EFFECT OF URBANIZATION ON RAINFALL OVER KILIMANJARO REGION

By

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i

DECLARATION

I hereby declare that this research project is my work and has not been presented in any University or learning institution for academic award.

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ABSTRACT

Precipitation is a key link in the global water cycle and a proxy for changing climate. This study sought to assess the effects of urbanization on precipitation in Kilimanjaro region based on observed rainfall and population data between the period 1982 and 2012. Graphical analysis was used to determine space time variability of rainfall amount, frequency and intensity while the relationship between urbanization and rainfall was achieved through correlation and regression analysis.

The slope of regression line showed that trend of total rainfall over urban areas (Moshi) was decreasing more than rural areas (Kia and Same) with increasing frequencies of rainy days. Annual rainfall showed highest peak in April and November with the number of rainy days reducing with increasing threshold value of rainfall category. Graphical analysis indicated a bimodal rainfall distribution over the region with highest peak during April óMay óJune and lowest peak in November óDecember -January while the slopes of regression line were all noted to be quite small with values of less than 0.3. Regression analysis indicated a positive relationship between rainfall and population over all stations except same with coefficient of determination (R2) values less than 9% and thus little influence of population on the amount of rainfall received over Kilimanjaro region. Correlation analysis showed that rainfall and population were negatively related over Lyamungu Moshi and Kia with correlation coefficient values of -0.23, -0.16 and -0.30 respectively. At 95% significance level, the student t test showed that these correlations were not significantly related to population as all values of t computed were less than t tabulated.

Over Kilimanjaro region changes in population had little influence on rainfall amount, intensity, and frequency over Kilimanjaro region. However, the slight modification in rainfall over urbanized environment would necessitate convenient approaches and planning to help prevent modification of rainfall and thus urban climate. Therefore, this information will form basis of urban policy formulation towards limiting further changes in urban environment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.1   Introduction

Assessing rainfall anomaly is a frequent practice in determining climate of an area. Rainfall is an important weather parameter which can be extremely variable in space and time, and also due to the local conditions prevailing at a particular area.

It is estimated that by 2025, 80% of the world's population will live in cities (UNFPA 1999). Urban area modifies the boundary layer processes through the creation of Urban Heat Island (UHI), increases in surface roughness and the contribution of pollution increase the number of cloud condensation nuclei over urban regions, with complex series of feedback to cloud formation and precipitation (Anna, 2012)

Population increase in urban areas brings implications certainly for agriculture, urban planning, water resource management, but also for weather and climate forecasting. Urbanization rapidly spreads all over the world, and markedly modifies, through altering surface energy budget in cities, local and regional atmospheric properties, especially the planetary boundary layer (PBL), atmospheric stability and turbulence.

Urban areas can be much affected by rainfall than in rural areas, yet many of the weather forecast models that we rely on every day do not include urban land surfaces. Understanding urban rain could improve the weather forecast for heavily populated regions, giving more accurate warning of potential flood-producing rains. And that information could save human life and property today.

As cities around the world grow at a rapid rate, the need to understand their influence on the local and regional climate becomes more necessary. It is known that urban areas have an influence on their local climate (Arnfield 2003, Shepherd 2005), as changes in land use and land cover continuously alter energy and moisture fields as well as circulation patterns above urban environments.

1.2 Problem statement

Urban and suburban areas in Kilimanjaro region are observed to grow as a result of population growth.

Urbanization growth is expected to modify the boundary layer processes through the creation of surface roughness and the contribution of pollution increase the number of cloud condensation nuclei over urban regions, with complex series of feedback to cloud formation and precipitation

Extensive urbanization influences weather and local climate through complex urban use and development activities. Change in rainfall pattern in both space and time caused by urbanization is one of the challenges that are faced in major cities.

Most of the weather forecasting from Tanzania Meteorological Agency targets homogeneous zones for monthly and seasonal weather review. Local factors caused by increased different activities due to population increase contribute to these changes in rainfall pattern.

1.3 Hypothesis

The hypothesis of this study is stated that changes in urbanization (population) in Kilimanjaro region have no effect on rainfall.

1.4 Objectives of Study

The main objective of the study was to assess the influence of urbanization on rainfall in Kilimanjaro region. To achieve this main objective, four specific objectives were pursued. These include;

i)   To determine the space and time variation of rainfall amount in Kilimanjaro region

ii)   To determine the space and time variation of categorized rainfall days (frequency) over Kilimanjaro region

iii)   To determine the space and time variation of rainfall intensity over Kilimanjaro region.

iv)   To determine the relationship between population and rainfall in Kilimanjaro region

1.5 Justification

Rainfall is an important weather parameter which remains extremely variable in space and time which is caused by the climate of a particular area. Assessing rainfall anomaly is a frequent practice in determining the climate of an area. Over urban areas, rainfall variability is attributed to the prevailing local conditions. Some of these local conditions include modified land surface parameters such as roughness lengths, heat storage and anthropogenic heat emissions (Kanda, 2007) which is caused by buildings, industries and number of vehicles which contribute to an increased aerosol concentration and temperature.

If weather forecasting would target specific cities especially urban areas then the forecasting would be more helpful to people by giving more accurate weather forecasting and warnings for the potential of flood producing rains on agriculture, urban planning, disaster management etc.

Improved understanding of the influence of urban centers on local climate will be of significant benefit to decision makers dealing with climate-sensitive issues. This information would provide insight of the contribution of urbanization to rainfall modifications and thus improves the accuracy of models used in weather forecasting and warnings for potential reduction of economic and social costs of extreme events such as flush floods.

1.6 Area of study

This section describes the physical characteristics and climatology of the area of study.

1.6.1 Kilimanjaro Region

Kilimanjaro is one of the 30 regions of Tanzania. The capital of the region is Moshi. The Kilimanjaro Region is home to Mount Kilimanjaro. The region is bordered to the north and east by Kenya, to the south by the Tanga Region, to the southwest by the Manyara Region, and to the west by the Arusha Region as shown in Figure 1. It is located at Coordinates: 3°20 05.58 S 37°20 25.37 E. The population of the Kilimanjaro Region was 1,640,087 in 2012 (URT, 2012)
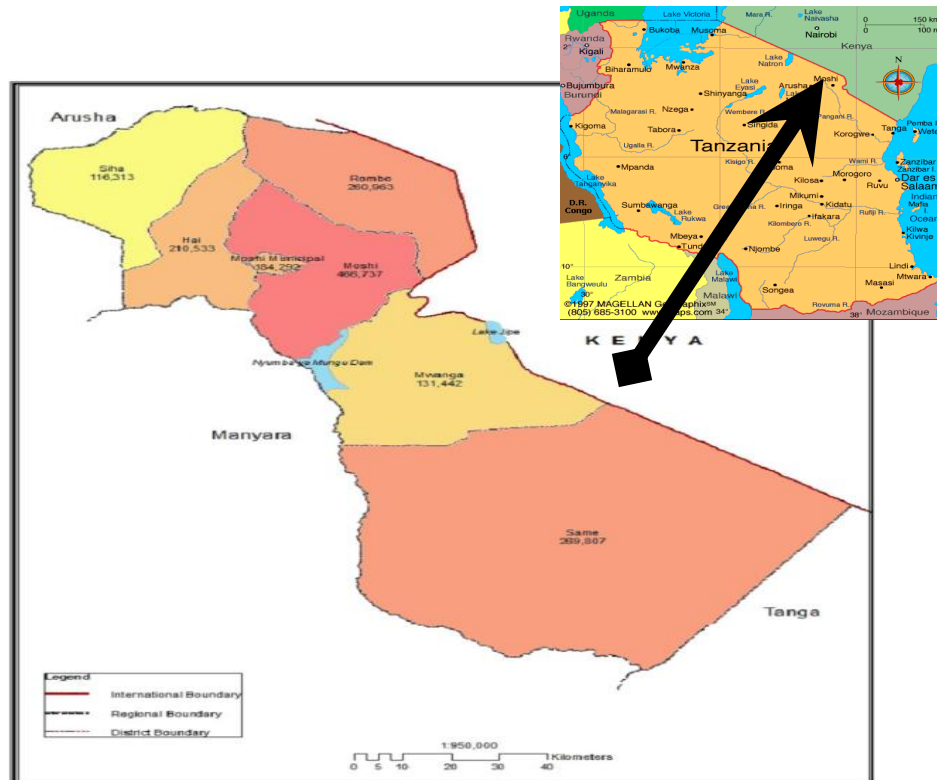
Figure 1: Kilimanjaro region population distribution by district/council 2012 ((The map of Tanzania is given for orientation)

1.6.2 Climatology

Kilimanjaro region is located in the northern Tanzania the region in which the highest mountain in Africa is found. The mountain range in this region extends from the western Indian Ocean to Lake Victoria.

This area experiences two main rainy seasons namely the ‑long rainsø season from March to May and the short rains season from October to December, associated with the northward and southward movement of the Inter-Tropical Convergence Zone (ITCZ), respectively.

The short rains are associated with the re-establishment and south-ward passage of the near-equatorial trough and accompanying wind confluence over the western Indian Ocean. Long rains are more abundant, whilst short rains are more variable (Kabanda and Jury, 1999)

The weather and climate over northern Tanzania is mainly influenced by monsoons, the ITCZ, subtropical anticyclones, African jet streams, and easterly/westerly wave perturbations.

Teleconnections with global-scale systems like the El Niño/Southern Oscillation (ENSO) and regional systems play an important role.

CHAPTER TWO

2   Literature review

Many studies evaluated the relationship between the urban areas and precipitation (Sherpherd, 2005). As early as 1921, Horton (1921) noted a tendency of thunderstorm formation over large cities rather than the rural environment.

Data from the Tropical Rainfall Measuring Mission (TRMM) satellite's precipitation radar (PR) were employed to identify warm-season rainfall (1998ó2000) patterns around Atlanta, Georgia; Montgomery, Alabama; Nashville, Tennessee; and San Antonio, Waco, and Dallas, Texas. Results reveal an average increase of about 28% in monthly rainfall rates within 30ó60 km downwind of the metropolis, with a modest increase of 5.6% over the metropolis. Portions of the downwind area exhibit increases as high as 51%. The percentage changes are relative to an upwind control area. It was also found that maximum rainfall rates in the downwind impact area exceeded the mean value in the upwind control area by 48%ó116 % (Shepherd et al, 2002).

In the past 30 years, several observational and climatological studies have theorized that the UHI (Urban Heat Island) can have a significant influence on mesoscale circulations and resulting convection. Early investigations found evidence of warm-season rainfall increases of 9%ó17% over and downwind of major urban cities (shepherded, 2005).

The Metropolitan Meteorological Experiment (METROMEX) was an extensive study that took place in the 1970s in the United States to investigate modification of meso scale and convective rainfall by major cities. In general, results from METROMEX have shown that urban effects lead to increased precipitation during the summer months.

In cities, natural land surfaces are replaced by artificial surfaces that have very different thermal properties (e.g. heat capacity, specific heat, and thermal inertia). Such surfaces are typically more capable of storing solar energy and converting it to sensible heat resulting in urban air to be 2-10° warmer than that in surrounding nonurban areas (Oke, 1988).

There is renewed debate on how the urban environment affects precipitation variability. Shepherd (2005) provides a recent review of possible mechanisms for urbanization to enhance or

initiate precipitation or convection. They include enhanced convergence due to increased surface roughness in the urban environment, Enhanced sensible heat fluxes, Destabilization due to urban heat island (UHI)-thermal perturbation of the boundary layer and resulting downstream translation of the UHI circulation or UHI-generated convective clouds and Enhanced aerosols in the urban environment for cloud condensation nuclei sources.

The twentieth century witnessed the rapid urbanization of the world's population. The global proportion of urban population increased from a mere 13 per cent in 1900 to 29 per cent in 1950 and, according to the 2005 Revision of World Urbanization Prospects, reached 49 per cent in 2005. Since the world is projected to continue to urbanize, 60 per cent of the global population is expected to live in cities by 2030. According to the latest United Nations population projections, 4.9 billion people are expected to be urban dwellers in 2030 (United Nations Population Division, 2005)

Through an increased population in urban areas, natural surfaces (grass, crops, and soil) are replaced by man-made surfaces (concrete and pavement) with thermal properties (albedo, thermal conductivity, and emissivity) different from nonurban areas. It has long been (Shepherd et al. 2002) found that rainfall is modified by major urban areas according to the observations from space borne rain radar on the TRMM satellite. Many early modeling studies also have indicated that the urban areas leads to enhanced surface convergence over the downwind of the urban region, and thus results in enhanced precipitation. They found that the distance downwind where rain formed depend upon the strength of surface heating amplitude, the wind speed, and the relative humidity (Carraca,2007)

However, it should be noted that the effects of urban areas on precipitation may depend on the climate regime and geographical locations of cities.

When urbanization occurs, the surface heat and moisture fluxes, and the overlying temperatures, humidity, and winds are significantly altered from what would occur if the region remained rural, as CAPE (convective available potential energy) and CIN (convective inhibition) is altered. Spatial variations in the CAPE and CIN and in the mesoscale circulations that result from landscape heterogeneity, such as from urbanization, can focus on deep cumulus convection

(Kishtawal, 2009), using coupled atmosphere land models, quantified the relative changes in sensible and latent heat fluxes as a function of urban land cover for Oklahoma City, Atlanta and Houston respectively. Enhanced sensible heat flux was likely one factor related to the resolved urban-induced precipitation. These three studies also noted enhanced low-level convergence at the urbanórural interface. Low-level convergence from the urban-induced meso-circulation may serve as an initial or complementary source of lift required for convection.

All these works show a close link between the daily extreme and heavy precipitation weather events and precipitation climatic trend. In most countries that have experienced a significant increase or decrease in monthly or seasonal precipitation the tendency has been for this change to be directly related to a change of the same sign in the amount of precipitation falling during the heavy and extreme precipitation events. Therefore, in this study, I will investigate the influences of urban expansion in Moshi on heavy summer precipitation through the use of climatological data.

CHAPTER THREE

3 Data and Methodology

3.1 Source of data

In this study, observed rainfall and population Data were used. Rainfall data was sought from the Tanzania Meteorological Agency for the period between 1982 and 2012 from Lyamungu, Kia, Same and Moshi stations. Moshi airport station was used as a representative for urban environment. Population Data was obtained from the Tanzania Population and Housing Census of 2012 (URT, 2012)

3.2 Data quality control

Data quality control applied in this study was homogeneity test using single mass curve

3.2.1 Estimation of Missing data

In this study, there was no missing data observed therefore the procedure for calculating missing data was not performed. Data analysis was conducted using standard statistical methods. The methods employed in this study include time series analysis, graphical analysis, Correlation analysis and regression analysis.

3.2.2 Homogeneity Test

In this study the quality of the estimated data was examined using single mass curve which involve the plotting of the station rainfall totals against time. In this method, the straight line indicates a homogeneous record whilst heterogeneity would be indicated by significant variations of some of the plots from the straight line.

3.3 Methodology

Different methods which have been used to analyze data include the following:

3.3.1 Space time variability of rainfall amount, frequency and intensity over Kilimanjaro region

Space time variability of rainfall amount over Kilimanjaro region was assessed using two methods. These were time series analysis and graphical analysis. These two methods are discussed below.

3.3.1.1 Time series analysis

Time series analysis was used to study the effect of urbanization on rainfall over Kilimanjaro region. Trend analysis as one of the component of the Time series analysis was used to study variation on rainfall days in Kilimanjaro region.

This involves plotting the graphs of total annual rainfall against time to investigate the trend of rainfall over Kilimanjaro region.

Trends refers to long term movement of a time series (Muhati et al, 2007).Many methods are available to describe trends in climatological data. These methods may be classified into several categories, some of which are: graphical, polynomial, and statistical methods. In present study the trend analysis was established through a graphical plot of the rainfall data series.

3.3.1.2 Graphical Analysis

Graphical analysis was used to show variation of rainfall amount between rural and urban in Kilimanjaro region.

This method involved plotting frequency of rainfall (days) against time (months). In this method different rainfall category was set based on greater or equal to 1mm, 5mm and 20mm rainfall to determine the intensity of rainfall during different months. The advantage of this method is that it provides quick visual observation of the presence trend at a given time. Moreover the use of the graphical approach for trend analysis is simple. On the other hand graphical methods has shortcoming such as its subjectivity as they depends on individual judgments. To overcome this shortcoming, the coefficient of determination (R^2) was calculated so as to quantify the graphical results. The slope of linear regression line was also computed. The slope is the vertical distance divided by the horizontal distance between any two points on the line, which is the rate of change along the regression line and given by equation 1 below.

$$b = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2}$$

í ..1

In the equation above, x represented independent variables (time) while y represented dependent variables (rainfall amount, category or intensity).

3.3.2 Relationship between urbanization and rainfall over Kilimanjaro region

The relationship between urbanization and rainfall was investigated using correlation and regression analysis.

3.3.2.1 Correlation analysis

Correlation analysis was done to determine the degree of relationship between urbanization parameter (population) and rainfall amount in Kilimanjaro region as shown in equation 2

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2 \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

í í í í í í í í í í í í í í í í í í í ..2

In Equation 2, r_{xy} is the correlation coefficient, n is the sample size, xi and yi are the variables being correlated and $(\bar{x}), (\bar{y})$ are the mean values of variables being correlated.

The computed correlation values were tested for statistical significance at 95% confidence level using the student-t- test as shown in the formula below;

$$t_{n-2} = r \sqrt{\frac{n-2}{1-r^2}}$$

í ..3

In Equation 3 above, t is the value of the student-t-test n is the number of observations and r - is the correlation being tested

3.3.2.2 Regression Analysis

A simple linear regression model was applied to show the relationship between population and annual total rainfall and rainfall days. A trend is a gradual increasing or decreasing change over time and is usually associated with cumulative natural phenomenon such as urbanization of an area. The analysis was used to investigate the urbanization induced trend in rainfall in

Kilimanjaro region. This was done by analyzing changes in rainfall with reference to population at a given district in which the station is located. Linear rainfall trend and the coefficient of determination (r^2) were computed from the regression model.

CHAPTER FOUR

4   Results and discussion

The results obtained in this study using the methods outlined in the preceding chapter are discussed in this section

4.1   Data quality control

In all the stations, less than 10% of data were missing. Therefore, estimation of missing data was not performed. The results for test of homogeneity of rainfall datasets are presented in the Figures 2 to 5.
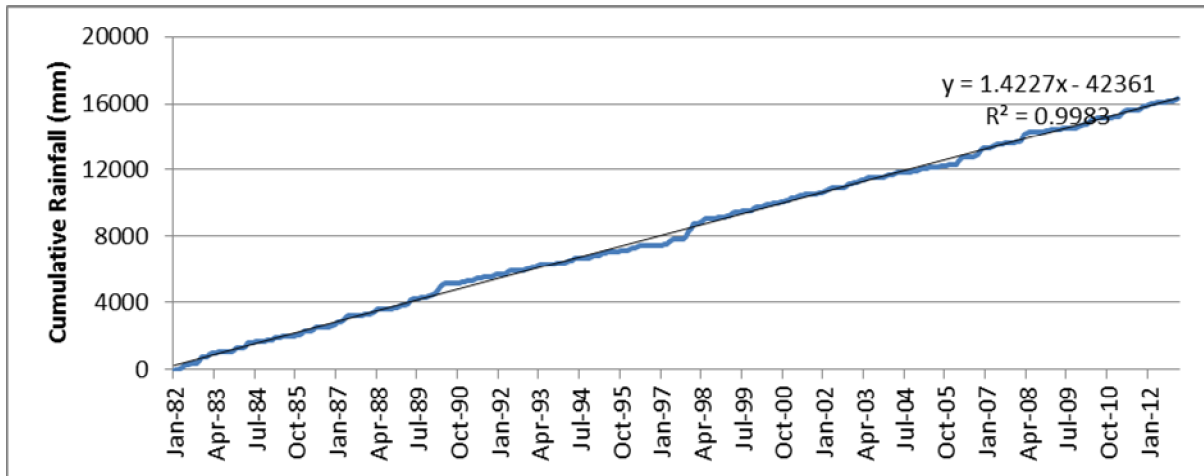

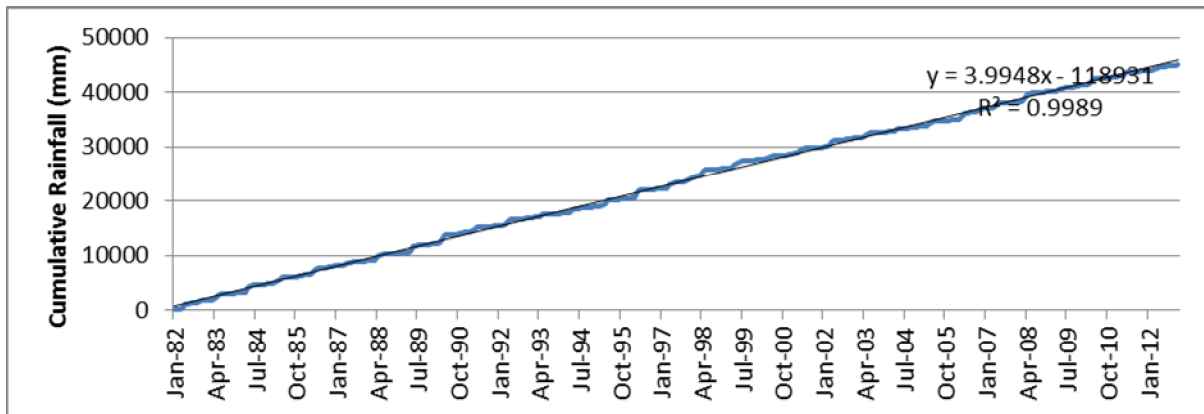Figure 2: Single mass curve of cumulated rainfall over Same

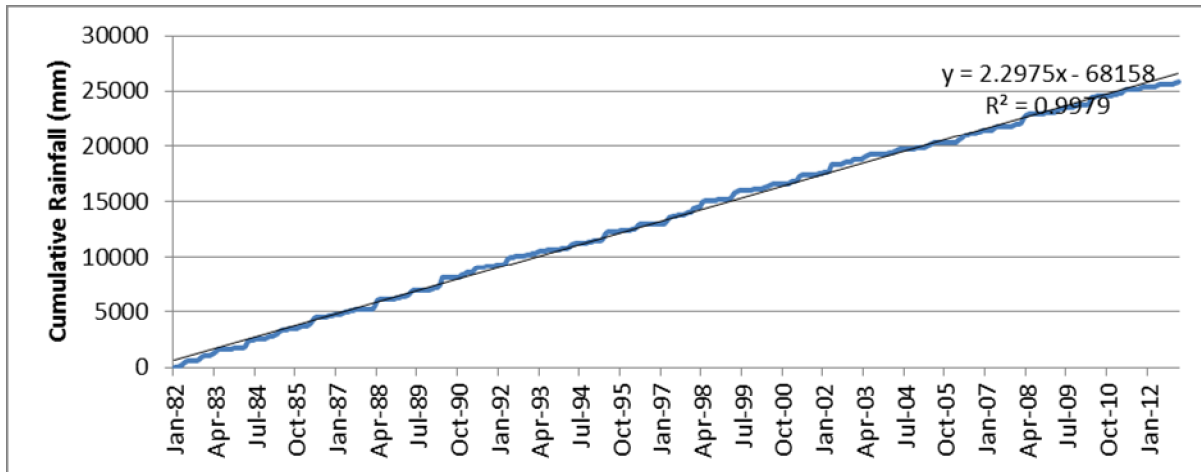Figure 3: Single mass curve of cumulated rainfall over Lyamungu

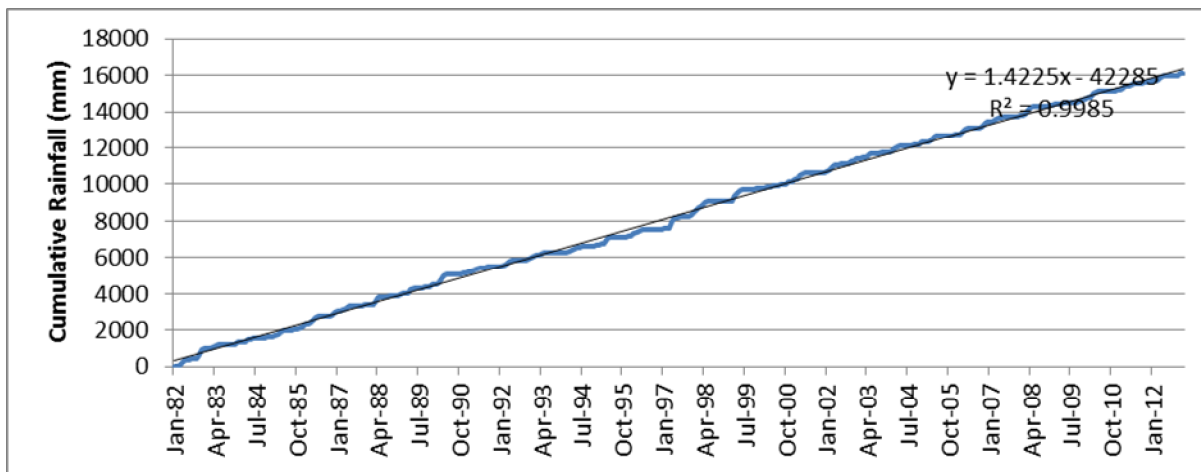Figure 4: Single mass curve of cumulated rainfall over Kia

Figure 5: Single mass curve of cumulated rainfall over Moshi

The graphs of cumulated rainfall (figures 2 -5) in all had coefficient of determination (R^2) values all above 0.99. These implied that more than 99% of data were within the line of best. Therefore, rainfall data set available was consistent and valid and thus homogeneous and considered useful for further analysis.

4.2 Space time variability of rainfall amount and rainy days over Kilimanjaro region

The graphs of total annual rainfall were plotted against time to investigate the trend of rainfall over the Kilimanjaro region. The Table 1 shows the slope of regression line while the Figures 6 - 9 presents graphical plots of annual variation of rainfall amount and frequency.

14

Table 1: Slope of regression line for rainfall stations over Kilimanjaro region

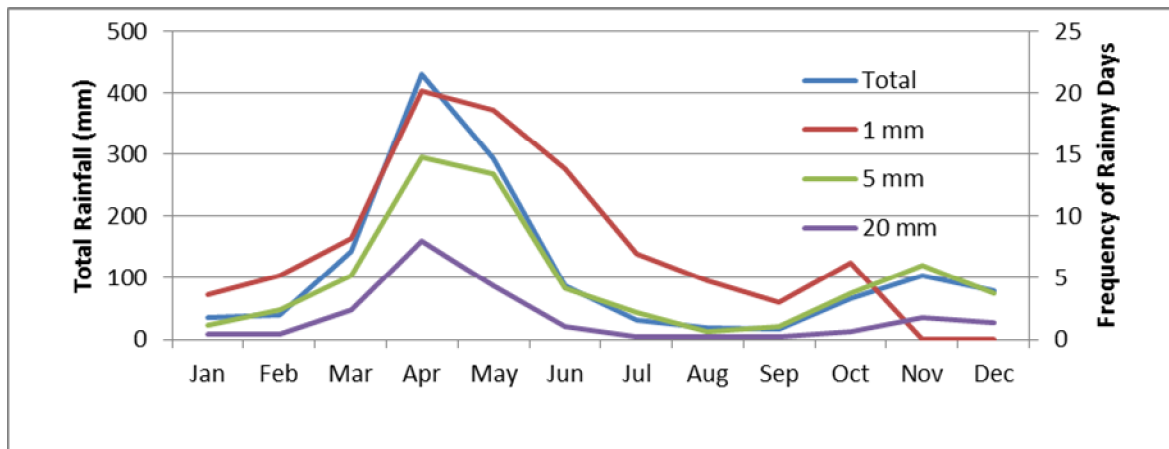| Station	Slope of Regression Line			
Station	Total rainfall	$\times$ 1 mm	$\times$ 5	$\times$ 20
Lyamungu	-7.3	0.04	0.57	0.46
Moshi	-7.5	0.03	0.37	0.47
Kia	-2.90	0.06	0.40	0.35
Same	-0.86	0.03	0.37	0.47

Figure 6: Annual variation of rainfall amount (mm) and rainy days over Lyamungu station
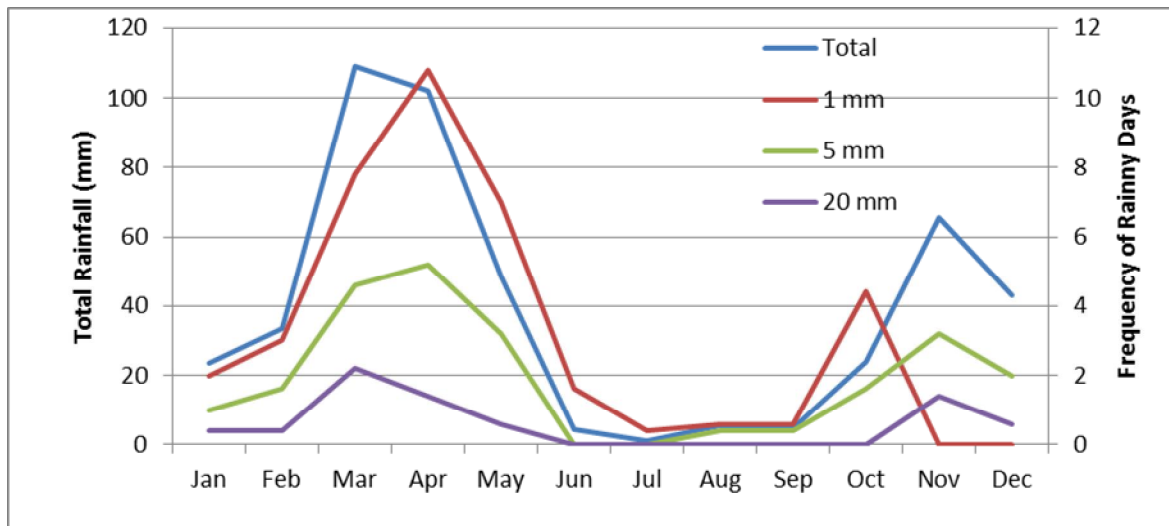

Figure 7: Annual variation of rainfall amount (mm) and rainy days over Kia station
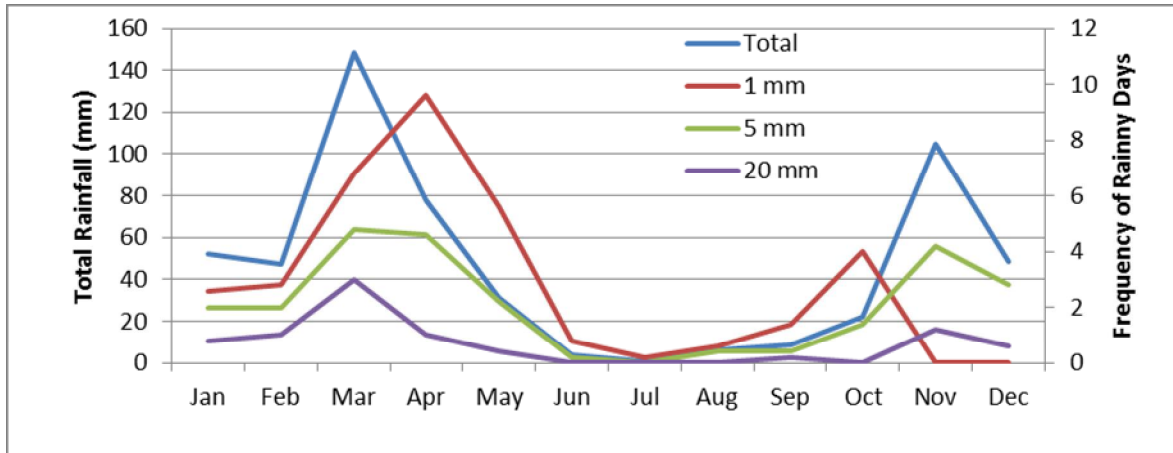
15

Figure 8: Annual variation of rainfall amount (mm) and rainy days over Moshi station
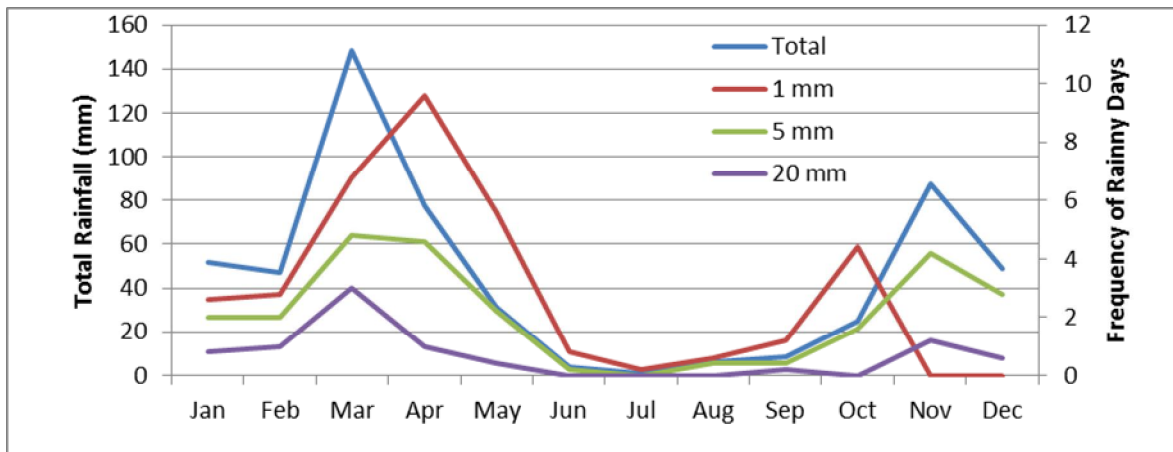

Figure 9: Annual variation of rainfall amount (mm) and rainy days over Same station
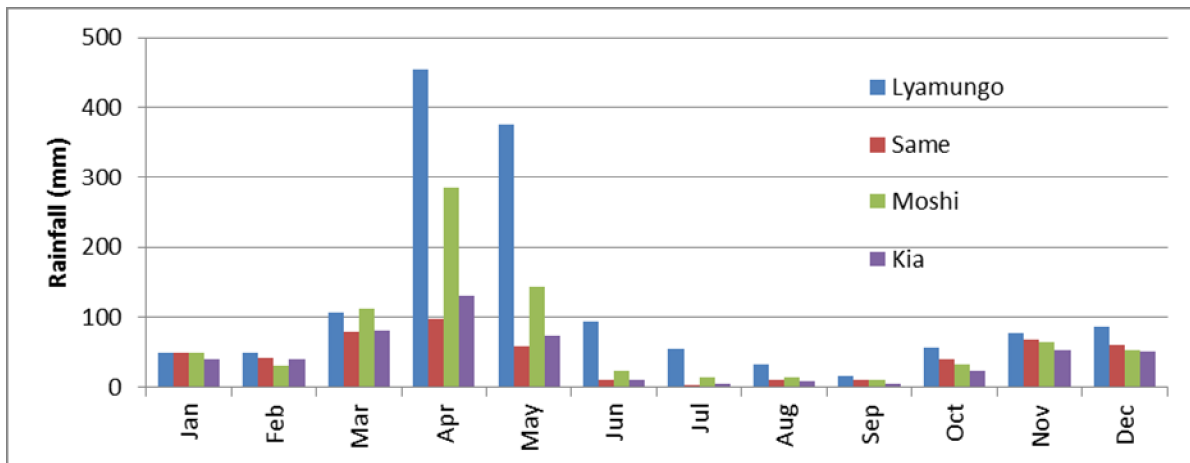

Figure 10: Annual variation of rainfall amount (mm) Over Lyamungo, Same, Moshi and Kia region from 1982 to 2012

16

In all stations (table 1), the slope of regression line showed the trend of total rainfall at both urban and rural areas were decreasing with Moshi and Lyamungu indicating greater decrease than Kia and Same while the frequencies of rainy days were increasing. These differences might be attributed to the differences in data used as slope of total rainfall was computed based on the 31 year period monthly rainfall data (1981 to 2012) while rainy days were computed based on daily rainfall data for five years (2008 to 2012). Annual time series of rainfall showed highest peak in April and November. This implied that Kilimanjaro region received bimodal rainfall. The study also noted that number of rainy days reduced with increasing threshold. Lyamungu station recorded the highest amount of rainfall while Same rainfall station recorded the least amount of rainfall during the March óApril óMay Season

4.3   Space time variability of rainfall intensity over Kilimanjaro region

The graphs of total annual rainfall were plotted against time to investigate the trend of rainfall over Kilimanjaro region. The Table 2 and Figure 11 -13 show the slope of regression line of and graphical plots of rainfall intensity over Kilimanjaro region.

Table 2: Slope of regression line of rainfall intensity over Kilimanjaro region

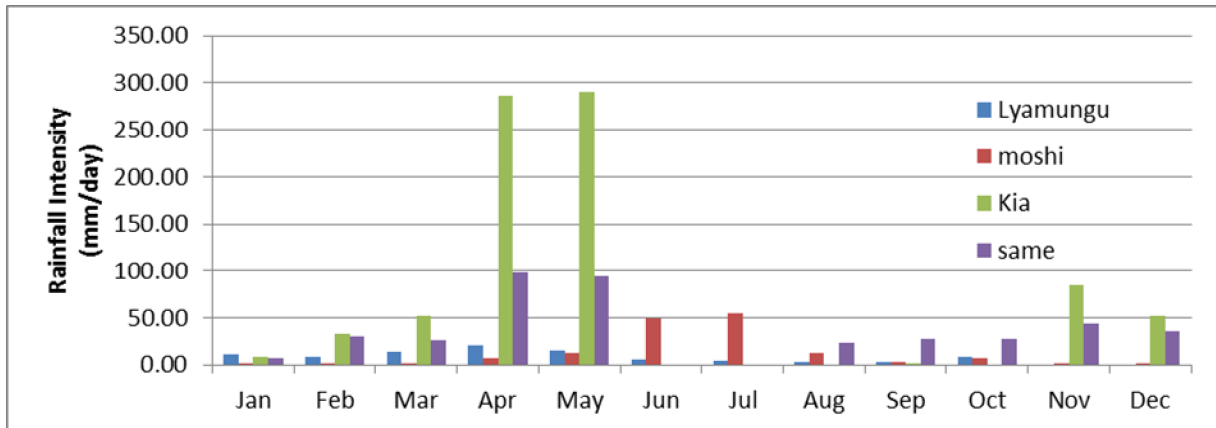| Station	Rainfall Intensity		
	$\times$ 1 mm	$\times 5$	$\times 20$
Lyamungu	-0.0020	-0.0019	0.0007
Moshi	-0.0006	-0.0083	-0.0089
Kia	-0.0038	-0.0002	-0.0035
Same	-0.0173	-0.0513	-0.0007

Figure 11: Seasonal variation of rainfall intensity for 1 mm rainfall category over various stations in the Kilimanjaro region
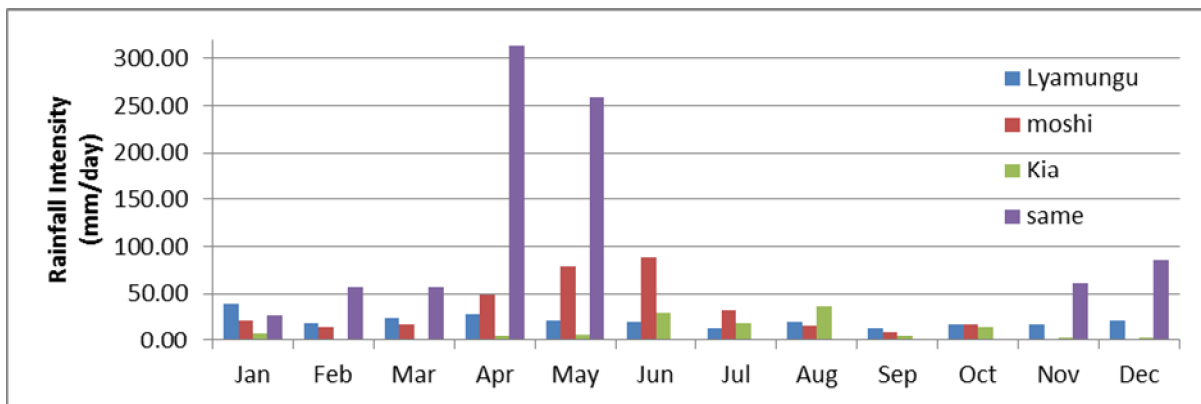

Figure 12: Seasonal variation of rainfall intensity for 5 mm rainfall category over Kilimanjaro region
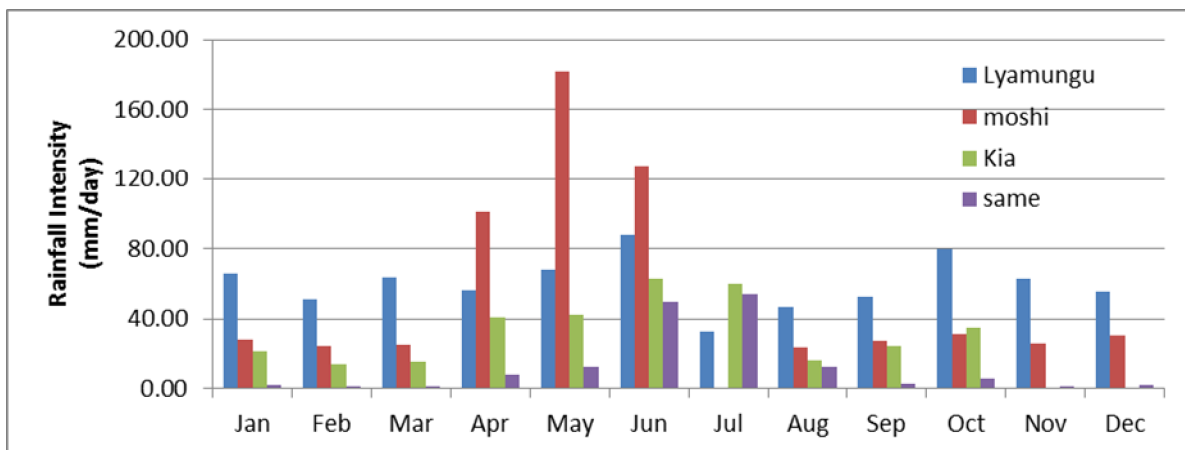

Figure 13: Seasonal variation of rainfall intensity for 20 mm rainfall category over Kilimanjaro region

Graphs of seasonal variation of rainfall intensity (figures 11 -13) depicted a bimodal rainfall pattern with highest peak in May during the April May June period and lowest peak in December during the November December January Period. These patterns followed the bimodal rainfall pattern experienced over Kilimanjaro region.

The slope of regression line showed rainfall intensity was decreasing at all stations based on the ×1 mm and × 20 mm rainfall category while the ×5 mm category decreased in Kia and Same stations and increased Lyamungu and Moshi stations. However, the slopes of regression line were all noted to be quite small of less than 0.3. This indicated that rainfall intensity observed over Kilimanjaro region was changing at a small rate.

4.4   Relationship between urbanization and rainfall over Kilimanjaro region

The effects of population on rainfall over Kilimanjaro region were investigated using both regression and correlation analysis. The results are presented in the following subsection.

4.4.1   Regression Analysis

Results of regression analysis are presented in figures 14 -17.

Figure 14: Regression between population and rainfall over Lyamungu
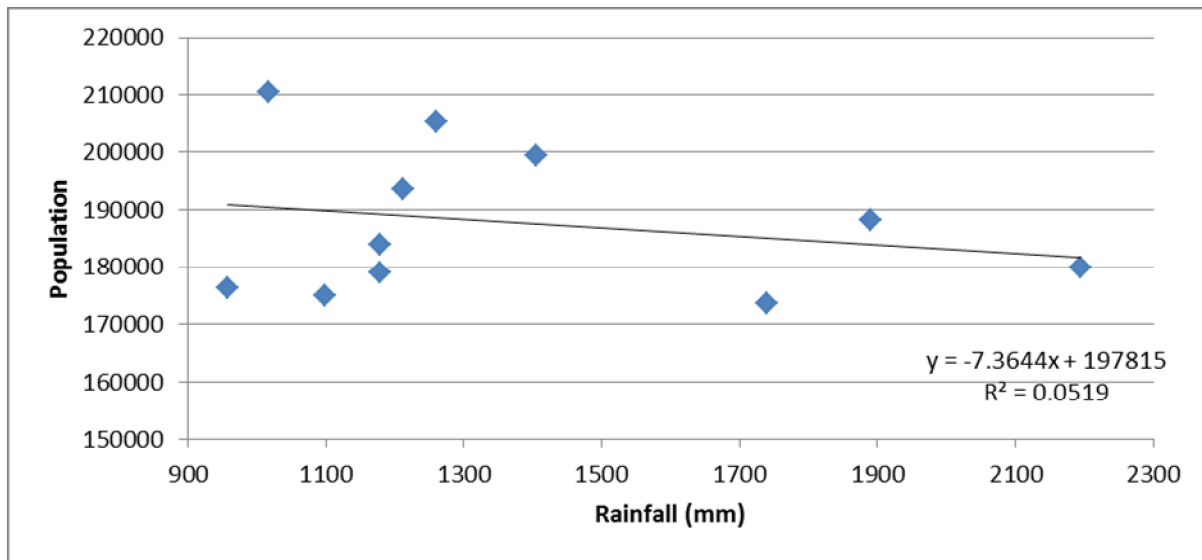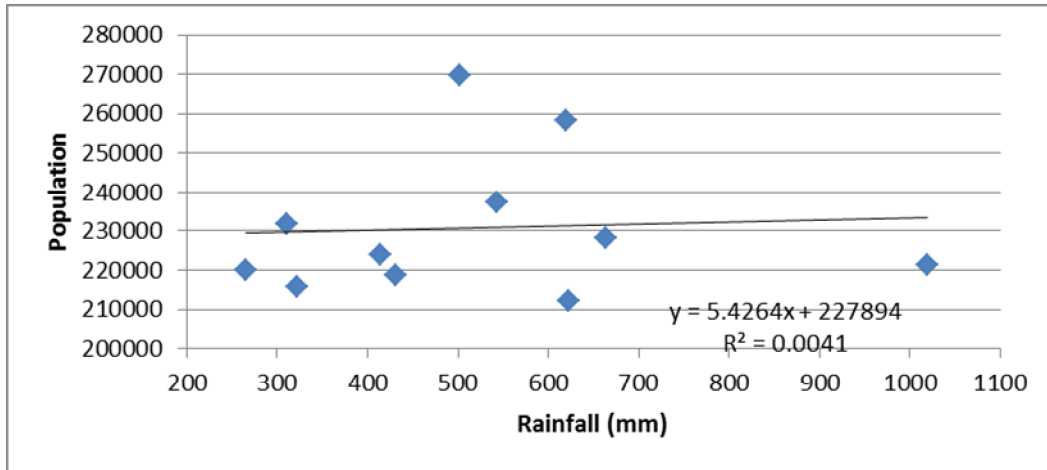
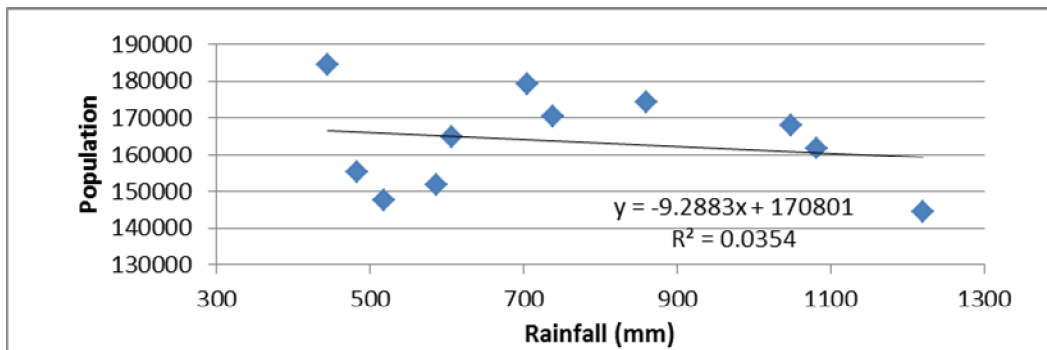Figure 15: Regression between population and rainfall over Same

Figure 16: Regression between population and rainfall over Moshi
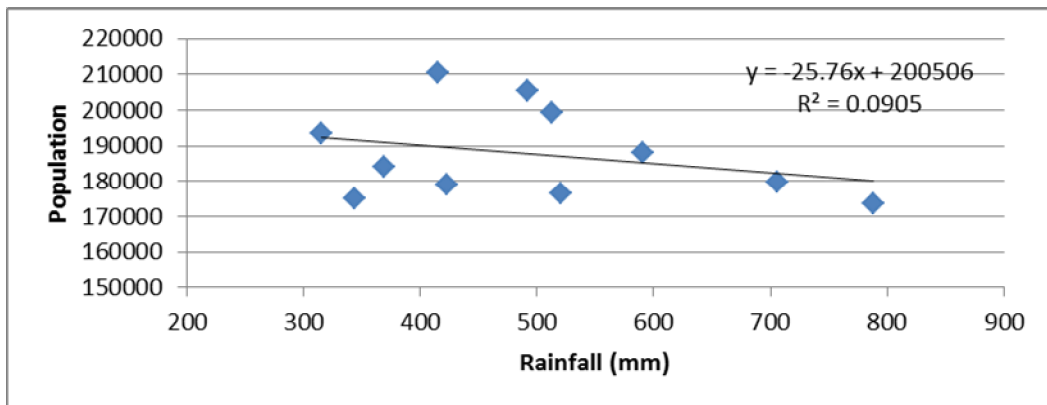
Figure 17: Regression between population and rainfall over Kia

Based on the regression analysis, Figures 14 -17 showed that rainfall over stations except same had negative relationship with population. However, the coefficient of determination (R^2) value

were all less than 9% which indicated that increasing population had little influence on the amount of rainfall received over Kilimanjaro region.

4.4.2 Correlation Analysis

Results of correlation analysis of rainfall amount, frequency (rainy days), intensity and population are presented in the table 3, 4 and 5 respectively

Table 3: Correlation between Rainfall Amount and Population

Station	Correlation Coefficient	t test	
		t computed	t tabulated
Lyamungu	-0.23	-0.702	2.26
Same	0.06	0.192	2.26
Moshi	-0.19	-0.575	2.26
Kia	-0.30	-0.946	2.26

Table 4: Correlation between Rainfall Frequency and Population

	Statistic	×1	×5	×20
Lyamungu	Pearson correlation	-0.638	-0.625	-0.891
	t test	-1.433	-1.387	-3.391
	t tabulated	**2.571**	**2.571**	**2.571**
Moshi	Pearson correlation	0.010	0.575	0.007
	t test	0.017	1.216	0.012
	t tabulated	**2.571**	**2.571**	**2.571**
Kia	Pearson correlation	-0.206	0.722	-0.607
	t test	-0.365	1.806	-1.324
	t tabulated	**2.571**	**2.571**	**2.571**
Same	Pearson correlation	0.010	0.683	0.096
	t test	0.018	1.619	0.167
	t tabulated	**2.571**	**2.571**	**2.571**

Table 5: Correlation between Rainfall Intensity and Population

Station	Statistic	×1	×5	×20
Lyamungu	Correlation coefficient	-0.270	-0.121	0.095
	t computed	-0.485	-0.212	0.165
	t tabulated	**2.571**	**2.571**	**2.571**
Moshi	Correlation coefficient	-0.028	-0.458	-0.134
	t computed	-0.048	-0.892	-0.234
	t tabulated	**2.571**	**2.571**	**2.571**
Kia	Correlation coefficient	-0.012	-0.118	-0.399
	t computed	-0.021	-0.206	-0.754
	t tabulated	**2.571**	**2.571**	**2.571**
Same	Correlation coefficient	-0.829	-0.628	0.079
	t computed	-2.577	-1.396	0.138
	t tabulated	**2.571**	**2.571**	**2.571**

Correlation analysis of rainfall amount and population (table 3) indicated a relation over Lyamungu Moshi and Kia with correlation coefficient of -0.23, -0.16 and -0.30 respectively. At 95% significance level, the student t test showed that these correlations were not significantly related to population as all computed values of t were less than tabulated values of t.

Correlation analysis of rainfall frequency for different categories (rainfall amount equal or greater than 1, 5 and 20 mm) showed either positive or negative correlations as shown in table 4. A test of significance at 95% confidence level showed that only 20 mm rainfall frequency category was significantly related to population as the magnitude of t computed (-3.391) was greater than t tabulated (2.571). This indicated that increased population had a negative effect on rainfall amount of 20 mm or more category in Lyamungu. Moreover, Lyamungu area is located downwind of the urbanized Moshi Municipality and pollutants transported and dispersed downwind could have resulted to observed relationship.

Correlation analysis between rainfall intensity and population (table 5) showed negative relationship in most stations. However, 1 mm or more rainfall category over same was

significantly related to population as the magnitude of t computed (-3.710) was greater than the t tabulated (2.571). The high number of rainfall days in Lyamungu station can also be caused by the orographic effect where by the wind ward area receive rainfall throughout the year as observed from the graphs of rainfall intensity.

This relationship could be attributed to short period of data that was available (eleven years). Moreover, population data used was linearly extrapolated based on the 2002 and 2012 census and thus contributed to observed relationship

CHAPTER FIVE

5   Summary, Conclusions and Recommendations

This chapter presents the summary, conclusion and recommendation of the study.

5.1   Summary

Rainfall is an important weather parameter which can be extremely variable in space and time. The extensive observed urbanization is thus expected to influence weather and local climate through complex urban use and development activities. Change in rainfall pattern in both space and time caused by urbanization is one of the challenges that are faced in major cities.

Rainfall is an important weather parameter which can be extremely variable in space and time. The extensive observed urbanization is thus expected to influence weather and local climate through complex urban use and development activities. Change in rainfall pattern in both space and time caused by urbanization is one of the challenges that are faced in major cities.

This study aimed to assess the influence of urbanization on rainfall in the Kilimanjaro region through determination of space time variation of rainfall amount, rainfall frequency (rainy days), rainfall intensity and their relationship with urbanization indicator (population). The objectives were achieved through time series, correlation and regression analysis.

Based on the slope of the regression line, the trends of total rainfall at both urban and rural areas were noted to be decreasing. Moshi and Lyamungu indicated greater decrease than Kia and Same while the frequencies of rainy days was increasing. Annual time series of rainfall showed highest peak in April and November. This implied that Kilimanjaro region received bimodal rainfall. The study also noted that the number of rainy days reduced with increasing threshold. Lyamungu station recorded the highest amount of rainfall while Same rainfall station recorded the least amount of rainfall during the March April May Season

Graphs of seasonal variation of rainfall intensity depicted a bimodal rainfall pattern with the highest peak in May during the April May June period and lowest peak in December during the November December January Period. These patterns followed the bimodal rainfall pattern experienced over Kilimanjaro region. The slope of regression line showed rainfall intensity was

decreasing at all stations based on the ×1 mm and × 20 mm rainfall category while the ×5 mm category decreased in Kia and Same stations and increased Lyamungu and Moshi stations. However, the slopes of regression line of rainfall intensity were all noted to be quite small with values less than 0.3.

Based on the regression analysis, rainfall over all stations except Same had negative relationship with population. However, the coefficient of determination (R^2) value were all less than 9% which indicated that increasing population had little influence on the amount of rainfall received over Kilimanjaro region. Correlation analysis showed that rainfall and population were negatively related over Lyamungu Moshi and Kia. At 95% significance level, the student t test showed that these correlations were not significantly related to population as all values of t computed were less than t tabulated. However, regression analysis showed that increased population had small contribution as attributed to small R^2 which were all less than 9.1%.

Correlation analysis of rainfall amount and population indicated a relation over Lyamungu Moshi and Kia. However, the student t test showed that these correlations were not significantly related to population. Correlation analysis of rainfall frequency for different categories showed that only 20 mm rainfall frequency category was significantly related to urbanization and thus population affected rainfall amount of 20 mm or more category in Lyamungu.

5.2   Conclusion

The findings of this study show that rainfall over Kilimanjaro region is changing. Stations which are located in urban areas tend to decrease more rapidly than stations located in the rural areas. In Moshi station which is the capital of the region, it is observed that rainfall intensity is very high as compared to other stations within the region.it is observed that in Moshi municipality the frequency of rainfall is low as compared to Lyamungu station which is typical rural. These changes could be attributed to a lesser extend to increased population over Moshi municipality mainly due to increased anthropogenic activities in the urban centers.

Lyamungu station shows high amount in total rainfall as compared to the rest of the stations within the region. This station have highest frequency of rainfall as compared to the rest of the stations which can also be attributed to its location as a rural area and also the station is on the

foot of Mount Kilimanjaro the highest mountain in Africa. This high number of rainfall days in Lyamungu station can also be caused by the orographic effect where by the wind ward area receive rainfall throughout the year as observed from the graphs of rainfall intensity.

5.3   Recommendations

Although changes in rainfall patterns could be attributed to increased urbanization, detailed research should be carried out to investigate individual factors responsible for the observed changes. Moreover, other indicators of urbanization such as land surface parameters should be factored into the study to quantify the individual contribution of different urbanization indicators. Relevant policies are also required to ensure that anthropogenic activities are not increased to extreme level.

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