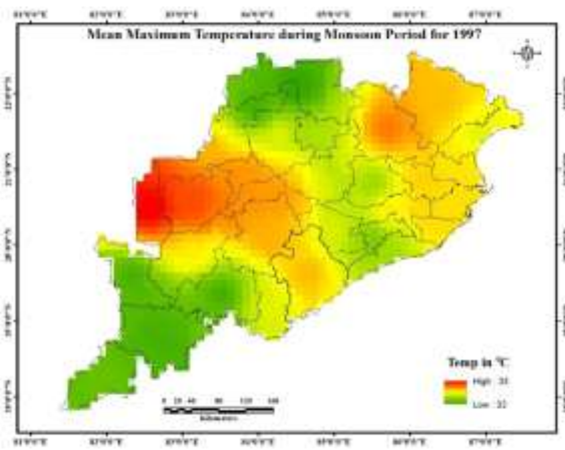


Fig. 4.2.2.1.C11

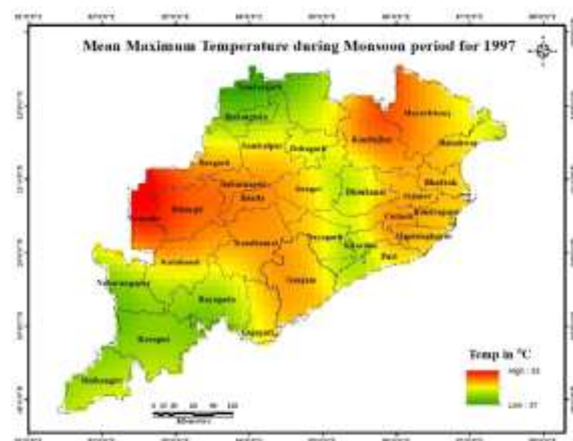


Fig. 4.2.2.1.D11

1998

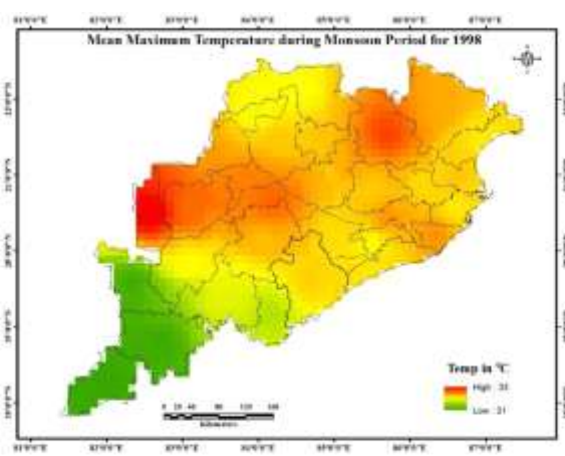


Fig. 4.2.2.1.C12

Fig. 4.2.2.1.D12

An analysis of fig.4.2.2.1.C7 and fig.4.2.2.1.D7 show the mean maximum temperature during monsoon period for the year 1993 as estimated by IDW and Spline interpolation techniques, respectively. The values range from 31-33^{0}C. Figures reveal that temperature was comparatively higher in the western region (Nuapada) of the state.

Mean maximum temperature observed during the monsoon period for the year 1994 as estimated by IDW and Spline techniques is represented in fig.4.2.2.1.C8 and fig.4.2.2.1.D8 respectively. The figures indicate that both the techniques showed the range of temperature to be 30-32^{0}C. can be inferred that temperature was comparatively higher in the northern region (Mayurbanj and Balasore) and some coastal region of Odisha.

A review of fig.4.2.2.1.C9 and fig.4.2.2.1.D9 show the mean maximum values estimated by IDW and Spline techniques, respectively for the year 1995. The value of the temperature showed the range of 32-34^{0}C (IDW) and 31-39^{0}C (Spline) Figures reveal that temperature was comparatively higher in the western (Nuapada) region of the state.

Mean maximum temperature observed during the monsoon period for the year 1996 as estimated by IDW and Spline techniques is represented in fig.4.2.2.1.C10 and fig.4.2.2.1.D10 respectively. The figures indicate that both the techniques showed the range of temperature to be 31-33^{0}C. It can be inferred that temperature was comparatively higher in the western region (Bolangir and Nuapada), central region and northern region of the state.

A review of fig.4.2.2.1.C11 and fig.4.2.2.1.D11 show the mean maximum temperature values as estimated by IDW and Spline techniques, respectively for the year 1997. The value of the temperature showed the range of 32-33^{0}C (IDW) and 31-33^{0}C (Spline). Figures reveal that temperature was comparatively higher in the western (Nuapada) region of Odisha.

An analysis of fig.4.2.2.1.C12 and fig.4.2.2.1.D12 show the mean maximum temperature during monsoon period for the year 1998 as estimated by IDW and Spline interpolation techniques, the values range from 31-33^{0}C and 31-34^{0}C respectively. Temperature was comparatively higher in the all other regions except southern region of Odisha.

YEAR **IDW** **SPLINE**

1999

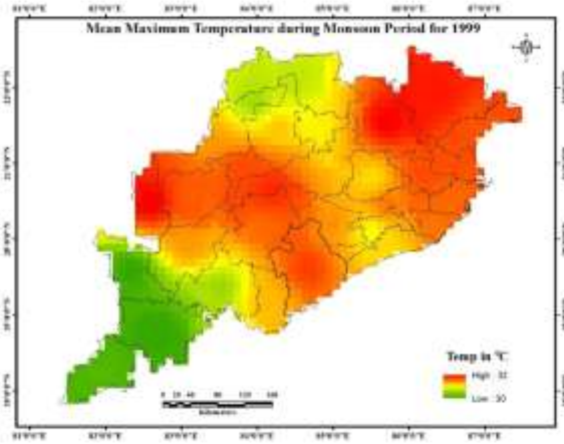


Fig. 4.2.2.1.C13

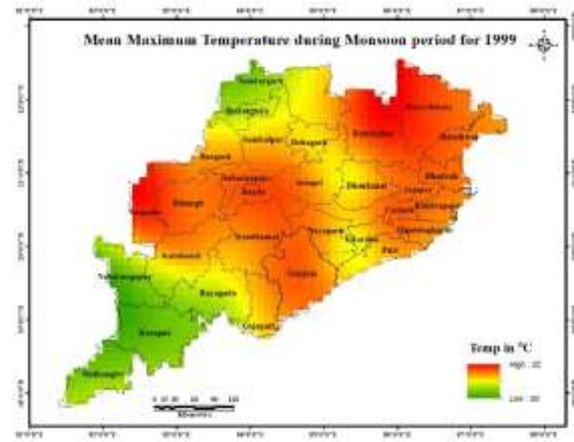


Fig. 4.2.2.1.D13

2000

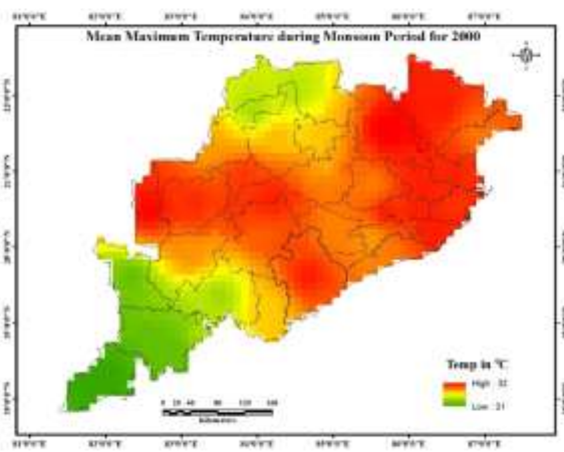


Fig. 4.2.2.1.C14

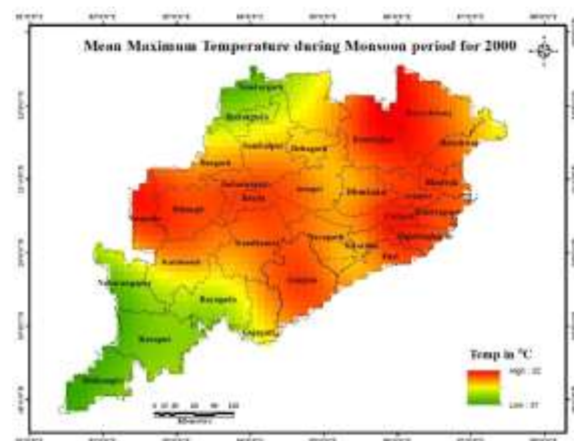


Fig. 4.2.2.1.D14

2001

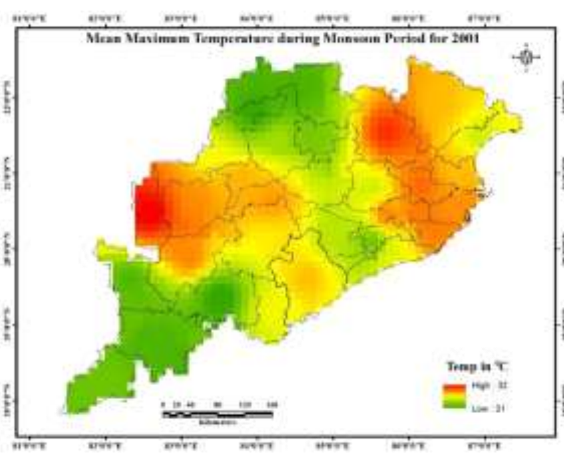


Fig. 4.2.2.1.C15

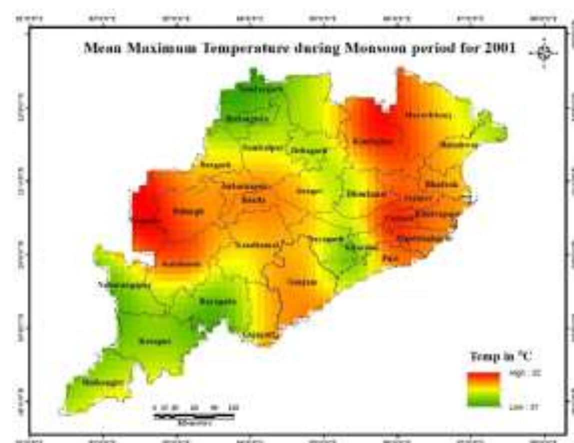


Fig. 4.2.2.1.D15

YEAR **IDW** **SPLINE**

2002

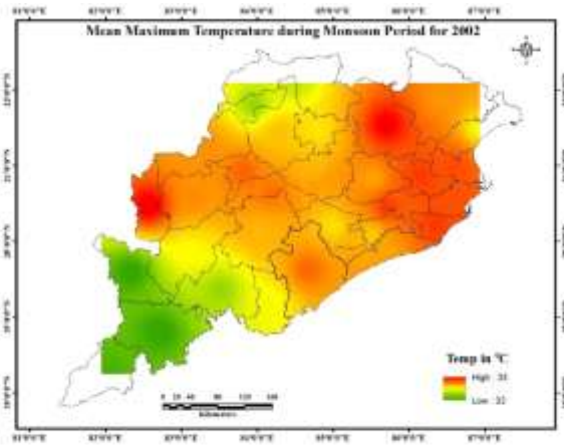


Fig. 4.2.2.1.C16

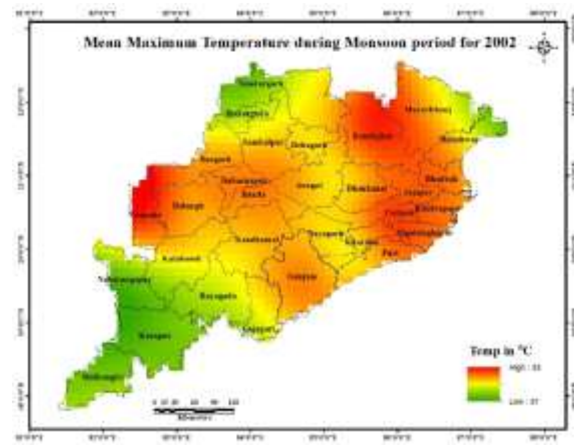


Fig. 4.2.2.1.D16

2003

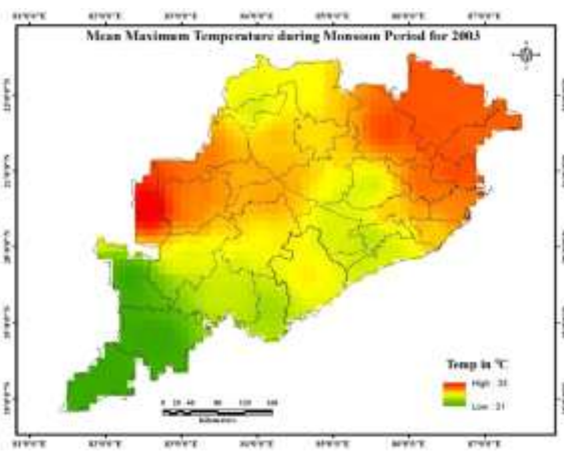


Fig. 4.2.2.1.C17

Fig. 4.2.2.1.D17

2004

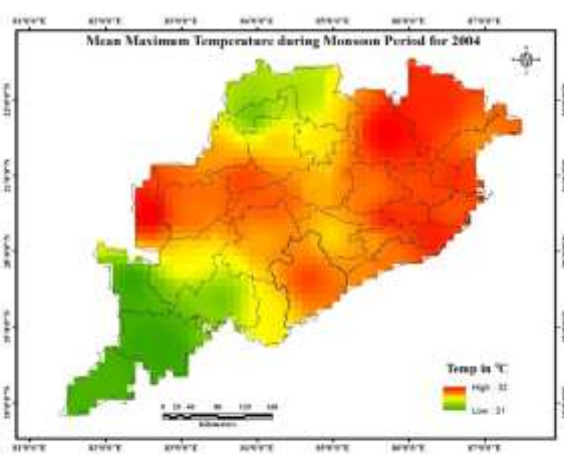


Fig. 4.2.2.1.C18

Fig. 4.2.2.1.D18

An analysis of fig. 4.2.2.1.C13 and fig. 4.2.2.1.D13 show the mean maximum temperature during monsoon period for the year 1999 as estimated by IDW and Spline interpolation techniques, respectively. The values range from 30-32^{0}C. Temperature was comparatively higher in the northern region (Mayurbanj), western region and central region of Odisha.

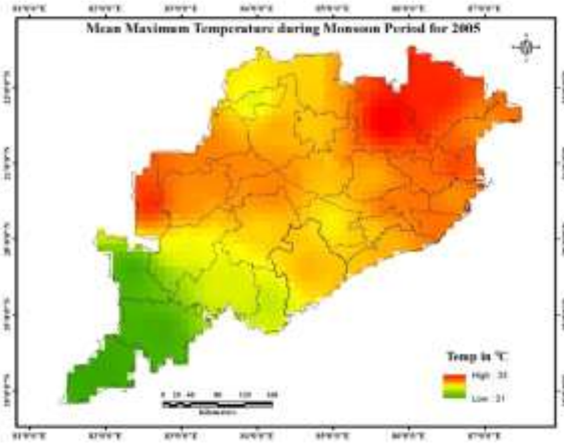
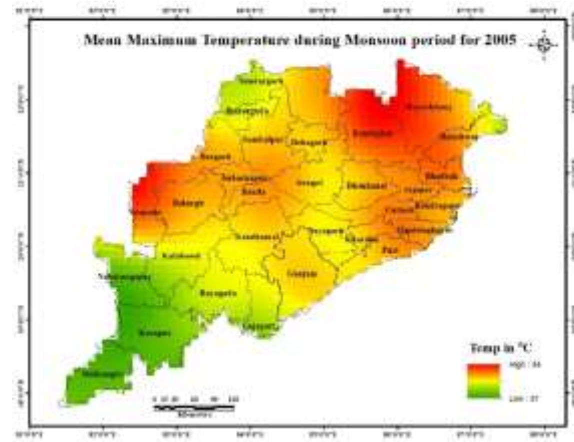
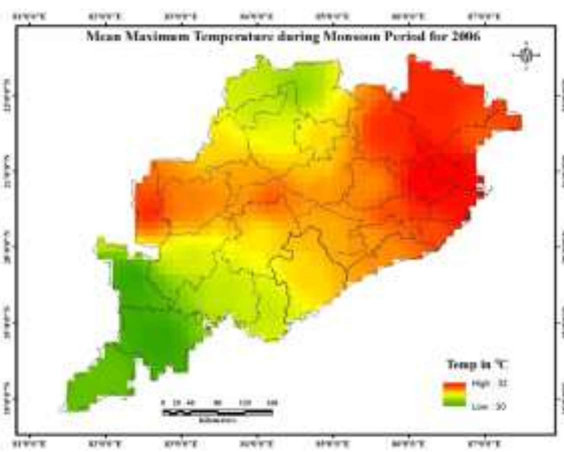
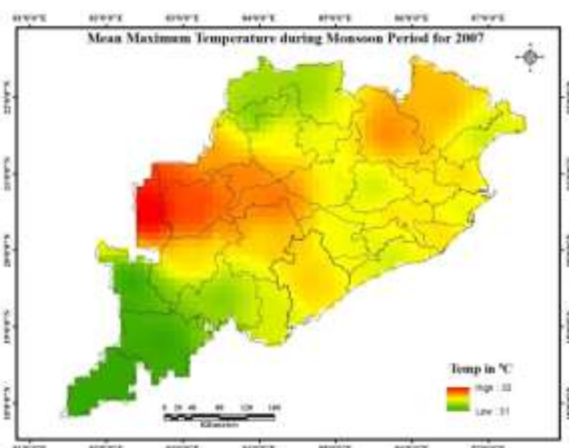
A review of fig. 4.2.2.1.C14 and fig. 4.2.2.1.D14 show the mean maximum temperature values estimated by IDW and Spline techniques, respectively for the year 2000. The value of the temperature showed the range of 31-33^{0}C (IDW) and 31-34^{0}C (Spline). Figures reveal that temperature was comparatively higher in the all coastal region, western region, and northern region of Odisha.

Mean maximum temperature observed during the monsoon period for the year 2001 as estimated by IDW and Spline techniques is represented in fig.4.2.2.1.C15 and fig. 4.2.2.1.D15 respectively. The figures indicate that both the techniques showed the range of temperature to be 31-32^{0}C. It can be inferred that temperature was comparatively higher in the western region (Nuapada, and Bolangir), northern districts like Mayurbanj and Keonjarh regions of the state.

An analysis of fig. 4.2.2.1.C16 and fig. 4.2.2.1.D16 show the mean maximum temperature during monsoon period for the year 2000 as estimated by IDW and Spline interpolation techniques, respectively. The values range from 32-33^{0}C and 31-33^{0}C. Temperature was comparatively higher in the northern region (Mayurbanj), western region and central region of Odisha.

Mean maximum temperature observed during the monsoon period for the year 2003 as estimated by IDW and Spline techniques is represented in fig. 4.2.2.1.C17 and fig.4.2.2.1.D17 respectively. The figures indicate values range from 31-33^{0}C for both the techniques. Temperature was comparatively higher in western region (Nuapada) northern region of the state.

A review of fig.4.2.2.1.C18 and fig.4.2.2.1.D18 shows the mean maximum temperature during monsoon period for the year 2004 as estimated by IDW and Spline techniques, the values range from 31-32^{0}C and 31-33^{0}C respectively. Figures reveal that temperature was comparatively higher in the western (Nuapada) region, coastal region and some northern region of the state.

YEAR	IDW	SPLINE
2005	 Fig. 4.2.2.1.C19	 Fig. 4.2.2.1.D19
2006	 Fig. 4.2.2.1.C20	 Fig. 4.2.2.1.D20
2007	 Fig. 4.2.2.1.C21	 Fig. 4.2.2.1.D21

YEAR **IDW** **SPLINE**

2008

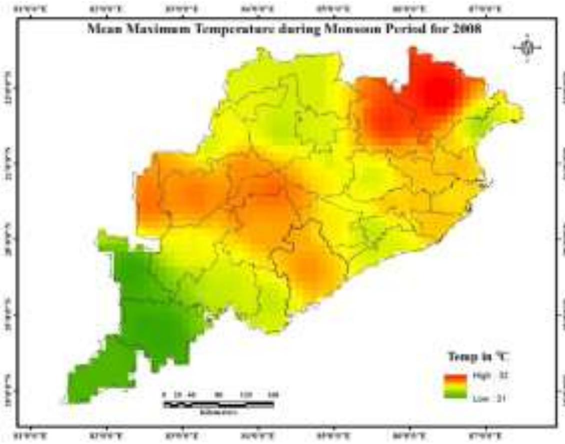


Fig. 4.2.2.1.C22

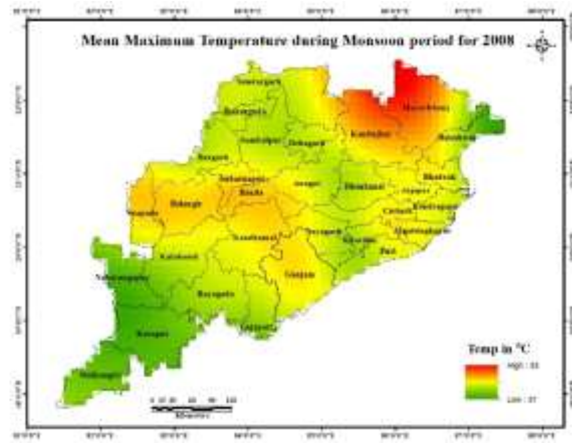


Fig. 4.2.2.1.D22

2009

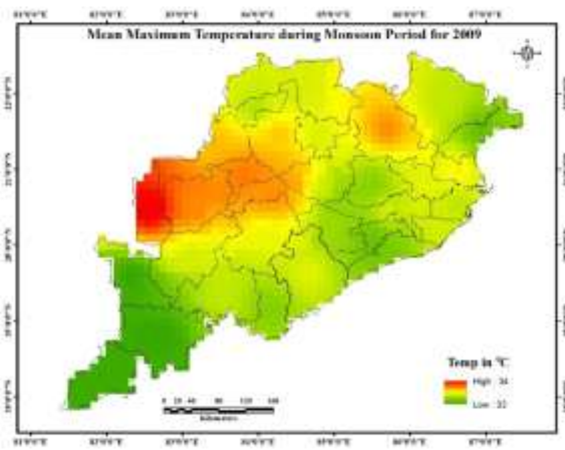


Fig. 4.2.2.1.C23

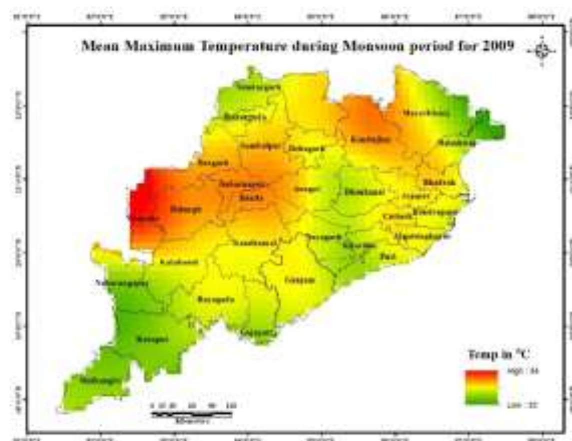


Fig. 4.2.2.1.D23

2010

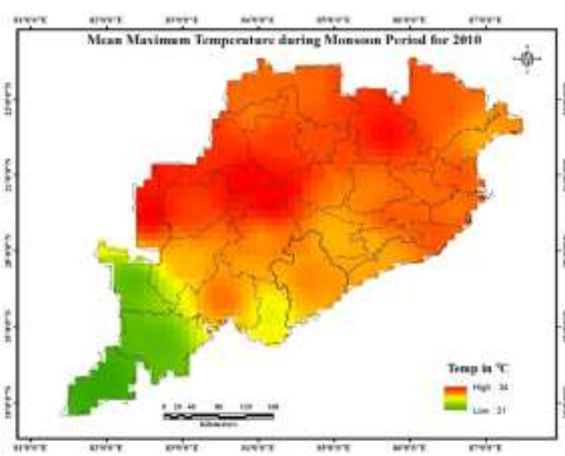


Fig. 4.2.2.1.C24

Fig. 4.2.2.1.D24

An analysis of fig. 4.2.2.1.C19 and fig. 4.2.2.1.D19 show the mean maximum temperature during monsoon period for the year 2005 as estimated by IDW and Spline interpolation techniques, respectively. The values range from 31-34^{0}C and 31-33^{0}C. Temperature was comparatively higher in the some parts of western and northern (Mayurbanj and Keonjarh) region of Odisha.

Mean maximum temperature observed during the monsoon period for the year 2006 as estimated by IDW and Spline techniques is represented in fig. 4.2.2.1.C20 and fig. 4.2.2.1.D20 respectively. The figures indicate that both the techniques showed the range of temperature to be 31-32^{0}C .It can be inferred that temperature was comparatively higher in the western region, northern regions and coastal regions like Bhadrak,Jajpur and Jagatsinghpur districts of Odisha.

A review of fig. 4.2.2.1.C21 and fig. 4.2.2.1.D21 show the mean maximum temperature values estimated by IDW and Spline techniques, respectively for the year 2007. The value of the temperature showed the range of 31-33^{0}C. Figures reveal that temperature was comparatively higher in the central, western (Nuapada) region of Odisha.

An analysis of fig.4.2.2.1.C22 and fig 4.2.2.1.D22 show the mean maximum temperature during monsoon period for the year 2008. The values range from 31-32^{0}C and 31-33^{0}C as estimated by IDW and Spline interpolation techniques, respectively. Temperature was comparatively higher in the northern (Mayurbanj) region of the state.

Mean maximum temperature observed during the monsoon period for the year 2009 as estimated by IDW and Spline techniques is represented in fig. 4.2.2.1.C23 and fig. 4.2.2.1.D23 respectively. The figures indicate values range from 32-34^{0}C. Temperature was comparatively higher in western region (Nuapada and Bolangir) of the state.

A review of fig. 4.2.2.1.C24 and fig. 4.2.2.1.D24 shows the mean maximum temperature during monsoon period for the year 2010 as estimated by IDW and Spline techniques, the values range from 31-34^{0}C. Figures reveal that temperature was comparatively higher in the all other region except southern region of the state.

An analysis of fig. 4.2.2.1.C25 and fig. 4.2.2.1.D25 show the mean maximum temperature during monsoon period for the year 2011 as estimated by IDW and Spline interpolation techniques, respectively. The values range from 31-33^{0}C and 30-33^{0}C. Temperature was comparatively higher in the some parts of western region, north coastal region and central regions of Odisha.

YEAR **IDW** **SPLINE**

2011

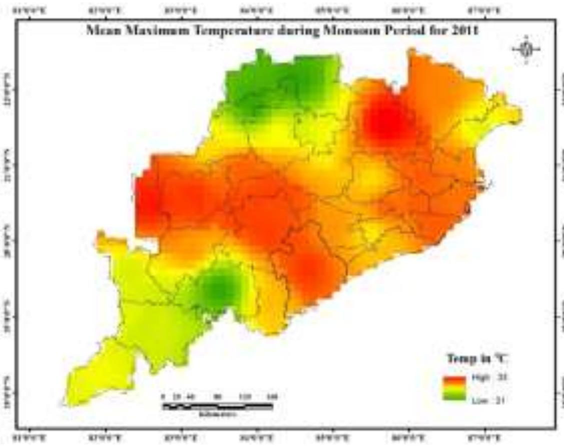


Fig. 4.2.2.1.C25

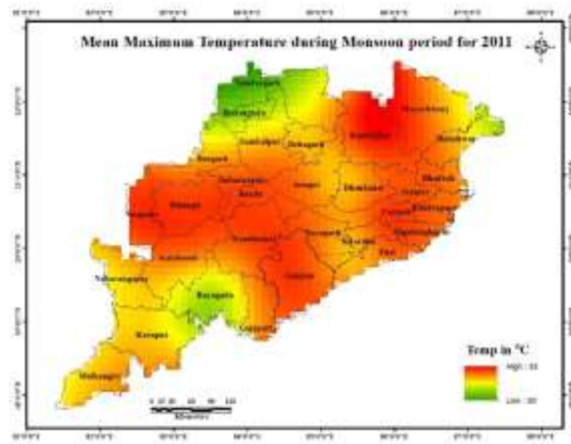


Fig. 4.2.2.1.D25

2012

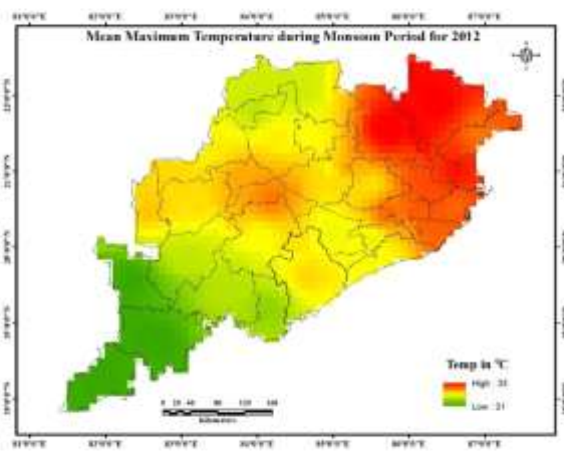


Fig. 4.2.2.1.C26

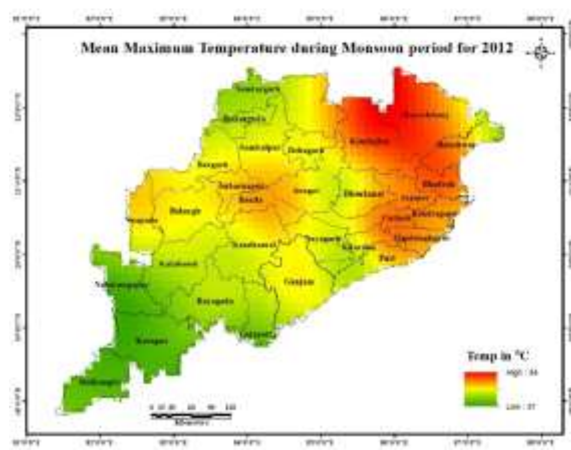


Fig. 4.2.2.1.D26

2013

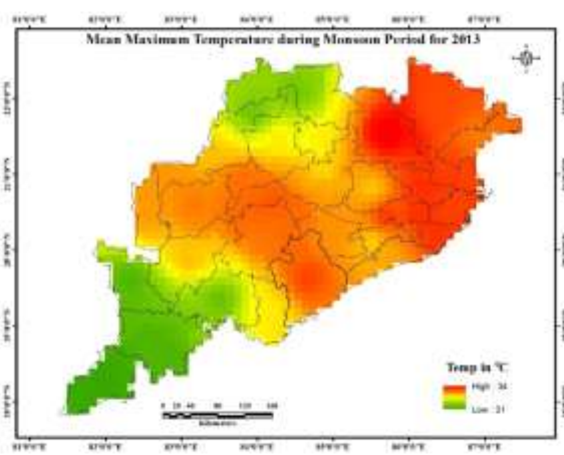


Fig. 4.2.2.1.C27

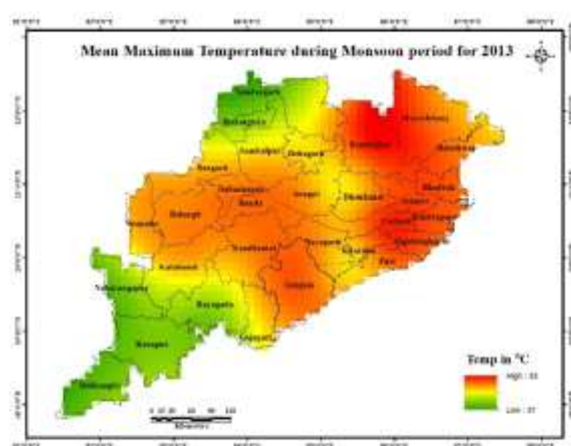


Fig. 4.2.2.1.D27

YEAR	IDW	SPLINE

2014

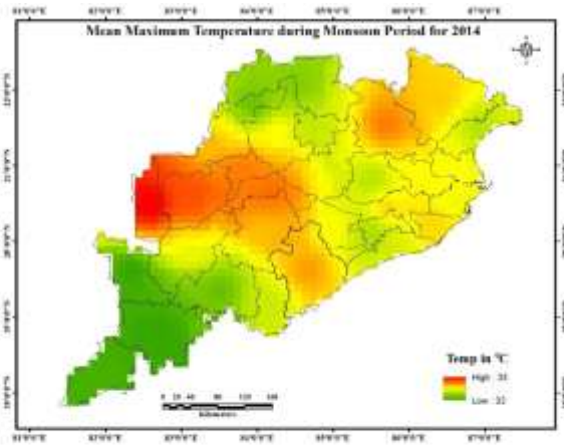


Fig. 4.2.2.1.C28

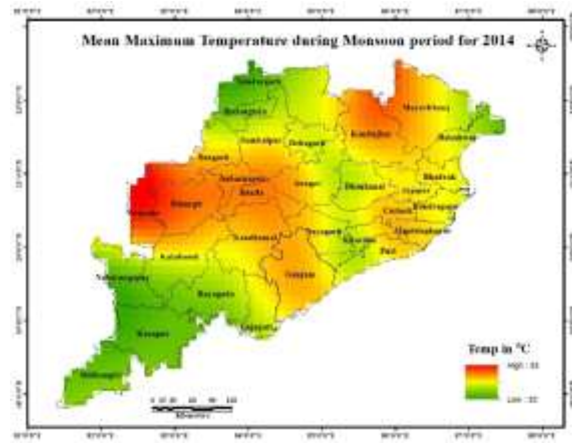


Fig. 4.2.2.1.D28

2015

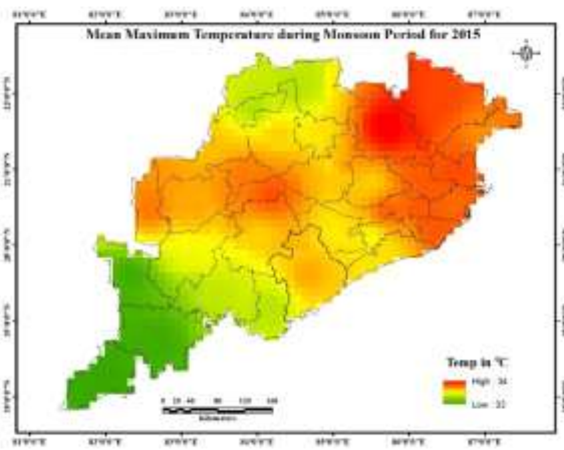


Fig. 4.2.2.1.C29

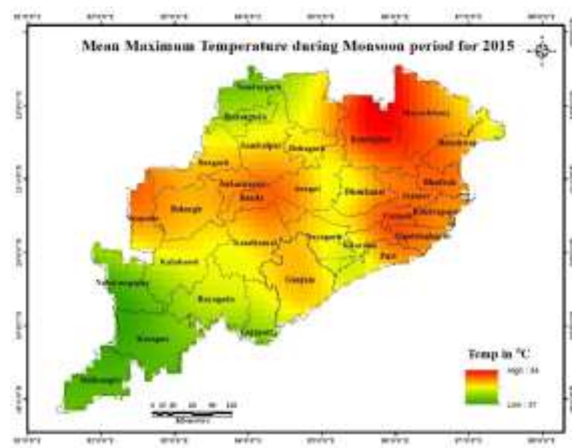


Fig. 4.2.2.1.D29

2016

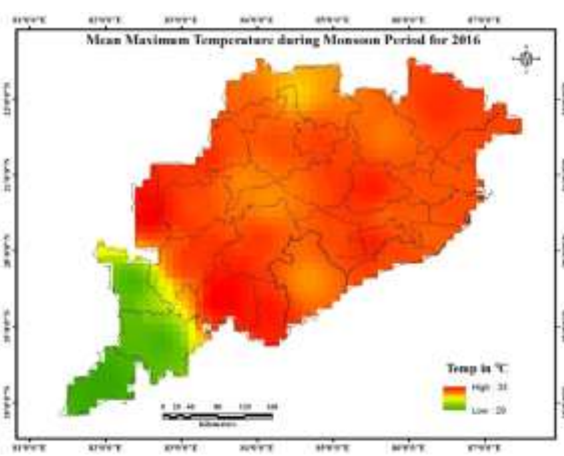


Fig. 4.2.2.1.C30

Fig. 4.2.2.1.D30

YEAR **IDW** **SPLINE**

2017

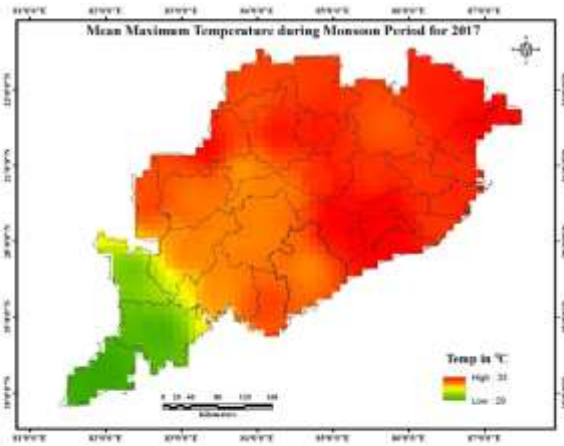


Fig. 4.2.2.1.C31

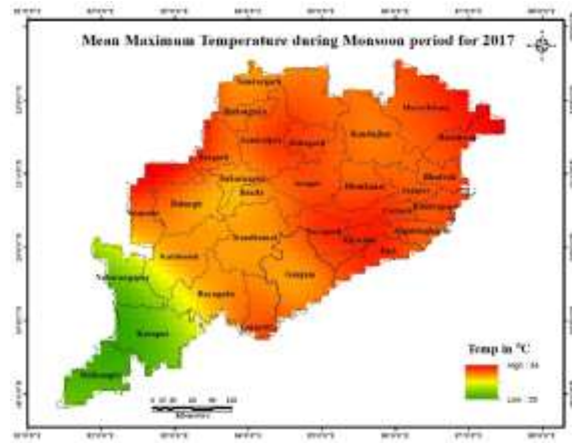


Fig. 4.2.2.1.D31

Mean maximum temperature observed during the monsoon period for the year 2012 as estimated by IDW and Spline techniques is represented in fig. 4.2.2.1.C26 and fig.4.2.2.1.D26 respectively. The figures indicate that both the techniques showed the range of temperature to be 31-33^{0}C and 31-34^{0}C. It can be inferred that temperature was comparatively higher in the northern (Mayurbanj) regions of the state.

A review of fig. 4.2.2.1.C27 and fig4.2.2.1.D27 show the mean maximum temperature values estimated by IDW and Spline techniques, respectively for the year 2013. The value of the temperature showed the range of 31-34^{0}C (IDW) and 31-33^{0}C (Spline). Figures reveal that temperature was comparatively higher in the northern and some coastal regions of Odisha.

An analysis of fig. 4.2.2.1.C28 and fig. 4.2.2.1.D28 show the mean maximum temperature during monsoon period for the year 2014. The values range from 32-33^{0}C. as estimated by IDW and Spline interpolation techniques, respectively. Temperature was comparatively higher in the northern region, western region (Naupada and Bolangir) of the state.

Mean maximum temperature observed during the monsoon period for the year 2015 as estimated by IDW and Spline techniques is represented in fig. 4.2.2.1.C29 and fig. 4.2.2.1.D29 respectively. The figures indicate values range from 32-34^{0}C (IDW) and 31-34^{0}C (Spine). Temperature was comparatively higher in western region (Nuapada and Bolangir), northern (Mayurbanj) region, and all coastal region region of the state.

A review of fig. 4.2.2.1.C30 and fig. 4.2.2.1.D30 shows the mean maximum temperature during monsoon period for the year 2016 as estimated by IDW and Spline techniques, the values range from 29-33^{0}C and 29-34^{0}C respectively. Figures reveal that temperature was comparatively higher in the all the regions except southern region of the state.

A review of fig. 4.2.2.1.C31 and fig. 4.2.2.1.D31 shows the mean maximum temperature during monsoon period for the year 2017 as estimated by IDW and Spline techniques, the values range from 29-33^{0}C and 29-34^{0}C respectively. Figures reveal that temperature was comparatively higher in the all the regions except southern region of the state.

Table No: 4.2.2.2 Mean minimum temperature for monsoon season

YEAR | **IDW** | **SPLINE**

1987

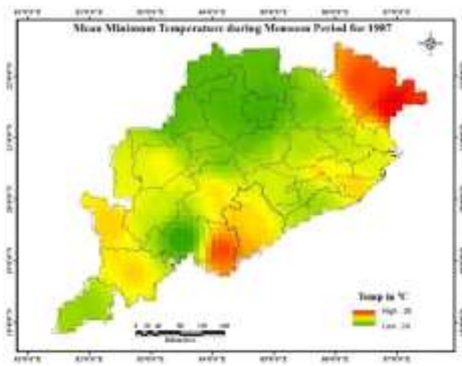


Fig. 4.2.2.2.E1

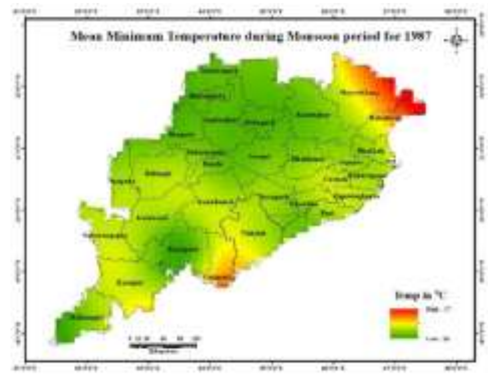


Fig. 4.2.2.2.F1

1988

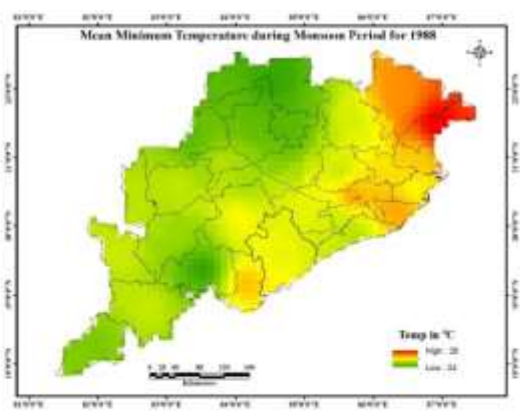


Fig. 4.2.2.2.E2

Fig. 4.2.2.2.F2

1989

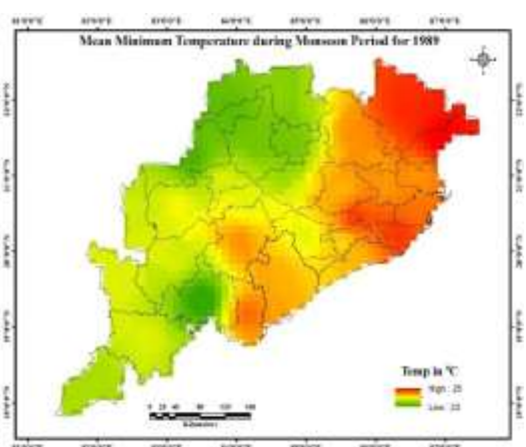


Fig. 4.2.2.2.E3

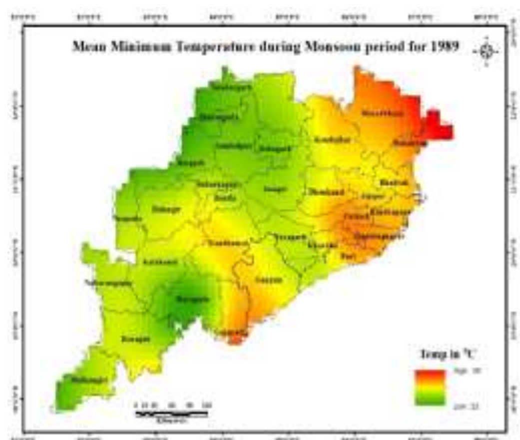


Fig. 4.2.2.2.F3

YEAR	IDW	SPLINE

1990

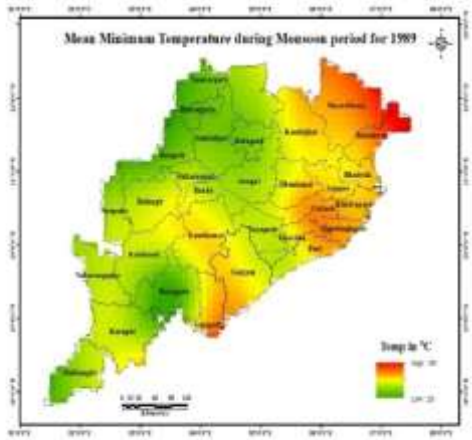


Fig. 4.2.2.2.E4

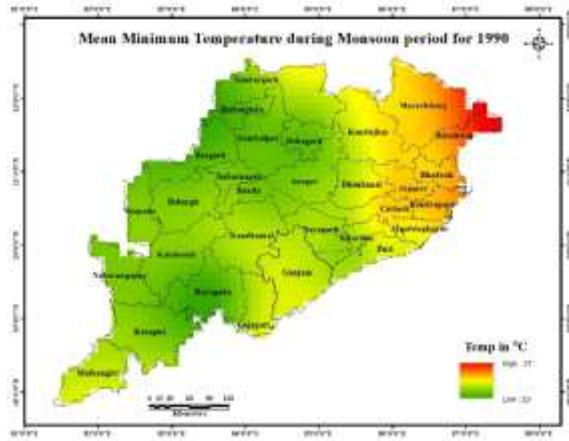


Fig. 4.2.2.2.E4

1991

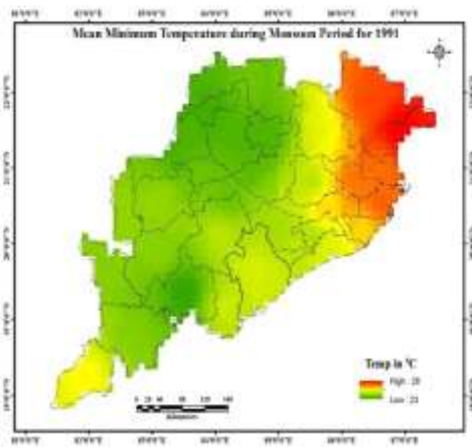


Fig. 4.2.2.2.E5

Fig. 4.2.2.2.E5

1992

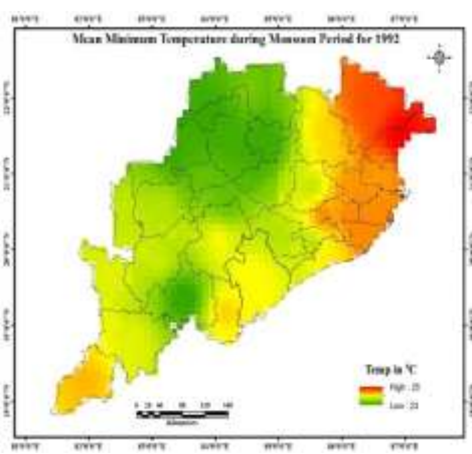


Fig. 4.2.2.2.E6

Fig. 4.2.2.2.F6

An analysis of fig. 4.2.2.2.E1 and fig.4.2.2.2.F1 show the mean minimum temperature during monsoon period for the year 1987 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 24-26^{0}C (IDW) and 24-27^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 1988 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E2 and fig.4.2.2.2.F2, respectively. The figures indicate that both the techniques showed the range of temperature to be 24-26^{0}C (IDW) and 24-27^{0}C (Spline). It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E3 and fig.4.2.2.2.F3 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 1989. The value of the temperature showed the range of 23-25^{0}C (IDW) and 23-26^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E4 and fig.4.2.2.2.F4 show the mean minimum temperature during monsoon period for the year 1990 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 23-26^{0}C (IDW) and 23-27^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 1991 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E5 and fig.4.2.2.2.F5, respectively. The figures indicate that both the techniques showed the range of temperature to be 23-26^{0}C (IDW) and 23-27^{0}C (Spline). It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E6 and fig.4.2.2.2.F6 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 1992. The value of the temperature showed the range of 23-25^{0}C (IDW) and 23-26^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

YEAR **IDW** **SPLINE**

1993

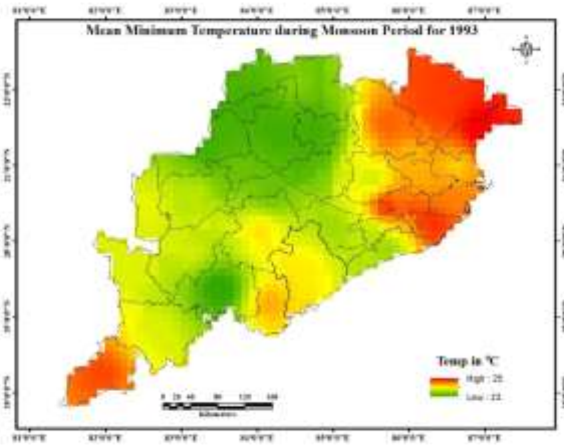


Fig. 4.2.2.2.E7

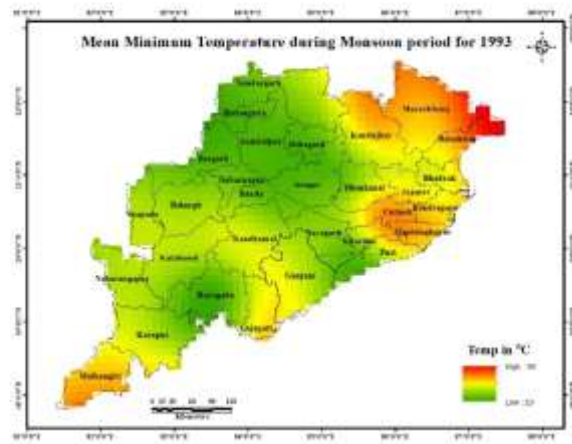


Fig. 4.2.2.2.F7

1994

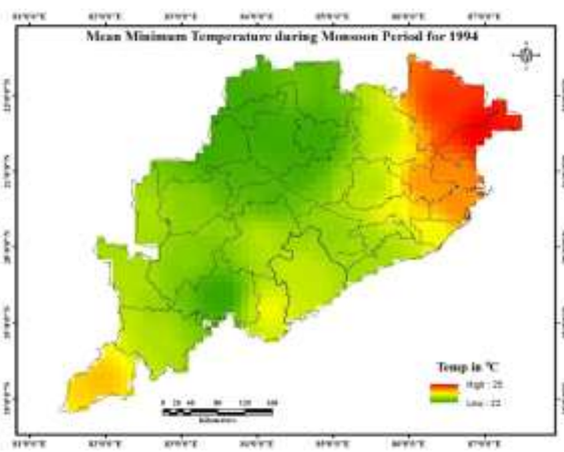


Fig. 4.2.2.2.E8

Fig. 4.2.2.2.F8

1995

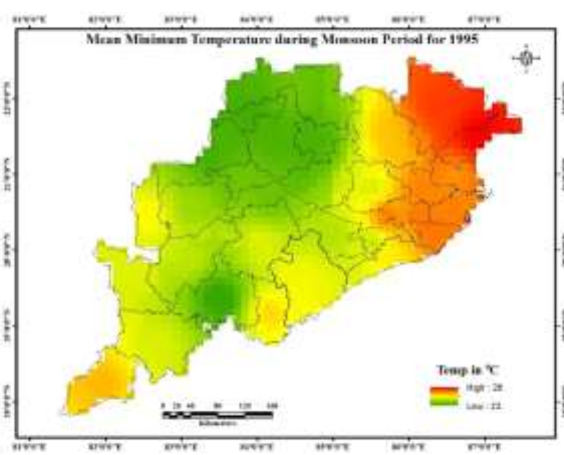


Fig. 4.2.2.2.E9

Fig. 4.2.2.2.F9

YEAR **IDW** **SPLINE**

1996

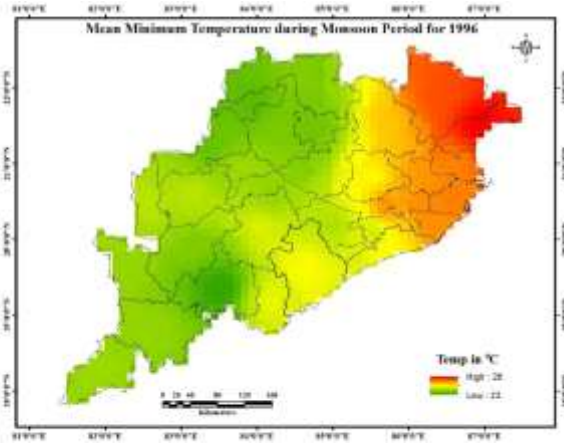


Fig. 4.2.2.2.E10

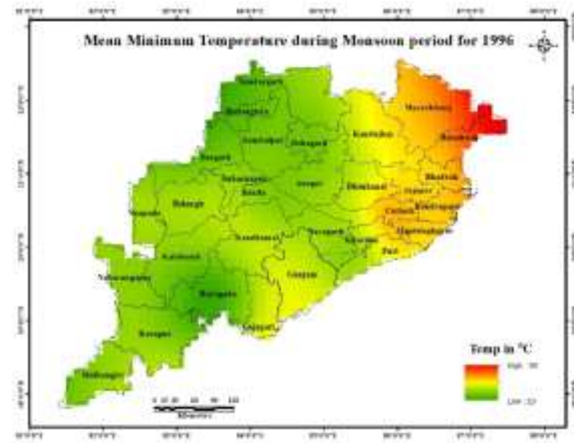


Fig. 4.2.2.2.F10

1997

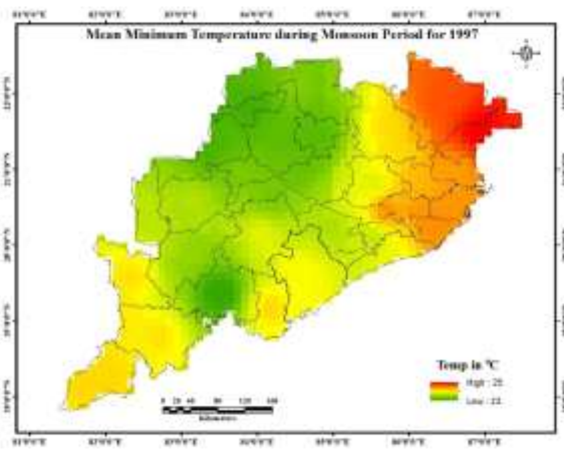


Fig. 4.2.2.2.E11

Fig. 4.2.2.2.F11

1998

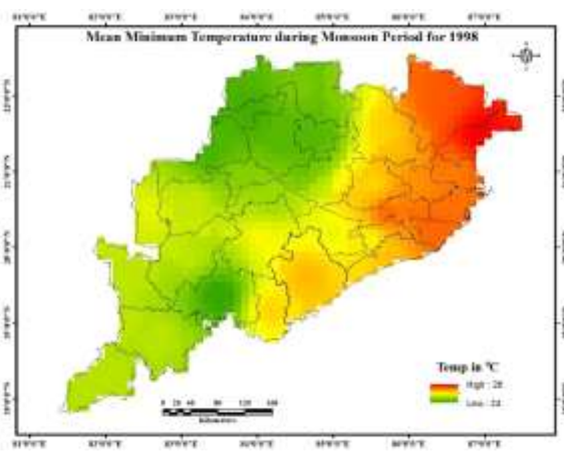


Fig. 4.2.2.2.E12

Fig. 4.2.2.2.F12

An analysis of fig. 4.2.2.2.E7 and fig.4.2.2.2.F7 show the mean minimum temperature during monsoon period for the year 1993 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 23-25^{0}C (IDW) and 23-26^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 1994 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E8 and fig.4.2.2.2.F8, respectively. The figures indicate that both the techniques showed the range of temperature to be 22-25^{0}C (IDW) and 23-26^{0}C (Spline).It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E9 and fig.4.2.2.2.F9 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 1995The value of the temperature showed the range from 23-26^{0}C. Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E10 and fig.4.2.2.2.F10 show the mean minimum temperature during monsoon period for the year 1996 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 23-26^{0}C. Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 1997 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E11 and fig.4.2.2.2.F12, respectively. The figures indicate that both the techniques showed the range of temperature to be The values ranges from 23-25^{0}C (IDW) and 23-26^{0}C (Spline).It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E12 and fig.4.2.2.2.F12 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 1998. The value of the temperature showed the range of 24-26^{0}C (IDW) and 24-27^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E13 and fig.4.2.2.2.F13 show the mean minimum temperature during monsoon period for the year 1999 as estimated by IDW and Spline interpolation techniques,

YEAR **IDW** **SPLINE**

1999

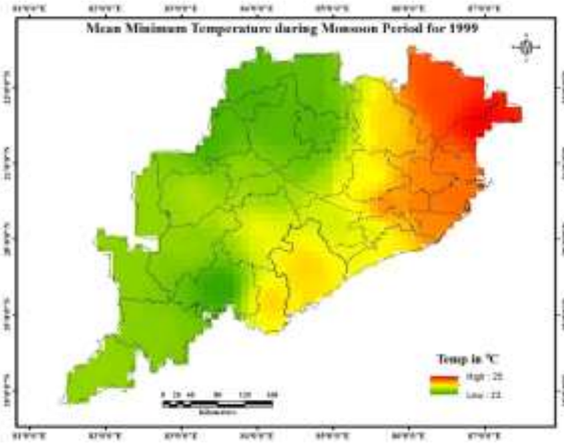


Fig. 4.2.2.2.E13

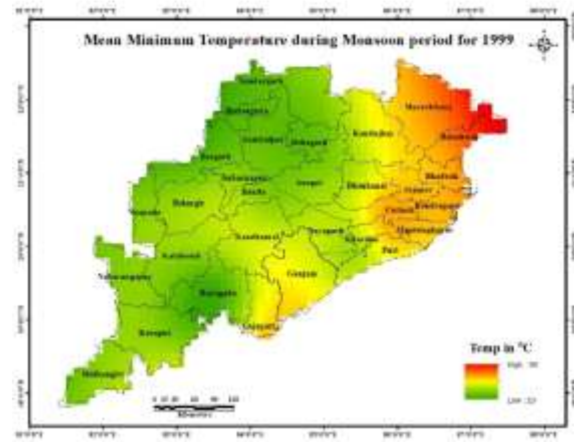


Fig. 4.2.2.2.F13

2000

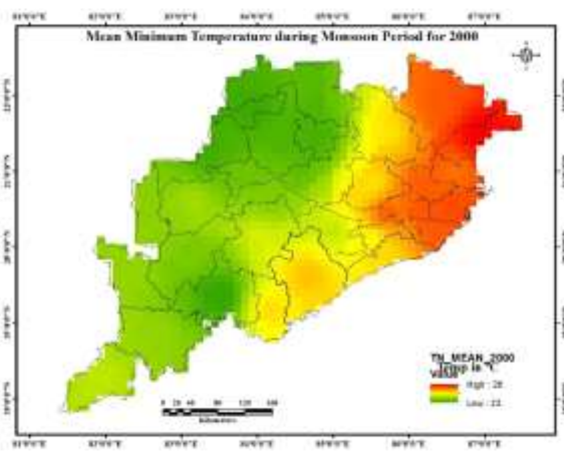


Fig. 4.2.2.2.E14

Fig. 4.2.2.2.F14

2001

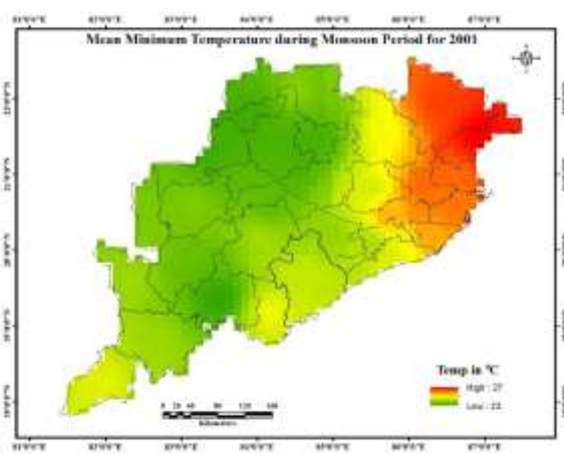


Fig. 4.2.2.2.E15

Fig. 4.2.2.2.F15

YEAR **IDW** **SPLINE**

2002

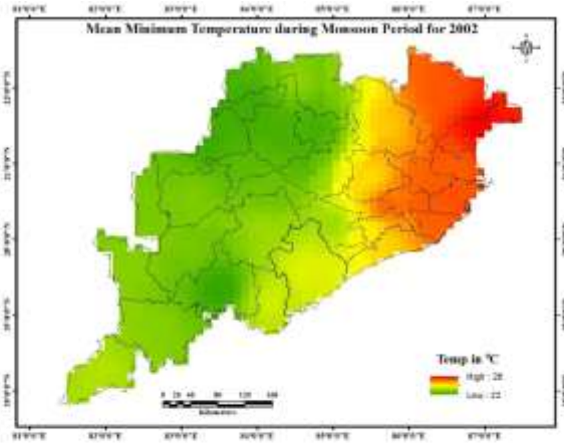


Fig. 4.2.2.2.E16

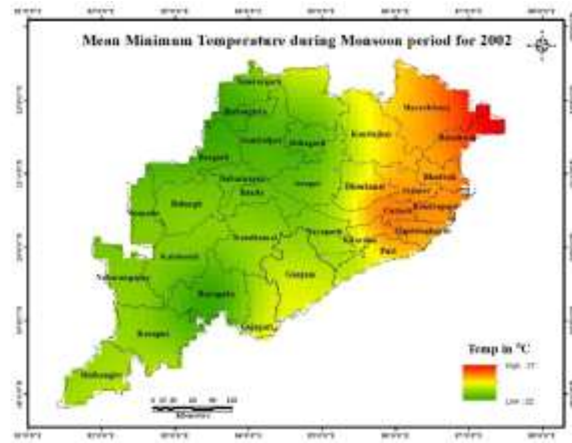


Fig. 4.2.2.2.F16

2003

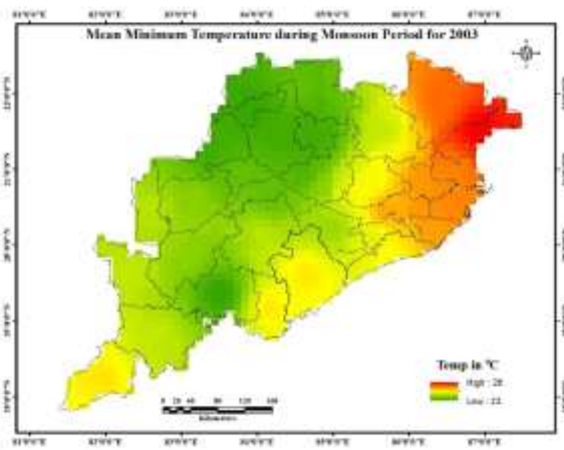


Fig. 4.2.2.2.E17

Fig. 4.2.2.2.F17

2004

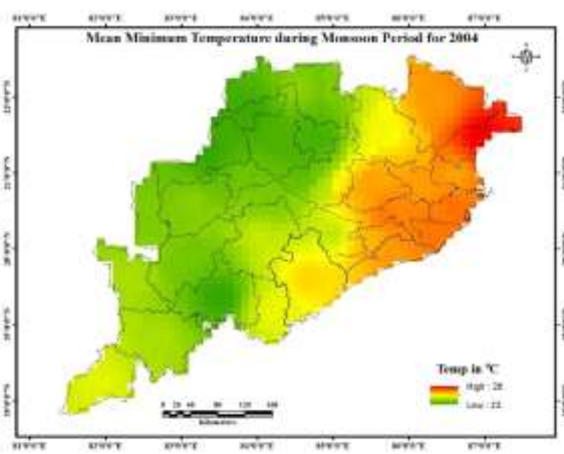


Fig. 4.2.2.2.E18

Fig. 4.2.2.2.F18

respectively. The values ranges from 23-25^{0}C (IDW) and 23-26^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 2000 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E14 and fig.4.2.2.2.F14, respectively. The figures indicate that both the techniques showed the range of temperature to be 23-26^{0}C (IDW) and 23-27^{0}C (Spline). It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E15 and fig.4.2.2.2.F15 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 2001. The value of the temperature showed the range form 23-27^{0}C Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E16 and fig.4.2.2.2.F16 show the mean minimum temperature during monsoon period for the year 2002 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 22-26^{0}C (IDW) and 22-27^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 2003 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E17 and fig.4.2.2.2.F17, respectively. The figures indicate that both the techniques showed the range of temperature to be 23-26^{0}C (IDW) and 23-27^{0}C (Spline). It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E18 and fig.4.2.2.2.F18 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 2004. The value of the temperature showed the range of 23-26^{0}C (IDW) and 23-27^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E19 and fig.4.2.2.2.F19 show the mean minimum temperature during monsoon period for the year 2005 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 24-26^{0}C (IDW) and 23-27^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

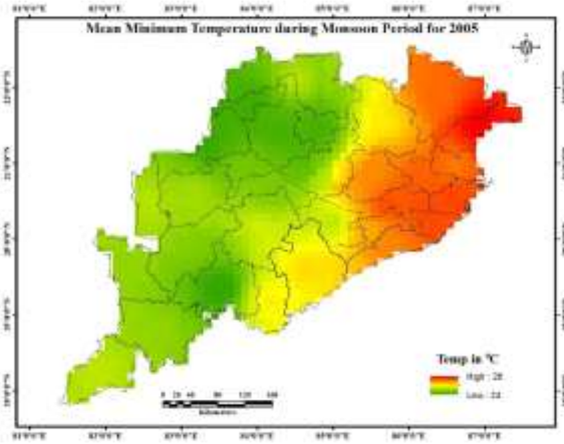
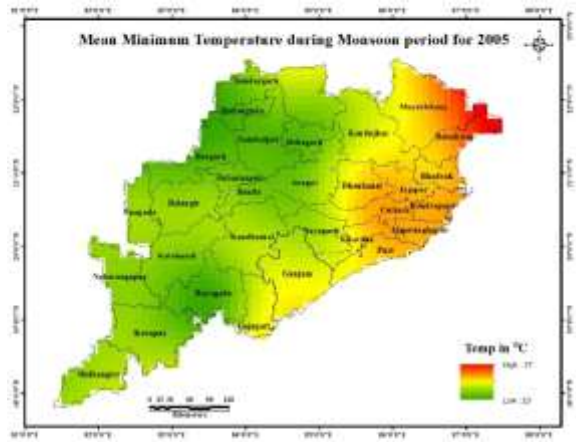
YEAR	IDW	SPLINE
2005		

Fig. 4.2.2.2.E19

Fig. 4.2.2.2.F19

2006

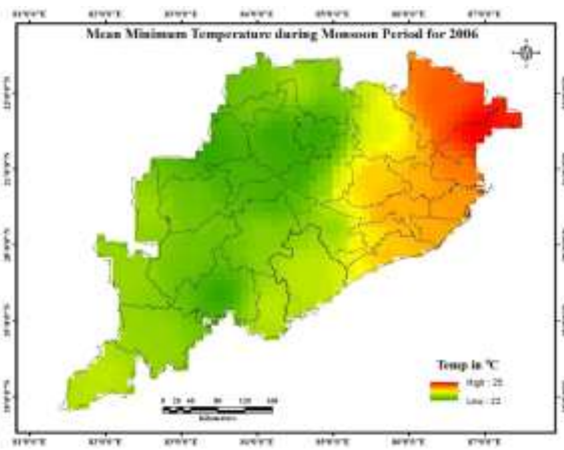


Fig. 4.2.2.2.E20

Fig. 4.2.2.2.F20

2007

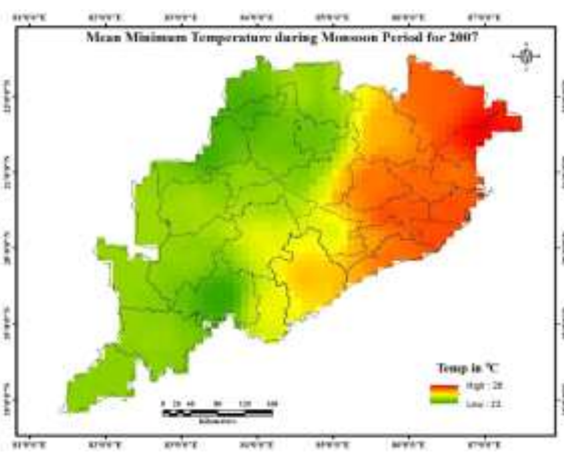


Fig. 4.2.2.2.E21

Fig. 4.2.2.2.F21

YEAR	IDW	SPLINE

2008

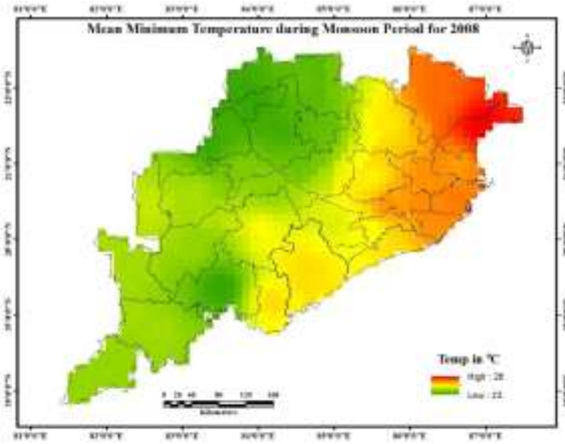


Fig. 4.2.2.2.E22

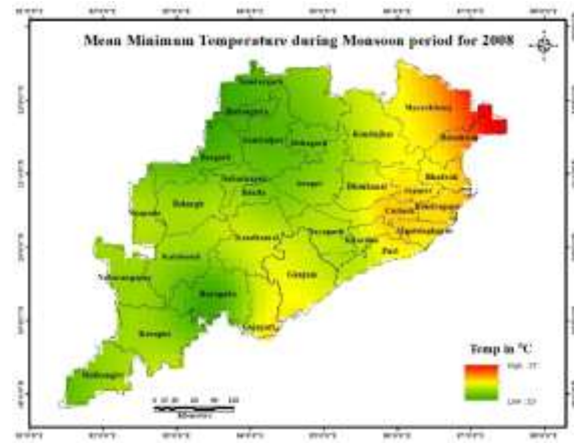


Fig. 4.2.2.2.F22

2009

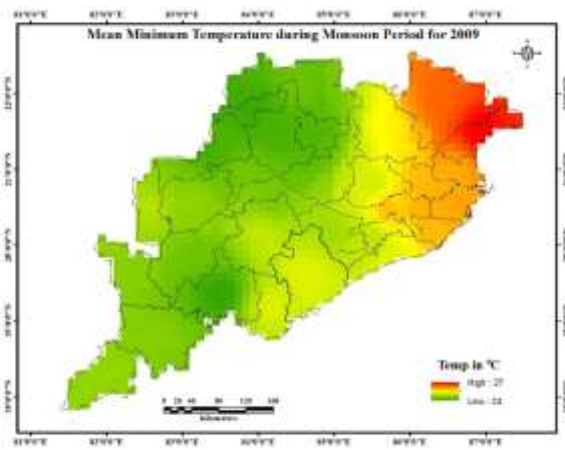


Fig. 4.2.2.2.E23

Fig. 4.2.2.2.F23

2010

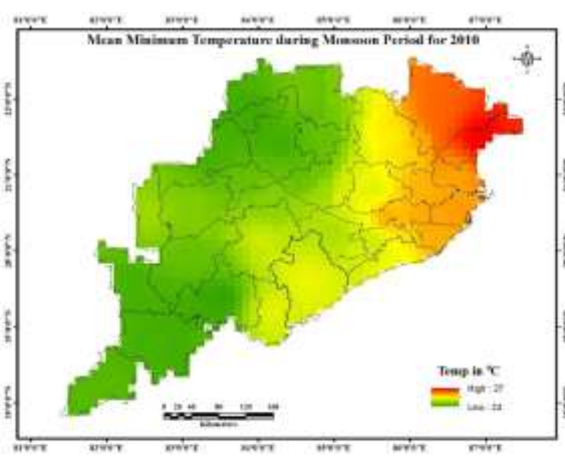


Fig. 4.2.2.2.E24

Fig. 4.2.2.2.F24

Mean minimum temperature observed during the monsoon period for the year 2006 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E20 and fig.4.2.2.2.F20, respectively. The figures indicate that both the techniques showed the range of temperature to be 22-25^{0}C (IDW) and 22-27^{0}C (Spline).It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E21 and fig.4.2.2.2.F21 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 2007. The value of the temperature showed the range from 23-26^{0}C (IDW) and 23-27^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E22 and fig.4.2.2.2.F22 show the mean minimum temperature during monsoon period for the year 2008 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges of 23-26^{0}C (IDW) and 23-27^{0}C (Spline).. Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 2009 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E23 and fig.4.2.2.2.F23, respectively. The figures indicate that both the techniques showed the range of temperature to be the values ranges from 24-27^{0}C (IDW) and 24-28^{0}C (Spline).It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E24 and fig.4.2.2.2.F24 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 2010. The value of the temperature showed the range of 24-27^{0}C (IDW) and 24-28^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E25 and fig.4.2.2.2.F25 show the mean minimum temperature during monsoon period for the year 2011 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 23-26^{0}C (IDW) and 23-27^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

YEAR	IDW	SPLINE

2011

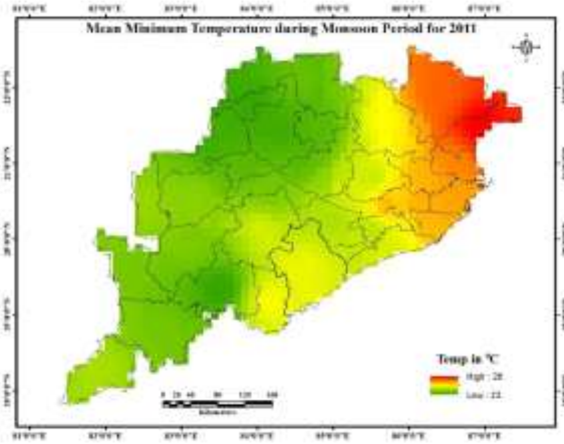


Fig. 4.2.2.2.E25

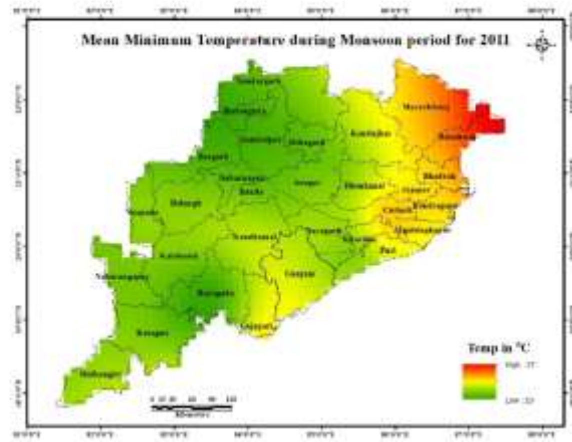


Fig. 4.2.2.2.F25

2012

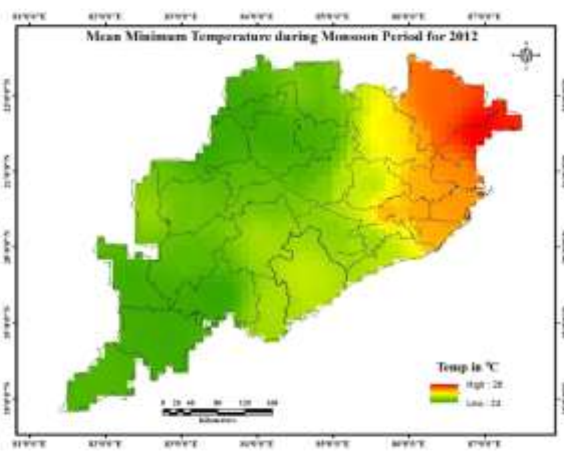


Fig. 4.2.2.2.E26

Fig. 4.2.2.2.F26

2013

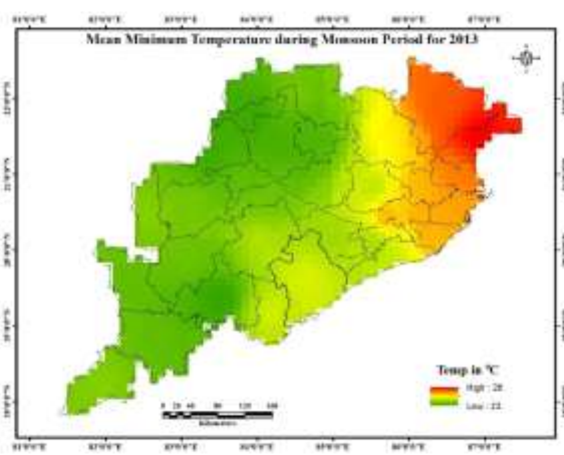


Fig. 4.2.2.2.E27

Fig. 4.2.2.2.F27

YEAR **IDW** **SPLINE**

2014

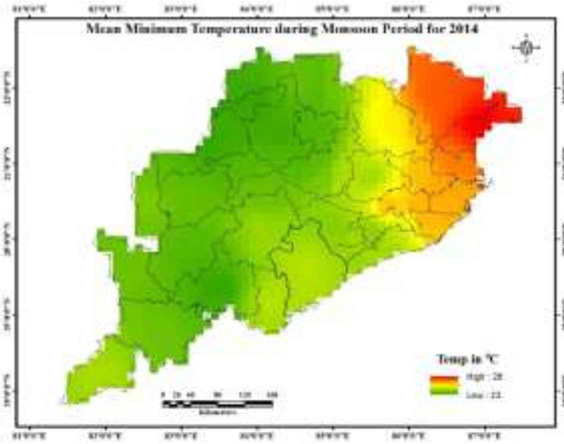


Fig. 4.2.2.2.E28

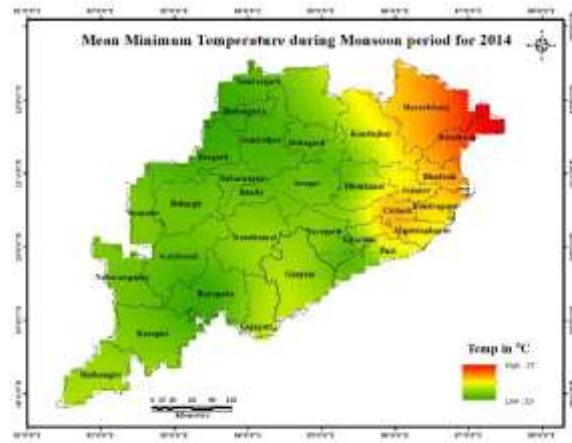


Fig. 4.2.2.2.F28

2015

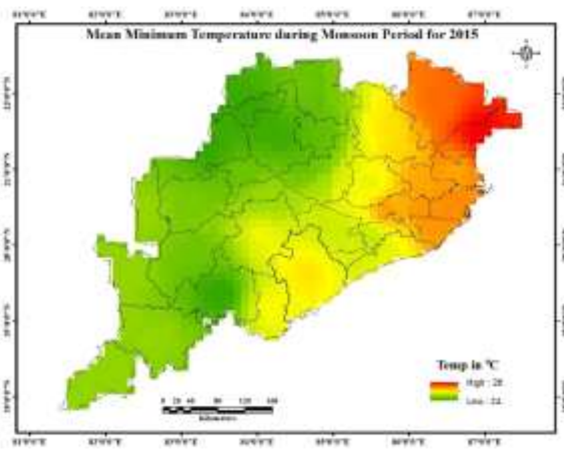


Fig. 4.2.2.2.E29

Fig. 4.2.2.2.F29

2016

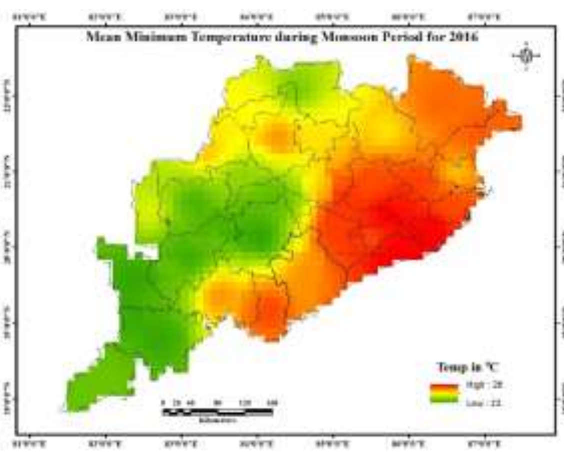
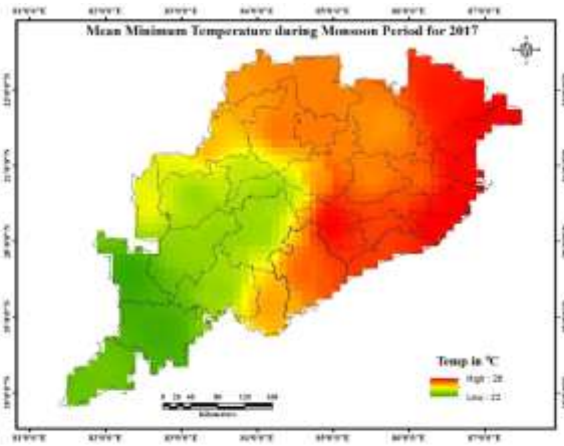
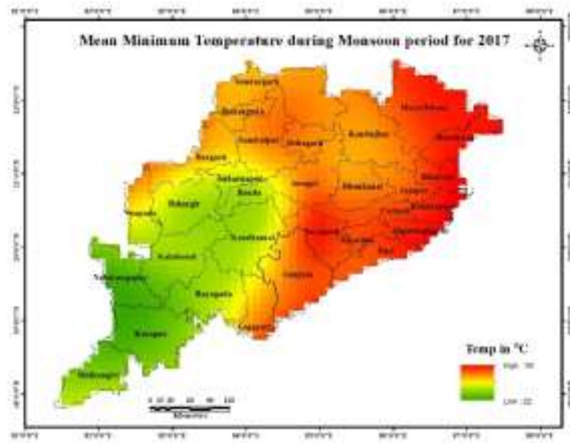


Fig. 4.2.2.2.E30

Fig. 4.2.2.2.F30

YEAR	IDW	SPLINE
2017		
	Fig. 4.2.2.2.E31	Fig. 4.2.2.2.F31

Mean minimum temperature observed during the monsoon period for the year 2012 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E26 and fig.4.2.2.2.F26, respectively. The figures indicate that both the techniques showed the range of temperature to be 24-26^{0}C (IDW) and 23-27^{0}C (Spline). It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E27 and fig.4.2.2.2.F27 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 2013. The value of the temperature showed the range of 23-26^{0}C (IDW) and 23-27^{0}C (Spline). Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E28 and fig.4.2.2.2.F2/8 show the mean minimum temperature during monsoon period for the year 2014 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from 23-26^{0}C (IDW) and 23-27^{0}C (Spline). Temperature is comparatively higher in the some parts of western and central region of Odisha.

Mean minimum temperature observed during the monsoon period for the year 2015 as estimated by IDW and Spline techniques is represented in fig.4.2.2.2.E29 and fig.4.2.2.2.F29, respectively. The figures indicate that both the techniques showed the range of temperature to be 24-26^{0}C (IDW) and 24-27^{0}C (Spline). It can be inferred that temperature is comparatively higher in the western and north eastern regions of the state.

A review of fig.4.2.2.2.E30 and fig.4.2.2.2.F30 show the mean minimum temperature values estimated by IDW and Spline techniques, respectively for the year 2016. The value of the temperature showed the range from 23-26^{0}C. Figures reveal that temperature is comparatively higher in the central, western, north eastern, southern region of Odisha.

An analysis of fig. 4.2.2.2.E31 and fig.4.2.2.2.F31 show the mean minimum temperature during monsoon period for the year 2017 as estimated by IDW and Spline interpolation techniques, respectively. The values ranges from from 22-26^{0}C Temperature is comparatively higher in the some parts of western and central region of Odisha.

Table No: 4.3.1 Occurrence of extreme rainfall over Odisha

SL.NO	District	TOTAL NO OF EVENTS (1994-2017)			FREQUENCY PER YEAR			RECENTAGE OF EXTREME		
		EXTREME	V. HEAVY	HEAVY	EXTREME	V.HEAVY	HEAVY	EXTREME	V.HEAVY	HEAVY
1	Angul	9	94	493	0.39	4.1	21.43	1.51	19.07	82.72
2	Balasore	18	244	1149	0.75	10.17	47.88	1.28	17.29	81.43
3	Bargarh	16	192	814	0.67	8	33.92	1.57	18.79	79.65
4	Bhadrak	9	107	530	0.38	4.46	22.08	1.39	16.56	82.04
5	Bolangir	22	169	806	0.92	7.04	33.58	2.21	16.95	80.84
6	Boudh	1	55	205	0.04	2.29	8.54	0.38	21.07	78.54
7	Cuttack	29	252	1169	1.21	10.5	48.71	2	17.38	80.62
8	Deogarh	1	55	205	0.04	2.29	8.54	0.38	21.07	78.54
9	Dhenkanal	7	80	469	0.29	3.33	19.54	1.26	14.39	84.35
10	Gajapati	9	88	420	0.38	3.67	17.5	1.74	17.02	81.24
11	Ganjam	20	221	1303	0.83	9.21	54.29	1.3	14.31	84.39
12	Jagatsinghpur	10	181	705	0.42	7.54	29.38	1.12	20.2	78.68
13	Jajpur	28	158	1009	1.17	6.58	42.04	2.34	13.22	84.44
14	Jharsuguda	8	92	409	0.33	3.83	17.04	1.57	18.07	80.35
15	Kalahandi	84	318	1075	3.5	13.25	44.79	5.69	21.53	72.78
16	Kandhmal	26	259	952	1.08	10.79	39.67	2.1	20.94	76.96
17	Kendrapara	20	183	915	0.83	7.63	38.13	1.79	16.37	81.84
18	Keonjhargarh	44	152	810	1.83	6.33	33.75	4.37	15.11	80.52
19	Khurda	13	152	753	0.54	6.33	31.38	1.42	16.56	82.03
20	Koraput	15	221	924	0.63	9.21	38.5	1.29	19.05	79.66
21	Malkangiri	13	92	511	0.54	3.83	21.29	2.11	14.94	82.95
22	Mayurbhanj	40	390	1913	1.67	16.25	79.71	1.71	16.65	81.65
23	Nawarangapur	22	219	917	0.92	9.13	38.21	1.9	18.91	79.19
24	Nayagarh	12	123	545	0.5	5.13	22.71	1.76	18.09	80.15
25	Nuapada	6	54	259	0.25	2.25	10.79	1.88	16.93	81.19
26	Puri	22	286	943	0.92	11.92	39.29	1.76	22.86	75.38
27	Rayagada	15	111	685	0.63	4.63	28.54	1.85	13.69	84.46
28	Sambalpur	53	181	657	2.21	7.54	27.38	5.95	20.31	73.74
29	Sonepur	9	88	489	0.38	3.67	20.38	1.54	15.02	83.45
30	Sundargarh	12	184	1082	0.5	7.67	45.08	0.94	14.4	84.66
	State				**1.03**	**8.69**	**40.17**	**1.93**	**17.54**	**80.53**

4.3.1. Extreme rainfall occurrence

A review of table 4.3.1 indicate the occurrence of extreme rainfall event over Odisha. The state of Odisha as a whole received one extremely heavy, eight very heavy and forty heavy rainfall events in years during 1994 to 2017. The average frequency of extremely heavy rainfall at district level was highest in Kalahandi, 3.50 events per year. In 6 districts the frequency was one or more than one per year. With regards to very heavy rainfall, highest occurrence was seen in Mayurbhanj (16.25/year), followed by Kalahandi (13.25/year) and Puri (11.92/year). All the districts received very heavy rainfall, minimum being in Deogarh (2.29/year). The Mayurbhanj district received maximum heavy rainfall events (79.71/year), followed by Ganjam (54.29/year) during the study period. Most of the districts receiving more frequent heavy rainfall were the coastal districts. When percent share of three events was analysed, it showed 1.93, 17.54 and 80.53% respectively for the state. Among the districts, Sambalpur, received maximum percent of extremely heavy rainfall events (5.95%) followed by Kalahandi (5.69%). Most of the districts, namely, Bolanlngir, Jajpur, kandhamal, keonjhar, Malkangiri and Sambalpur got more than 2% extremely heavy rainfall events. In the districts of north coastal and central Odisha, namely, Mayurbhanj, Balasore, Bhadrak, Cuttck, Angul and Dhenkanal, it was only 1 to 2%. In case of the second category, very heavy rainfall events, most of the districts of Odisha received 15 to 20% of total extremes in a year. Puri is the only coastal district, which got maximum percentage (22.86%) of very heavy rainfall events. Other districts, which got more than 20% occurrence of very heavy rainfall events were Boudh, Kandhamal, Kalahandi, Deogarh, Jagatsinghpur and Sambalpur and all are located interior. As regards to the occurrence of the third category, heavy rainfall events, it was high in case of central and north-western districts of Odisha, namely, Sundargarh, Sonepur, Rayagada, Jajpur, Ganjam and Dhenkanal. Among them the district of Sundargarh, received it most frequently (84.66%), while the Kalahandi district received the lowest (72.78%). Other than the above districts had the range within 75 to 80% frequency of Heavy Rainfall events.

Table No: 4.3.2 Record one-day extremely heavy rainfall events in different blocks of Odisha state (1994-2017)

SL.NO	DISTRICT	BLOCK	DATE	YEAR	Rainfall (in mm)
1	ANGUL	Kishorenagar	16-Jul	2001	261
			13-Aug	2006	274.6
		Pallahara	23-Jun	1996	265
			20-Jun	2003	250
			18-Aug	2004	278
			28-Jun	2005	340
			29-Jun	2005	299
			31-Jul	2005	262
			05-Aug	2014	402
2	GANJAM	K.S.Nagar	24-Oct	2013	250
		Kukudakhandi	10-May	1995	255
			18-Oct	1999	297
			13-Oct	2013	292
		Polasara	18-Oct	1999	350
			13-Oct	2013	282
		Purusottampur	18-Oct	2013	280
		Shoragada	18-Oct	1999	287
			07-Oct	2003	275
		Aska	24-Oct	2013	283.1
		Belaguntha	13-Oct	2013	265
		Bhanjanagar	04-Nov	2012	269
		Buguda	13-Oct	2013	323
		Chikiti	13-Oct	2013	295
		Dharakote	24-Oct	2013	276
		Digapadahandi	07-Oct	2003	256
			24-Oct	2013	260
		Ganjam	11-May	1995	280
		Khalikot	18-Oct	1999	265
			03-Jul	2006	245
3	BALASORE	Baliapal	18-Aug	1996	271
			21-Oct	2004	290
			21-Jul	2014	280
		Bhogarai	21-Oct	2005	285
		Jaleswar	18-Jun	2008	249
			19-Jun	2008	288
		Kharia	23-Sep	2007	258

			18-Jun	2008	312
			21-Jul	2014	245
			04-Aug	2014	265
		Oupada	31-Oct	1999	345
			01-Nov	1999	400
			11-Jul	2001	282
		Remuna	26-Jul	1996	324
			27-Jun	1997	276
		Semulia	07-Oct	2003	250
		Soro	01-Nov	1999	275
4	BARAGARH	Ambabhan	15-Jun	1994	280
			31-Jul	2005	305
		Bhatalli	15-Jun	1994	402
		Bheden	20-Aug	1997	246
			15-Jul	2001	249
			13-Aug	2006	360
		Bijepur	31-Jul	1997	250
			28-Aug	2003	259
			13-Aug	2006	324
			30-Aug	2006	318
			22-Jul	2014	270
			31-Jul	2014	247
		Gaisilete	28-Aug	2003	295
		Sohela	13-Aug	2006	315
			30-Aug	2006	287
			22-Jul	2014	255
			31-Jul	2014	300
5	JAGATSAINGHPUR	Ranganathpuram	05-Aug	2007	305
		Balikuda	17-Sep	1994	252.2
		Nanugaon	05-Aug	2007	300
			06-Aug	2007	265
		Kujanga	29-Oct	1999	265
		Erasama	30-Jul	1997	540
			26-Jul	1998	250
			09-Sep	1998	270
			15-Nov	1998	450
			16-Nov	1998	255
			02-Aug	1999	250
6	JAJPUR	Barachana	12-Aug	2007	320

		Bari	29-Aug	1994	270
			16-May	1995	288
			08-Aug	1995	250
			30-Oct	1999	375
			31-Oct	1999	290
			30-Jul	2005	260
		Binjharpur	29-Aug	1994	261
			30-Oct	1999	280
			30-Jul	2005	260
		Danagadi	07-Oct	2003	290
			30-Jul	2005	250
			18-Sep	2008	325
		Dashratpur	18-Sep	2008	350
			17-May	2015	250
		Dharmasala	18-Sep	2008	270
		Jaipur	Oct-32	1999	290
		Korei	30-Oct	1999	286
			18-Sep	2008	301
		Rasalpur	16-May	1995	255
			30-Jul	2005	251
		Sukinda	11-May	1995	320
			16-May	1995	257
			31-Jul	1997	256
			11-Jun	1999	287
			30-Oct	1999	390
			31-Oct	1999	315
			20-Jun	2003	275
			30-Jun	2005	293
			17-Jun	2011	250
7	JHARSUGUDA	Jharsuguda	17-Aug	2012	277
		Kirmira	17-Aug	2012	273
		Laikera	08-Aug	2004	306
			17-Aug	2012	350.2
		Bhabanipatna	05-Jul	2001	278
			06-Jul	2001	260
			13-Sep	2005	265
			04-Jul	2006	300
8	KHALAHANDI	Dharmagarh	04-Jul	2006	380
			07-Aug	2007	260

		Golamunda	04-Jul	2006	390
		Jaiptna	26-Aug	2003	340
			03-Jul	2006	300
		Junagarh	14-Jun	2004	276.6
			04-Jul	2006	307.4
			12-Aug	2007	335
		Kalampur	04-Aug	2003	251
			27-Aug	2003	289
			14-Jun	2004	340
			03-Jul	2006	453
			04-Jul	2006	418
			30-Sep	2006	262
			07-Aug	2007	339
			05-Aug	2010	270
			16-Oct	2010	245
			24-Jun	2013	400
			21-Jul	2014	255
		Karlamunda	27-Aug	2003	350
			13-Sep	2005	252
			04-Jul	2006	497
			30-Aug	2006	276
			19-Sep	2008	276
		Kesinga	13-Jun	2001	359
			14-Jun	2004	260
			04-Jul	2006	268
			20-Jul	2009	296
			27-May	2014	280
		Koksara	03-Jul	2006	287
		Langigarh	17-Jul	2017	254.4
		M.rampur	13-Jun	2001	245
			06-Jul	2001	255
			27-Aug	2003	295
			05-Sep	2003	485
			14-Jun	2004	318
			04-Jul	2006	299
			14-Jul	2009	260
		Narla	06-Jul	2001	425
			07-Jul	2001	435
			14-Jun	2004	300

			04-Jul	2006	339
			17-Jul	2017	395.1
		T.h.rampur	22-Jul	1996	245
			31-Jul	1997	380
			20-Aug	1997	278
			21-Aug	1997	345
			19-Jul	2000	276
			30-Aug	2000	362
			13-Jun	2001	525
			14-Jun	2001	305
			06-Jul	2001	273
			08-Jul	2001	340
			20-Aug	2001	257
			26-Aug	2003	300
			27-Aug	2003	542
			14-Jun	2004	475
			12-Aug	2004	312
			22-Aug	2004	315
			13-Sep	2005	320
			19-Sep	2005	260
			03-Jun	2006	700
			04-Jun	2006	350
			03-Aug	2006	450
			29-Jun	2007	325
			07-Aug	2007	430
			13-Aug	2007	260
			09-Aug	2008	387
			11-Aug	2008	280
			12-Aug	2008	295
			19-Sep	2008	270
			14-Jul	2009	315
			05-Aug	2010	250
			27-Jul	2012	281
			06-Aug	2012	424
			20-Aug	2012	250
			13-Jun	2013	310
			14-Jun	2013	356
			24-Jun	2013	660
			27-May	2014	270

			21-Jul	2014	405
			22-Jul	2014	338
			16-Sep	2015	292
			16-Jul	2017	260
9	KANDHAMAL	Baliguda	18-Aug	1994	290
			06-Sep	2003	326
			02-Aug	2006	251
			30-Aug	2006	299
			04-Aug	2012	294
		Chakapada	13-Oct	2013	288
		Daringibadi	07-Aug	2007	255
		Khajuripada	13-Oct	2013	265
		Kotagarh	06-Sep	2003	280
		Nuagaon	18-Aug	1994	274
			21-Aug	1997	282
			28-Aug	2003	327
			15-Jun	2004	275
			30-Aug	2006	260
			18-Sep	2008	270
		Phiringia	09-Jul	1994	265
			21-Aug	1997	281
			04-Jul	2006	285
			02-Aug	2006	263
			13-Aug	2006	292
			30-Aug	2006	324
			30-Jun	2007	261
		Phulbani	19-Aug	2012	250
		Rakia	18-Sep	2005	246
		Tikabali	04-Jul	2006	295
			02-Sep	2006	319
		Tundibandh	12-Jul	2000	273
			28-Aug	2003	267
			07-Sep	2003	355
10	KENDRAPARA	Aul	29-Oct	1999	475
			30-Jul	2005	260
		Derabis	29-Oct	1999	482
		Garadapur	29-Oct	1999	487
		Kendrapara	30-Jul	1997	253
			29-Oct	1999	480

			26-Jul	2003	245
			25-Oct	2013	249
		Mohakalpur	28-Jul	1999	295
			29-Oct	1999	495
			26-Jul	2003	345
			18-Sep	2008	245
		Marshaghai	29-Oct	1999	470
		Pattamundi	16-May	1995	300
			30-Jul	1997	370
			29-Oct	1999	455
			28-Jun	2014	270
		Rajkannika	29-Oct	1999	479
		Rajnagar	29-Oct	1999	480
			18-Sep	2008	310
11	KEONJHAR	Anandpur	30-Oct	1999	380
			31-Oct	1999	415
			16-Jun	2011	270
			17-Jul	2011	300
			21-Jul	2014	275.2
		Champua	26-Jul	2013	360
		Ghasipura	30-Oct	1999	314
			31-Oct	1999	333
		Hatadihi	30-Oct	1999	340
		Jhumpura	29-Jun	2005	263
		Joda	06-Jul	2007	304
			07-Jul	2007	260
		Teloki	28-Jun	2005	358
			17-Jun	2011	265
12	KHURDA	Baliyant	30-Oct	1999	340
			31-Oct	1999	272
		Banapur	10-May	1995	250
			03-Jul	2001	255
			03-Jul	2002	255
			03-Jul	2006	255
		Bhubaneswar	11-May	1995	245
			30-Oct	1999	364
		Begunia	13-Oct	2013	290
		Chilika	10-May	1995	299
			03-Jul	2001	270

			03-Jul	2002	270
			03-Jul	2006	270
13	KORAPUT	Boipariguda	22-Jul	1996	254
			18-Jun	1999	250
			15-Jun	2004	245
			04-Jun	2006	300
		Bandugaon	08-Jul	2001	500.8
		Dsamantpur	04-Sep	1994	317.5
			29-Jun	2007	310
		Jeypore	22-Jul	1996	246
			03-Jul	2006	253.6
			28-Jun	2007	272
			28-Jul	2014	267
		Kotpad	13-Jun	2013	258
		Laxmipur	13-Oct	2014	270
		Nandapur	04-Aug	2006	341
			21-Jul	2014	250
		Narayanpatna	13-Oct	2014	290
		Pottangi	14-Aug	2006	317
14	MALKANGIRI	Kalimela	06-Jun	2000	270
			04-Aug	2006	282.4
			20-Jun	2015	280
		Khariiput	04-Aug	2006	336.4
			11-Jul	2013	273
		Kourukonda	17-Jun	1999	392
			04-Aug	2006	281
			20-Jun	2015	254
		Kudumulguma	18-Jun	1999	338
			14-Jun	2004	303.6
			11-Jul	2014	295
		Malkangiri	04-Aug	2006	286
		Padia	04-Aug	2006	280
15	MAYURBHANJ	Bahalda	06-Jul	2007	310
			18-Jun	2008	338
			19-Jun	2008	424
			22-Jun	2012	285
			13-Oct	2013	263
			28-Jul	2015	370
		Baripada	19-Jun	2008	305

			26-Oct	2013	250
		Bijathala	06-Jul	2007	259.6
			13-Aug	2007	375.4
			26-Jul	2013	320
			13-Nov	2013	258.4
		Besoi	13-Nov	2013	352
		G .B.Nagar	13-Sep	1994	275
			13-Oct	2013	294
		Jamda	18-Jun	2008	260
		Kapatipada	30-Oct	1999	284
			23-Sep	2007	315
			22-Sep	2011	258
		Khunta	13-Sep	1994	275
			13-Oct	2013	294
		Kuliana	07-Aug	1999	300
			06-Jul	2007	260
		Rairangapur	18-Jun	2008	322
			19-Jun	2008	319
		Thakumunda	20-Jun	2003	246
			28-Jun	2005	320
			13-Aug	2007	248
		Tiring	28-Jun	1997	325
			19-Jun	2008	360
		Udala	30-Oct	1999	315
16	NAWRANGPUR	Chandahandi	15-Jun	2004	280
			07-Aug	2007	287
		Dabugaon	15-Aug	2010	486
		Jharigaon	25-Sep	2006	282
			07-Aug	2007	291
			05-Aug	2010	305
			13-Oct	2010	255
			21-Jul	2014	260
			21-Jun	2015	330
		Kosagumuda	05-Aug	2010	266
			18-Sep	2010	262
			14-Jun	2013	280
		Nandahandi	05-Aug	2010	270
		Nawarangpur	12-Sep	2005	302
			25-Sep	2006	247

		Papadahandi	25-Sep	2006	271
			07-Aug	2007	275
		Raighar	12-Aug	2006	320
			07-Aug	2007	297
		Tentulikhunti	05-Aug	2010	283
			16-Sep	2015	278
		Umerkote	07-Aug	2007	345
17	NAYAGARH	Gania	21-Aug	1997	280
		Khandapara	30-Jul	2005	288
			13-Jul	2009	412
			19-Jul	2009	262
			13-Aug	2009	412
			19-Aug	2009	262
			20-Apr	2011	267
			19-Aug	2012	282
			13-Oct	2013	285
		Nayagarh	13-Jul	2009	345
			13-Aug	2009	345
		Ranpur	13-Oct	2013	296
18	NUAPUDA	Boden	19-Sep	2008	350
		Khariar	04-Jul	2006	250.6
			19-Sep	2008	295
			27-May	2014	248.8
		Kumana	30-Aug	2006	250
		Nuapara	21-Jul	2014	265
19	PURI	Astarang	21-Aug	1997	274
			06-Aug	2007	264
		Brahmagiri	03-Jul	2001	315
			03-Jul	2002	315
			09-Sep	2005	261
			30-Jun	2006	315
		Gop	30-Oct	1999	245
		Kakatpur	28-Sep	1995	286
			30-Oct	1999	310
			05-Aug	2007	247
		Kanas	20-Oct	2017	274
		Krushnaprasad	19-Jul	2009	276
		Nimapara	27-Sep	1995	280
			11-Sep	1998	258

		Puri	18-Aug	1994	250
			14-May	1995	336
			20-Aug	1997	273
			12-Aug	2001	300
			12-Aug	2002	300
			09-Aug	2006	300
			06-Aug	2007	270
			29-Jul	2008	255
		Satyabadi	18-Aug	1994	266
			11-Sep	1998	257
20	RAYGADA	Chandrapur	21-Aug	1997	270.4
			03-Jul	2006	245
			07-Aug	2007	397
		Gunupur	03-Jul	2006	275.4
		Kashipur	15-Jun	2004	250
			03-Jul	2006	400
			30-Sep	2006	258
		Kolnara	03-Jul	2006	264
		Padmapur	03-Jul	2006	250
		Raygada	03-Jul	2006	299
		Dhakanud	05-Aug	1997	371
			22-Aug	2006	267
			03-Aug	2014	313
			05-Aug	2014	314
			05-Aug	2016	270
21	SAMBALPUR	Bamara	23-Jun	1996	280
			08-Aug	2004	255.6
		Jamankir	05-Aug	2014	256
		Jujumura	23-Jul	1995	261
			05-Aug	1997	302
			30-Jul	2005	308
			30-Jul	2005	265
			13-Aug	2006	375
			22-Aug	2006	292
			23-Aug	2006	252
			19-Sep	2008	355
			21-Jul	2009	300
			04-Aug	2014	295
			05-Aug	2014	257

		Kochinda	17-Jul	2001	369
			05-Aug	2011	369
			05-Aug	2014	319
		Rengali	15-Jun	1994	325
			05-Aug	2014	276
		Maneswar	17-Jul	2001	270
			17-Jul	2011	270
		Natideul	05-Aug	2014	279
		Rairakahol	05-Aug	1997	258
			17-Jul	2001	284
			30-Jul	2005	310
			17-Jul	2011	284
22	SUBARNAPUR	Binika	31-Jul	1997	272
			31-Jul	2005	292
			12-Aug	2006	250
			13-Aug	2006	402
		B.m.pur	09-Jul	1994	271
		D.pali	14-Jun	2015	255
		Sonepura	19-Aug	2005	256
		Tarbha	28-Aug	2003	293
			19-Sep	2008	256
			18-Jul	2009	261
23	SUNDARGARH	Balisankara	11-Jul	2015	252
		Bisra	24-Jul	2017	297
		Bonai	17-Sep	1994	252
			29-Jun	2005	265.5
		Gurundia	29-Jun	2005	251
		Lahunipara	29-Jun	2005	280
		Lathikata	20-Aug	2007	328
		Lephripara	20-Jul	1994	270
			25-Jun	1998	250
		Rajgangpur	20-Aug	2007	274
		Subdega	11-Jul	2015	260
		Sundargarh	13-Jul	1994	253
			20-Jun	2003	347
			11-Jul	2015	278
		Tangalbali	11-Jul	2015	254
24	BHADRAK	Basudevpur	31-Oct	1999	335
			07-Oct	2003	285

		Bhadrak	30-Oct	1999	361
			31-Oct	1999	446
		Bhandripokari	31-Oct	1999	300
		Chandbali	30-Oct	1999	248
			07-Oct	2003	269.4
			29-Jul	2005	250.8
		Tihidi	25-Jul	2003	255
25	BOLANGIR	Bolangir	24-Jul	1995	275.5
			06-Sep	2003	316
		Bangamunda	15-Jun	2004	254
			30-Aug	2006	459
		Deogaon	19-Sep	2008	280
		Punitala	06-Sep	2003	302
		Gudvella	28-Aug	2003	448
			15-Jun	2004	380
			04-Jul	2006	367
			30-Aug	2006	277
			18-Sep	2008	262
			19-Sep	2008	255
			21-Jul	2013	270
		Patnagara	24-Jul	1995	291.8
			19-Sep	2008	270
		Muribahal	15-Jun	2004	275
		Saitala	18-Sep	2008	250
		Titilagarh	13-Jun	2001	350
			15-Jun	2004	307.6
			04-Jul	2006	319.8
			19-Sep	2008	250.8
			27-May	2014	276.6
26	BOUDH	Kantamal	19-Sep	2008	259
27	CUTTACK	Athagarh	30-Jul	1997	261
			29-Aug	2003	275
			30-Jul	2005	270
			20-Sep	2007	268
		Bankidampad	30-Oct	1999	272
			23-Jul	2009	257
			19-Aug	2012	478
			13-Oct	2013	381
		Barang	30-Jul	2005	248

			02-Aug	2007	312
		Cuttacksadar	08-Sep	2005	280
			02-Aug	2007	330
		Kanatapur	30-Oct	1999	245
			12-Aug	2001	265
			29-Aug	2001	259
			12-Aug	2002	265
			29-Aug	2002	259
			12-Aug	2006	265
			29-Aug	2006	259
			02-Aug	2007	335
		Mahanga	06-Oct	2004	255
			30-Jul	2005	275
		Niali	30-Jul	1997	261
			11-Sep	1998	256
			30-Oct	1999	245
		Salipur	30-Oct	1999	250
		Tangi-choudwar	30-Oct	1999	272
			30-Jul	2005	254
		Tigiria	30-Jul	2005	284
28	DEOGRH	Deogrh	19-Sep	2008	259
29	DHENKANAL	Hindol	30-Jul	2005	265
			25-Oct	2013	300
		Odapada	30-Oct	1999	250
			30-Jul	2005	260
30	GAJAPATHI	Gosani	25-Oct	2013	270
		Gumma	03-Jul	2006	330
		Mohana	18-Aug	1994	253
		Nugada	16-Sep	1994	275
			10-May	1995	350
			11-May	1995	260
			31-Aug	1995	307
			03-Jul	2006	300
		R.udayagiri	03-Jul	2006	252
			07-Sep	2014	258
			13-Oct	2014	257.6

4.3.2. Record one-day extremely heavy rainfall events in different blocks of Odisha state

The result pertaining to highest one day rainfall are depicted under the table 4.2.1.each district was analyzed for one day rainfall for a time period of 24 years the highest one day rainfall recorded and the correspondent year are the represented in the following result

Erasama (Jagatsingpur) was found to have experienced an extremely heavy rainfall 540 mm on 30 th July 1997 whereas Pallahara (Angul) and Bhatalli (Baragarh) were found to receive an extremely heavy rainfall of 402 mm which was received on 5th August 2014 and 15th June 1994, respectively. Similarly Oupada (Balasore) and Polasara (Ganjam) received a slightly lesser extreme heavy rainfall of 400 mm and 350 mm on 1st November 1999 and 18th October 1999, respectively.

T H Rampur (Kalahandi) was found to have experienced an extremely heavy rainfall of 700 mm on 3rd June 2006 whereas Mohakalpur (Kendrapara) and Sukinda (Jajpur) were found to receive an extremely heavy rainfall of 495 mm (29th October 1999) and 390 mm (30th October 1999) respectively. Similarly Tundibandh (Kandhamal) and Laikara (Jharsuguda) received a slightly lesser extreme heavy rainfall of 355 mm (7th September 2003) and 350.20 mm on (17^{tht} August 2012) respectively.

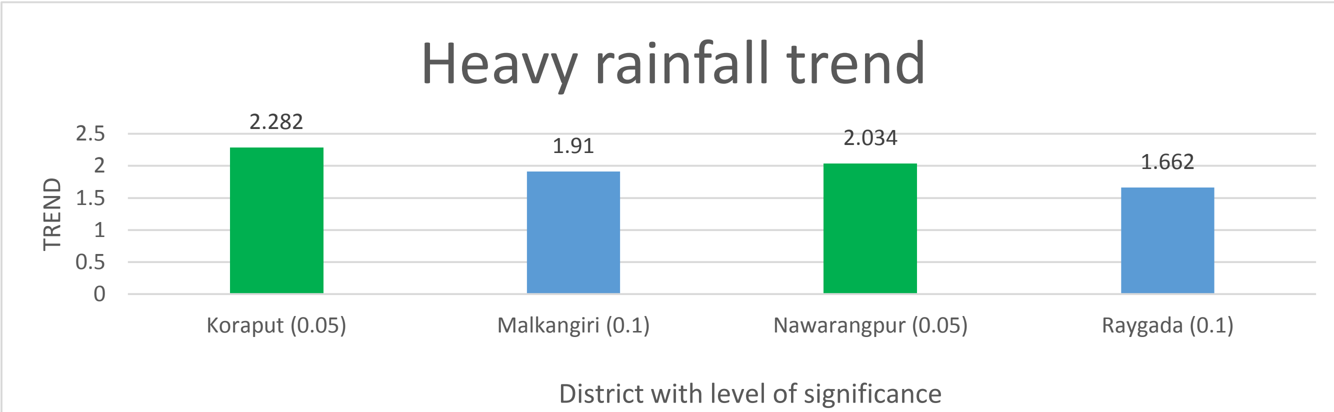
Bandugaon (Koraput) was found to have experienced an extremely heavy rainfall of 500.8 mm on 8th July 2001 whereas Bahalda (Mayurbhanj) and Anandpur (Keonjar) were found to receive an extremely heavy rainfall of 424.20 mm (19th June 2008) and 415 mm (31st October 1999) respectively. Similarly Kurukolda (Malkanagiri) and Bhubaneswar (Khordha) received a slightly lesser extreme heavy rainfall of 392 mm (17th October 1999) and 364 mm on (30^{tht} August 1999) respectively.

Babugaon (Nabrangpur) was found to have experienced an extremely heavy rainfall of 486 mm on 15th August 2010 whereas Khandapara (Nayagarh) and Kashipur (Rayagad) found to receive an extremely heavy rainfall of 412 mm (13th July2009) and 400 mm (13th July 2006) respectively. Similarly Boden (Nuapada) and Puri (Puri) received a slightly lesser extreme heavy rainfall of 350 mm (19th September 2008) and 336 mm on (14th June 1995) respectively.

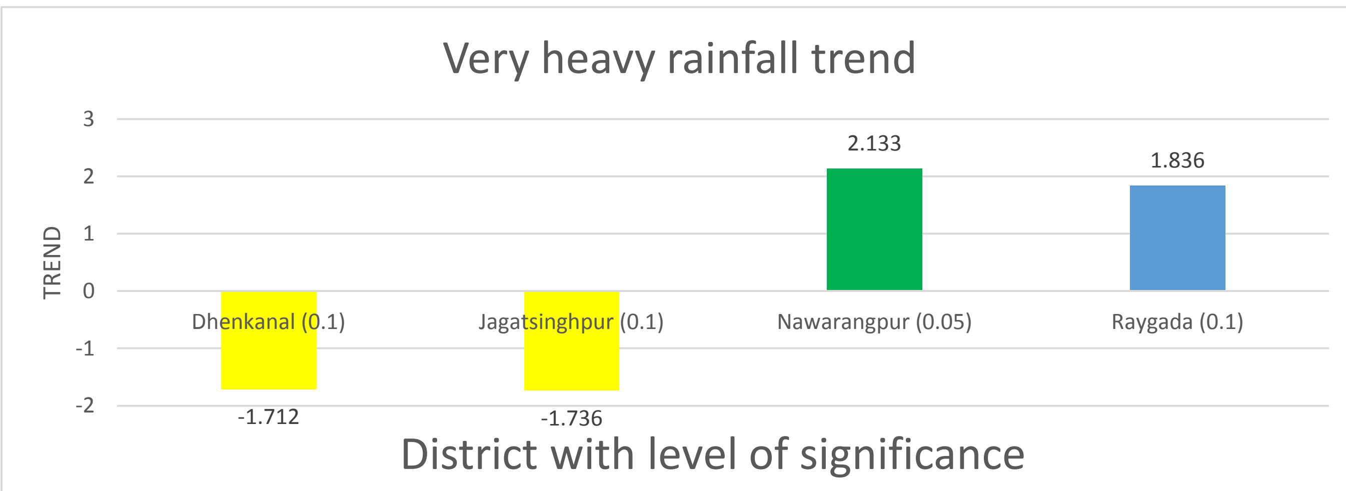
Bangamunda (Bolangir) was found to have experienced an extremely heavy rainfall of 459 mm on 30th August 2006- whereas Bhadrak (Bhadrak) and Binika (Subarnapurre) found to receive an extremely heavy rainfall of 30th October 1999) and 402 mm (13th August 2006) respectively. Similarly Kochinda (Sambalpur) and Sundergarh (Sundargarh) received a slightly lesser extreme heavy rainfall of 369 mm (5th August 2011) and 347 mm on (20th June 2006) respectively.

Bankidampada (Cuttack) was found to have experienced an extremely heavy rainfall of 478 mm on 19th August 2012 whereas Nugada (Gajapati) and Hindole (Dhenkanal) found to receive an extremely heavy rainfall of 350 mm (10th May 1995) and 300 mm (25th October 2013) respectively. Similarly Deogrh (Deogarh) and Kantamal (Boudh) received a slightly lesser extreme heavy rainfall of 259 mm in both districts on 19th August 2008 and 19th September 2008, respectively.

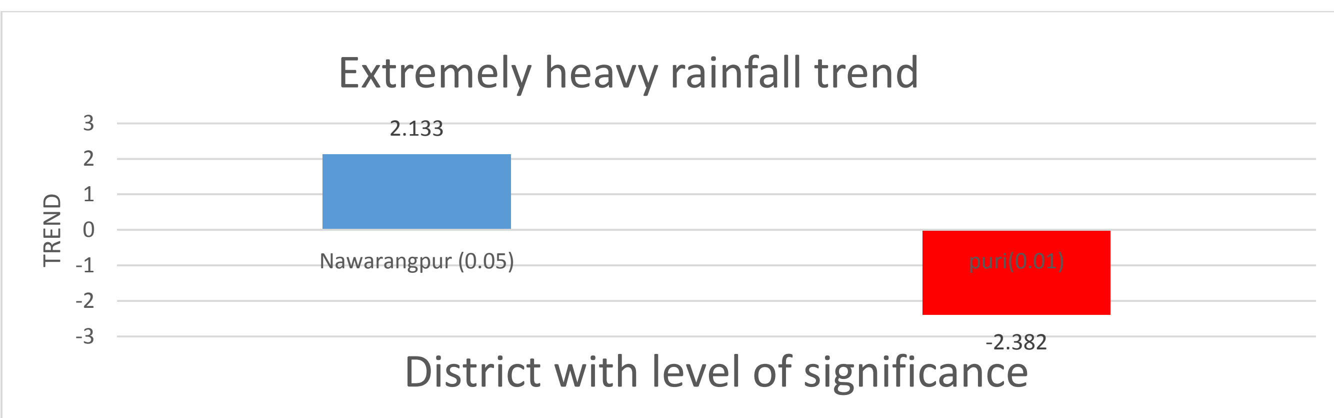
4.3.3. Trend analysis of extreme events in study area



4.3.3(a)



4.3.3 (b)



4.3.3 (c)

4.3.3. Extreme rainfall trend

Number of extreme rainfall events showed an increasing trend in few districts, but remained unchanged in all other districts except Puri. During the period between 1994 and 2017, the Extremely Heavy Rainfall event increased significantly (95% significance) in Nawarangapur district, while it decreased in Puri district, Such a decreasing trend in Puri was significant even at 99% confidence level, which showed a definite decreasing trend of Extremely Heavy Rainfall. Rest of the districts did not show any trend of Extremely Heavy Rainfall even at lower confidence level (90%). The second category, very heavy rainfall events, increased significantly (95% significance) in Nawarangapur and Rayagada (90% significance). In Dhenkanal and Jgatsinghpur the increase was significant at 90% confidence level. The third category of extreme rainfall, heavy rainfall, increased in Nawarangapur and koraput at 95% confidence level, In Malkangiri and Raygada at 90% confidence level.

5. DISCUSSION

Results of investigation presented in previous chapter and discussed in this chapter under these sub headings

5.1 Completion of data in study area

We have developed the station data by merged with IMD gridded data. The data from the station were having many missing values, the missing values have been filled with IMD gridded data. This merged rainfall data has been used for further analysis. The merged rainfall product has been used for development of gridded data at 1×1 km gridded resolution using GIS platform. We have accumulated the rainfall data for the monsoon period and developed the gridded data for that period 1994-2017 in raster format. This raster data can be further extracted to ASCII (American Standard Code for Information Interchange) for further analysis. Thus data can't be used for further analysis and we can show regenerate the data in different format as required. This data set will help us to do analysis at very granular level.

5.2 Monsoonal distribution by different interpolation techniques

5.2.1 Rainfall

The fig 4.2.1.A_1 to 4.2.1.A_{24} explained the seasonal distribution of rainfall pattern in the coastal state, Odisha. The rainfall pattern was analyzed using two interpolation techniques viz, IDW and Kriging. The analysis showed that there was a significant difference between the values obtained by IDW as compared to those values obtained using Kriging technique. In general, the values obtained using IDW technique showed more accuracy and near realistic values as compared to Kriging technique, where as in kriging the values showed a deviation with increased lower limit and decrease upper limit values then that of IDW technique. The distance and the degree of variation between the sampled data point considered while estimating to show the best results. When the data is spatially correlated (a distance or directional). Since the assessment point does not pass through any of the point values thereby causing the fluctuation in the actual interpolated values are absorbed in the technique of Kriging is most appropriate in studies pertaining to soil science and geology rather than meteorological studies, the above said reasons can be attributed to the deviation of the values from those obtained by IDW technique. On the other hand, the values obtained by IDW techniques are found to be more appropriate. The possible reason from this can be due to the fact that IDW considered the dense evenly spaced point during the interpolation. The cell values being influenced by increased or decreased number of sample points can also be an important reason for the accuracy of the IDW technique. However, IDW technique may not be found more appropriate for estimation of the data in peaks and mountainous areas. IDW determines the values of calculating, a weighted average of known values within a specific neighborhood. The findings obtained are in line with those obtained by Mohammed *et al*. (2014) and Haylock *et al*. (2008). However, the findings that IDW is more appropriate than Kriging technique is against the findings obtained by Tomasz *et al.* (2016).

A perusal Fig 4.2.1. A1 to 4.2.1 A24 shows the rainfall pattern in the state of Odisha, the state of Odisha is being divided into five physiographic divisions viz, Northern region, Southern region, western region, central region and coastal plains. The analysis showed that the southern region of the state receives maximum rainfall during the monsoonal months as compared to other regions. The possible reason for this might be the pattern of monsoonal wind as the monsoon enters the state from the southern part of the state. Another important feature which can be attributed to this is the topography of the southern region, the southern region comprises of hilly areas which eventually become responsible for orographic rains, from among the districts in the southern region Malkangiri, Koraput and Nabarangpur districts receive high rainfall as compared to Gajapati and Rayagada districts. The coastal plain of the state showed to have received lesser rainfall during the monsoonal month. The Global phenomenon like El Nino and the variability in the topography, the orographic rain shadow area due to the leeward effect of Eastern Ghats are the possible reasons that can be attributed to the low rainfall in the coastal plain of the Odisha. The coastal plain cover the Balasore, Bhadrak, Kendrapara, Jagatsinghpur, Puri, Khurda and Ganjam districts among the other regions in the state. The western regions appears to be an exception regarding the rainfall pattern even though western Odisha receives more seasonal average rainfall as compared to the south and coastal regions, in the seasonal rainy days and remains dry and a drought-like situation prevails in the region due to high temperature and low relative humidity during the monsoon season. On the other hand wind pattern that moves clouds and moisture to the atmosphere become the cause for lesser rainfall in the study period. However, there were few exceptions in the rainfall pattern observed for nearly two and half decades they, were the years of

1997, 2002, 2005, 2007 and 2011 which experienced a higher rainfall than the seasonal average, the findings of the study are in line with those obtained by Gowda *et al*. (2017).

5.2.2. Temperature (T max and T min)

Fig. 4.2.2.1.C1 to Fig. 4.2.2.1.C31, Fig. 4.2.2.1.D1 to Fig. 4.2.2.1.D31 While Fig. 4.2.2.2.E1 to Fig. 4.2.2.2.E3, Fig. 4.2.2.2.F1 to Fig. 4.2.2.2.F31 Represent the Tmax and Tmin temperature of different districts in Odisha respectively. This estimation carried out using interpolation techniques such as IDW and Spline. The spline estimates showed a better range and more accurate values as compared to IDW techniques. The Tmax and Tmin values shown by these interpolation techniques remains more or less similar with very minute variation in the Tmax and Tmin values. The possible reason that can be attributed to the consideration of accuracy in the values given by Spline interpolation techniques may be that it provides an accurate estimation of climate by allowing for spatially varying dependence on topography. In addition to this, it also provides a direct estimation of interpolation error and efficient diagnosis of data errors. The fact that underlying statistical model for spline techniques with latitude and longitudinal position may also be the reason for the accuracy and better consideration of the values of spline techniques as compared to IDW. However, IDW techniques too has few advantages such as it can estimate extreme changes in terrain (such as cliffs and fault lines) and it can interpolate well the dense evenly spaced points. The smoothing of the surface and the capability to estimates the points above maximum and below the minimum become an added advantage the estimation of temperature pattern using spline techniques.

Review of Fig4.2.2.1.C1 to Fig. 4.2.2.1.C31 and Fig. 4.2.2.1.D1 to Fig. 4.2.2.1.D31 Represent the Tmax values for the regions estimated by IDW and Spline interpolation techniques respectively. The figures indicate that the western region of the Odisha appears to have high Tmax values as compared to the rest of the state. The western region by virtue of its angle of incidence is near to tropic of cancer as a result of which the region receives greater insolation as compared to the southern, central and coastal regions. Presence of relatively lesser vegetation and forest in the western region (except Sundargarh district) and the absence or very few number water bodies (such as lakes) have been in existence in the above-mentioned region be some of the important reasons for obtaining higher Tmax values in western region. Similarly central and southern regions have shown less Tmax values during the study period. The important reason that can be attributed to this may be the presence of comparatively higher percentage of forest and vegetation by virtue of which the region remains relatively cooler, the diurnal and annual ranges of temperature in these regions is relatively low due the influence of south-west monsoon which brings the rains earlier in this region than western part. However, there are few exceptions in some years (1999, 2004, 2006, 2010, 2013,2017) which showed a higher Tmax values in the all-regions (except southern region) this may be due to long-term variation in the climatic phenomenon such as global warming which may be have been responsible for a high temperature during the above mentioned years.

Similarly Fig. 4.2.2.2.E1 to Fig. 4.2.2.2.E31 and Fig. 4.2.2.2.F1 to Fig. 4.2.2.2.F31 showed that the southern region and the central region showed a minimal or lower temperature as compared to the rest of the state. The possible reason for this might be the topographic variation that is present in the southern region. The monsoonal period covered under the study exerts a significant influence in lowering the temperature and keeping the area relatively cooler as compared to northern, coastal and western part (except Sundargarh). On the other hand, the northern and north coastal part showed a relatively lower number of Tmin values as a result of which the region is relatively warmer as compared to southern and central regions. The findings obtained are in line with those obtained by Frick *et al.* (2014), Hong *et al.* (2005).

5.3.1 Occurrence of extreme rainfall during study period

Four features of the spatial distribution of extreme rainfall as analyzed from extreme heavy rainfall defected in the Table 4.3.1 occurrence of extreme rainfall. Firstly, the districts receiving extremely heavy rainfall events are in two clusters. The first cluster comprised of seven coastal districts, namely Balasore, Mayurbhanj, Jajpur, Kendrapada Cuttack, Puri, and Ganjam. The second cluster consisted of five interior districts, namely Sambalpur, Bargarh, Bolangir, Nawarangpur, Kandhamal, and. Keonjharghar. Secondly, the second category, very heavy rainfall events, increased in four south interior districts, Kalahandi, Nawarangapur, Koraput, Bargarh and Nuapada and two north Odisha district Mayurbhanj, Balasore, Paradoxically, these districts included Deogarh, Boudh and Nuapada, which are most often affected by drought. Thirdly, all three categories of rainfall extremes increased in Nawarangapur, Mayurbhanj, and Balasore and which are mostly affected by flood. The districts adjoining to Nawarangapur also showed increasing trend of extreme events. Kalahandi, showing highest one-day rainfall, is one such adjoining district. Fourthly, most of the districts showing an increasing trend of occurrence are in interior south Odisha. The frequency of extreme rain events increased in all the interior districts, namely Kalahandi, Mayurbanj, Sambalpur and Nawarangapur. While decreased in western districts namely Deogarh, Boudh and Nuapada. The results were partly similar to that of Goswami *et al*. (2006), who reported significant rising trends in the frequency and the magnitude of extreme rain events and a significant decreasing trend in the frequency of moderate events over central India.

5.3.2 One day rainfall record during study period

Erasama (Jagatsingpur) was found to have experienced an extremely heavy rainfall 540 mm on 30 th July 1997 whereas Pallahara (Angul) and Bhatalli (Baragarh) were found to receive an extremely heavy rainfall of 402 mm which was received on 5th August 2014 and 15th June 1994, respectively. Similarly Oupada (Balasore) and Polasara (Ganjam) received a slightly lesser extreme heavy rainfall of 400 mm and 350 mm on 1st November 1999 and 18th October 1999, respectively. T H Rampur (Kalahandi) was found to have experienced an extremely heavy rainfall of 700 mm on 3rd June 2006 whereas Mohakalpur (Kendrapara) and Sukinda (Jajpur) were found to receive an extremely heavy rainfall of 495 mm (29th October 1999) and 390 mm (30th October 1999) respectively. Similarly Tundibandh (Kandhamal) and Laikara (Jharsuguda) received a slightly lesser extreme heavy rainfall of 355 mm (7th September 2003) and 350.20 mm on (17tht August 2012) respectively. Bandugaon (Koraput) was found to have experienced an extremely heavy rainfall of 500.8 mm on 8th July 2001 whereas Bahalda (Mayurbhanj) and Anandpur (Keonjar) were found to receive an extremely heavy rainfall of 424.20 mm (19th June 2008) and 415 mm (31st October 1999) respectively. Similarly Kurukolda (Malkanagiri) and Bhubaneswar (Khordha) received a slightly lesser extreme heavy rainfall of 392 mm (17th October 1999) and 364 mm on (30tht August 1999) respectively.

Babugaon (Nabrangpur) was found to have experienced an extremely heavy rainfall of 486 mm on 15th August 2010 whereas Khandapara (Nayagarh) and Kashipur (Rayagad) found to receive an extremely heavy rainfall of 412 mm (13th July2009) and 400 mm (13th July 2006) respectively. Similarly Boden (Nuapada) and Puri (Puri) received a slightly lesser extreme heavy rainfall of 350 mm (19th September 2008) and 336 mm on (14th June 1995) respectively. Bangamunda (Bolangir) was found to have experienced an extremely heavy rainfall of 459 mm on 30th August 2006- whereas Bhadrak (Bhadrak) and Binika (Subarnapurre) found to receive an extremely heavy rainfall of 30th October 1999) and 402 mm (13th August 2006) respectively. Similarly Kochinda (Sambalpur) and Sundergarh (Sundargarh) received a slightly lesser extreme heavy rainfall of 369 mm (5th August 2011) and 347 mm on (20th June 2006) respectively. Bankidampada (Cuttack) was found to have experienced an extremely heavy rainfall of 478 mm on 19th August 2012 whereas Nugada (Gajapati) and Hindole (Dhenkanal) found to receive an extremely heavy rainfall of 350 mm (10th May 1995) and 300 mm (25th October 2013) respectively. Similarly Deogrh (Deogarh) and Kantamal (Boudh) received a slightly lesser extreme heavy rainfall of 259 mm in both districts on 19th August 2008 and 19th September 2008, respectively.

5.3.3. Trend analysis of extreme rainfall events in study area

Trend analysis of all three categories showed a mixed trend in different districts of Odisha. For example, Koraput, Malkangiri,Rayagada and Nawarangapur showed increasing trend in extreme rainfall events, while coastal districts Jagatsingpur, Dhenkana and Puri showed decreasing trend. Such types of results were also reported by Rakhecha and Pisharoty (1996), mixed trends in different parts of the country. Parts of the Peninsula showed a significant increasing trends at 95% level of confidence. The decreasing trend in Jagatsingpur, Dhenkana and Puri was similar to that of southern Peninsula and the lower Ganga valley, exhibiting a decreasing trend at the same level of significance. When frequency and time series trend are considered together, it is found that extreme events are spread over the southeren and coastal regions of the state. The results confirm the findings of Ramesh and Goswami (2007) that in genesis and evolution of extreme rainfalls of intensity greater than 350 mm/day during the June to August period, the oceanic environment has a minor role to play.

SUMMARY AND CONCLUSION

The study on climate variability assumes a greater significance in this regard. The long-term weather events, their occurrence and the predictions are the crux of the research study which is to be carried out. The present study is an attempt to prepare the grid data at a micro level (block level) to supplement the agro-meteorological research and development. Our research approach was done with different tools and methodology. We have used ArcGIS as GIS tools, MATLAB for data preparation and Quality Check for missing period. Different Interpolation techniques has been used for Rainfall and temperature data.

In general the geostatistical (kriging) and inverse distance weighted (IDW) methods are preferable for seasonal and daily rainfall interpolation over Thiessen polygons, polynomial interpolation, or other deterministic methods. Data sets of spatially irregular meteorological observations interpolated to a regular grid are important for climate analyses such interpolated data sets allow best estimates of climate variables at locations away from observing stations.

The present study was carried out with different interpolation techniques such as Inverse Distance Weighting (IDW) for rainfall and temperature analysis, Kriging for rainfall and Spline for temperature using geographical information system (GIS) to create micro level gridded datasets for rainfall and temperature from the point data. The analysis exhibited that IDW technique gives best result for rainfall analysis and Spline technique gives a good result for temperature. The analysis revealed that the southern region (Malkanagiri, Koraput, Raygada, Nabrangpur, and Kalahandi) of the state receives maximum rainfall during the monsoonal months as compared to other regions of the state. The study gives an inference that the highest monsoonal rainfall in the state was received in Thuamal Rampur block of Kalahandi district. It was in 2006 which had a range of 348-4257 mm. Similarly, the lowest rainfall was received in Balaipal block of Angul district in 1995. It had the range of 118-2058 mm. The study was exhibited that the western region (Jharsuguda, Sambalpur, Deogarh, Baragarh, Sonepur, Bolangir, Nuapada) of the Odisha appears to have high maximum temperature (Tmax) values during the monsoon period as compared to the rest part of the state. Similarly, southern (Koraput, Malkangiri, and Nabaragpur) and some parts of central regions have low minimum temperature (Tmin) values during the monsoon period as compared to the rest part of the state.

Odisha state is frequently impacted by the weather hazards and extreme rainfall is one of them. The present study was carried out to determine the trend of the extreme rainfall events during 1994-2017. Block level daily rainfall data were used in identifying the extreme rainfall events while district-level aggregation was used in per cent extreme events and frequency of extreme events per year under three categories viz; Heavy (64.5-124.5 mm per day rainfall), Very Heavy (124.5-224.5 mm per day rainfall) and Extremely Heavy rainfall (≥244.5 mm per day rainfall) as per the criteria given by IMD. The state on an average received one extremely heavy rainfall, eight very heavy rainfall and forty heavy rainfall events in a year. Maximum percentage of extremely heavy rainfall occurred in Sambalpur (5.95 %), very heavy rainfall in Puri (22.86 %) and heavy rainfall in Sundergarh (84.66 %). A record of one-day rainfall event clearly indicated that Thuamal Rampur block of Kalahandi district experienced extremely heavy rainfall (700 mm) on 3rd June 2006.

CONCLUSION

Our Research analysis concluded that IDW technique is best for rainfall and Spline technique gives a good result for temperature. This analysis revealed that the southern region (Malkanagiri, Koraput, Raygada, Nabrangpur and Kalahandi) of the state receives maximum rainfall during the monsoonal months as compared to other regions of the state In case of temperature, the western region (Jharsuguda, Sambalpur, Deogarh, Baragarh, Sonepur, Bolangir, Nuapada) of the Odisha appears to have high maximum temperature (Tmax) values as compared to the rest part of the state. Analysis of extreme rainfall events in all three categories during 1994-2017 showed a mixed trend in different districts of Odisha. The state as a whole received one extremely heavy, eight very heavy, and forty heavy rainfall events in a year. In terms of percentage of occurrence of each category out of the total extreme events, maximum % of extremely heavy rainfall occurred in Sambalpur (5.95%), very heavy rainfall in Puri (22.86%) and heavy rainfall in Sundargarh (84.66%). Trend analysis showed that the number of extreme rainfall events increased in few districts, namely, Koraput, Malkangiri, Rayagada and Nawarangapur and did not change in other districts. Puri district observed a decrease in frequency of extremely heavy rainfall category. Record high one-day rainfall events were recorded in twenty districts during 1994 to 2017, surpassing the earlier records, which could be attributed to climate change induced by global warming.

FUTURE WORK

The present study is an attempt to prepare the gridded data set at a micro level (block level) to supplement the agro-meteorological research and development. We produce data into maps but we unable to produce gridded data (values) at micro level because of many constraints. Now we presently prepare asci format data which should be convert into grid level it need some specific computer programing it can be studied in future. this grided data mainly helps to study the data in a granular level with high accuracy

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