IMPACT OF URBANIZATION AND LAND USE CHANGES ON CLIMATE

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ABSTRACT

The study examines the effects of urbanization and land use changes on climatic environment of Visakhapatnam city. A detailed study was carried out with regard to urban heat islands and to examine the nature and intensity of heat islands in the city. This study is very important in city planning for the avoidance of air pollution hazards. Trend analysis of the temperatures has been carried out in order to assess the effects of urbanization on thermal climate. The regression analysis gives an indication of overall tendency of the temperature. The mean annual temperature varies from 23.5°c to 30.9°c; mean maximum summer (April-June) temperature varies from 32.8°c – 34.0°c and mean minimum winter (Dec – Feb) temperature ranges from 17.5°c – 19.3°c. The mean annual rainfall is 954mm and Visakhapatnam receives maximum amount of rainfall during post monsoon period (Oct-Nov) due to cyclonic activity. The trends of both annual and monsoonal rainfall at Visakhapatnam over a period of 50 years, from 1951 to 2000 are also examined.

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INTRODUCTION

With the increasing emphasis on planning for healthier and comfortable physical environment in cities, the need to recognize the role of cities in creating climatic change has become greater. This paper on climate impacts of urbanization demonstrates that the rapid urbanization and land use changes and their influence in modifying or creating climates which add to the city residents discomfort and even ill health. It is recognized that the climate of cities generally tend to be warmer than those of the surrounding countryside. Cities differ from the countryside not only in respect of their temperature but also in respect of other climatic elements. Very often, the city itself is the cause of climatic differences. Its compact mass of buildings and pavements and urban activities of its inhabitant are a considerable source of heat. Each city has its own landscape profile and thereby has its own climate. Hence it is difficult to infer the climate of all cities by generalizing from observations within one or a few cities.

Urbanization is one phenomenon that may cause changes in local and even regional climate. Urban development has introduced changes in land surface characteristics which in turn have changed the local climate into what can be defined as “urban climate”. The natural environment found in the rural side favored by an equable climate blessed with clean air and ample pure water, is indeed a wondrous and a most precious resource for mankind. Urban climates are mostly inferior in quality to rural climates, especially in relation to human health and well-being. It is clear that cities are warmer, cloudier, less sunny and less humid than surrounding rural environments. The city atmosphere is liable to pollution, greenhouse gases, dust, smoke and smog. These have the effects of changing the thermal properties of the atmosphere, cutting down the passage of sunlight and providing abundant condensation nuclei. The increase of particulate matter in the atmosphere is bound to affect the climate since particles not only scatter and absorb solar radiation but also have an effect on the outgoing radiation from the surface of the earth. Consequently cities receive less solar radiation than rural areas. And there is yet another fact, that cities have 10 per cent or more clouds which also affect the incoming solar radiation. City wind speeds are lower than those in the surrounding open country, owing to the scattering effect of the buildings and blocks (Landsberg, 1970). Another important distinguishing element between the urban and rural settings having a strong climatic impact is the vegetation cover. Rural areas have lower humilities as they are surrounded by agricultural lands and natural vegetation.

STUDY AREA

The present study discusses the effects of urbanization on climatic environment of Visakhapatnam city, Andhra Pradesh, India. The study with regard to urban micro climate is confined to Visakhapatnam main city area only. Based on topographical conditions, the city and its environs can be divided into four categories viz., hill ranges, upland area, central plain region and coastal zone. Visakhapatnam enjoys a characteristic tropical maritime climate. All the elements of the climate – temperature, rainfall, wind and humidity hardly exhibit well marked seasonal variations. Its natural local climate owes its origin to the peculiar topography on the north and on the south and the vast water body on the east contributing to the interesting land and sea breeze circulations.

METHODOLOGY

The most obvious method for the measurement of the temperatures over a city is to take observations at a number of locations simultaneously which require considerable equipment and man power. To facilitate the adequate coverage of the entire city some 12 traverses have been selected, each traverse covering about 15 to 20 pre-selected representative spots, in each section of the city. The observation period was near the minimum temperature epoch, when the heat island effects are known to be most prominent. Days with clear skies and calm winds were chosen as far as possible. On the day of observation, the survey was started form a suitable terminal point of the traverse. Surface temperature data were collected using thermometers at a number of predetermined points. Observations were completed as quickly as possible in order to minimize the effect of time changes during the observation period. The surveys were always terminated with repetition of observation at the starting point and observations were reduced to a common time base. Thermographs were also installed at representative locations to know the temperature trends. The observational points were so chosen as to ensure adequate representation of all parts (residential, commercial, industrial etc.) of the city. The temperatures were then plotted on a map of the city and isotherms were drawn taking topography into consideration. The survey programmes were conducted periodically and the temperature data for Visakhapatnam were obtained on representative days during the winter season and also summer season during the years 2007- 2008 and 2009.

RESULTS AND DISCUSSION

Urban – Rural Climatic Differences:

The temperature in an urban area is usually higher than in the surrounding rural areas. To examine the temperature distribution between urban and rural environments, field surveys were carried out in Visakhapatnam urban complex and surrounding rural areas and surface temperature and humidity data were collected and compared. The results reveal that the rural environments with 80% of area under agricultural land use have shown lower temperatures and higher humidities over urban areas. The temperatures of urban centers of Visakhapatnam were higher by 5°c to 6°c and relative humidities were less by 10% over the surrounding rural areas (Table.1).

Table.1: Temperature and Humidity variation between Urban and Rural Environments (Dec, 2008)

Urban	**Temp (°c)**	**Relative Humidity (%)**
Jagadamba	21.8	84
Poorna Market	22.0	82
KGH Junction	21.6	86
Dabagardens	21.4	84
Rural	Temp (°c)	Relative Humidity (%)
Madhurawada	17.0	96
Endada	15.6	90
Zoo park	15.0	90
Ravindranagar	17.1	92

The natural or agricultural vegetation in the countryside contributes to moderate air temperature, higher humidity and cooler climate. On the other hand, the city climates are likely to be more continental due to lack of vegetation and therefore, have higher temperature ranges and lower humidities. The resulting temperature and humidity profiles sometimes produce peculiarities in local rainfall distributions in a city quite different from the country where rainfalls are of longer duration.

The rates of cooling of urban and rural environments also differ widely due to marked different land surfaces. Fig.1 shows urban/rural cooling rates during February 2008. To analyze cooling rates between urban and rural areas, hourly temperature data (18:00 to 06:00) have been collected at Visakhapatnam city centre and rural area (Ravindranagar), simultaneously. It is evident from the results that the temperature decreases from 25.8°c to 22.5°c at urban centre, 25°c to 20.2°c at sub-urban and from 24°c to 18.6°c at rural area (Fig.1). The rate of decrease of temperature or cooling rate is 0.4°c/hr at urban centre, 0.8°c/hr at sub-urban and 1.0°c/hr at rural area. The cooling rate is very high in rural areas where 80% of land is covered with vegetation and higher values of humidity.

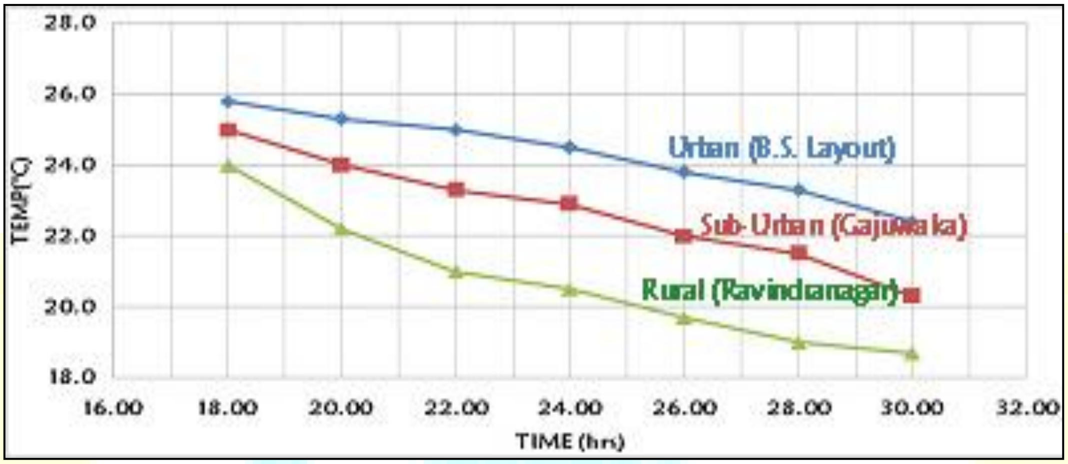

Fig.1: Urban Cooling Rate

Visakhapatnam is rapidly growing industrial city and it has grown into an urban agglomeration with a population of more than 1.5 million. The trend towards urbanization and industrialization has resulted a change in micro climate and wide spread of environmental pollution. Visakhapatnam exhibits a characteristic tropical maritime climate. All the elements of climate – temperature, wind, rainfall and relative humidity hardly exhibit a well-marked seasonal variation. Its natural local climate owes its origin to the peculiar topography on the north and the south and the vast water body on the east contributing to the interesting land and sea breeze circulation. The mean annual temperature varies from 22.6°c to 30.9°c (Table.2) and May is the hottest month. It is observed that the mean maximum temperature is the highest in May (34.0°c) and the mean minimum temperature is the lowest in January (17.5°c). From March to June the day temperatures become uncomfortable but the sea breeze modifies them to some extent.

Visakhapatnam receives an annual rainfall of 954mm. October is the wettest month with maximum rainfall of 212mm (Table.2) which is on account of cyclonic activity in the Bay of Bengal. The period from middle of June to the first week of the December is marked as rainy season at Visakhapatnam. The cyclones originating in the Bay of Bengal usually travel towards north-west and cross the coast taking a northerly or north-easterly direction. Severe cyclones may occasionally occur in this region causing heavy damage to crops and property. In fact Visakhapatnam receives maximum amount of rainfall in the transitional period .i.e. from October to November due to cyclonic activity. The mean monthly relative humidity at Visakhapatnam remains high all through the year as it is coastal station. Humidity varies from 72% in the month of December to 84% in July at 0830IST. The higher relative humidities of 83% to 84% are observed in the evening from May to September at 1730IST (Table.2). The high humidity of air combined with higher temperature during the hot season makes the climate uncomfortable. Winds are generally light to moderate in speed. However, they relatively strong during the summer and south west monsoon seasons. The prevailing wind direction at Visakhapatnam is westerly during the summer and southwest monsoon seasons and they are easterly during the post monsoon and winter season.

Table.2: Visakhapatnam – Temperature, Rainfall and Relative Humidity

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature (°c)													
Mean Max Temp	27.7	29.2	31.2	32.8	34.0	33.7	31.7	32.0	31.6	30.9	29.3	27.7	30.9
Normal Temp.	22.6	24.2	26.9	29.3	30.9	30.5	28.8	29.0	28.6	27.7	25.2	23.0	27.2
Mean Min Temp	17.5	19.3	22.6	25.9	27.9	27.4	26.0	26.0	25.6	24.5	21.2	18.3	23.5
Rainfall(mm)	10.4	21.6	11.2	18.5	48.3	100.8	112.0	121.2	168.1	212.1	112.8	17.3	954.3
Relative Humidity (%)													
0830 IST	77	77	74	73	75	80	84	82	81	78	74	72	77
1730 IST	78	73	72	80	83	83	82	83	84	79	73	74	79

Urban Heat Islands:

The rapid urbanization, industrialization and land use and land cover changes have brought about micro climatic changes particularly with regard to its thermal structure. The well documented climatic modification of the city is urban heat island. Of the many meteorological parameters that are affected by urbanization, temperature anomalies are widely reported (Landsberg, 1970; Chandler, 1970) and Lowry (1977). Oke (1974, 1979, 1987 & 1999) has given a comprehensive review of urban heat island studies. Philip, Daniel and Krishnamurthy (1974) and Murthy (1979 & 1999) have analyzed the formation of heat islands in some Indian cities during winter months. There are many reports about heat island phenomena from all over the world. Numbers of technical papers were presented during the international conference on urban climate organized by WMO during Nov'99 at Sydney. International organizations such as WMO, WHO, UNEP and International Geographical Unions are actively involved in the urban climatic studies.

One of the best-known effects of urbanization on the local climate is urban warming. This phenomenon is commonly referred to as the 'urban heat island' (UHI). A range of factors vary between rural and urban areas and contribute to the UHI, including the thermal properties of materials, the height and spacing of buildings, and air pollution levels. These factors result in more of the Sun's energy being captured, absorbed and stored in urban surfaces than in rural surfaces during the day, and a slower loss of this energy at night, resulting in higher air temperatures in urban areas. In addition, less evaporation takes place in the typically drier urban areas, with a reduction in associated cooling. Finally, urban areas also have greater inputs of heat as a result of the high density of energy use in cities. All this energy, used in buildings and for transport, ultimately ends up as heat. Strategic planning is required which takes account of these factors, particularly in the context of climate change.

The intensity of the UHI for a particular city will have significant spatial and temporal variations. Its maximum intensity is typically reached several hours after sunset (Oke, 1987). During the August 2003 heat wave in London the temperature difference between urban and adjacent rural locations reached 9°c on occasions (Greater London Authority, 2006b). Watkins et al. (2002) reported on an extensive series of measurements, made in London in the period 1999–2000, which demonstrate in detail the behaviour of London's UHI. Considerable research has performed in using remotely sensed information to detect thermal characteristics of urban surfaces. Price (1979) showed that for many large cities satellite sensed temperatures were 10-15°c warmer than surrounding rural areas in the New-York city- New England region.

Land use changes modify the micro climate to large extent and urban population expose to heat stress and discomfort. It is now well established that heat island phenomena are the result of urban/rural energy balance and stability differences, which in turn produce different rates of cooling and warming. Heat island is not an instantaneous phenomenon but progressively develops following sunset. The growth and intensity of heat island depends upon the cooling rates of urban and rural environments. Because of the markedly different surfaces, the rates of cooling of urban/rural environs differ widely and the growth of the heat island intensity varies with time of the night.

A better understanding of the urban heat island is important for a variety of reasons. The radiation absorbed warms the ambient air increasing the low level stability and consequently preventing the pollution dispersal which will result in an increase in pollution concentration. The urban heat island adds to the development and self-sustenance of a "dust-dome" and a "haze hood" of contaminating particles. It also helps in setting up of the recirculation of pollutants thus making the pollution problems more serious. In addition, it has also been suggested that the urban heat island causes human discomfort and higher death rates during heat waves. A beneficial effect of the night time heat island is to make warm and comfortable conditions in winter at higher latitudes.

The surface temperature distribution in the city during December 2007 is shown in **Fig.2.** It was observed that the isotherms tend to run parallel to the coast and the urban heat island was found over the congested and closely built-up areas. The temperature difference between city centre and periphery was 3°c. Another warm zone was located over the industrial area in the southern part of the city where the temperature variation was only 1°c. In the north, the isotherms with the values ranging 18°c to 20°c run parallel to the hill ranges. **Figure 3** shows the surface temperature distribution during January 2008. The isotherm with higher temperature of 23°c was identified over residential area in the northeastern part of the city. The lowest temperature of 20°c was observed in the peripheral zone along the western corridor of the city. Temperature varies from 20°c along the sub-urban zone to 23°c over dense residential colony. Filed surveys were conducted in different parts of the city to collect data about the distribution of humidity. Observations with regard to relative humidity reveal that it varies from 90% **(Fig.4)** along the eastern part of the city due to its proximity to the coast to 85% towards interior. In the southwestern part of the city humidity varies around 80%.

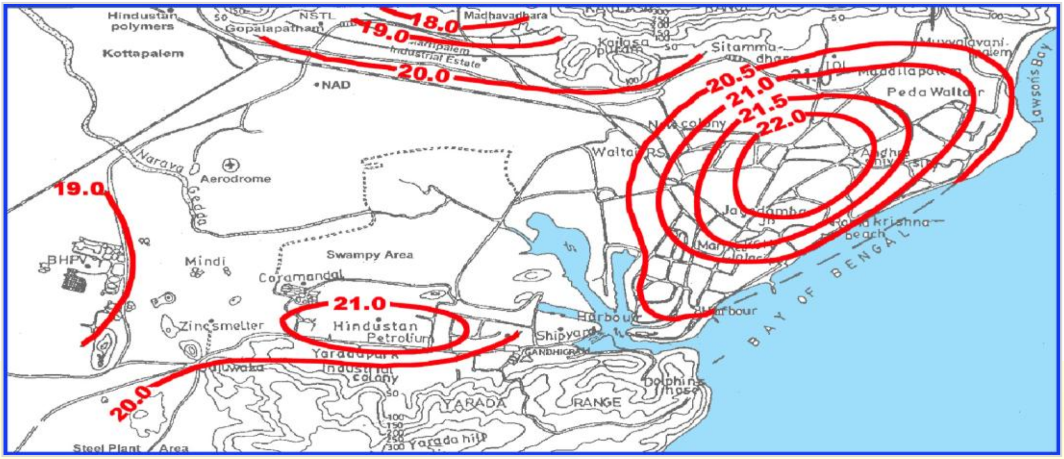

Fig.2: Visakhapatnam - Surface temperature (°c) distribution (Dec, 2007)

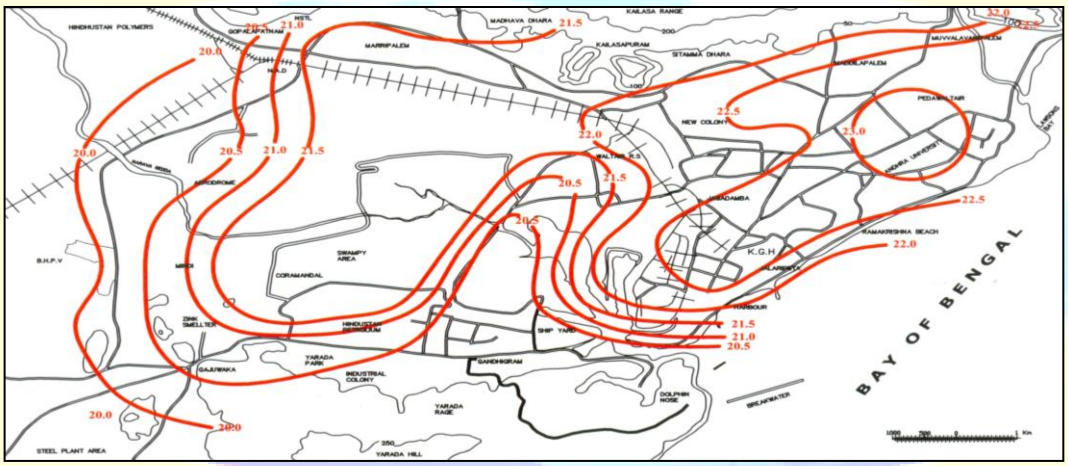

Fig.3: Visakhapatnam-Surface Temperature (^{0}c) Distribution (Jan, 2008)

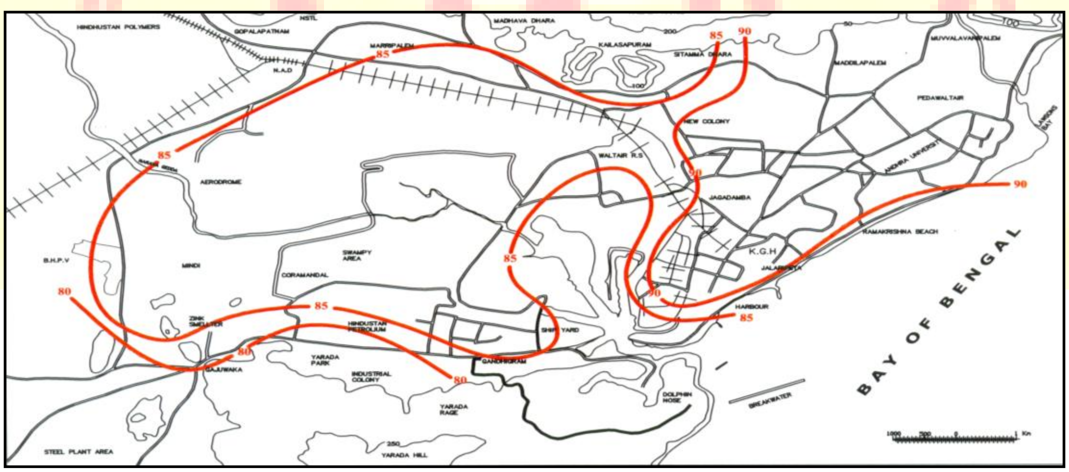

Fig.4: Visakhapatnam-Humidity (%) Distribution (Dec, 2007)

Study was extended to identify heat island during summer season also. Hence, field surveys were conducted during summer period and temperature data were collected and analyzed. **Figure.5** shows surface temperature distribution during the hottest month, May

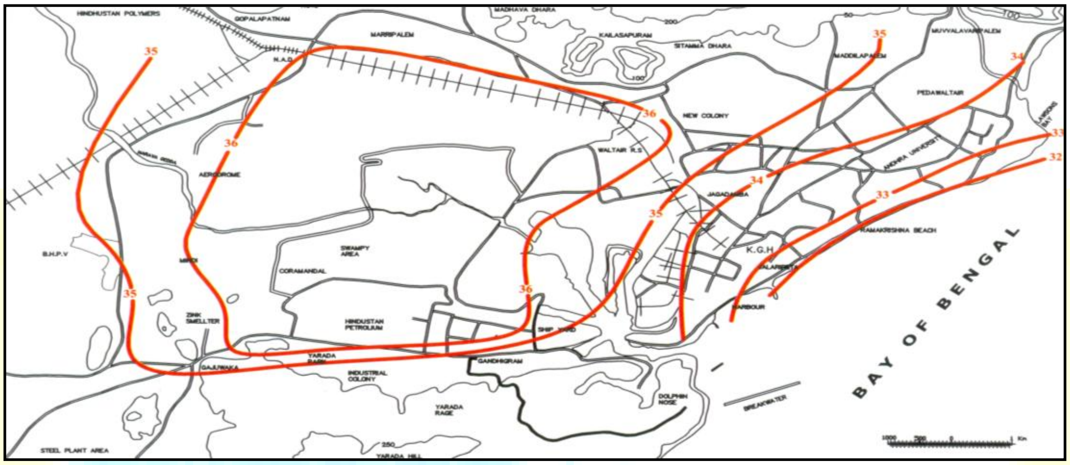

Fig.5: Visakhapatnam-Surface Temperature (^{0}c) Distribution (May, 2008)

2008 at the time of maximum temperature epoch, where temperature varies from 32°c along the coast to 35°c at sub-urban area along the western part of the city. It was observed that the temperature difference between city centre and sub-urban was 3°c. Along the coast, temperature varies from 32°c to 33°c due to maritime influence. The field observations during summer season are very important to study the impact heat island on human comfort as Visakhapatnam is a coastal city and summer is oppressive and uncomfortable. Humidity varies from 75% along the coastal region **(Fig.6)** to 55% towards interior of the city. As it is the summer season the relative humidity values are low compared to winter season.

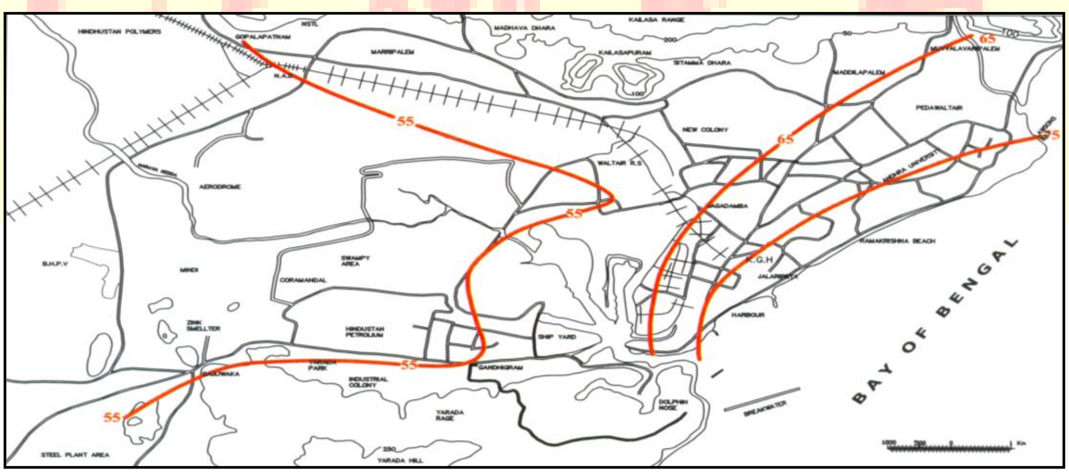

Fig.6: Visakhapatnam-Humidity (%) Distribution (May, 2008)

Having seen the general pattern of temperature distribution over the city and having identified the general areas susceptible to the formation of heat island, some more surveys were conducted during the winter period in 2008 and 2009. The lowest temperature of 21°c was recorded in the northwestern part of the city and the highest temperature of 24.4°c was observed at the city core area, Poorna-market **(Fig.7)**. The isotherm of 24°c was extended upto Waltair uplands in the northeastern part of the city which is highly densely populated

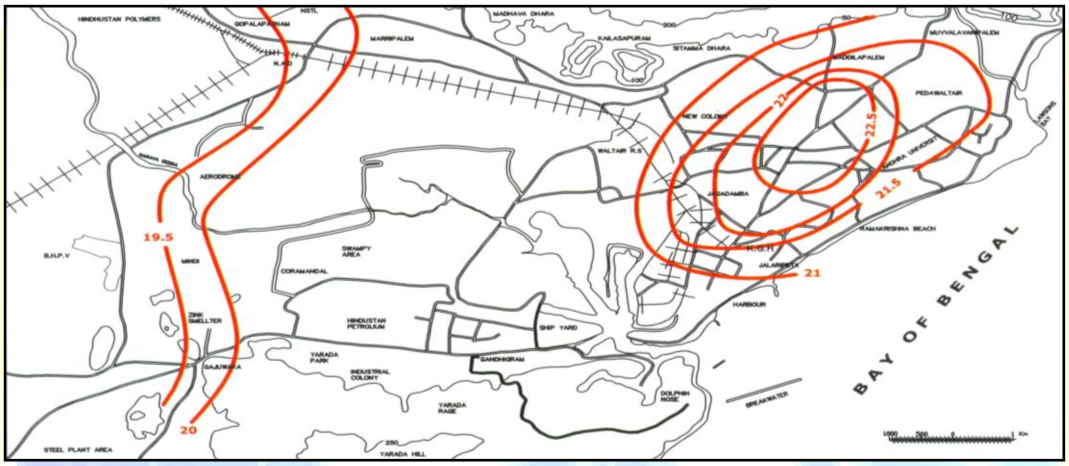

Fig.7: Visakhapatnam-Surface Temperature (^{0}c) Distribution (Dec, 2008) area.

The intensity of heat island was 3.4°c. The isotherms with the value of 22°c run over the most part of the city. Temperature distribution over the city during winter season of 2009 is shown in **Fig.8**. The pattern of isotherms is similar to that of December 2007 and the highest temperature of 22.5°c was observed in the northeastern part of the city where as the western part, sub-urban zone of the city shows the lowest temperature of 19.5°c. Further south of the city where steel plant is located, the temperature was 18.5°c only. Then the intensity of heat island was 4°c. The study reveals that the intensity of heat island at Visakhapatnam varies from 3°c to 4°c.

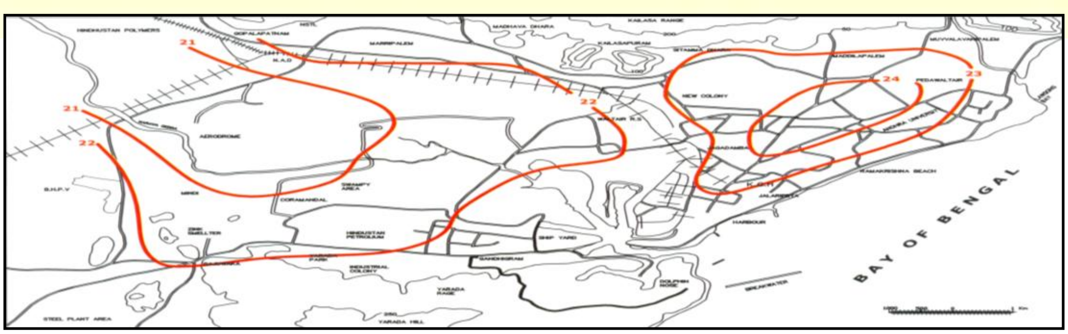

Fig.8: Visakhapatnam-Surface Temperature (^{0}c) Distribution (Jan, 2009)

From the study it was observed that heat islands can be formed under all meteorological conditions during all seasons but heat islands of higher intensities can be developed only during winter season under calm conditions **(Table.3)**. At Visakhapatnam, the formation of heat island is controlled by topography; urban morphology and proximity to large water body i.e. Bay of Bengal. The land and sea breeze circulation also interacts with heat island. Hence, intensity of heat island is 3°c to 4°c at Visakhapatnam unlike other Indian cities, where the intensities are more than 4°c. Heat island increases discomfort both outdoors and indoors. During summer season demand for electricity increases in tropical cities and urban heat island magnifies this demand and more energy is used for indoor cooling. As energy consumption is a major source of greenhouse gases, the concentration of greenhouse gases increases with intense use of energy which leads to climate change. By designing, building and operating urban areas in an energy efficient way, significant decreases in greenhouse gas emissions can be achieved.

Table.3: Visakhapatnam – Heat Island Intensity

Month	**Heat Island Intensity** (at the time of Min.Temp epoch)	**Month**	**Heat Island Intensity** (at the time of Min.Temp epoch)
January	4	July	2
February	4	August	2
March	3	September	2
April	2	October	2
May	2	November	3
June	2	December	4

It is clear that climatic discomfort is strongly increased by urban heat islands. Heat wave conditions coupled with heat island during summer season causes human discomfort and higher death rates. The urban heat island helps to concentrate almost all pollutants released in urban settings particularly ozone, through the promotion of background thermal radiation. Indoor discomfort also increases with high temperatures and it can be reduced by making modifications in the design and orientation of building. Careful setting of vegetation around the building has been recognized as a means of cooling. A direct consequence of landscaping would be lower temperature effect on building surfaces as it reduces the thermal load on building and create comfortable environment. In an investigation, the surface temperatures of a common brick wall were compared with those of a brick wall covered with vegetation. It was noticed that the surface temperatures at the inner side of the covered wall were about 2°c lower than those at the uncovered wall throughout the whole day.

Climatic Trends

Climate is known for variations and changes over time and space**.** Climate change has emerged as a major challenge for the sustainable urban settlement. It has been extensively discussed in academic as well as in political domain. Regional and local consequences of climate change may be compounded by urbanization. In recent years the climate change and variability due to anthropogenic causes have received considerable attention (IPCC 2001). Industrialization, urbanization and changes in land use pattern are some of the anthropogenic activities related to climate change. Recent studies IPCC (2001) have reported about increase in surface ozone and surface load of aerosols from major urban locations. A recent study by Shende & Gaikwad (2003) has revealed that impact of urbanization is also seen in the chemical composition of aerosols and the precipitation of rainwater in India. A study by Mohapatra (2002) about the climatic trends in different meteorological parameters in Bangalore supports the findings of Rupa Kumar, Krishna Kumar & pant (1994) about trends in maximum and minimum temperatures in India. Rao, Jaswal & De 2000 have shown the effect of urbanization on climate at some important locations.

Temperature Trends

The present study examines the trends in maximum and minimum temperatures over Visakhapatnam and tries to establish a link between urbanization and climate trends. Hence, the monthly maximum and minimum temperatures were collected from the weather reports of India Meteorological Department and data were analyzed. Trend analysis of the temperature has been carried out in order to assess the effect of urbanization on thermal climate. Trends of maximum and minimum temperatures have been evaluated by means of linear regression with time as independent variable. The regression analysis gives an indication of overall tendency of the temperature. It is observed that there is an increasing trend of maximum temperature of 0.2°c/40 years but trend is insignificant. With regard to minimum temperatures there is significant increasing trend of temperatures i.e. 0.7°c over a period of 40 years. There is not much variation in the distribution of both maximum and minimum temperatures during the decade 1980 to 1990 **(Fig.9)**. The analysis of temperature reveals that there is a general increasing trend in both the temperatures during the period 1950 to 1990.

Visakhapatnam being a tropical coastal station exhibits extreme temperatures and higher humidities, which cause distress conditions. The summer months of April, May and June with maximum temperatures of 35°c to 40°c are uncomfortable with oppressive heat. The analysis of summer maximum temperatures shows that the city is prone to heat waves with extreme maximum temperatures with the departure of 6°c to 8°c from the normal and city experienced ninety four heat waves, out of which sixty three are moderate and thirty one are severe heat waves over a period of fifty years i.e. from 1951 to 2000 **(Table.4)**. During heat wave conditions, urban heat island causes extra thermal stress resulting in increased urban death rates.

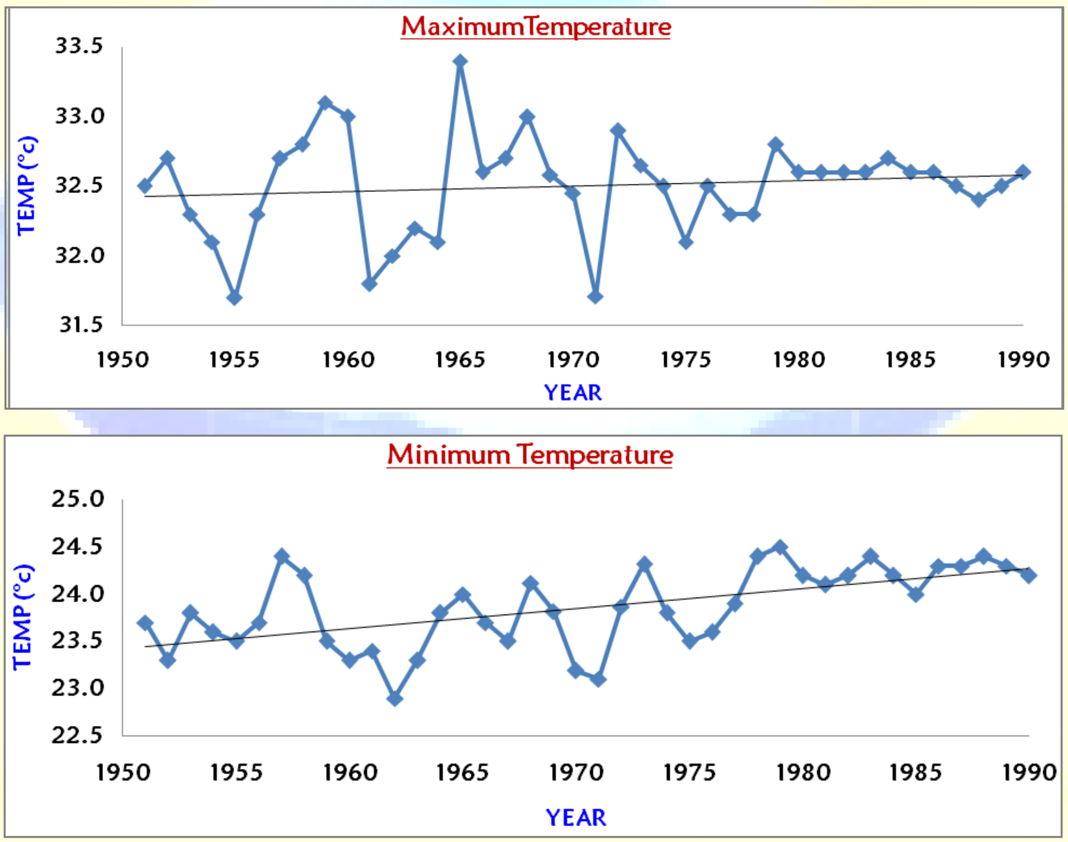

Fig.9: Temperature Trends

Table.4: Visakhapatnam - Frequency of Heat Waves (1951-2000)

Type	**Month**			
	April	May	June	Total
Moderate	14	24	25	94
Severe	-	12	19	

There is evidence that aggressive behaviour and heat deaths are increased in tropical cities during hot weather. Higher temperatures cause increased health risk to city dwellers because increased temperatures are associated with heightened levels of secondary pollutants such as ozone.

Precipitation Trends

Trend analysis of both annual and seasonal rainfall has been carried out to observe temporal variations in rainfall. The analysis of rainfall for the monsoon and annual is presented here with a view to assess the impact of urbanization on rainfall distribution. The percentage departure of annual rainfall from normal at Visakhapatnam is shown in **Fig.10a**. Annual rainfall of each year is expressed as percentage deviation from normal. The bars above the mean value show the positive departures from the normal rainfall i.e. excessive rainfall years. The bars below the mean value indicate negative deviations i.e. deficit of rainfall from normal. For the purpose of present discussion, annual rainfall exceeding 125 percent of the normal is considered as excessive rain or wet year. If the annual rainfall is less than 75 percent of the normal, it is treated as dry year. The analysis of annual rainfall over a period of 50 years i.e. 1951 to 2000 shows that there are more negative departures from normal during the period 1965 to 1985**(Fig.10a).** From 1985 onwards there are positive departures from the normal indicating that an increasing trend of rainfall **(Fig.10a).** Regression lines have been fitted to assess smooth trend of rainfall. It is evident from the **Fig.10b** that there is an increasing trend of rainfall over a period of 50 years.

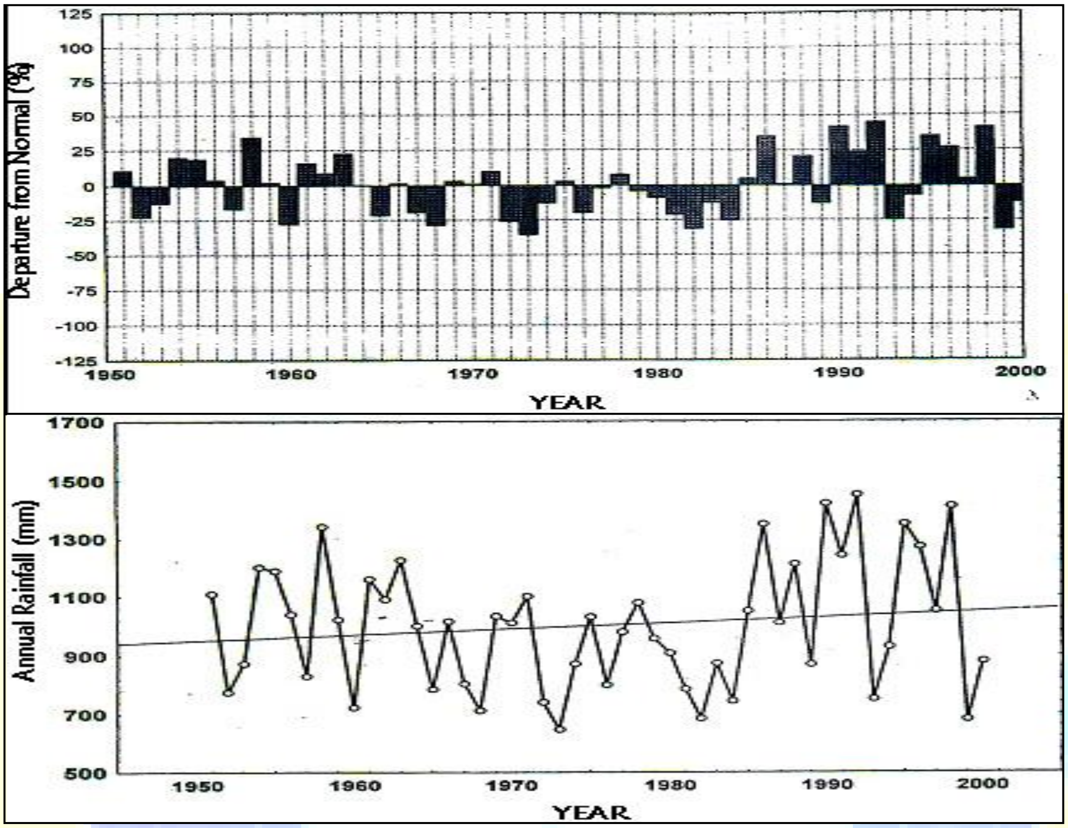

Fig.10 (a&b): Visakhapatnam – Rainfall Trends

An attempt is also made to examine the trend of annual rainfall over a period of 100 years i.e. 1901 to 2000. The total period of 100 years is divided into two climate periods, 1901 to 1950 and 1951 to 2000 and statistical technique "semi average" method is applied to identified the trend. Average annual rainfall was computed per each climatic period and results are compared. The mean annual rainfall of Visakhapatnam during the period 1901 – 1950 was 954mm whereas the mean value during the period 1951 to 2000 was 1004mm. It shows that there is an increase of rainfall and it may be attributed to increasing urbanization.

Monsoon rainfall departures are examined and wet and dry years are identified. The analysis of monsoon rainfall reveals that there are more wet years than dry years at Visakhapatnam. Monsoon rainfall of individual year is classified as wet or dry year when the percentage departure is above or below by 25 percent from normal rainfall. There are many extreme rainfall years with more than 25 percent departure from normal. 1987 is the driest year with 50 percent of negative departure from mean rainfall of 574mm and 1988 is the wettest year with more than 50 percent of positive departure from normal. From 1988 onwards there are many wet years **(Fig.11a)**. The results indicate that there is a general increasing trend in the monsoon rainfall. Trend analysis of monsoon rainfall has been carried out over a period of 35 years i.e. 1970 to 2005. It is observed that there is positive trend of rainfall **(Fig.11.b)** with an increasing trend of 115mm over a period of 35 years which indicates the rapid growth of the city.

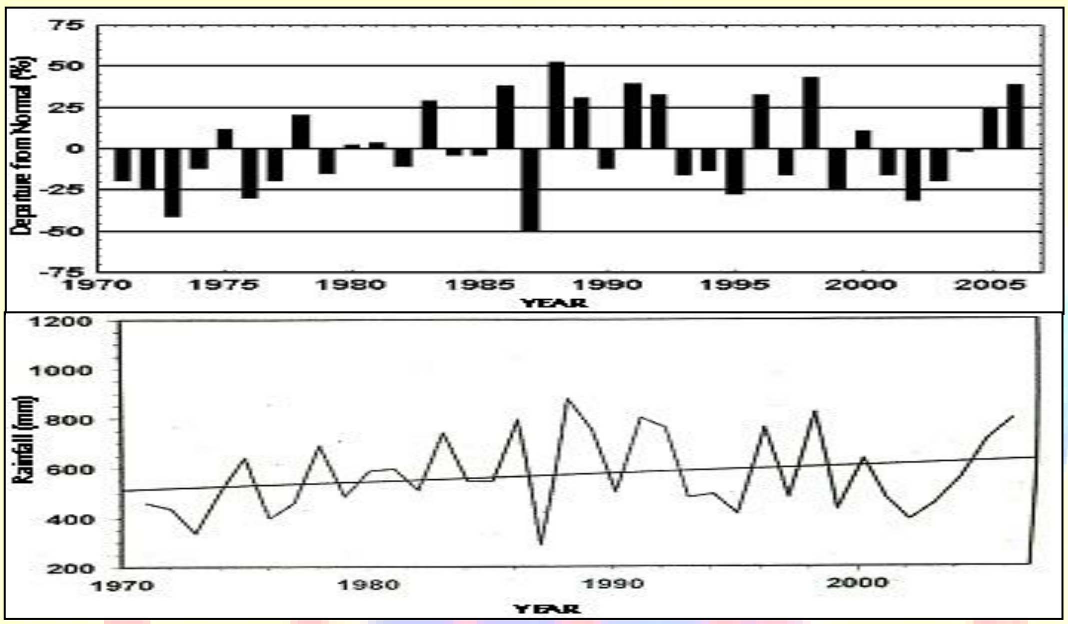

Fig.11 (a&b): Seasonal (monsoonal) Rainfall Trends

An attempt is made to identify extreme rainfall events, the days with rainfall of more than 100mm. The daily rainfall patterns from 1985 to 2002 have been analyzed. The results reveal that Visakhapatnam recorded more number of extreme rainfall days when compared to other stations of Andhra Pradesh State.

CONCLUSION

The rapid urbanization, industrialization and land use / land cover changes have brought about micro climatic changes particularly with regard to its thermal structure. The well documented climatic modification of the city is urban heat island. The study reveals that heat islands can be found under all meteorological conditions during all seasons and but heat islands of higher intensities are observed only during winter season under calm conditions. At Visakhapatnam the formation of heat island is controlled by topography and urban morphology. The land and sea breeze circulation also interacts with the heat island. Hence, intensity of heat island is 3°c to 4°C at Visakhapatnam unlike other Indian cities where the intensities are more than 4°c. This study is important in city planning for the avoidance of possible air pollution hazards. Heat island also causes human discomfort during heat wave conditions of summer.

The rate of cooling of urban and rural environments also differs widely due to marked different land surfaces. Field surveys were conducted to observe cooling rates between urban and rural environment. Analysis of hourly temperature data reveals that the rate of decrease of temperature or cooling rate is 0.4°c / hr at urban centre of Visakhapatnam, 0.8°c / hr at sub-urban and 1.0°c / hr at rural area. Trend analysis of the temperatures has been carried out to assess the affect of urbanization on thermal climate. Trends of maximum and minimum temperatures have been evaluated by linear regression analysis. It is observed that there is an increasing trend of maximum temperature of 0.2°c / 40 years but trend is insignificant. With regard to minimum temperature, there is significant increasing trend of temperature i.e. 0.7°c over a period of 40 years. Trend analysis of both annual and seasonal rainfall (monsoon) has been carried out to observe temporal variations in rainfall. The results reveal that there is an increasing trend of rainfall both in annual and seasonal distributions over a period of 50 years i.e. 1951 – 2000.

Proper application of climatic knowledge in land use, urbanization and building design can contribute to improved human health, environment, energy usage and other social and economic benefits.

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