Climate change analysis to study land surface temperature trends

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Abstract— **Climate change is a matured area and it is of current social and economic concern. It has drawn political attention due to recent global efforts to curb its damaging effect. Due to increased availability of geographical data, the knowledge discovery from datasets is critical for climate change science and its impacts. This research work discusses the prospects of analysing climate change w.r.t recorded trends in abiotic factors such as land surface temperature using data mining. A region based study on India has been conducted in order to compute and analyse the recorded trends against proposition of "human influence climate change" advocated especially for developing economy. The approach used here is graphing and clustering techniques such as K-means. The experimental results show the demographics professing the ground reality of global warming.**

Keywords: climate change; cluster analysis; K-means algorithm; data mining; range-series graphs;

I. INTRODUCTION

"The Intergovernmental Panel on Climate Change (IPCC), on its fourth assessment report showcased that, increased frequency of rising temperature trends leading to more frequent natural hazards that prove detrimental to global population, health, and economies"[1].The global average surface warming projected result in more temperature increase worldwide from 20th to 21st century (0.6 to 4 °C)[2].Climate change is essentially a chronic change in statistical distribution of weather. Large raw data has been collected over past two centuries creating an opportunity to observe trends of climate change w.r.t several observed environmental factors such as precipitation patterns, changes in ambient temperature, sea level rise and cyclonic activity. Such developments have shown interest in the genre of climate change research and calls for employment of renewable techniques.

Contemporary research has been fueled by systematic collection, pre-processing, analysis and inference of data. But in the past decade there has been an exponential growth in dataset size and complexity which has proven to be increasingly difficult to parse by traditional approach [3]. "The data has its set of advantages and disadvantages that need to be addressed before a domain that can be investigated using data driven techniques. These data can be qualitatively and quantitatively analysed using data mining techniques" [4].

India's strategic and geo-political location on the globe showcases it as an interesting problem statement in the domain of climate research. India is located "to the north of the equator between 6° 44′ and 35° 30′ north latitude and 68° 7′ and 97° 25′ east longitude". The Indian coast line is about 7517 km surrounded with the Indian Ocean, the Arabian Sea and the Bay of Bengal. The primary reason for the warming is due to the Himalayan Mountains in the north that keep the cold wind from blowing in. The Thar Desert attracts the summer monsoon winds blowing in the monsoon in the country. Despite the diversity in the landscape the Indian landmass is considered to be mostly tropic or semi-tropic.

The Knowledge Data Discovery (KDD) involves a series of data related methods viz. cleaning, integration, transformation, mining, and finally, Presentation that proven a viable approach to extract meaningful information from raw data. This research work uses statistical methods for region (federal states and major cities) based knowledge discovery on climate change in India. The scope of the work considers land surface temperature changes.

A two-step process has been adopted to compute and analyse the given temperature trends. Firstly, statistical conventional methods such as histogram, scatter graph, scatter matrix and range series graphs have been used for major Indian cities. This was done in order to substantiate the premises and proposition of the hypothesis mentioned above and to quantify these assertions so as to observe the increase in pace of climate change. In the second step, the study has employed statistical clustering using K-means for categorizing major cities into different clusters at an interval of 25 years using monthly readings. This was needed to study the previous climate change trends on more region specific level and then to correlate those with the relative difference between Carbon foot-print of the regions which attribute to observe transitions of climate. Therefore, clustering is necessary to observe a clear contrast between selected regions with different history of environment degradation. The overall objective of this research is to test the widely held hypothesis by contemporary scientific community by "*Consumption intensive countries especially those reliant on primary production as major source of income, have seen greatest effects of climate change such as an unnatural change in temperature trends which have sped up the process of global warming*".

The organization of the sections following is as follows: Literature reviews the work related to climate change in Section II, Section III discusses the research methodology and experimental setup required in Section IV. The results and observations have been explained in Section V and Section VI concludes the paper and describes the future scope as well.

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III. LITERATURE REVIEW

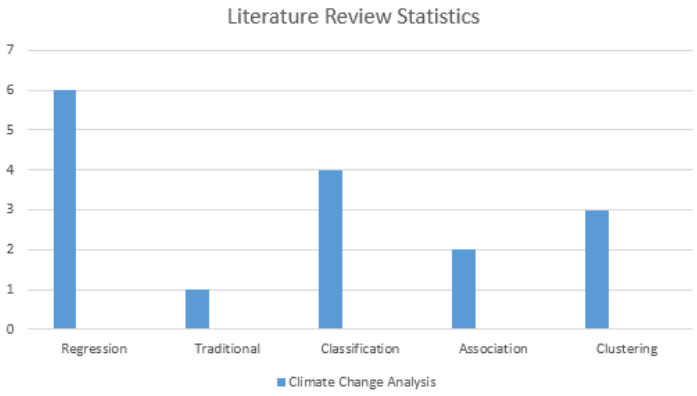
Initial investigations into the existing climate change research, points to the fact that data science is absent in making primary role w.r.t climate change research [5]. There are several factors that have contributed to this. First, by the tradition assumption of and practices of data mining are not properly followed by the climate change data. Second, the climate change science is centered on certain evaluation factors and tasks. Lastly, the challenges and data of climate science have yet to make rounds in the data science community which requires a considerable amount of time

In India, climate change is a primary domain of research since ratifying of The Paris Climate Treaty in October 2016. A literature overview gives us an insight into ongoing and completed research done in this domain by authorities such as Centre for Climate Change Research (CCCR). This is helpful in predicting weather patterns in Indian Summer Monsoon Rainfall (ISMR) which is quite important from agricultural planning point of view and also distribution of water [6].

Additionally, "data mining has been the key to document chief features of regional monsoon climate change based on climate reconstructions derived from high resolution proxies and to understand the long-term monsoon climate variability over the Asian region" [7].

There were a number of studies in the past decade that support the applicability of data mining for climate change analysis as shown in Table 1. The various data mining techniques are discussed in the next section.

From the literature overview a bar chart has been plotted as shown in Figure 1. The chart depicts higher usage of regression based methods (mostly for prediction purposes)



followed by classification and clustering methods.

Figure 1: Data mining techniques used with climate change analysis

A. Data Mining and Techniques

The automated extraction of hidden useful patterns in databases of large size and high number of variables involved is known as Data mining, or knowledge discovery in databases (KDD). The techniques involved in Data Mining are mainly of two types: Supervised and Unsupervised learning techniques [8].

B. Statistical Perspective on Data Mining

Our area of study is to employ the statistical methods for knowledge discovery we discuss them as follows:

1. Traditional Statistics

"Graph mapping and visualising techniques such as histograms, EM algorithm, distribution graphs, scatter multiple, least squares and least absolute deviation, standard deviation etc. In Addition, analysis of variance (ANOVA, MANOVA, ANCOVA), Efficient Estimation by Maximum likelihood are some of the commonly used techniques in this domain" [9].

2. Statistical Prediction using regression

"Techniques such as Linear, Non-Linear, Multi-Linear, Coefficient, Logistic regression based on estimating relationships between variables. This includes many techniques for modelling and analysing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors')" [10]. More specifically, regression analysis helps in predicting future values for dependent variable based on pre-defined values of independent values and understand how one changes w.r.t other.

Table 1: Data mining techniques used in Climate Change research

Name of the Author/ Year	Technique/Attribute Selected	Analysis/Objective and Usage
"Folorunsho Olaiya; Adesesan Barnabas Adeyemo/2012	"Artificial Neural Network and Decision Tree algorithms/ mean weather variables"	"Weather Prediction and Climate Change via data mining "
Auroop R Ganguly and Karsten Steinhaeuser/2008	"The spatial and spatiotemporal data mining "	"Mapping climate requirements to solutions available in temporal, Spatial and spatiotemporal data mining".
Amanda B. White, Praveen Kumar/2005	"Regression tree Induction or classification and prediction/ topographical elevation"	"Understanding topographic control on climate-induced inter-annual vegetation variability over the United States"
Michael R. Kearney, Brendan A. Wintle, Warren P. Porter /2010	"Mechanistic and Correlative SDM modelling/ comparative analysis on basis of multi gridded meteorological dataset and also	To provide congruent forecasts under climate change

	Apriori Trees"	
Jeremy Mennis Diansheng Guo/ 2009	Literature Review	Introduction to Spatial data mining and geographic knowledge discovery
D Ramesh, BV Vardhan / 2013	"K-Means and MLR Technique- Comparative Analysis"	Data mining application in agriculture yield data in response to climate change
Ankita Joshi Bhagyashri Kamble/2015"	"Decision tree algorithm for classifying weather parameters / Temperature, Rainfall and Evaporation"	Weather Forecasting and Climate Changing Using Data Mining

3. Hypothesis Predicting and False Discovery Rate

"A statistical hypothesis is a hypothesis that is testable on the basis of observing a process that is modelled via a set of random variables. A statistical hypothesis test is a method of statistical inference. Commonly, two statistical data sets are compared, or a data set obtained by sampling is compared against a synthetic data set from an idealized model" [11]. Additionally, "The False Discovery Rate (FDR), namely the expectation of the pro-portion of false discoveries. The false discovery rate is one way of conceptualizing the rate of type I errors in null hypothesis testing, when conducting multiple comparisons" [11].

4. Statistical Classification

"Classification is a classic data mining technique based on machine learning. Basically, classification is used to classify each item in a set of data into one of the predefined set of classes or groups" [12]. Classification method makes use of mathematical techniques such as decision trees, linear programming, neural network and statistics.

5. Clustering and Association

Both clustering and association techniques include unsupervised techniques that is used with label-less datasets. "Association rule learning is a method for discovering interesting relations between variables in large databases. The association technique is used in *market basket analysis* to identify a set of products that customers frequently purchase together. Whereas, Clustering is a data mining technique that makes a meaningful or useful cluster of objects which have similar characteristics using the automatic technique" [13]. The difference lies in the fact that, in Clustering objects are put in defined classes in clustering but classification techniques involves assigning objects into classes that are predefined.

C. Tools Used

"RapidMiner studio has been used for analysis in this research. RapidMiner, can be used for text or data mining, machine learning, predictive and business analysis. RapidMiner include making a process based model using drag and drop technique of operators" [14]. Analysis include plotting of data on various charts like scatter, bars or histogram etc.

III. METHOLODOLOGY

The following pipeline (ref. Figure 2) and iterative approach for data mining and analysis methodology, is conducted:

1. Firstly, the root data mining process is collection of data. Here the meteorological data for Indian regions of past century has been collected.
2. The Collected data has been pre-processed to include relevant data and error free data. Additionally, the missing values are removed.
3. The statistical analysis was conducted using 'R' tool for analyzing temperature trends of India and selected regions. Appropriate charts were obtained to understand the nature of climate change (scatter plot, range series etc.).
4. In clustering analysis 'RapidMiner' tool was used to produce cluster for the past 25 years.
5. Clusters are compared with each other on the basis of temperature difference occurring over a month, year and decade. This is done to assert if and by how much temperatures have risen.

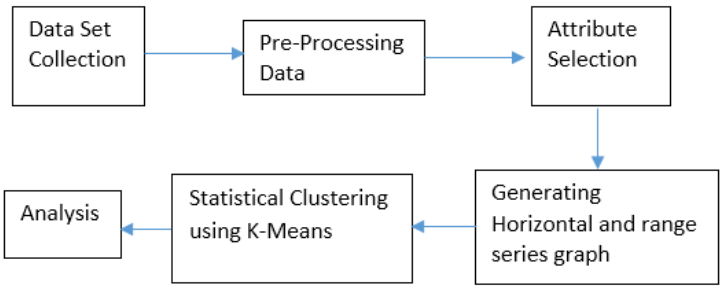


Figure 2: Methodology Adopted

IV. EXPERIMENTAL SETUP

A. Dataset Collection

The data used for this work was collected from online repository of Berkeley Earth, California from NASA's GISTEMP and UK's HadCrutBerkeley. The case data covers the period of 1750-2013, that was arranged for 243 regions around the world with state wise, major city wise and

meteorological station wise that was of importance. The average temperatures are calculated by determining the arithmetic average using daily maximum and minimum temperatures. The calculation for a daily average is as follows: "Add the day's maximum and minimum temperatures, divide by 2 and round to the nearest whole number. For a 31-day month, like May, add the 31 daily highs and 31 daily lows, divide by 62, and round to one decimal place. Degree Celsius has been used as the unit of temperature". The dataset collected initially was humongous and thus Data Pre-processing, Data Selection, and Data Mining were used in succession in order to simplify data for research.

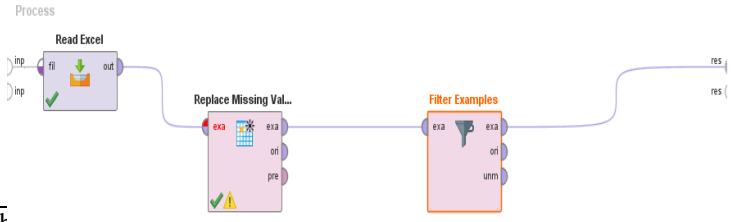
B. Data Selection

The Data preprocessing, involved using an appropriate model to convert data was developed.

1. Due to variation in visit time for early measurement of thermometer led to error in data. The data prior to 1940 was excluded from the analysis.

2. The data from 1940 to 1980 was excluded as meteorological weather stations had to be moved and this caused disruption in measurement process [15].

3. The data for past 25 years was considered for



Attrib...	...	...
Dt	Date	Year and month considered
AvgTemp	Float	Average ambient land surface temperature
AvgTempUnc	Float	Uncertainty in measured temperature
Region	Polynomial	City or State showcased for dataset
Country	Polynomial	Country showcased for dataset
Longitude	Float	Vertical Coordinates
Latitude	Float	Horizontal Coordinates

analysis in this research work.

4. The meteorological dataset has seven (7) attributes, Table 2 contains the type and description of data and a screenshot of final dataset in Fig 3. The number of instances was 20000.

Figure 3: Land surface temperature dataset (screenshot)

Table 2: Attributes of Climate Change Data Collected

B. Model Construction for overall India Statistical Analysis

During this model construction for statistical analysis of overall Indian Peninsular to obtain graph charts such as histograms, scatter plots etc. , and This involved use of both the 'R' tool and 'RapidMiner' for analysis as listed below:

1. First, by using online R tool code snippets was done to obtain range series graph for the last 10, 25 and 50 years.

2. Second, use of RapidMiner has been done to obtain histogram and scatter plots for the past 25 years.

3. A comparative analysis of both the above has
been studied in Case Study 1 in order to show the statistical outputs for overall India.

4. The decision for choosing the two different tools for overall analysis has been done in order to combine the more descriptive charts exclusively available in 'R' with convenience of model based process construction in RapidMiner.

Both these techniques have been shown in Figure 4 and 5 respectively. They are contrasted in order to show difference of process involved in either.

```
ggplot(IND_50, aes(Year, AverageTemperature)) +
  geom_line(size = 2, aes(colour = AverageTemperature)) +
  scale_colour_gradient(low="orange", high="red") +
  scale_x_continuous(breaks=seq(1960, 2015, 5)) +
  scale_y_continuous(breaks=seq(23.5, 26, 0.2)) +
  theme(plot.background = element_rect(fill='NA') ,legend.key=element_rect(fill=NA)) +
  geom_smooth(method = "lm", se=FALSE, color="red") +
  ggtitle("Surface Temperature of India in the last 50 Years")

#Plotting the increase in temperature in last 25 years
IND_25 <- subset(Avg_temp_IND, Year > 1988)

ggplot(IND_25, aes(Year, AverageTemperature)) +
  geom_line(size = 2, aes(colour = AverageTemperature)) +
  scale_colour_gradient(low="orange", high="red") +
  scale_x_continuous(breaks=seq(1990, 2015, 3)) +
  scale_y_continuous(breaks=seq(23.5, 26, 0.2)) +
  theme(plot.background = element_rect(fill='NA') ,legend.key=element_rect(fill=NA)) +
  geom_smooth(method = "lm", se=FALSE, color="red") +
  ggtitle("Surface Temperature of India in the last 25 Years")
```

Figure 4: R code snippet used to obtain range series graphs

Figure 5: RapidMiner model for overall Indian dataset

C. Model Construction for region based study using Clustering

The model for clustering analysis of regional areas was done to obtain clusters of climatically similar cities and show scatter plots of these clusters. This involved the use of 'RapidMiner' in order to cluster and then analyse the city wise dataset as

dt	AvgTemp	AvgTempUnc	Region	Country	Latitude	Longitude
1/1/1988	21.505	0.397	Ahmadabad	India	23.31N	72.52E
2/1/1988	23.89	0.339	Ahmadabad	India	23.31N	72.52E
3/1/1988	26.72	0.559	Ahmadabad	India	23.31N	72.52E
4/1/1988	32.019	0.22	Ahmadabad	India	23.31N	72.52E
5/1/1988	34.383	0.717	Ahmadabad	India	23.31N	72.52E
6/1/1988	32.859	0.44	Ahmadabad	India	23.31N	72.52E
7/1/1988	28.687	0.219	Ahmadabad	India	23.31N	72.52E
8/1/1988	28.181	0.231	Ahmadabad	India	23.31N	72.52E
9/1/1988	29.326	0.305	Ahmadabad	India	23.31N	72.52E
10/1/1988	27.84	0.269	Ahmadabad	India	23.31N	72.52E
11/1/1988	24.213	0.21	Ahmadabad	India	23.31N	72.52E
12/1/1988	21.679	0.477	Ahmadabad	India	23.31N	72.52E
1/1/1989	18.796	0.334	Ahmadabad	India	23.31N	72.52E
2/1/1989	21.698	0.373	Ahmadabad	India	23.31N	72.52E
3/1/1989	26.2	0.422	Ahmadabad	India	23.31N	72.52E
4/1/1989	30.333	0.439	Ahmadabad	India	23.31N	72.52E
5/1/1989	33.463	0.281	Ahmadabad	India	23.31N	72.52E
6/1/1989	31.34	0.362	Ahmadabad	India	23.31N	72.52E
7/1/1989	28.759	0.332	Ahmadabad	India	23.31N	72.52E
8/1/1989	27.502	0.591	Ahmadabad	India	23.31N	72.52E
9/1/1989	28.648	0.15	Ahmadabad	India	23.31N	72.52E
10/1/1989	27.939	0.261	Ahmadabad	India	23.31N	72.52E

given below:

1. The first stage is to carry out statistical clustering and thus this has been done via a K-Means based process

model. Initially data were fed to the process via using AverageTemperature as clustering label as shown in Figure 6. The resultant clustered data with four distinct clusters which have been explored in the Result and Analysis is shown in Figure 7.

2. Finally after the generation of a clustered data, a separate process was constructed in order to compute region specific temperature trends as shown in Figure 8.

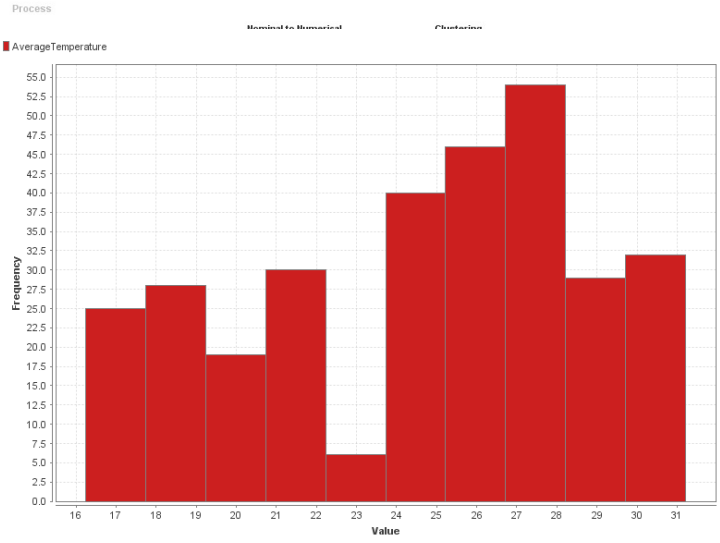
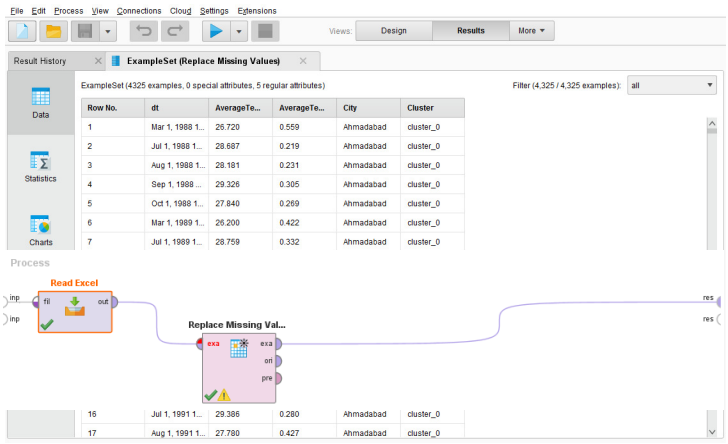


Figure 6: Training data for statistical clustering using K-Means

Figure 7: Clustered Data post K-means training

Figure 8: Testing process created to analyse the clustered data

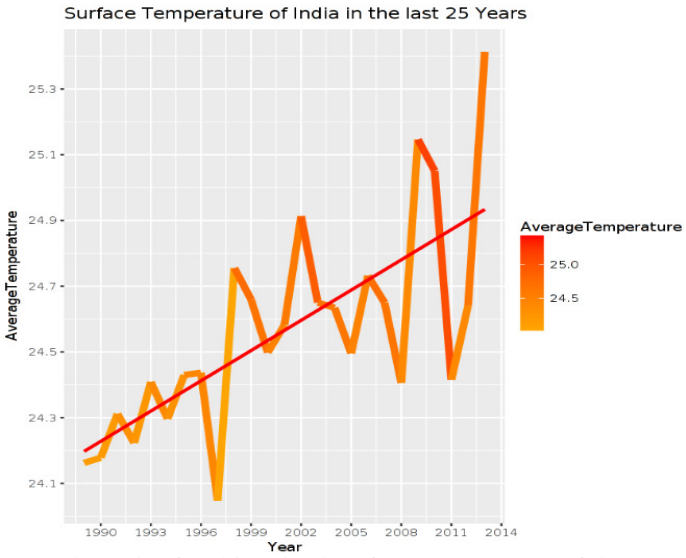


V. RESULT AND ANALYSIS

The result and analysis portion has been split into two separate case studies as discussed earlier.

CASE STUDY I - Overall Analysis of Indian Peninsular (Statistical)

The case study was done to apply conventional statistical data mining methods such as histogram, scatter graph ,scatter matrix and range series graphs in order to visualize the most general trends of ambient land surface temperature (of the past century) for both overall Indian peninsular and Major cities. The methodology and model construction have been discussed in the previous section.



- Observation 1:- The frequent temperature trends of complete dataset (25 years) is shown in Figure 9 in form of a Histogram. The X- axis shows Temperature in Degree Celsius for the complete recorded dataset while the Y-axis shows the Frequency. It can be seen from the histogram that 27°-28° C has been the most frequently occurring temperature and this clearly shows proof to the claims of Indian temperature being mostly tropic and semi-tropic rather than arid or wet.

Figure 9: Histogram plot of Average Temperature trends of India for over last 25 years

Further, a scatter plot has been obtained for overall India, from 1988 to 2013 i.e. 2015 and that maps the temperature intensity against date timeline (Figure 10).

- Observation 2:-From this plot it can be inferred that the transition period between winter to spring and subsequent summer to fall have seen a rise in peak temperature

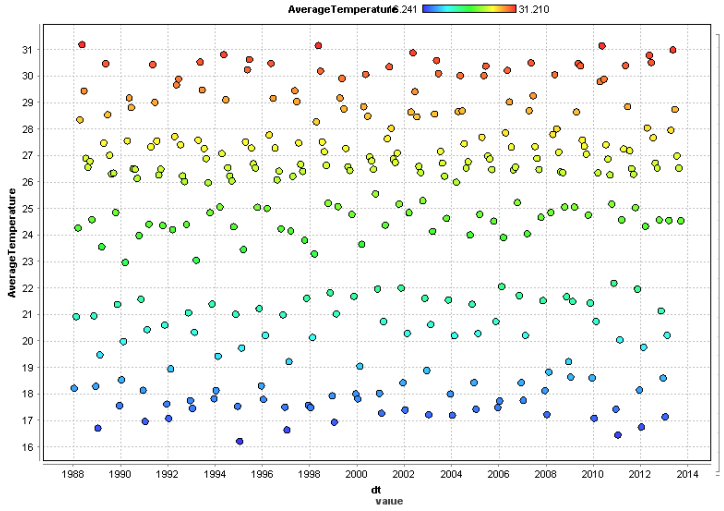


Figure 10: Scatter plot of Average Temperature trends of India for over last 25 years

Finally, we have compared the range series graph for Indian subcontinent for last 10, 25 and 50 years generated via R as shown in Figure 11.

- Observation 3:- This leads us to a very important finding i.e. it took 25 years for the temperatures to raise from 24.0 C to 24.2 C, but only last 15 years to raise from 24.2 C to 24.5 C. *That's a 150% raise in the surface temperatures in just one and half decade.*

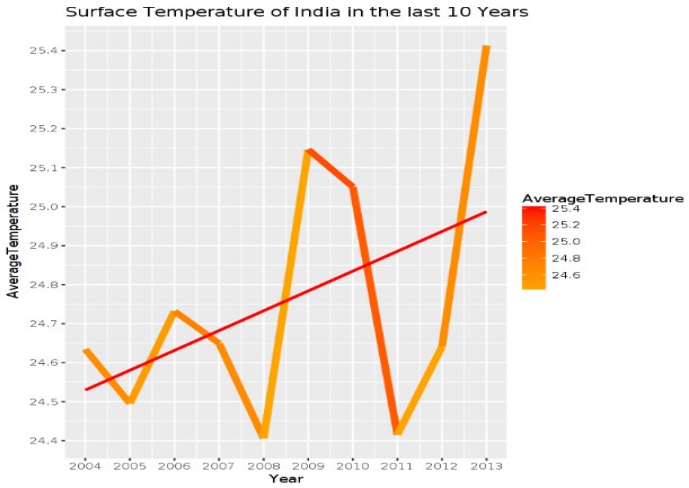
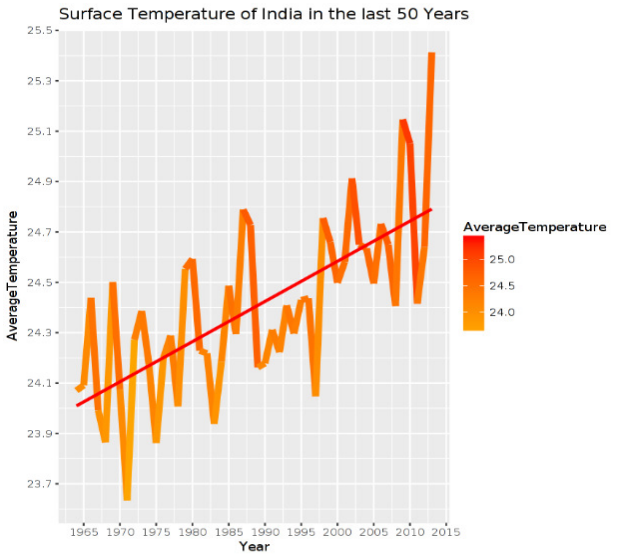


Figure 11: Range Series graphs comparison for India in past 10, 25 and 50 years

Summary of Study -

The mentioned findings from this particular case study are quite substantial and indicate towards a country wide transition in climate change at least from temperature point of view. The second case study however focuses on region specific trends observed. For this we have selected following cities based on their consumption and location attributes: Ahmedabad, Delhi, Calcutta, Bombay and Bangalore. This analysis is done to correlate temperature trends with the relative difference between Carbon foot-print of these regions



which attribute to observed transitions of climate.

CASE STUDY II- Region based Analysis of Climate Change (K-Means)

This case study investigated into the cluster analysis of region specific dataset than that of Indian subcontinent as before. The cluster frequency results have been shown in Figure 12.

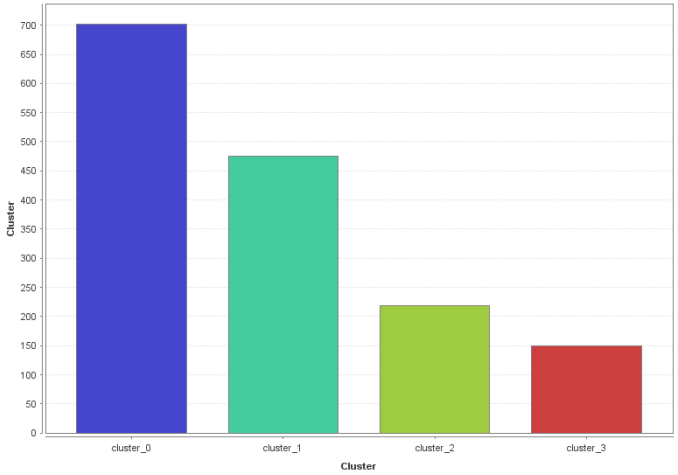
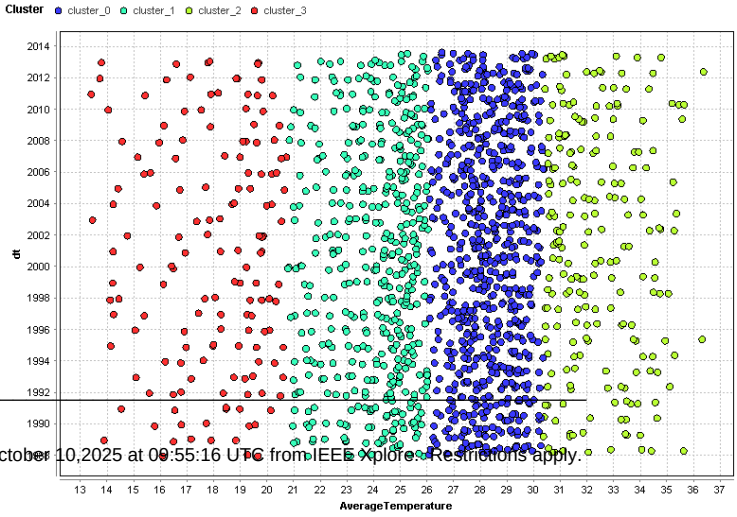


Figure 12: Cluster frequencies after K-means applied

The following figure of the dataset shows clusters and instances for each entry after having applied the K-means



and entries were sorted accordingly.

Figure 13: Cluster frequencies after K-means applied

The following scatter plot has been obtained. According to the clusters shown in Figure 11 important result have been obtained as it clearly shows all the selected regions contrasted according to their cluster division, time series and the temperature trends. The final concluding observation are:

- Observation 4:- Here we can observe that the cities in the cluster 2 which are Delhi, Bangalore and Ahmedabad are more production and consumption intensive and thus lie towards the higher range of temperature trends for summer seasons.
- Observation 5:- Furthermore it has been found out (Figure 14), that cluster 1 contains Calcutta which is heavily populated but lags behind in per capita usage primary transportation polluter such as heavy trucks and cars has shown much less temperature increase then those in cluster 2 (which does not contain Calcutta). So in this way the clusters have differentiated the selected cities as per levels of pollution.

Figure 14: Scatter Plot for entire K-Means clustered dataset

- Observation 6 - Further, as we can see the rise in temperature trends in cities such as Delhi in particular (Figure 15) has not been constant which used to the case, this is mostly due to very heavy consumption and production levels of the capital city and especially also due to large numbers of households owning more than 2 vehicles. The carbon footprint of Delhi is ever increasing and has significantly harmed the environment around.

Figure 15: Delhi scatter plot mapping temperature v/s year from 1900-2010

VI. CONCLUSION

In this study simple statistical approach to data mining in climate change via using both conventional approaches such as graphing techniques and clustering of regional data using K-means has been used. Statistical methods have proven a viable approach to climate change data analysis due to their property to show contrast more than other techniques. Additionally K-means is simple to implement, identifies groups and has a good computational efficiency.

In conclusion, the primary objective of this paper as mentioned in Introduction has been met. Through observation 1 to 6 it has been established that there is indeed a sped up of climate change in India and that too more intensively in production and consumption rich areas. This shows that the unnatural global warming is a product of this human influence in climate change.

This research can form the groundwork for identifying key regions in India and attributing to them appropriate causes when it comes to urgent need to counter adverse effects of climate change such as global warming. Seasonal climate change prediction can be the future scope of this work. Regression based prediction technique can also be used to keep track of other abiotic factors other than temperature trends example precipitation, cyclonic activities etc.

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REFERENCES

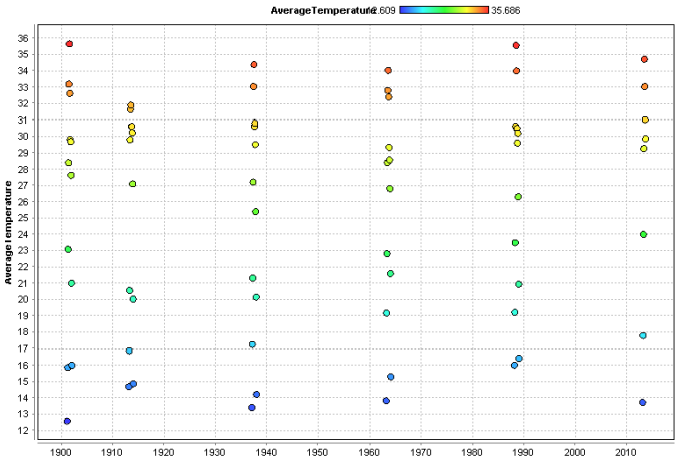
[1] “Kumar, K. Rupa, et al. "High-resolution climate change scenarios for India for the 21st century." *CURRENT SCIENCE-BANGALORE*- 90.3 (2006): 334.

[2] Change, Intergovernmental Panel On Climate. "IPCC." *Aspectos Regionais e Setoriais da Contribuição do Grupo de Trabalho II ao 4º Relatório de Avaliação “Mudança Climática 2007” do IPCC* (2007).

[3] Zhu, Xingquan, ed. *Knowledge Discovery and Data Mining: Challenges and Realities: Challenges and Realities*. Igi Global, 2007.

[4] Faghmous, James H., and Vipin Kumar. "A big data guide to understanding climate change: The case for theory-guided data science." *Big data* 2.3 (2014): 155-163.

[5] Kumar, K. R., Sahai, A. K., Kumar, K. K., Patwardhan, S. K.,



Mishra, P. K., Revadekar, J. V., ... & Pant, G. B. (2006). High-resolution climate change scenarios for India for the 21st century. *CURRENT SCIENCE-BANGALORE*-, *90*(3), 334.

[6] James H. Faghmous and Vipin Kumar (2014) A Big Data Guide to Understanding Climate Change: The Case for Theory-Guided Data Science

[7] Liao, Chia-Wen, and Yeng-Horng Perng. "Data mining for occupational injuries in the Taiwan construction industry." *Safety science* 46.7 (2008): 1091-1102.

[8] Short Term Climate Prediction and Variability at http://moes.gov.in/programmes

[9] White, Amanda B., Praveen Kumar, and David Tcheng. "A data mining approach for understanding topographic control on climate-induced inter-annual vegetation variability over the United States." *Remote Sensing of Environment* 98.1 (2005): 1-20.

[10] An Overview of Data Mining Techniques by Alex Berson, Stephen Smith, and Kurt Thearling (2005)

[11] Ezekiel, Mordecai, and Karl A. Fox. "Methods of correlation and regression analysis: Linear and curvilinear ." (1959).

[12] Yoav Benjamini, Moshe Leshno "STATISTICAL METHODS FOR DATA MINING" (2005)

[13] Witten, Ian H., and Eibe Frank. *Data Mining: Practical machine learning tools and techniques*. Morgan Kaufmann, 2005.

[14] Hofmann, Markus, and Ralf Klinkenberg, eds. *RapidMiner: Data mining use cases and business analytics applications*. CRC Press, 2013.

[15] Wang, Yonggang, and Bart Geerts. "Estimating the evaporative cooling bias of an airborne reverse flow thermometer." *Journal of Atmospheric and Oceanic Technology* 26.1 (2009): 3-21".