Study on the trends of rainfall and temperature patterns to identify the influence of climate variation in coastal cities in Sri Lanka.

P.K.B.D.B. Bandara[1], A.B. Jayasinghe[2], C.C. Abenayake[3], P.K.S. Mahanama[4]

[1]*Research Assistant, Faculty of Architecture, University of Moratuwa, Moratuwa, Sri Lanka, E-mail* *dilekabandara@gmail.com*
[2]*Lecturer, Department of Town & Country Planning, University of Moratuwa, Moratuwa, Sri Lanka, E-mail* *amilabjayasinghe@gmail.com*
[3]*Lecturer, Department of Town & Country Planning, University of Moratuwa, Moratuwa, Sri Lanka, E-mail* *chethika.abenayake@yahoo.com*
[4]*Dean, Faculty of Architecture, University of Moratuwa, Sri Lanka, E-mail* *mahanama_pks@yahoo.com*

Abstract
Climate change has been universally recognized as a fundamental human development challenge in 21st century and thereafter; which impacts both natural and built environment. Although different parts of the world are predicted to be affected by climate change to varying degrees, many of the studies focused on climate change in global or region level. However, there is a dearth of climatological studies addressing the temporal trends in rainfall and temperature at city scale. On other hand recent rainfall and temperature extremes have adverse impacts on the natural and built environment of most of coastal cities in Sri Lanka. In this context this research attempted to examine trends of rainfall and temperature patterns over the last four decades in seven coastal cities (namely; Rathmalana, Hambantota, Trincomalle, Puttalam, Katunayake, Batticaloa and Galle) in Sri Lanka to see whether they support to claim the long-term climate change by identifying temporal trends in the rainfall and temperature during the period of 1971-2011. The findings of the study revealed averaged over all stations; the indices of temperature extremes indicate warming of both daily minimum and maximum temperature between 1971 and 2011. For precipitation, most of the indices show significant changes. Relative to the changes in the total amounts, there is a very significant change in the precipitation extreme days. Accordingly this study emphasize the need of integrating the climatic variations wisely in the urban planning can invest the capital of the country to the development rather than unnecessarily spend it on post disaster rehabilitations.

Key words – Climate variation, Rainfall and temperature trends, Coastal cities, Urban Development

1. Introduction
Rational scientific analysis of climatic factors or climatic dimensions and its practices seems to be ignored in the urban planning (Hebbert M., Mackillop F., 2011) and its relevant decision making process in both developed and developing regions considering climate as un-influensable factor in urban planning. But in the history our ancestors had taken the maximum benefits from the knowledge and experience they had about the climate and its variations in ancient city planning as many of the urban designs of the

ancient civilizations originated with the geomantic understanding of the relationships between built forms and climatic factors as sun, rain, wind etc.

But at present ignoring the climatic factors in urban planning already has influenced to the modern developing and developed world as rapidly expanding urban settlements in the world are and will continue to face severe climatic risks in light of climate change specially in the category of developing regions. Urban populations will increasingly be forced to cope with increased incidents of flooding, air and water pollution, heat stress and vector-borne diseases (Wilbanks et al. 2001; Parry et al. 2007). Specially the cities in developing countries are at particular risk due to their high density populations rather than the developed countries (although the developed countries contributed to the extreme causes of the climate change), a lack of adequate drainage channels, a concentration of solid and liquid waste, expansive informal settlements and urban expansion onto risky sites.

In the twentieth century, the global average temperature has risen 0.6 degrees Centigrade, and even given aggressive measures to curb greenhouse gas emissions, scientists expect an estimated 2.2°C additional rise by 2100, with temperatures continuing to rise for centuries thereafter. This can have a direct effect on human health and energy use (IPCC, 2001c), particularly in urban areas, where it is exacerbated by the heat island effect. Mean sea level has risen 10-20 centimeters in the 20th century, due to glacial melting and the expansion of sea water as it warms. While the specific amount of melting is difficult to predict, the IPCC expects 30-50 centimeters of sea level rise by 21004 (IPCC, 2001c). This is a critical issue for major cities, which tend to be clustered near coasts, particularly in developing countries. Even in Europe, 70% of the largest cities have areas that are less than 10 meters above sea level (McGranahan, 2007).

Since most of the economic activities of the most of the countries are being produced from this coastal city based region whereas majority of the total population are lining in this region. In order to make sure the stability of the country's economic base as well as the social well-being, this sort of climate change adaptation planning approaches in the development plans initiatives are highly demanded today and importantly in future. Higher global average temperatures and sea level rise are the most widespread and predictable effects. (Hebbert M., Mackillop F., 2011)

As a developing country; Sri Lanka, with a tropical climate pattern, has higher vulnerability for climate change impacts in extreme weather conditions such as high intensity of rainfall or extreme dry periods on unpredicted or unexpected periods of the year. Some of the cities in the country have already being experiencing the impacts of climate change specially which are located at the coastal region of Sri Lanka. As an island country, the coastal areas itself is an important environmental as well as economic resource to the country. The coastal zone of Sri Lanka consists of around 25% of total land area, hosts around one third of the country's population, accommodates over two thirds of all industrial facilities, and over 80% of tourism infrastructure (UNEP, 2001). Marine fisheries play a pivotal role in Sri Lanka's fish supply. According to the National Aquaculture Development Authority (NARA), in 2011, around 86% of total fish supply has come from marine fisheries. The marine fish catch comprises of 58% from coastal areas and 42% from off-shore. The contribution of the coastal sector to the national GDP is on the rise (Nayanananda O.K., 2007). The share of coastal GDP in national GDP has increased from around 35% in 1983 to 43% in 2005. Agriculture, fisheries, trade, and tourism have been playing a major role in growing the coastal economy over the years. The contribution must have now increased further following the end of war in 2009. Importantly the coastal area of Sri Lanka plays major role in strengthen the economic, environmental as well as historic identity of the country but with the unexpected changes of the climatic conditions have being already interfered to the stability of all these aspects of Sri Lanka as a victim of climate change.

As this kind of studies are very limitedly done to the coastal urban areas; the findings of this study will be useful to the urban plan implementing agencies, decision makers, researches in taking the decisions on future development plans and align with urban planning process. This research has built on few selected indicators such as yearly rainfall, monsoon rainfall, and number of rainy days, average maximum and minimum daily temperature with the reason that these selected indicators are mostly combined and influence to the built environment of the city. As an example; the unpredicted excessive rainfall or temperature in unexpected time of the year can mess up the day today activities of the people persuading the built environment by causing floods or droughts with post health hazards. And these climatic variations can change the day today work plans of the people and as well as working and infrastructure networks of the built environment; by increasing wear on technical infrastructure and the external walls of buildings and by increasing the risk of flooding in certain areas.

In this context this research attempted to examine trends of rainfall and temperature patterns over the last four decades in coastal cities Sri Lanka to see whether they support to claim the long-term climate change by identifying temporal trends in the rainfall and temperature during the period of 1971-2011 in Sri Lanka. Subsequently, study findings contribute to the literature which emphasizes the importance of examine trends of rainfall and temperature patterns to urban planning discussion around this topic in research and policy circles.

2. Literature review

2.1 Climate Variability and Climate Change

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC) in its Article 1, defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition, and "climate variability" attributable to natural causes.

Climate refers to the average weather conditions in a place over many years (usually at least 30 years) (EPA, 2003). Climate is traditionally defined as the description in terms of the mean and variability of relevant atmospheric variables such as temperature, precipitation and wind. Climate can thus be viewed as a synthesis or aggregate of weather. This implies that the portrayal of the climate in a particular region must contain an analysis of mean conditions, of the seasonal cycle, of the probability of extremes such as severe frost and storms, etc. Following the World Meteorological Organization (WMO), 30 years is the classical period for performing the statistics used to define climate. This is well adapted for studying recent decades since it requires a reasonable amount of data while still providing a good sample of the different types of weather that can occur in a particular area. However, when analyzing the most distant past, such as the last glacial maximum around 20 000 years ago, climatologists are often interested in variables characteristic of longer time intervals. As a consequence, the 30-year period proposed by the WMO should be considered more as an indicator than a norm that must be followed in all cases. This definition of the climate as representative of conditions over several decades should, of course, not mask the fact that climate can change rapidly. Nevertheless, a substantial time interval is needed to observe a difference in climate between any two periods. In general, the less the difference between the two periods, the longer is the time needed to be able to identify with confidence any changes in the climate between them.

2.2 Climate and meteorological parameters

Meteorology is the science that deals with the atmosphere and its phenomena. Major areas of research concern the weather, weather forecasting and atmospheric composition. There are number of climate and meteorological parameters which can be used to investigate and understand the changing patterns of climate. Each climate index is based on certain parameters and describes only certain aspects of the climate, so there are a variety of climate indices that have been defined and examined in numerous publications. Means and extreme values, linear trends and standard deviations of longtime time series can be calculated for each of these climate parameters. These results are a simple form of climate indexes, as they already describe changes in climate (Integrated climate data center). Some of the mostly used climatic indices are listed below;

Table 1: Mostly used climatic indices

Parameter	Definition	Indices
Precipitation	The recording of precipitation amounts started a begin of weather recording. After some technical developments the duration of a precipitation event was recorded, too. Additionally information about the type of precipitation (rain, snow, hail) was collected by the	• Maximum 1- and 5-day precipitation per Year • Simple precipitation intensity index • Annual count of days when the precipitation is greater than a defined limit • Maximum length of dry spell • Maximum length of wet spell • Annual total precipitation when rain rate is above a defined limit

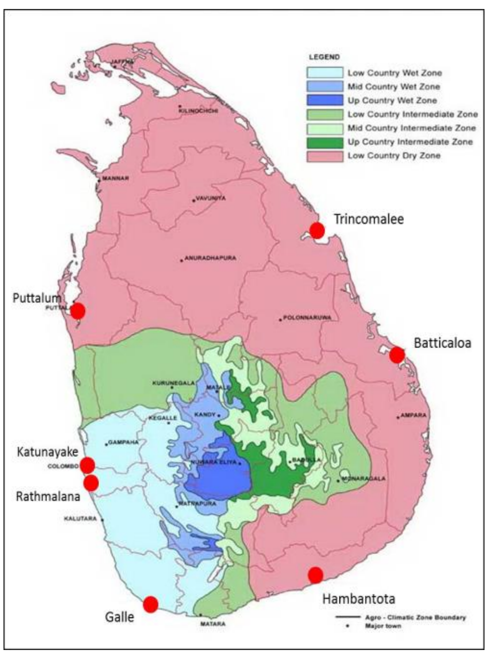
	observer	(Percentile) • Annual total precipitation in wet days
Temperature	The air temperature is an atmospheric parameter that is recorded since the start of weather recording. The air temperature is measured daily in 2 m height above ground and long time series exist for many stations. Additional to the current temperature the daily minimum and maximum values are recorded that are used for index calculations as well.	• Number of frost and ice days • Number of summer days and tropical nights • Extreme values during a specific period • Exceeding specific limits (Percentile) • Daily temperature range • Heating degree day • Warm and cold spell duration • Growing season length

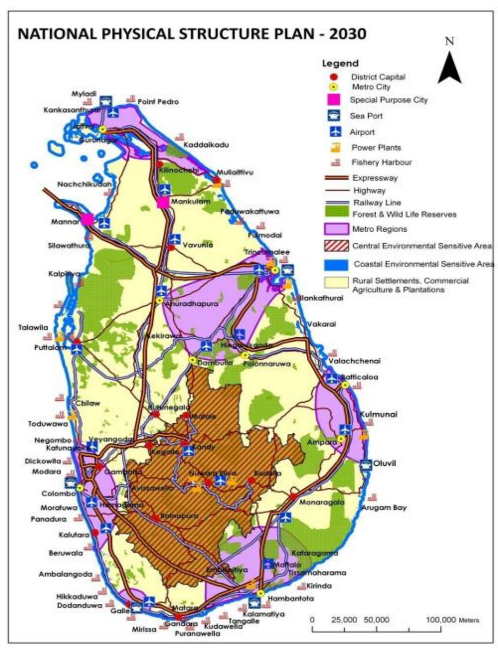
Source: Integrate climate data center, University of Hamburg

3. Methodology

3.1 Study area

This research is built on analyzing daily rainfall and temperature data collected at seven coastal meteorological stations of the Department of Meteorology Sri Lanka that are Rathmalana, Hambantota, Trincomalle, Puttalam, Katunayake, Batticaloa and Galle.





Map 1: Location of selected observatory stations of the study along the climatic zones (left) and proposed metro regions (right) of Sri Lanka

(Source: Author constructed based on National Physical Plan Sri Lanka 2030, NPPD and National Atlas, Sri Lanka)

All the selected seven meteorological observatories are coastal cities. The rationale behind selecting these seven cities as main observatories were these seven stations are well distributed - over the entire country in varied climatic regions (wet zone and dry zone) and ongoing and proposed major urban developments are mostly concentrated in these areas. The brief introduction on the seven selected observation stations is given in the following table

Table 2: Selected observatory stations for the study

Observation Station	Climatic Zone	Elevation (m)	Metro region according to National Physical Structure Plan – Sri Lanka
Rathmalana	Wet zone	6	Western Metro Region
Katunayaka	Wet zone	2	Western Metro Region
Galle	Wet zone	12	Southern Metro Region
Hambantota	Dry Zone	16	Southern Metro Region
Trincomalee	Dry Zone	3	North Central Metro Region
Puttalam	Dry Zone	2	-
Batticaloa	Dry Zone	3	Eastern Metro Region

3.2 Data sources

This study is totally based on the secondary data which collected from the Department of Meteorology. Daily rainfall data were collected for the period of 40 years from 1971 to 2011 for selected 7 meteorological observatories

Statistical analysis such as linear and polynomial regression and time series analyses were utilized to examine periodic changes in daily, annual and seasonal contexts using the parameters as yearly rainfall, number of rainy days, monsoon rainfall and maximum and minimum daily temperature

4. Results and discussion

4.1 Yearly rainfall

In order to examine trends in the yearly rainfall, the annual rainfall was obtained from the original daily rainfall record at each station. Regression analysis was performed on the yearly rainfall at each station. See Table 3 for the results.

Table 3: Trends in the yearly rainfall for the period from 1971 – 2011

Station	Liner Trends				Polynomial Trends
	m (Slope)	c (Intercept)	R^2	Remarks	Remarks
Hambantota	-0.5697	1595.7	0.005	Cannot be considered as a significant one according to the R^2 values	Did not show significant change

Galle	6.4842	-1075.8	0.021	Cannot be considered as a significant one according to the R^2 values	Did not show significant change
Rathmalana	47.438	9317.7	0.660	Increase in annual rainfall	10 year moving averages ($R^{2=}$0.73) seem to show an significant increase in peak rainfall in 10 year cycle (Ex: 1970s:1500mm, 1980s:1600mm, 2010s:2000mm)
Katunayaka	-9.2558	2042.3	0.053	Cannot be considered as a significant one according to the R^2 values	Did not show significant change
Puttalam	-0.7323	2592.0	0.005	Cannot be considered as a significant one according to the R^2 values	Did not show significant change
Trincomalee	-0.2227	1877.8	0.0005	Cannot be considered as a significant one according to the R^2 values	Did not show significant change
Batticaloa	16.994	-3218.7	0.578	Increase in annual rainfall	10 year moving averages ($R^{2=}$0.82) seem to show an very significant increase in peak rainfall in 10 year cycle (Ex: 1970s:1600mm, 1980s:1800mm, 1990s:3000mm, 2010s:3600mm)

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

As it is produced the annual rainfall of the country is conventionally considered as ranging between 1000mm in the dry zone to more than 5000mm in the wet zone. With this mean annual rainfall; a special spatial pattern has built up all over the Sri Lanka. But at present the unequal and unbalance lengths and seasons shows great variation of rainfall distribution throughout the year in Sri Lanka. When considering the trend of the yearly rainfall in seven selected cities; it is observable that Rathmalana in wet zone and Batticaloa in dry zones how significant increase (significant one as the R^2value is close to 0.6) in yearly annual rainfall while other five cities do not show significant changes. 5 year and 10 year moving averages in Batticaloa city seem to show an increase in rainfall (figure 1), but even the averages show strong variations. At the end of the observation period (after 2001) the yearly rainfall is 300 mm (25% increases) higher than at the beginning (1970-1977).

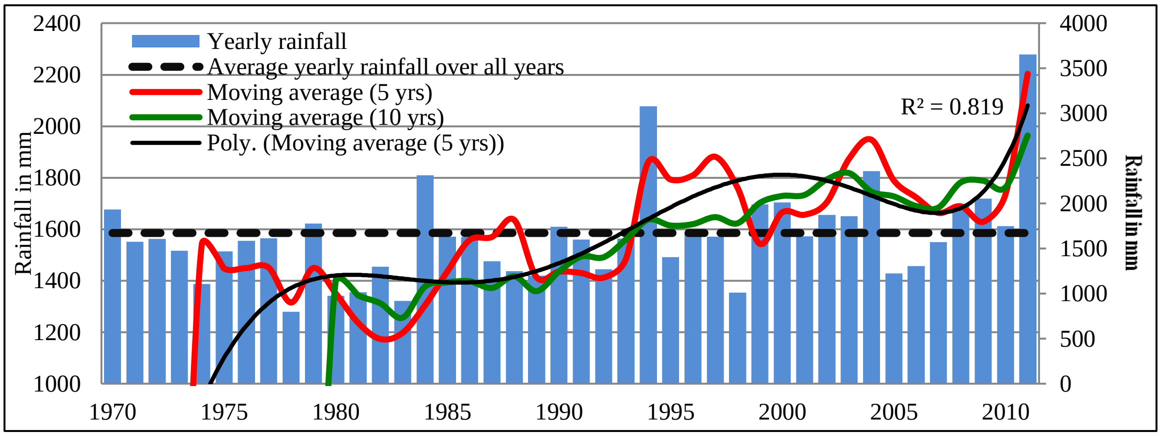


Figure 4.1.1:Annual Rainfall variations - Batticaloa Station
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

5 year and 10 year moving averages in Rathmalana seem to show a significant increase in rainfall (figure 2), at the end of the observation period (after 2001) the yearly rainfall is 500 mm (25% increases) higher than at the beginning (1980-1990). 10-year polynomial tends (significant one as the R^2value is more than 0.7) clearly shows that annual rainfall of Rathmalana weather station continually increase in rapid rate.

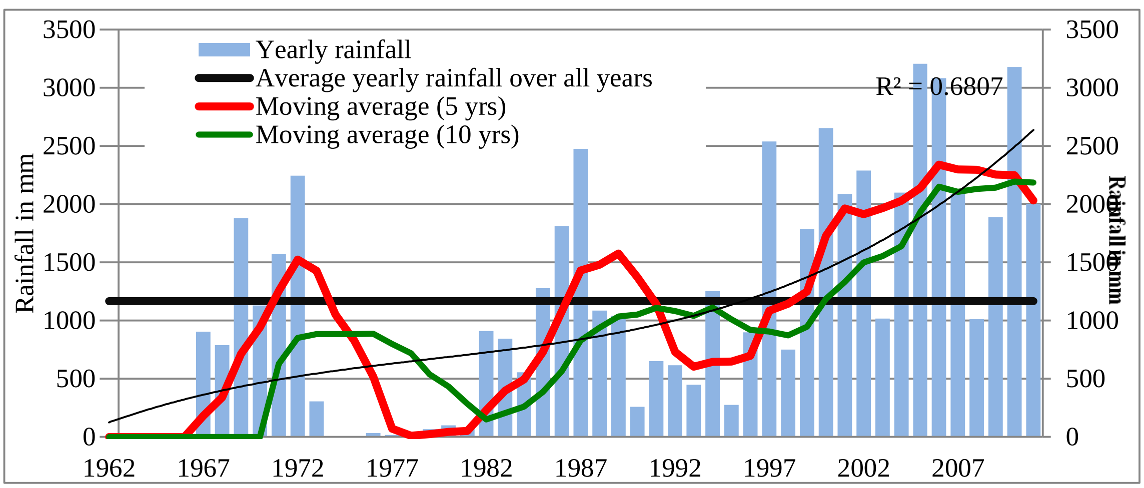


Figure 4.1.2:Annual Rainfall Variation – Rathmalana Station
Note: The unusual trend found for 1972-1982 may be due to the missing values
*Source***:** Prepared by Authors based on Meteorology data, Meteorology Department, SL

4.2 Monsoon Rainfall

Table 4: Trends in the monsoon rainfall for the period from 1971 – 2011

Station	**Northeast-monsoon (December-February)**	**First Inter-monsoon (March - April)**	**Southwest-monsoon (May-September)**	**Second Inter-monsoon (October-November)**
Hambantota	The 10 year moving averages ($R^{2=}$-0.23) seem to show a slit decrease (Ex: 1980s:150mm, 2010s:80mm)	Did not show significant change	The 10 year moving averages ($R^{2=}$0.27) seem to show a slit increase (Ex: 1980s:100mm, 2010s:200mm)	Did not show significant change
Galle	The 10 year moving averages ($R^{2=}$0.21) seem to show a slit increase (Ex: 1980s:270mm, 2010s:370mm	Did not show significant change	The 10 year moving averages ($R^{2=}$0.88) seem to show a continues increase (Ex: 1980s:800mm, 1990s:1000m, 2000s:1100mm 2010s:1300mm	Did not show significant change
Rathmalana	Did not show significant change	Did not show significant change	Show an very significant increase ($R^{2=}$0.754) ((Ex: 1990s:600mm, 2010s:1400mm)	Show an very significant increase ($R^{2=}$0.626) ((Ex: 1990s:400mm, 2010s:1300mm)
Katunayaka	Did not show significant change	Did not show significant change	Did not show significant change	Did not show significant change
Puttalam	Did not show significant change	Did not show significant change	Did not show significant change	Did not show significant change
Trincomalee	Did not show significant change	Did not show significant change	Did not show significant change	Did not show significant change
Batticaloa	Show an very significant increase ($R^{2=}$0.596) ((Ex: 1990s:150mm, 2010s:400mm	Did not show significant change	Did not show significant change	Show an very significant increase ($R^{2=}$0.668) ((Ex: 1990s:800mm, 2010s:2500mm

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

In considering the trends in monsoon rainfall; again the Rathmalana and Batticaloa has shown a significant increase in monsoon rainfall. In the case of Rathmalana; a considerable increment of Southwest monsoon ($R^{2=}$0.754) and second inter monsoon ($R^{2=}$0.626) can be clearly observed with the positive R^2factor while Batticaloa showed a substantial increase of second inter monsoon ($R^{2=}$0.596) as well as the North-east monsoon ($R^{2=}$0.668). From the other five stations even though Galle and Hambantota has also shows silt increase trend of the Southwest monsoon it is only very slight increase of the monsoon rainfall trend which can't be taken significantly. The important factor is that in Hambantota, it has shown silt decrease in trend of Northeast monsoon rainfall. These factors can be clearly displayed in a graphical form as follows. Considering the "Southwest-monsoon season from May to September in Galle observatory station, the moving average for 5 years trend shows slight increase after 1995 and continued till 2003 while the moving average for 10 years trend shows a considerable increase from 1993 – 1999 and then 2003 – 2009 with positive R^2factor ($R^{2=}$ 0.8808)

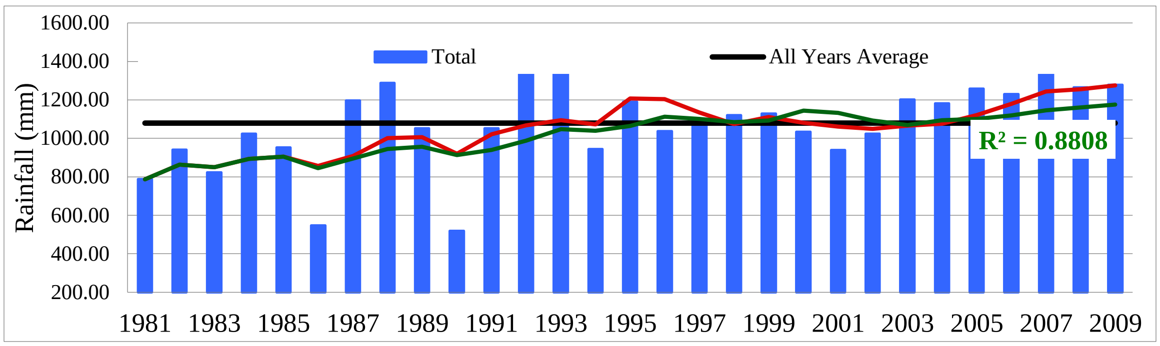


Figure 4.2.1: Rainfall "Southwest-monsoon (May-September)" season – Galle Station
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

As it has clearly shown in the below graph, Rathmalana observatory station shows significant increase of both "Southwest-monsoon season" from May to September ($R^{2=}$ 0.754) and "Second Inter-monsoon season" from October to November ($R^{2=}$ 0.4624). Considering the "Southwest monsoon" as well as the "Second Inter-monsoon" in Rathmalana; both of the seasons shows to start the increment from 1993 and continuously increased till 2008.

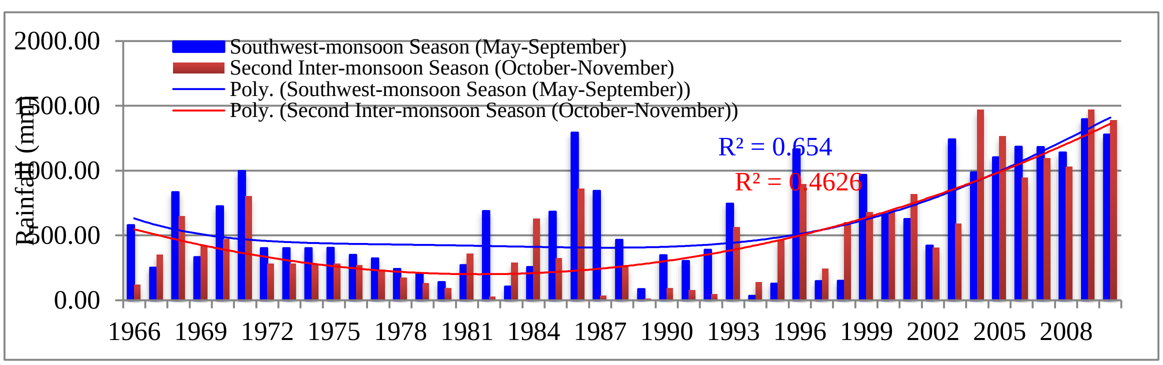


Figure 1.2.2: Rainfall "Southwest-monsoon (May-September)" and Second Inter-monsoon (October-November) season – Rathmalana Station
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

When considering the Batticaloa Station; the "First Inter-monsoon" shows mostly a steady pattern with very tiny increments till 2003 and after it appears to be slightly increased till 2009 ($R^{2=}$0.501). But the "Northeast monsoon" effected to the Batticaloa station shows very significant increase after the year 2006 ($R^{2=}$0.6237) with the increment pattern shows from 1991 slightly.

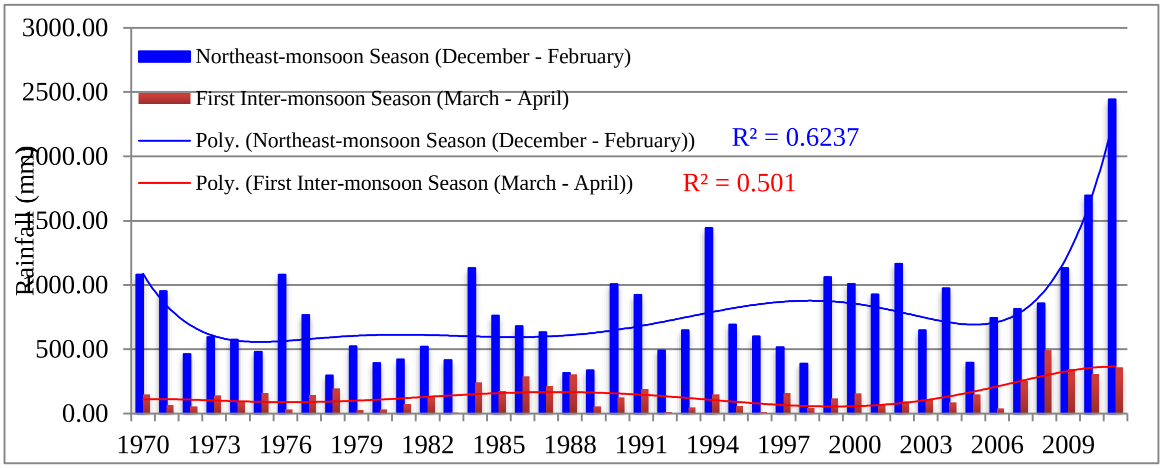


Figure 4.2.3: Rainfall "Northeast-monsoon (December-February)" and Frist Inter-monsoon (December-February) season – Batticaloa Station

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

4.3 Rainy Days

In order to examine trends in the number of rainy days, the annual number of rainy days and extreme rainy days were obtained from the original daily rainfall record at each station. Regression analysis was performed on the number of rainy days at each station. Extreme rainy days includes number of days more than the 90 percentile, 95 percentile and 99 percentile of rainfall according to the station between 19712011. See Table 5 for the results.

Table 5: Trends in the rainy days for the period from 1971 – 2011

Station	No. of rainy days	Extreme rainy days (90%)	Extreme rainy days (95%)	Extreme rainy days (99%)
Hambantota	Slightly decrease $R^{2=}$0.29 m (Slope)=-0.433 c (Intercept)=970	Slightly increase R^2=0.23 m (Slope)=0.19 c (Intercept)= -362	Increase R^2=0.43 m (Slope)=0.53 c (Intercept)= -1002	Slightly increase R^2=0.22 m (Slope)=0.47 c (Intercept)= -243
Galle	Slightly decrease $R^{2=}$0.31 m (Slope)=-0.400 c	Slightly increase R^2=0.34 m (Slope)=0.16 c (Intercept)= -287	Increase R^2=0.47 m (Slope)=0.59 c (Intercept)=-1021	Very significant increase R^2=0.53 m (Slope)=0.72 c (Intercept)= -1211

	(Intercept)=991			
Rathmalana	Slightly increase $R^{2=}0.59$ m (Slope)=0.134 c (Intercept)=926	Increase R^2=0.53 m (Slope)=0.86 c (Intercept)= -1698	Significant increase R^2=0.67 m (Slope)=0.79 c (Intercept)= -1321	Very significant increase R^2=0.64 m (Slope)=0.82 c (Intercept)= -1041)
Katunayaka	Slightly decrease $R^{2=}0.49$ m (Slope)=-0.510 c (Intercept)=1151	Insignificant increase R^2=0.20 m (Slope)=0.06 c (Intercept)= -66	Increase R^2=0.55 m (Slope)=0.57 c (Intercept)= -1132	Slightly increase R^2=0.32 m (Slope)=0.35 c (Intercept)= -335
Puttalam	Slightly decrease $R^{2=}0.43$ m (Slope)=-0.425 c (Intercept)=946	Insignificant increase R^2=0.27 m (Slope)=0.04 c (Intercept)= -53	Slightly increase R^2=0.44 m (Slope)=0.27 c (Intercept)= -428	Slightly increase R^2=0.22 m (Slope)=0.29 c (Intercept)= -473
Trincomalee	Slightly decrease $R^{2=}0.33$ m (Slope)=-0.321 c (Intercept)=738	Insignificant increase R^2=0.11 m (Slope)=0.03 c (Intercept)= -36	Slightly increase R^2=0.27 m (Slope)=0.22 c (Intercept)= -319	Slightly increase R^2=0.39 m (Slope)=0.23 c (Intercept)= -503
Batticaloa	Slightly decrease $R^{2=}0.44$ m (Slope)=-0.355 c (Intercept)=810	Slightly increase R^2=0.58 m (Slope)=0.29 c (Intercept)= -378	Significant increase R^2=0.77 m (Slope)=0.73 c (Intercept)= -1426	Very significant increase R^2=0.63 m (Slope)=0.91 c (Intercept)= -1121

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

The number of rainy days in a season is of particular importance for, hydro system, drainage network, industrial activities and day today urban activities. Examining trends in the variability of the number of extreme rainy days is vital as it is a decisive factor in urban flooding including flash flood. With regard to the number of rainy days received in each season, considering the R^2 factor of the each study stations; all the study stations have shown slight decreases in number of rainy days. But there is considerable increase in extreme rainy days. Considering the extreme rainy days (90%, 95% and 99%)Galle, Rathmalana and Batticaloa shows very significant increase of the trends in rainy days. Polynomial trends of all seven cities (refer figure 4.3.1) to understand the significant increase

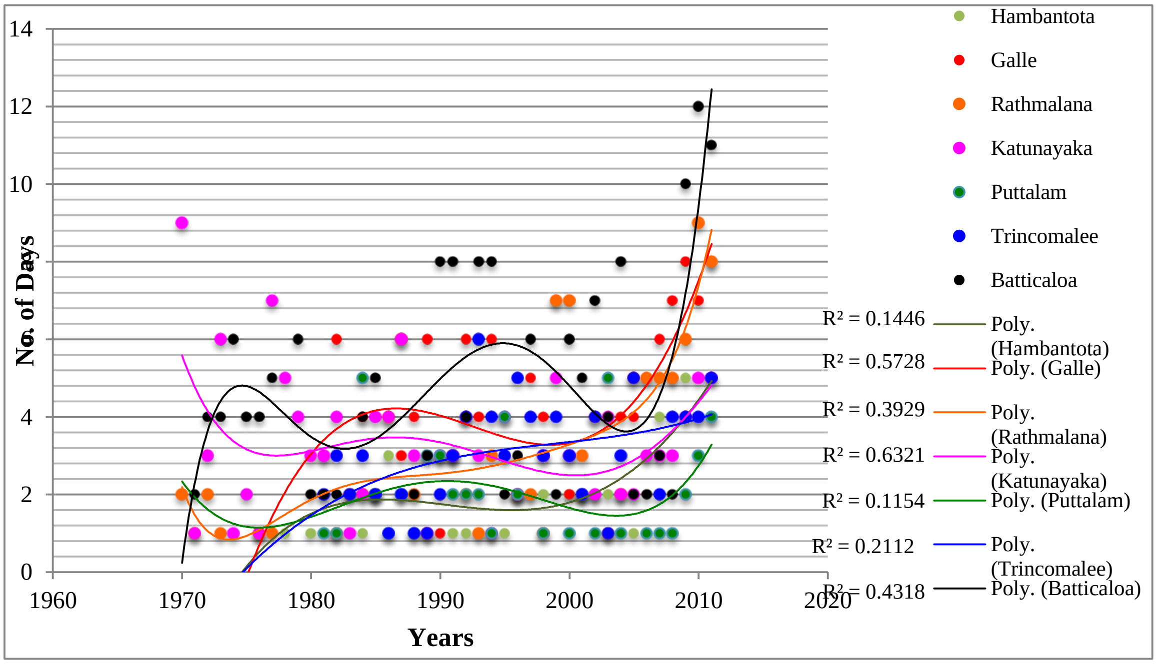


Figure 4.3.1:No. of days above 99% percentile of daily rainfall from all daily recodes
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

4.4 Maximum and minimum daily temperature

4.4.1 Average maximum and minimum daily temperature

Average maximum and minimum daily temperature is also one of important indicator to identify the changing trends of the climate as it will be a factor which changes the built environments and purposely the changes of usual human activities. As an examples when temperature increase or decrease people used to use more air conditions or heaters according to their preferences and the structures of the buildings and built ups will be also changed accordingly

Referring to the results obtained by the seven observation stations; Hambantota, Galle, Trincomalee and Batticaloa show positive trends in average maximum daily temperature while Rathmalana, Katunayaka and Puttalam show negative trends. Considering the average minimum daily temperature; while Rathmalana and Trincomalee show significant decrease all the other five stations shows significant increase in average minimum temperature. The important observation is that in Rathmalana study stations shows significant decrease in both average maximum and minimum daily temperature

Table 6: Trends in the average maximum and minimum temperate for the period from 1971 – 2011

Station	Average maximum daily temperate	Average minimum daily temperate
Hambantota	Significant increase m (Slope)=0.034; $R^{2=}$0.92 1980s: 30.25^{0}C 2010s: 31.20^{0}C	Significant increase m (Slope)=0.033; $R^{2=}$0.53 1980s: 24.30^{0}C 2010s: 25.15^{0}C
Galle	Significant increase m (Slope)=0.021; $R^{2=}$0.21 1980s: 29.16^{0}C 2010s: 29.96^{0}C	Insignificant increase m (Slope)=0.007; $R^{2=}$0.04 1980s: 25.10^{0}C 2010s: 25.25^{0}C
Rathmalana	Significant decrease m (Slope)= -0.034; $R^{2=}$0.22 1980s: 28.12^{0}C 2010s: 27.19^{0}C	Significant decrease m (Slope)= -0.037; $R^{2=}$0.27 1980s: 24.10^{0}C 2010s: 23.10^{0}C
Katunayaka	Significant decrease m (Slope)= -0.022; $R^{2=}$0.36 1980s: 31.32^{0}C 2010s: 30.93^{0}C	Significant increase m (Slope)=0.085; $R^{2=}$0.26 1980s: 24.90^{0}C 2010s: 26.90^{0}C
Puttalam	Insignificant decrease m (Slope)= -0.010; $R^{2=}$0.33 1980s: 31.78^{0}C 2010s: 32.99^{0}C	Insignificant increase m (Slope)=0.011; $R^{2=}$0.10 1980s: 24.48^{0}C 2010s: 24.67^{0}C
Trincomalee	Significant increase m (Slope)=0.038; $R^{2=}$0.57 1980s: 31.75^{0}C 2010s: 31.56^{0}C	Insignificant decrease m (Slope)= -0.001; $R^{2=}$0.10 1980s: 25.07^{0}C 2010s: 24.98^{0}C
Batticaloa	Significant increase m (Slope)=0.033; $R^{2=}$0.61 1980s: 37.20^{0}C 2010s: 38.00^{0}C	Insignificant increase m (Slope)=0.0065; $R^{2=}$0.08 1980s: 24.60^{0}C 2010s: 24.80^{0}C

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

4.4.2 Daily maximum and minimum daily temperature

When observing the trends in the daily maximum and minimum temperate for the period from 1971 – 2011; Hambantota, Rathmalana, Trincomalee and Batticaloa have very significant increase in number of days above the 95% percentile for temperature while number of days below the 1% and 5% percentile for temperature in those seven stations do not show significant changing pattern.

Table 7: Trends in the daily maximum and minimum temperate for the period from 1971 – 2011

Station	No. of days above the 95%-percentile for	No. of days above the 99%-percentile for	No. of days below the 5%-percentile for	No. of days below the 1%-

	temperature	temperature	temperature	percentile for temperature
Hambantota	Very Significant increase	Significant increase	Significant decrease	Slightly decrease
Galle	Slightly increase	Did not show significant change	Did not show significant change	Did not show significant change
Rathmalana	Very Significant increase	Did not show significant change	Did not show significant change	Did not show significant change
Katunayaka	Very Significant increase	Did not show significant change	Did not show significant change	Did not show significant change
Puttalam	Did not show significant change	Did not show significant change	Did not show significant change	Did not show significant change
Trincomalee	Very Significant increase	Did not show significant change	Did not show significant change	Did not show significant change
Batticaloa	Very Significant increase	Did not show significant change	Did not show significant change	Did not show significant change

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

Number of days above the 95% and 99% percentile for temperature-amounts are considered as extreme events. Figure 6 shows that, In Hambantota, the number of days with temperature above 95% ($R^{2=}0.69$) and 99% ($R^{2=}0.46$) seems to significant increase in last decade. According to the meteorological information it has increased by 15 days by 2010s in comparison to 1990s.

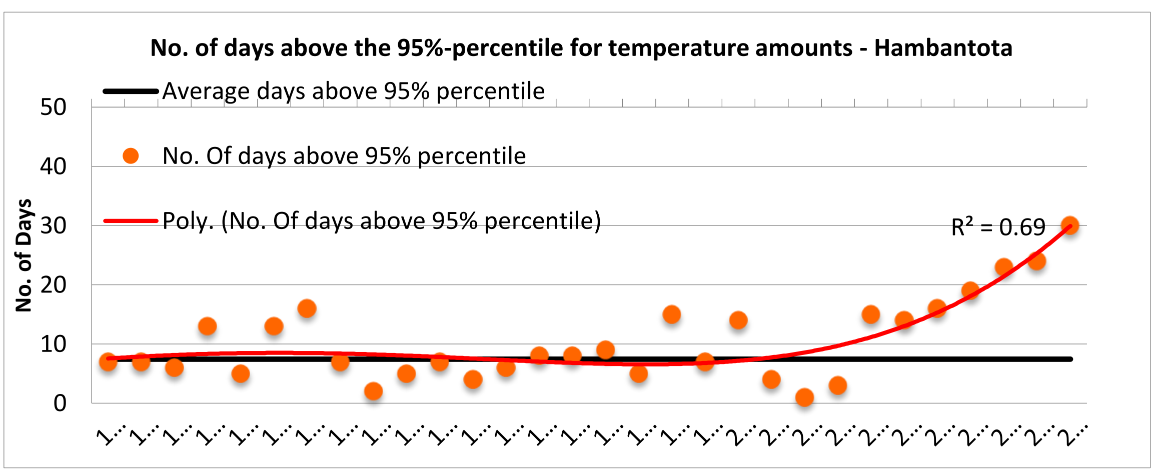


Figure 4.4.1: No of days above 95% percentile for temperature amounts - Hambantota

Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

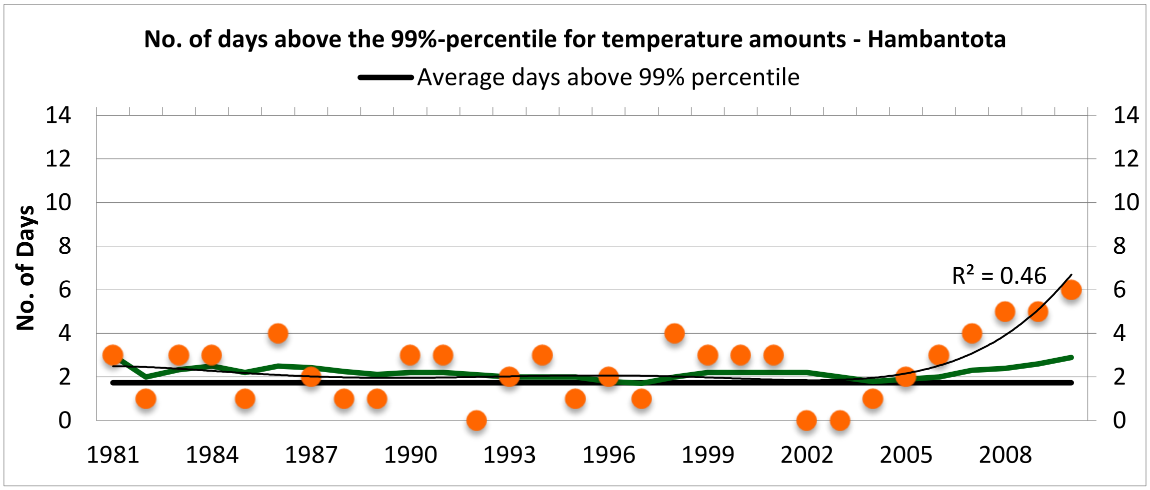


Figure 4.4.2: No of days above 99% percentile for temperature amounts - Hambantota
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

Number of days above the 95% percentile for temperature amount is considered as extreme events. Figure 8 shows that, In Katunayaka, the number of days with temperature above 95% (R^2=0.6417) seems to significant increase continuously from the year 2005.

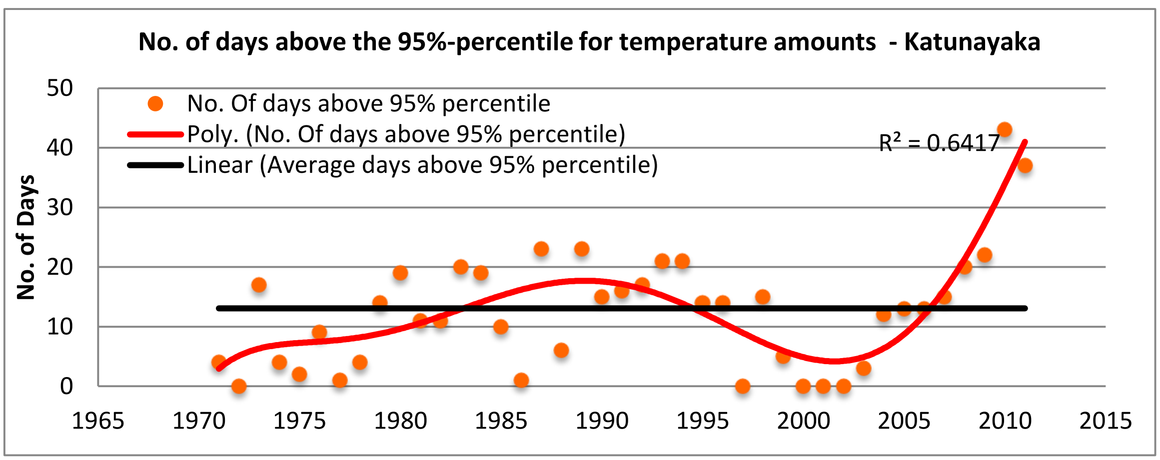


Figure 4.4.3: No of days above 95% percentile for temperature amounts - Katunayaka
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

Number of days above the 95% percentile for temperature amount is considered as extreme events. Figure 8 shows that, In Galle, the number of days with temperature above 95% (R2=0.5285) seems to significant increase continuously from the year 1995.

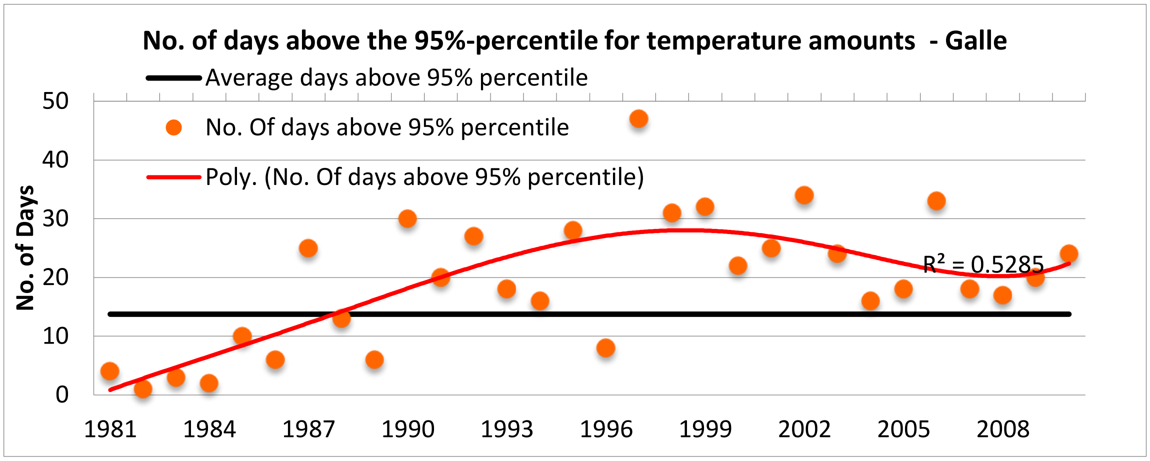


Figure 4.4.4: No of days above 95% percentile for temperature amounts - Galle
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

Number of days above the 95% percentile for temperature amount is considered as extreme events. Figure 9 shows that, In Rathmalana, the number of days with temperature above 95% (R^2=0.5466) seems to significant increase continuously from the year 1995.

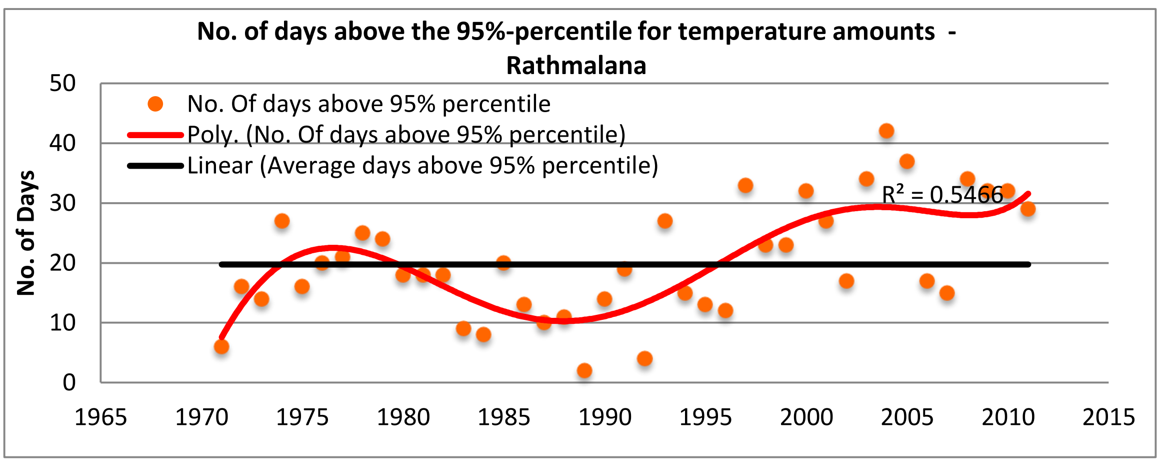


Figure 4.4.5: No of days above 95% percentile for temperature amounts - Rathmalana
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

Number of days above the 95% percentile for temperature amount is considered as extreme events. Figure 8 shows that, In Batticaloa, the number of days with temperature above 95% (R2=0.5466) seems to significant increase continuously from the year 1995.

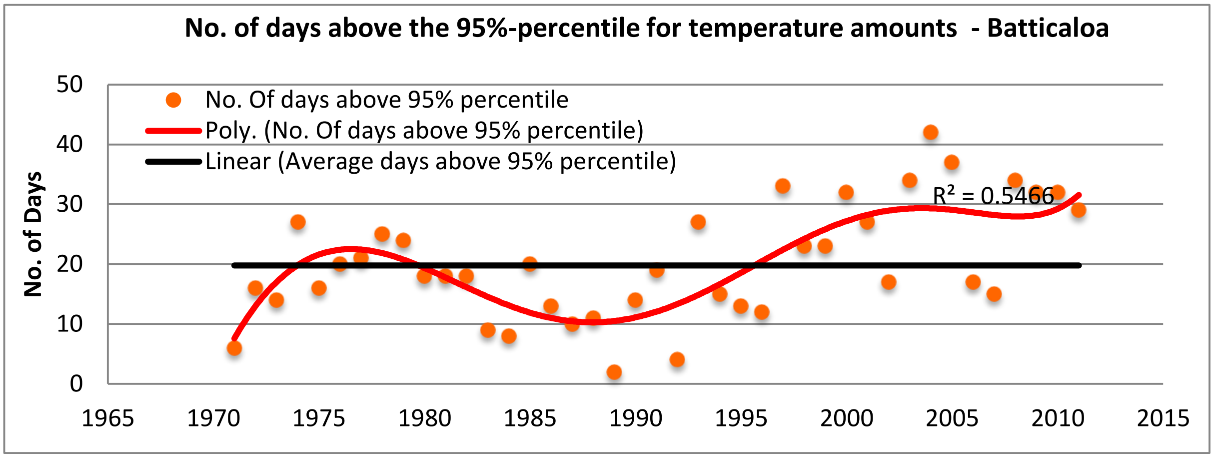


Figure 4.4.6: No of days above 95% percentile for temperature amounts -Batticaloa
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

Number of days above the 95% percentile for temperature amount is considered as extreme events. Figure 8 shows that, In Trincomalee, the number of days with temperature above 95% (R2=0.2294) seems to significant increase continuously from the year 1987.

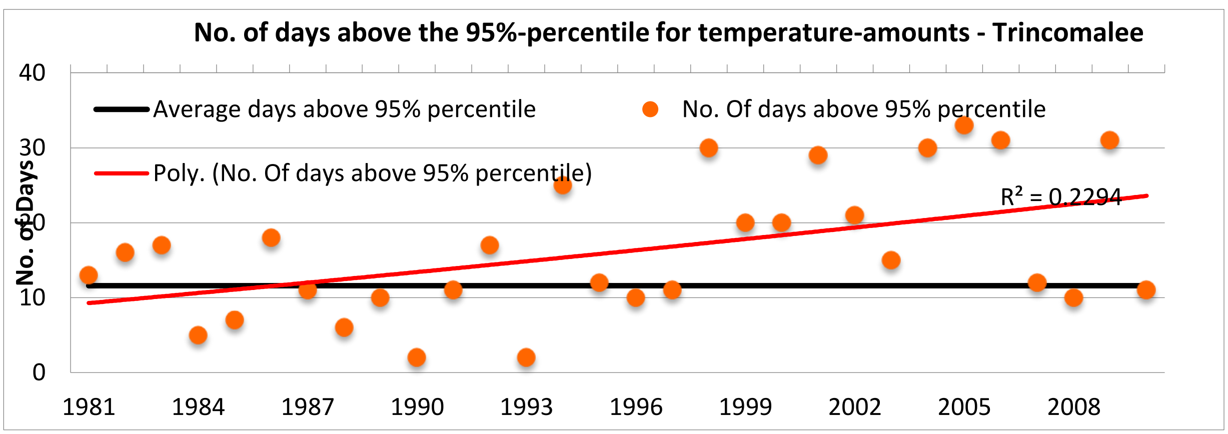


Figure 4.4.7: No of days above 95% percentile for temperature amounts -Trincomalee
Source: Prepared by Authors based on Meteorology data, Meteorology Department, SL

4.5 Summary of change

The results obtained by analyzing the selected climatic parameters of the study can be summarized as below. It gives clear understanding of the variation patterns of the different parameters in a way we can easily come to a conclusion

Table 8: Summery of the changes

Parameters	Observatory Stations						
	Wet Zone			Dry Zone			
	Rathmalana	Galle	Katunayaka	Hambantota	Puttalam	Trincomalee	Batticaloa
Yearly annual rainfall	SI	IC	IC	IC	IC	IC	SI
Monsoon Rainfall							
Northeast monsoon	IC	II	IC	ID	IC	IC	SI
First inter monsoon	IC	IC	IC	IC	IC	IC	IC
Southwest monsoon	SI	SI	IC	II	IC	IC	IC
Second inter monsoon	SI	IC	IC	IC	IC	IC	SI
Number of Rainy Days	II	ID	ID	ID	ID	ID	ID
Extreme rainy days (90%)	II	II	II	II	II	II	II
Extreme rainy days (95%)	SI	SI	SI	SI	II	II	SI
Extreme rainy days (99%)	SI	SI	II	II	II	II	SI
Average maximum daily temperature	SD	SI	SD	SI	ID	SI	SI
Average minimum daily temperature	SD	II	SI	SI	ID	ID	II
Number of extreme warm days							
Extreme warm days (95%)	SI	II	SI	SI	IC	SI	SI
Extreme warm days (99%)	IC	IC	IC	SI	IC	IC	IC

(SI: Significant Increase, II: Insignificant Increase IC: Insignificant Change, SD: Significant Decrees, ID: Insignificant decrease)

5. Conclusion

The findings of the study revealed that there are significant changes in climatic parameters such as rainfall and temperature of the selected seven coastal observatory stations which can be influenced to the decision making process of the urban planning. The slight or significant changes of the selected climatic parameters can highly influenced to the urban areas of specific locality as well as to entire region considering the concentrated activities in that specific areas. According to the results; although the number of rainy days has decreased in most of the observatory stations; the total annual rainfall has not decreased. This could indicate that the intensity of rainfall events may have increased together with increased durations of dry spells with maximized trend of the temperature. Practically with the nearby incidents which we heard about floods as well as the droughts also prove these findings as results of continuous climatic variations

In this context, the case for improved climate awareness in urban planning needs to be emphasized and essentially merged with the decisions in urban planning. Not only in Sri Lanka but also cities worldwide should have to begin to recognize their role in addressing anthropogenic climate change with modern city planning. As some examples; the increasing risk of floods needs to be controlled by identifying the areas that are most vulnerable to flooding and discouraging property development in those areas, by imposing regulations on planning in high-risk areas. More detailed recommendations can be issued in connection with local and regional plans and local authority regulations revised and supplemented as required. The easiest way to prepare for the effects of climate change is to factor them in when planning and developing new areas.

So emerging climatic variations according to the analyzed meteorological data has to be essentially considered in the process of decision making on urban planning because as this research revealed these climatic variables show different changing patterns. By integrating the climatic variations wisely in the urban planning can invest the capital of the country to the development rather than unnecessarily spend it on post disaster rehabilitations.

Acknowledgements

The data on rainfall and temperature variations those obtained through the project titled, ‘Climate response city development strategies for Sri Lankan cities’ which was undertaken by UN Habitat Asia/Pacific regional center, in consultation with Faculty of Architecture, University of Moratuwa 2010. And ‘Climate Resilient action plans for coastal urban areas of Sri Lanka’ which was undertaken by United Nations Human Settlement Program (UN- HABITAT), University of Moratuwa (UOM), Batticaloa Municipal Council (BMC), Negombo Municipal Council (NMC)In partnership with: Norwegian Institute for Water Research (NIVA)

References

Attry D.S, Tyagi A. (2010) Climate profile of India. Indian network on climate change assessment. India meteorological department, Ministry of earth sciences, New Delhi 23-39

Brinch E., Silver C. (2010) One hundred years of city planning's enduring and evolving connections. Journal of the American planning association 75, 113-122

Domroes, M., E. Ranatunge. (1993) A Statistical approach towards a regionalization of daily rainfall in Sri Lanka. I. J. of Climatology, 740-755

Folland, C. K., et.al (2001) Observed climate variability and change, in Climate Change 2001: The Scientific Basis. Third Assessment Report of the Intergovernmental Panel on Climatic Change, Cambridge Univ. Press, New York.85- 97

Hebbert M., Mackillop F. (2011) Urban Climatology Applied to Urban Planning - a knowledge circulation failure? Climate science in urban design working paper 4.3-30

Jayawardhane H.K.W, Sonnadara D.U.G, Jayewardane D.R. (2005) Trends of rainfall in Sri Lanka over the last century. Sri Lankan journal of physics 8-9, 6-11

Manawadu L., Fernando N. (2008) Climate change in Sri Lanka 3,4

Manton, M. J., et al. (2000), Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961– 1998. International journal on climatology 21, 269–284

Tank A.M.G.K. et al. (2006) Changes in daily temperature and precipitation extremes in central and south Asia. Journal of geophysical research vol. 111 1-3

Thivari R.C. (2006) Analytical study on variation of climatic parameters at Aizawl, Mizoram- India. Bulletin of Arunachal Forest Research 22 (1&2): 33-39