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RAINFALL VARIABILITY OVER SMALLER SPATIAL SCALE

1. The aim of this study is to investigate if the effect of rainfall variability and land use change is evidenced in a changing climate of a city and its surrounding area in South India. The statistical difference between stations with city and rural characteristics is the basis for a comparison. In this study trends of annual precipitation were investigated for Chennai city. Data were collected for three meteorological stations *i.e*., Nungambakkam located within the city and one station located on the city outskirts, Minambakkam considered as semi rural and Kanchipuram, considered as characteristic of rural location. The data were then statistically analyzed to understand the precipitation trends. Overall the gradients of trends in annual rainfall was higher for the city station when compared to the semi rural and rural stations. The rate of increase in the annual rainfall was found significantly higher for Nungambakkam compared to the semi rural station Minambakkam. Generally at city station the rate of change in the number of heavy rainfall (64.5 to 124.4 mm per day) days, very heavy rainfall (124.5 to 244.4 mm per day) and extremely heavy rainfall days (> 244.5 mm per day) was consistently higher than the semi rural and rural stations, Minambakkam and Kanchipuram respectively. The trends in light precipitation days at all stations may be related to variability in climate. However the greater number of heavy precipitation days at the stations with city character may be due to changes in land use.

2. *Need for the study* - The effect of land use changes, specifically the conversion of pervious land to

Fig. 1. Study area map

impervious land, affect the local climate, sometimes significantly. Local climates tend to be warmer due to the increased amount of heat released within a densely populated area. Average temperatures in city centers can increase even more due to the high density of construction materials such as pavement and roofing materials since they tend to absorb, rather than reflect, sunlight. Determining a relationship between city-rural precipitation differences and climate change is problematic due to the temporal and spatial variability of rainfall (Hughes, 2006). The processes that govern precipitation are much more complex. The state of current understanding with regard to temperature effects seems to be relatively well-defined, with generally higher temperatures observed over city areas. However, precipitation effects are not so clear. Much of the research to date suggests increase in city precipitation in comparison to rural locations (Landsberg, 1981, Oke, 1987). A study on climate trends in the Indian cities have shown that the increasing trends in the frequency of heavy rainfall over cities is significantly higher than rural areas (Kishtawal *et al.* (2009). De and Prakasa Rao (2004) have highlighted in their study that significant trends in rainfall over cities was observed only after period 1901-1950.

The migration of rural population to nearby city centers has resulted in the increase of impervious urban land. Even though it is well established that cities have higher temperatures in relation to surrounding rural areas the physics which explains conclusively the process of how land use changes is influencing the rainfall and *vice versa* is being researched (Shepherd (2005). Chennai, a tropical city characterized by high temperatures and humidity, has witnessed a rapid growth in population in the recent decades. Therefore, this paper aims to analyze the impact of land use change on rainfall conditions in the hot humid city of Chennai, India. The hypotheses behind the study are higher city-rural mean temperatures and higher city-rural mean precipitation, based on existing research. Data from the weather stations in Chennai city (Nungambakkam), Chennai semi-rural (Minambakkam) and Kanchipuram (rural) forms the basis of analysis.

TABLE 1

Precipitation day classification

Precipitation in mm per day	Precipitation day class
0.01 to 0.04	Trace precipitation day
0.1 to 2.4	Very Light precipitation day
2.5 to 7.5	Light precipitation day
7.6 to 35.5	Moderate precipitation day
35.6 to 64.4	Rather Heavy precipitation day
64.5 to 124.4	Heavy precipitation day
124.5 to 244.4	Very Heavy precipitation day
≥ 244.5	Extremely heavy precipitation day

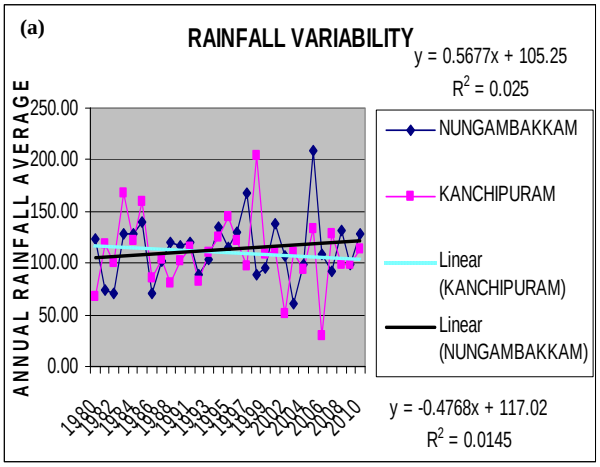
Source : India Meteorological Department (IMD)

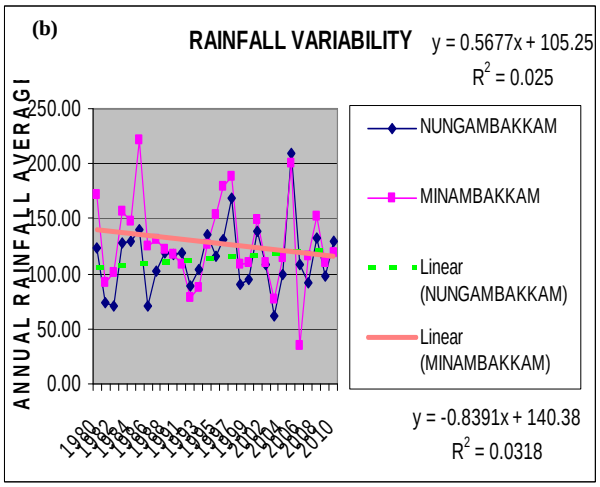
3. *Study area* - Chennai is located at 13° 04′ N, 80°17′ E on the southeast coast of India and in the northeast corner of Tamil Nadu (Fig. 1). The region is quite flat therefore topography has relatively little influence on climate. Chennai lies near the thermal equator. For most parts of the year, the weather of Chennai is hot and humid. The city gets most of its rainfall from the northeast monsoon winds (mid-September to mid-December). The average annual rainfall in the Chennai city is about 1,300 mm. April and May are the hottest months with temperature shooting up to 40 ºC.

4. *Methodology* - To understand the impacts of land use change on rainfall in Chennai Metropolitan Area - CMA, the time series data obtained from the three weather stations in Chennai were analyzed. The rainfall and rainy day trends of the CMA were studied, using historical daily rainfall records of Nungambakkam, Minambakkam and Kanchipuram meteorological stations, located within the study area for 30 years from 1980 to 2010. Being close to the Central Business District, the climatic data from the Nungambakkam meteorological station is assumed as city station. The demarcation of the meteorological stations was done based on a study done by Rose (2010) for the study area.

The daily precipitation of these stations was analysed in terms of the classification of India Meteorological Department (IMD) (Table 1).

To determine the trends in precipitation linear regression method was used (Dinpashoh *et al.* (2012). The magnitude of trend was determined by this method.





Figs. 2(a&b). City- rural precipitation differences for the Chennai region between 1980-2010

To test the statistical significance of this trend the nonparametric Mann-Kendall test was performed using XLSTAT software.

5. *Results and discussion* - In order to understand the precipitation differences between the city and rural stations, the precipitation data for the 1980-2010 period was analyzed using the methods discussed above. The analysis is expressed graphically in Figs. 2(a-b). The analysis was begun by plotting the annual rainfall averages for each year for the period 1980-2010. The slope of the regression line was positive for the city station and negative for the semi-rural and rural stations indicating that there was an increasing trend in the rainfall for the former and a decreasing trend for the latter stations. This may be due to effect of urbanisation on the local climate. The graph shows that overall the quantum of rainfall in the city station, Nungambakkam, is higher

TABLE 2

Highest frequencies of precipitation classes for city and rural stations between 1980-2010

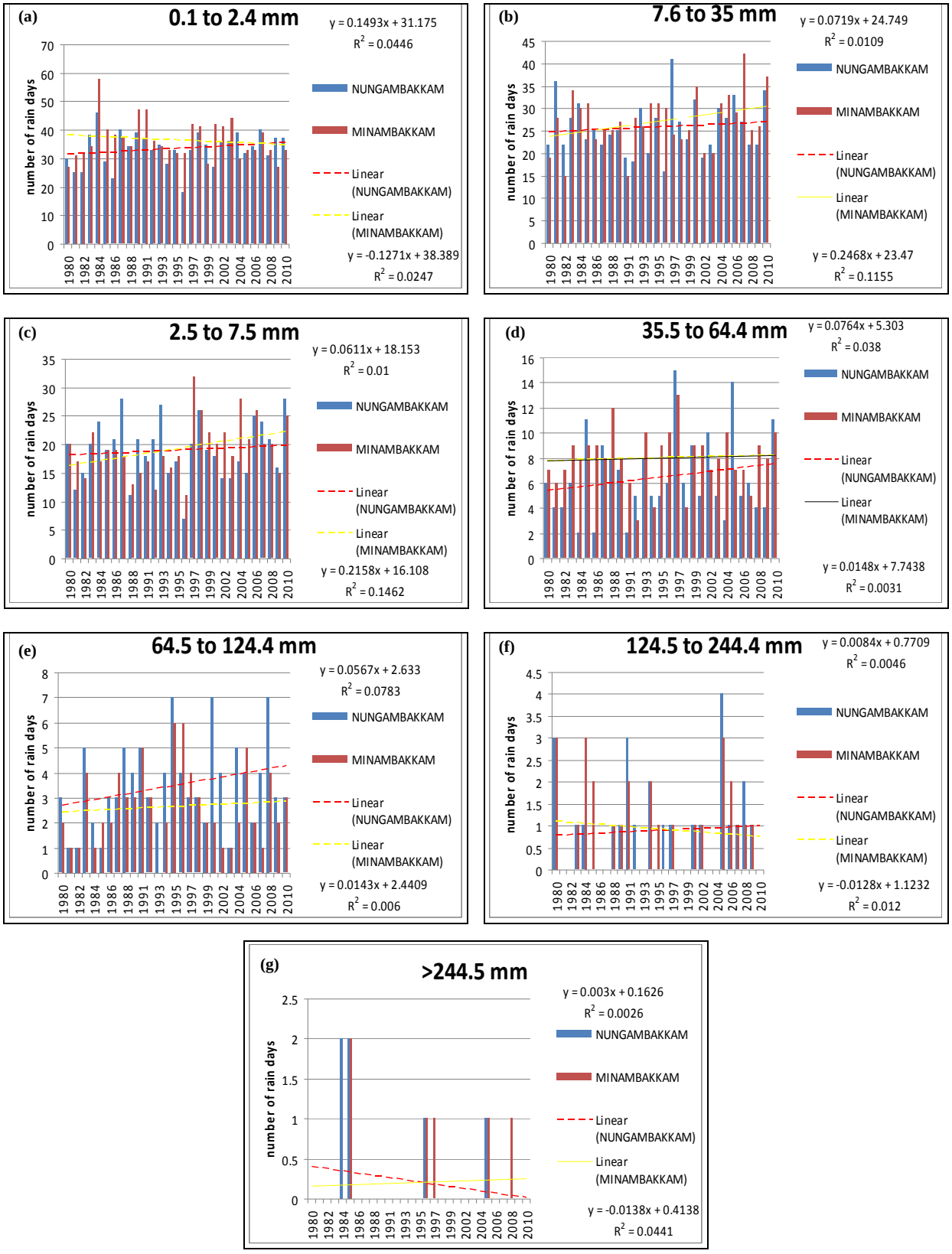
Toatal precipitation	Nungambakkam	Minambakkam	Kanchipuram
0.1 to 2.4 mm	46	58	18
2.5 to 7.5 mm	28	32	31
7.6 to 35.5 mm	41	42	39
35.6 to 64.4 mm	15	13	13
64.5 to 124.4 mm	7	6	10
124.5 to 244.4 mm	4	3	2
≥ 244.5 mm	2	2	1

than that of the rural stations, Kanchipuram and Minambakkam. The rate of increase in the rainfall at Nungambakkam station is higher than the Kanchipuram station indicated by the slopes of the regression equations as 0.567 for Nungambakkam, and -0.476 for Kanchipuram respectively.

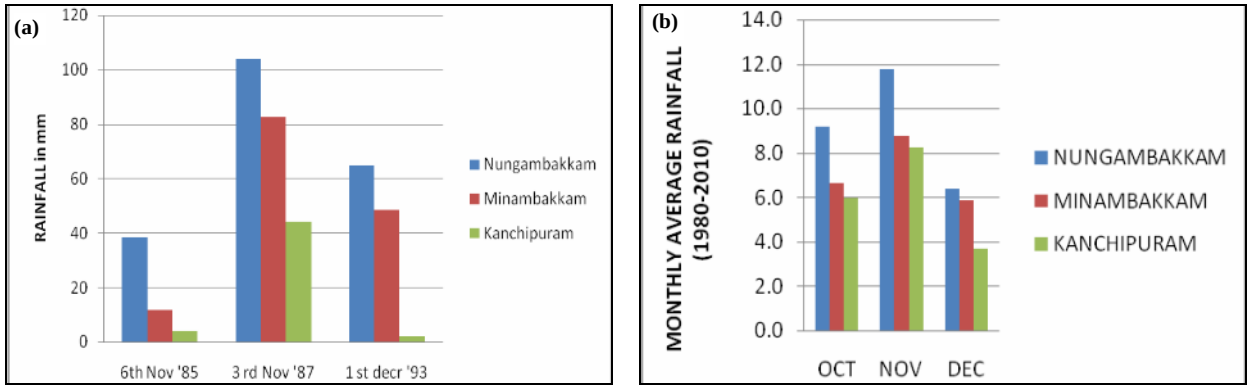
Also the slope of the trend line of Minambakkam station was negative of magnitude (-0.839). The question that arises here is even though the gradients of the trend lines of Nungambakkam station show an increase and Minambakkam and Kanchipuram stations show a decrease, are they significantly different from one another. Another statistical test, a two tailed t test was applied which revealed that at 95 per cent confidence level the p value equals 0.0166 for the Nungambakkam-Minambakkam stations. This value was less than the significance level of 0.05. Hence this test showed that the slope of Nungambakkam station was significantly higher than the slope of Minambakkam station. However the p value of the Nungambakkam- Kanchipuram station was 0.5646. Hence the difference between the two stations slopes was considered to be not statistically significantly different.

Another important effect of land use change is variation in the number of precipitation days. To investigate this a chart was prepared as shown in Table 2 below that explains the variations in the highest frequencies of precipitation classes for the Nungambakkam, Minambakkam and Kanchipuram stations.

From Table 2 it is seen that the number of very light precipitation days generally are higher at the city station than that of the rural station. This shows that land use change has increased severity of light rainfall days over a period of time. The trace rainfall days were not included



Figs. 3(a-g). Long term trends in the precipitation day classes in the monsoon period. The equations for the trend lines of Nungambakkam are displayed on the top right corner while for Minambakkam at the bottom right corners respectively



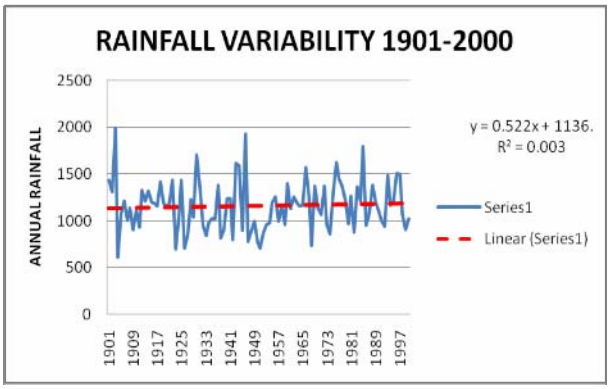
Figs. 4(a&b). Spatial variability of (a) daily rainfall (b) mean monthly rainfall in the corresponding months daily rainfall, at three rain gauge stations

in the analysis as all stations showed trace numbers in the rainfall days. Further, the numbers of precipitation days for each of the classes were plotted for the Nungambakkam-Minambakkam stations shown in Figs. 3(a-g) and Nungambakkam-Kanchipuram stations shown in the Appendix. As seen in graphs that follow in Figs. 3(a-g), the number of rather heavy, heavy and extremely heavy precipitation days are higher for city station, Nungambakkam when compared to semi rural station Minambakkam respectively.

The rate of increase in the number of heavy, very heavy and extreme rainfall days for the city station is higher as indicated by the slopes of 0.056, 0.008 and 0.003 compared to the semi-rural station of 0.014,-0.012, and -0.013 respectively. This suggests that other than climate variability land use is playing a role in causing an increase in heavy precipitation.

Further, to investigate whether there is a significant difference in the rainfall on the rainy days, at random three such days were chosen, the plots of which are shown in Fig. 4. It is interesting to note that on all three days Nungambakkam recorded higher rainfall than Minambakkam and Kanchipuram respectively. Also the monthly averages of rainfall indicate a similar trend. These results support the findings of the results shown in earlier sections regarding the rainfall differences between the 2 classes of stations.

6. *Conclusions* - This study demonstrates evidence for inadvertent climate modification by land use changes in Chennai regarding precipitation effects. This study supports the findings from other studies discussed earlier regarding the quantum of rainfall in city areas when compared to rural areas. Time series graphs were plotted for city-rural differences in annual precipitation for Chennai. This enabled a comparison to be made of any apparent city-rural differences in rainfall. Frequency charts were plotted for light and moderate to heavy rain days at Nungambakkam, Minambakkam and Kanchipuram for the period. This study enhances the findings of an earlier study carried out in Chennai city with regard to changes in micro climate. The analysis of city rural differences in rainfall characteristics for this region showed a trend toward increased rates of precipitation for the city station when compared to a rural station. Even though both stations showed trends that could be attributed to local climate variability, the difference in the rates of change is indicative of land use change that has been taking place during the period. Although there is no significant difference in light precipitation days, this difference becomes obvious in the heavy precipitation days. Therefore it is a better indicator of land use effects that could be influencing the higher rainfall rates in the region. The statistical analysis arrived at in this study have a limitation of short duration data. It might be important to note that throughout the period 1980 onward the rainfall and number of rainy days were greater in the city area than the rural area, but there is no evidence that this was not so in the period before that. So to substantiate that these differences are linked to land use change, studies highlighted in the review of literature *i.e.*, by De and Rao (2004) have been adopted to support the findings from this study. Also climatic datasets from the CRU dataset was used for the period 1901-2000 for Chennai, *i.e.*, Climate Research Unit (CRU) TS2.1 dataset, out of the Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia in Norwich, UK. This published dataset consists of interpolated (on a 0.5 degree latitude-longitude grid) global monthly rainfall, temperature, humidity and cloud cover data, from 1901 to 2002 (Mitchell and Jones, 2005). It was found that there were no significant trends in



Source : CRU dataset – Tyndall Center

Fig. 5. Rainfall trends for Chennai 1901-1950

annual (Fig. 5) rainfall during the period 1901-1950. Trends for rainfall appear to have begun only from 1951 onwards for the region.

The increase in the number of heavy and very heavy precipitation days for the city station also indicates the possibility of floods in future for the region. The results of the study may benefit local government with regard to planning and design of city areas to minimize effects on climate variability in future.

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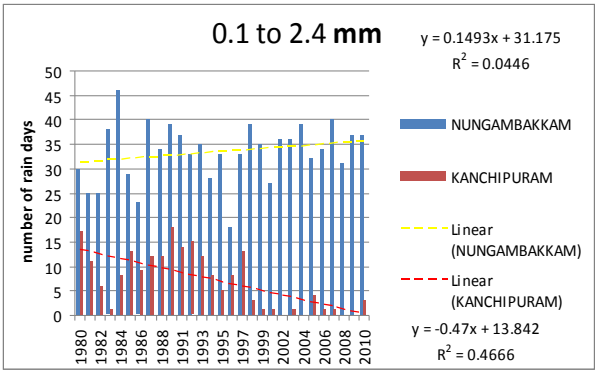
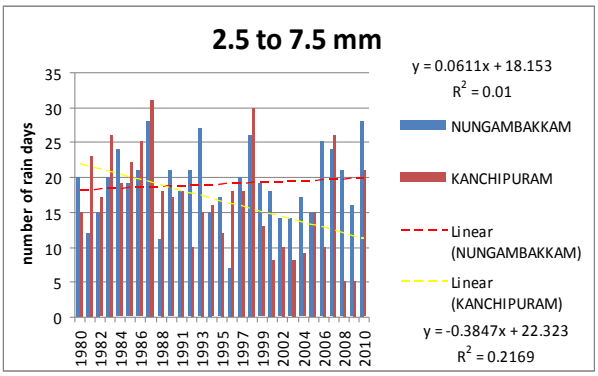
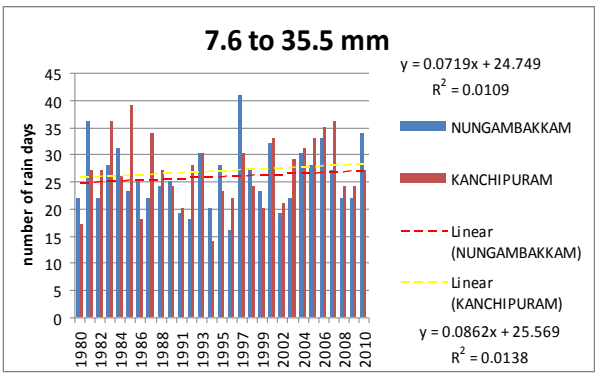
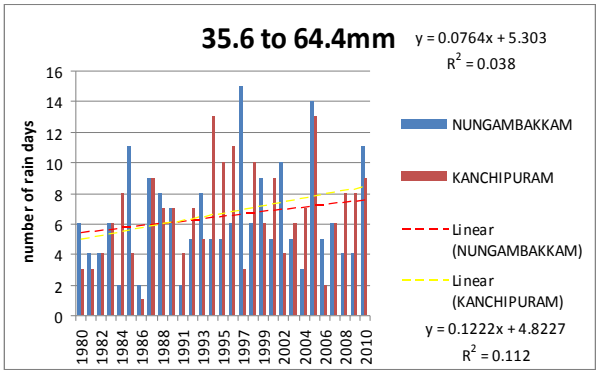
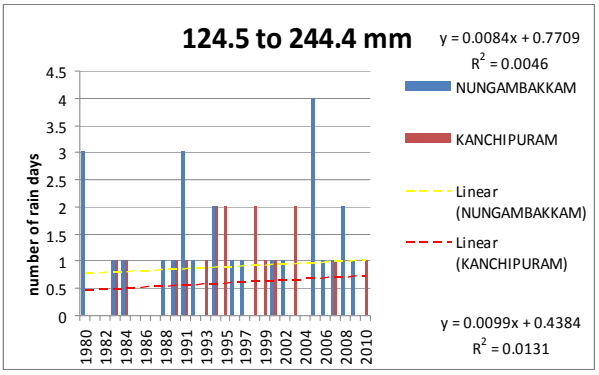
Appendix - Rainy day trends – city *vs* rural

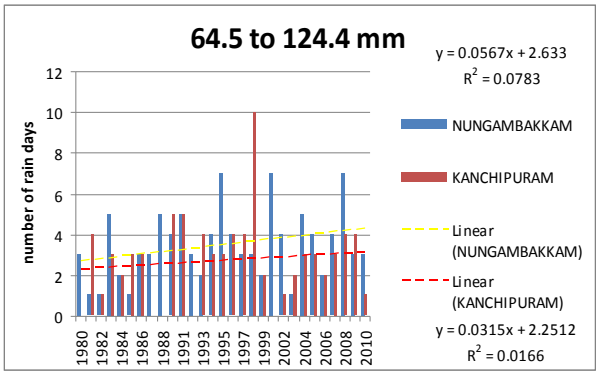


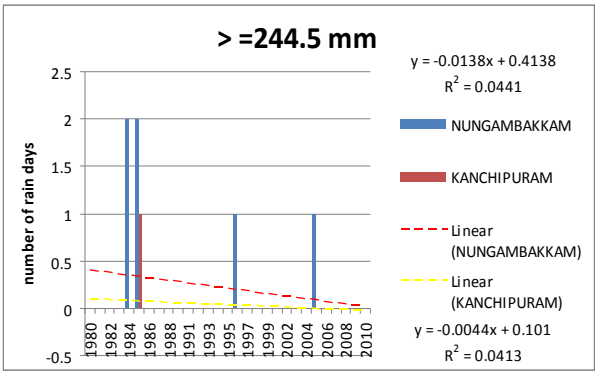





35.6 to 64.4mm
y = 0.0764x + 5.303
R2 = 0.038
number of rain days
NUNGAMBAKKAM
KANCHIPURAM
Linear (NUNGAMBAKKAM)
Linear (KANCHIPURAM)
y = 0.1222x + 4.8227
R2 = 0.112


124.5 to 244.4 mm
y = 0.0084x + 0.7709
R2 = 0.0046
number of rain days
NUNGAMBAKKAM
KANCHIPURAM
Linear (NUNGAMBAKKAM)
Linear (KANCHIPURAM)
y = 0.0099x + 0.4384
R2 = 0.0131


64.5 to 124.4 mm
y = 0.0567x + 2.633
R2 = 0.0783
number of rain days
NUNGAMBAKKAM
KANCHIPURAM
Linear (NUNGAMBAKKAM)
Linear (KANCHIPURAM)
y = 0.0315x + 2.2512
R2 = 0.0166


> =244.5 mm
y = -0.0138x + 0.4138
R2 = 0.0441
number of rain days
NUNGAMBAKKAM
KANCHIPURAM
Linear (NUNGAMBAKKAM)
Linear (KANCHIPURAM)
y = -0.0044x + 0.101
R2 = 0.0413