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Trends and Frequencies of Extreme Rainfall Events in the Urban Catchments of Dar es Salaam, Tanzania

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Abstract

Understanding the characteristics of extreme rainfall events is necessary for proper planning and management of urban flooding impacts. In this paper, daily rainfall data from four key weather stations for the period 1967-2017 were used to investigate temporal variability in annual, seasonal, and extreme rainfall in the urban catchments of Dar es Salaam, Tanzania. The Mann-Kendall trend analysis and Sen's slope estimator were used to quantify the magnitudes and significance of long-term trends in rainfall. The frequencies of extreme rainfall events were modelled using the Generalized Pareto model. Results of trend analysis provided evidence of a decrease in total annual rainfall, with the highest decrement being 6.59mm per year. The statistical significance of the decrease in total annual rainfall was inconclusive. Observations of increase in both annual and seasonal maximum rainfall were also made; with the highest increments being 1.01mm and 0.79mm per event, for annual and seasonal maximum rainfall, respectively. The statistical significance of the increase in annual maximum rainfall was certain at 3 out of 4 stations. Frequencies of extreme rainfall events investigated using the $R6$ threshold provided reasonable results based on actual experience in the study area. Results indicated that most of the pluvial and fluvial flooding are from rainfall events with a 2 to 10-year return period. This is indicative of issues with the drainage systems in the area; either in their designed capacity or the reduction of their water carrying capacity due to anthropogenic factors.

Keywords: *rainfall trends, frequency analysis, extreme rainfall, generalized pareto, catchment.*

1. Introduction

Climate change affects all components of the water cycle (Stagl et al., 2014). A more robust water cycle is projected due to the increase in greenhouse gas emissions (Stagl et al., 2014; IPCC, 2007). In the past half-century, the mean global temperature has increased by 0.3–0.6˚C. This increase in global temperature is estimated to further increase by 1.1–6.4˚C by 2100 (IPCC, 2018). It is estimated that a global temperature increase of 2.8–5.2˚C will lead to an increase in global evaporation and precipitation rates by 7-15% (Verma et al.,

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2011). For a long time, changes in natural extreme phenomena such as droughts, heavy rains and floods have been studied and observed in different parts of the globe, including Canada (Li et al., 2018), UK (Otto, 2017); India (Gautam & Bana, 2014); South Africa (Nangombe et al., 2018); Tanzania (Kijazi & Reason, 2009); Czech Republic (Elleder, 2015); and United States (Mallakpour & Villarini, 2015). All these studies indicate the significance of the knowledge and understanding of changes in climate extremes locally, regionally, and globally.

It is important also to try to relate any similarities and/or differences in trends between local, regional, and global extreme events while trying to study global climate change. Similarly, since events of extreme rainfall are directly linked to flooding, understanding the behaviour of extreme rainfall events is crucial in trying to explain the increased cases of flooding in the urban area of Dar es Salaam in recent years (including 2011, 2014, 2015, 2018, and 2019). Although flooding in urban Dar es Salaam can be attributed to different factors—including the lack of stormwater drainage systems, river valley encroachment, and poor dumping of solid waste (Sakijege et al., 2012)—rainfall remains to be the major driving force for surface-water runoff generation.

Investigating the behaviour of extreme rainfall is important because of the direct linkage between extreme rainfall events and flooding, with related significant negative impacts on the environment, societies, and economies (IPCC, 2013). Ngailo et al. (2016) ranked flooding second after epidemics among the top ten natural disasters that threaten the economy of Tanzania. In the past, cases of extreme rainfall and flooding have proven to be fatal in urban Dar es Salaam. This is in part due to Dar es Salaam having the highest population density in Tanzania ($\approx$ 3,133 people/km^2). Following the floods of April 2018 in Dar es Salaam, households' losses were estimated to be over US$100m; which was estimated to be 2–4% of the region's Gross Domestic Product (GDP) (Erman et al., 2019).

There is a paucity of studies assessing changes in climate extremes in urban areas of Tanzania. Previous studies have looked at the impacts of climate change on agriculture, livestock, and food security (Shemsanga et al., 2010; Rowhani et al., 2011; Mang'enya, 2018), carbon storage in vegetation (Beda, 2013), asset exposure to coastal flooding (Kebede & Nicholls, 2011), gender equality (Nelson & Stathers, 2009), etc. Previous research works on climate variability in urban areas of Tanzania have only studied the general trends of climatic variables based on mean values. Specifically, in Dar es Salaam, a decreasing trend in the number of rainy days per year has been observed over the past five decades. Also, despite a reported decline in mean annual rainfall in Dar es Salaam, a random variation in 24-hour maximum rainfall has been observed within the past decade (PASS, 2011).

This paper aimed to fill the gap left by the previous studies by investigating temporal variability in annual, seasonal, and extreme rainfall in the urban catchments of Dar es Salaam. The focus was on quantification of the magnitudes of historical annual, seasonal, and peak rainfall trends and frequencies of extreme rainfall. Thus, the specific objectives of the paper are to (i) investigate trends in annual and seasonal total and maximum rainfall; (ii) determine the best probability distribution fitting for daily extreme rainfall data; and (iii) determine the frequencies of extreme rainfall based on $R6$ threshold (i.e., data above the 94th percentile line or rainfall with 6% or less chance of being exceeded).

The significance of this study lies in the realization that its findings could be used as a baseline for identifying future variations in probabilities of extreme rainfall in the study area based on the likelihood of climate change scenarios. Also, the findings of the analysis of frequencies of extreme rainfall can be useful information for the engineering community since the concept of return period is commonly used when designing stormwater drainage structures of a specific locality.

2. Context and Methods

2.1 Study Area

This research was conducted in a selected 1200km^2 area within Pwani and Dar es Salaam regions in the eastern coastal part of Tanzania, between longitudes 39°01'18.37"–39°28'29.55" E, and latitudes 6°35'17.48"–7°59'18.92" S. The area consists of the Msimbazi, Kizinga, and Mzinga sub-catchments; covering 265.5km^2, 247.1km^2, and 686.4km^2, respectively. The valleys start from the highlands of Pwani region, running through the central urban portion of Dar es Salaam region, and draining the water into the Indian Ocean (Figure 1).

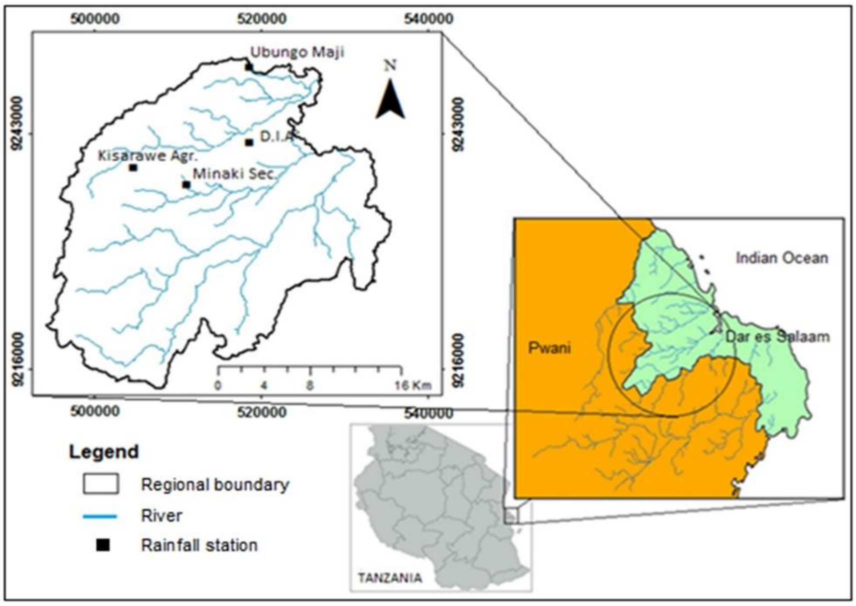

Figure 1: Study Area Location and the Rainfall Gauging Stations

Within the study area, the highlands of Pwani are approximately 240m above sea level, with a peak altitude of 339m; and receive an average of 1200mm of rainfall annually. The lowlands of the Dar es Salaam region are approximately 57m above sea level, with the lowest altitude of 15m; and receive an average of 1000mm of rainfall annually. The area has a bi-modal rainfall distribution, the two main rainy seasons being the long rains and the short rains. The long rains season (*masika*) occurs from mid-March to end of May, while the short rains (*vuli*) occur from mid-October to late December. The study area is characterized by tropical climatic conditions. It is generally hot and humid throughout the year, with mean daily temperatures ranging from 26˚C during the coolest season (June-September) to 35˚C during the hottest season (October to March) (Mahongo & Khamis, 2006).

Being the largest urban centre, and the commercial and industrial hub of Tanzania, Dar es Salaam plays a major role in the country's economic growth; contributing to approximately 16% of the country's GDP. The major economic activities include tourism, fishing, forestry, mining and quarry, and manufacturing. Characterized by a fast-growing population and rapid urbanization, it has the highest population density in the country; with about 70% of the total population living in unplanned areas. These attributes are described by Kebede and Nicholls (2011) as the fundamental dynamic factors behind most of the environmental degradation happening in the region.

2.2 Data Acquisition and Statistical Properties

The data for this paper – i.e., available daily rainfall records of four (4) rainfall gauging stations for the period 1967-2017—were collected from the archives of Tanzania Meteorological Agency (TMA). The gauging stations included the Dar es Salaam International Airport (D.I.A), Kisarawe Agriculture Centre (henceforth Kisarawe Agr.), Ubungo Maji, and Minaki Secondary School (henceforth Minaki Sec.) (Figure 1). Table 1 presents the attributes of the stations and the statistical properties of the collected data of daily rainfall records.

The observed variation in data range from one station to another was based on data availability. Data points used in the assessment of rainfall trends contained annual and seasonal totals and peak rainfall series (in seasonal and yearly based blocks) for the stated period of record in each rainfall station. Data sample used in modelling of the frequencies of extreme rainfall events contained values that were equal and above a threshold of 40mm (i.e., $R6$ threshold). This was the lowest boundary of extreme rainfall records from the study area; as determined by using the box plot technique. The rainfall time series were subjected to probability distribution fitting before and after data trimming using the $R6$ threshold. This was necessary for identifying the candidate model of probability distribution to use for extreme rainfall frequency modelling.

Table 1: Stations Information and Data Statistics

	STATION			
Data Statistic	***D.I.A***	***Kisarawe Agr.***	***Minaki Sec.***	***Ubungo Maji***
Station Code	9639029	9639043	9639017	96390482
Period of Record	1967-2017	1967-2014	1967-2002	1967-2009
No. of Years	51	48	36	43
Mean	12.77	14.50	13.04	12.93
Median	6.70	8.00	7.60	7.50
Variance	253.03	321.79	216.70	227.79
Std. Dev.	15.91	17.94	14.72	15.09
CV*	1.25	1.24	1.13	1.17
Skewness*	2.86	2.99	2.59	2.72
P25	2.90	3.50	3.70	3.10
P75	16.20	18.00	17.00	16.60
P90	32.10	35.60	31.51	30.70
P95	44.59	50.00	42.87	42.50
Max.	156.40	175.00	129.00	125.30
Upper Outlier Fence	36.15	39.75	36.95	36.85

Key: CV: Coefficient of variation; P: percentile; All units are in **mm**, except * are unitless

2.3 The Mann-Kendall Test

This non-parametric method (Mann, 1945; Kendall, 1975) was used to test if there are long-term trends in rainfall time series and their significance. The Mann-Kendall (MK) method was selected over several others (e.g., Spearman's Rho, parametric *t*-test, etc.) because it does not assume any particular probability distribution. Also, trend analysis using the MK method is less influenced by outliers in data. The statistical significance of the trends in this study was evaluated at 5% level of significance against the null hypothesis that trend does not exist.

Let $x_1, x_2, \ldots x_n$ be the data points in the time series with n records, and x_j be the data point at time j. Each data point is compared to the subsequent data point. The Mann-Kendall statistic, S, is initially assumed to be zero (no trend). S is then incremented by 1 if the subsequent data is higher than the previous one. Similarly, S is decremented by 1 if the subsequent data is lower than the previous one. The final value of S is the net result of all increments and decrements. The Mann-Kendall statistic, S, is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(X_j - X_k) \qquad (1)$$

where:

$$sign\left(X_j - X_k\right) = \begin{cases} 1 & if\ X_j - X_k > 0 \\ 0 & if\ X_j - X_k = 0 \\ -1 & if\ X_j - X_k < 0 \end{cases}$$

The trend can be said to be increasing when S is high and positive, and decreasing when it is a very low negative value. To further quantify the statistical significance of the trend, it requires computation of the probability associated with S and the sample size n. Blain (2013) described in detail the procedure to compute the probability associated with S.

For $n \geq 10$, the test statistic S is approximately normally distributed with a mean of zero and a variance of:

$$var\ (S) = \frac{n(n-1)(2n+5)}{18} \qquad (2)$$

The normal Z-test statistic is calculated as:

$$z = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}} & if\ S < 0 \end{cases} \qquad (3)$$

If $|Z| > Z_{1-\alpha/2}$, the null hypothesis is rejected at α level of significance. A positive value of Z indicates an upward trend, and a negative value indicates a downward trend.

2.4 The Sen's Estimator of Slope

The Theil-Sen's slope estimator (Sen, 1968) was used to determine the magnitude of linear trends in the time series of seasonal and annual peak rainfall values. The Sen's method calculates the slope of linear trends as a change in measurement per change in time. It is also known as the 'median of pair-wise slopes', and works better than the least-squares regression when the sample size is large (Gocic & Trajkovic, 2013). The slope estimates of pairs of data is computed as follows:

$$Q = \frac{X_j - X_k}{j - k} \qquad (4)$$

where:

Q = slope between X_j and X_k
X_j= data point at time j
X_k = data point at time k
j = time after time k

The median of slope estimates is the Sen's estimator of slope.

2.5 Modelling of Extreme Rainfall Events

The extreme value theory (EVT) has been widely applied to analyse and estimate extreme natural events (unusually large or small events), commonly using either the generalized pareto (GP) or the generalized extreme value (GEV) distributions. EVT is used to derive probability distribution of events at the far end of the upper or lower ranges of other probability distributions. It is also used to determine the probability of occurrence of events outside of the observed data series.

Based on the goodness of fit of the GP distribution (Pickands, 1975) to the extreme rainfall data in this paper, the GP distribution was used to model the tail values of gamma distribution. The gamma distribution was a good fit to the original series before extracting the extreme values. Exceedances over high thresholds (peak over threshold) method was used to obtain the extreme rainfall time series. This method was preferred over the maxima over fixed time period (block maxima) method because it provides a more efficient approach of obtaining the maxima time series for GP modelling. It also produces a longer series, and hence increases the modelling accuracy.

Let X be a random variable. The GP model functions within three sub-models (Reiss & Thomas, 2007) with cumulative distribution functions presented as:

Exponential (GP0), $\alpha = 0$:

$$W_0(x) = 1 - e^{-z}, z \geq 0 \qquad (5)$$

Pareto (GP1), $\alpha > 0$:

$$W_1\alpha(x) = 1 - z^{-\alpha}, z \geq 1 \qquad (6)$$

Beta (GP2), $\alpha < 0$:

$$W_2\alpha(x) = 1 - (-z)^{-\alpha}, -1 \leq z \leq 0 \qquad (7)$$

where $z = (x–\mu)/\sigma$, μ is the threshold or lower bound of X (i.e., a location parameter), σ is a scale parameter, and α is a shape parameter.

By re-parameterizing $\gamma = 1/\alpha$ of GP distribution functions $W_i, \alpha,$ a unified GP model is obtained as:

$$W_\gamma(x) = 1 - (1 + \gamma z)^{-\frac{1}{\gamma}} \text{ for } (1 + \gamma z) \geq 0 \qquad (8)$$

Depending on the shape parameter γ, W_γ is reduced to *Pareto* distribution ($\gamma > 0$), *Beta* distribution ($\gamma < 0$) and *Exponential* distribution ($\gamma = 0$; which is interpreted as $\gamma \to 0$ in the limiting sense). The Maximum Likelihood Estimate

(MLE) method was used to estimate the GP distribution parameters. The use of MLE was based on its wide applicability and better adaptability to the extreme value analysis. Zhao et al. (2019) described in detail the MLE method. The XTREMES software was used to implement the above GP distribution functions, and model extreme rainfall in this paper.

3. Results and Discussion

3.1 Magnitudes of Rainfall Trends

Table 2 shows the magnitudes of rainfall trends as determined by Sen's estimator of slope. The total annual rainfall was observed to be decreasing at 3 out of the 4 stations that were studied (Table 2). The highest decrement was observed at Ubungo Maji station, with a 6.59mm per year decrement. Minaki Sec. station had the shortest record of rainfall data, which could explain the deviation of its trend magnitude result from the rest of the stations (which had longer and most recent records).

Table 2: Sen's Slope Estimates for the Trend Magnitudes

Station	Annual Total	*Masika* Total	*Vuli* Total	Annual Max	*Masika* Max	*Vuli* Max
D.I.A	-4.65	-1.98	-2.13	**0.48**	0.36	0.07
Kisarawe Agr.	-4.61	6.39	3.95	**0.63**	0.39	0.1
Minaki Sec.	8.89	5.63	2.87	**1.01**	**0.79**	0.65
Ubungo Maji	**-6.59**	-2.64	-2.86	0	0.06	-0.15

Note: Bold values indicate statistical significance at 95% confidence level (+ for increasing and - for decreasing)

The calculated decrement of total annual rainfall at the D.I.A and Kisarawe Agr. stations (stations with the most recent records of rainfall) were observed to be almost similar in magnitudes. PASS (2011) reported a decreasing trend in the number of rainy days per year in Dar es Salaam over the past five decades. Also, Chang'a et al. (2017) used the mean percentage rainfall anomaly and the standardized precipitation index to observe a statistically non-significant decreasing trend of rainfall in many parts of Tanzania, including Dar es Salaam. These findings from previous studies are consistent with the observation of a decrease in total annual rainfall found in this paper.

Recorded annual and seasonal maximum rainfall events were found to be increasing at all the stations except for *vuli* maximum rainfall at the Ubungo Maji station. The highest increment was observed at the Minaki Sec. station for annual maximum rainfall events, with a magnitude of 1.01mm per event. For the most recent records, the highest increment was observed to be 0.63mm per annual maximum rainfall event at the Kisarawe Agr. station.

3.2 Significance of Rainfall Trends

Further analysis was conducted to ascertain the trend magnitude results obtained from the previous analysis. Testing of the significance of trend results was done for annual, seasonal totals, and peak rainfall data. Table 3 presents the results of the MK Test Z significance statistic. The results indicate that the decrease in the total annual rainfall was found to be statistically significant only at the Ubungo Maji station. Furthermore, previous observation of the increase in the magnitudes of annual maximum rainfall was ascertained by the results of statistically significant increasing trends of annual maximum rainfall at 3 (i.e., D.I.A, Kisarawe Agr., and Minaki Sec.) out of the 4 stations that were investigated (Table 3).

Table 3: Test Z Values for Testing of Trend Significance

Station	Annual Total	Masika Total	Vuli Total	Annual Max	Masika Max	Vuli Max
D.I.A	-1.4	-1.2	-1.1	**2.21**	1.68	0.28
Kisarawe Agr.	0	0.43	0.43	**2.13**	1.08	0.38
Minaki Sec.	1.82	1.62	1.08	**2.59**	**2.15**	1.62
Ubungo Maji	**-2.03**	-0.94	-1.49	0	0.24	-0.47

Note: Bold values indicate statistical significance at 95% confidence level (+ for increasing and - for decreasing)

Increase in seasonal maximum rainfall was hardly ascertained by the observation of a significant increase of *masika* maximum rainfall at the Minaki Sec. station alone. Identified statistically significant trends are graphically presented in Figure 2.

The finding of statistically significant trends of annual maximum rainfall at 3 out of 4 stations is crucial and could be used to explain the experienced increase in cases of urban flooding in Dar es Salaam in recent years. Although different factors could play a role in the occurrence of urban flooding, including—but not limited to—land-use and land cover changes, poor drainage systems and poor management of solid waste, rainfall is the major factor for surface-water runoff generation. Any combination of these factors will only intensify the flooding problem. Dar es Salaam urban land cover has been significantly modified. Since 1979, it has been observed to shift from being mostly a vegetated land and is turning into a barren land (Mzava et al., 2019). The observed shift in land cover and the findings of a statistically significant increase in peak rainfall in this paper indicate the likelihood of the alteration of hydrologic behaviours of the studied catchments. This scenario may lead to increased surface-water runoff generation, and increase the chances of flooding in the study area.

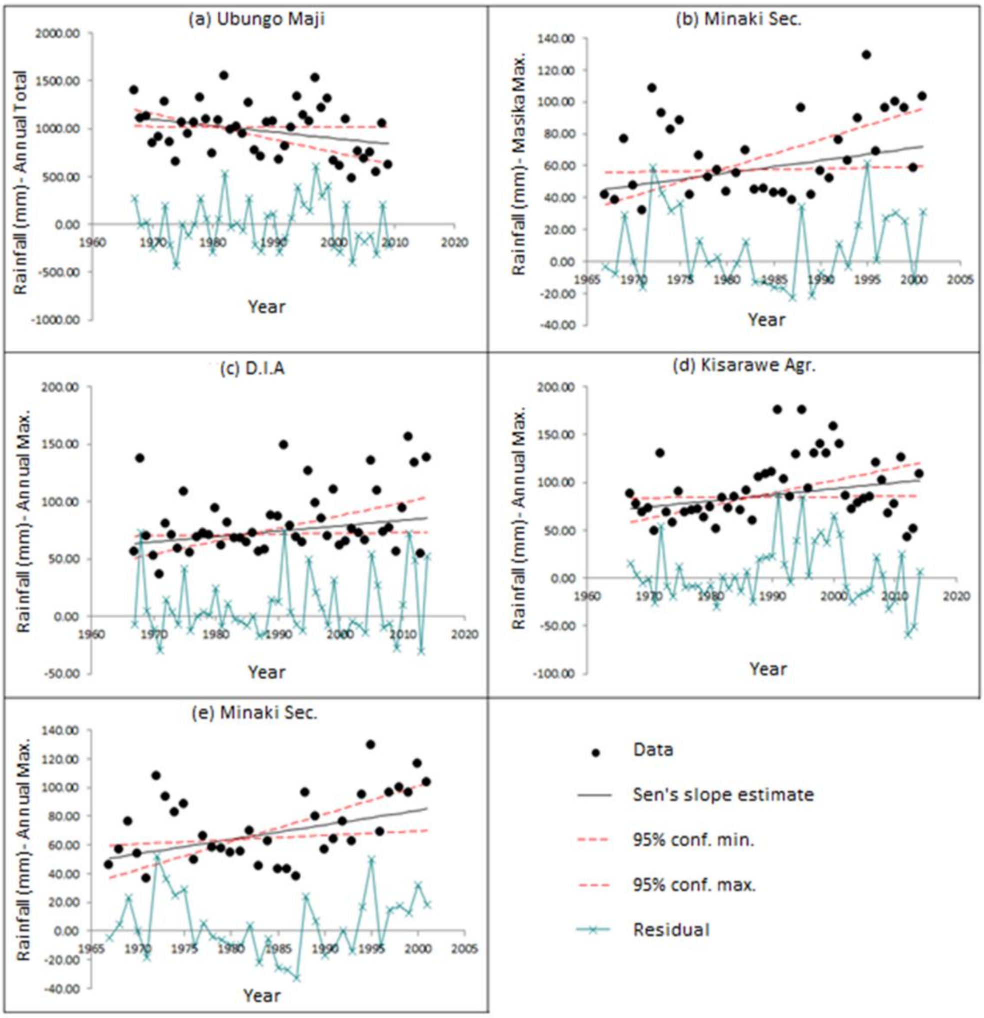

Figure 2: Identified Statistically Significant Trends at 95% Confidence Level

3.3 Extreme Rainfall Frequencies

The rainfall time series were subjected to probability distribution fitting before and after extracting the maxima extreme values. Using a graphical approach, the *gamma* distribution was observed to be the best fit for rainfall data before trimming the maxima extremes (i.e., when considering a complete set of data (rainfall ≥ 1mm)). After trimming the data by extracting the maxima extremes using the *R6* ($u \geq$ 40mm) threshold, and repeating the probability distribution fitting, the extracted series were observed to best fit the *generalized Pareto* (GP) distribution (Figure 3).

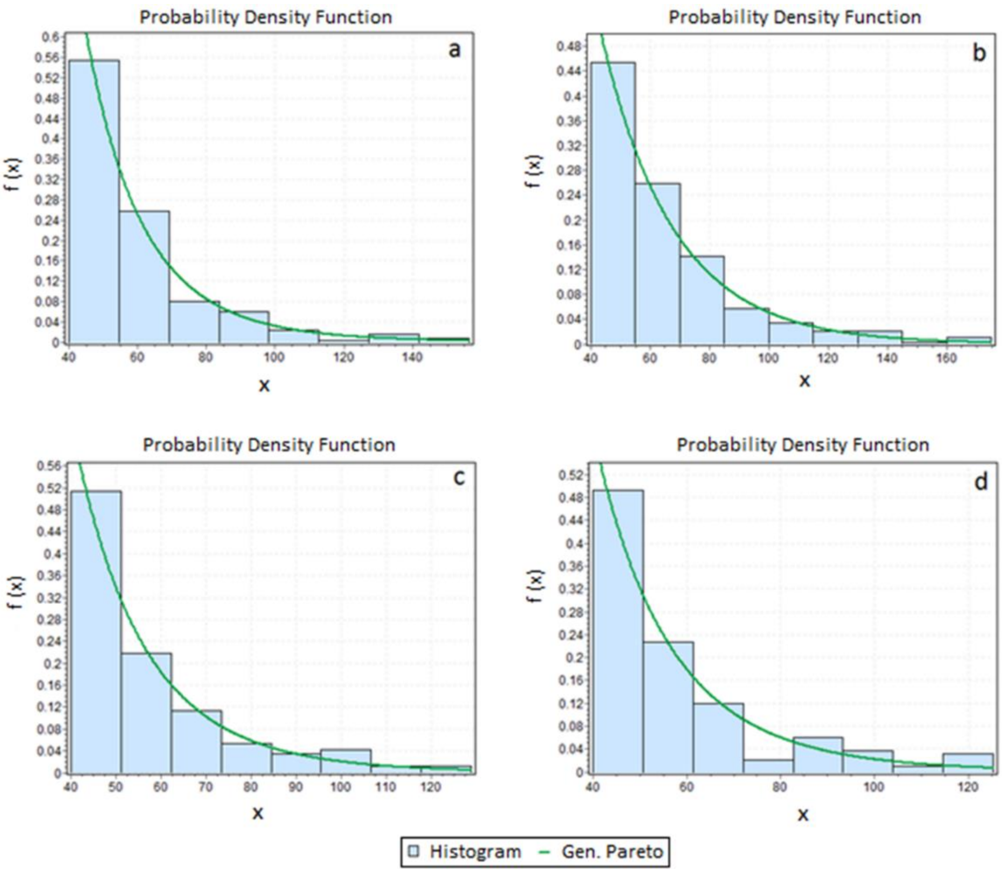

Figure 3: Fitted Probability Distribution for Rainfall Maxima Series at (a) D.I.A (b) Kisarawe Agr. (c) Minaki Sec. (d) Ubungo Maji

Figure 4 shows the extracted sample sizes of maxima extremes from daily rainfall data for each gauging station. Testing of the independence of the extracted rainfall extreme data points was performed using the sample autocorrelation plots (not shown); and no correlation between extreme rainfall events was observed in the data sample. Table 4 shows the GP distribution parameters estimated using the MLE method. Looking at the shape parameter (γ), it was found $\gamma > 0$ at all the stations; implying that the extracted rainfall maxima data sample is predominantly in the *Pareto* distribution sub-model of the GP model as described by equations (5) to (8). This observation was also supported by the results of the sample mean excess plots (not shown), which displayed a positive linear trend at all the gauging stations. The mean excess plots were also useful for checking the appropriateness of the selected threshold (u). The linearity of the mean excess plots was an indication of a properly selected u.

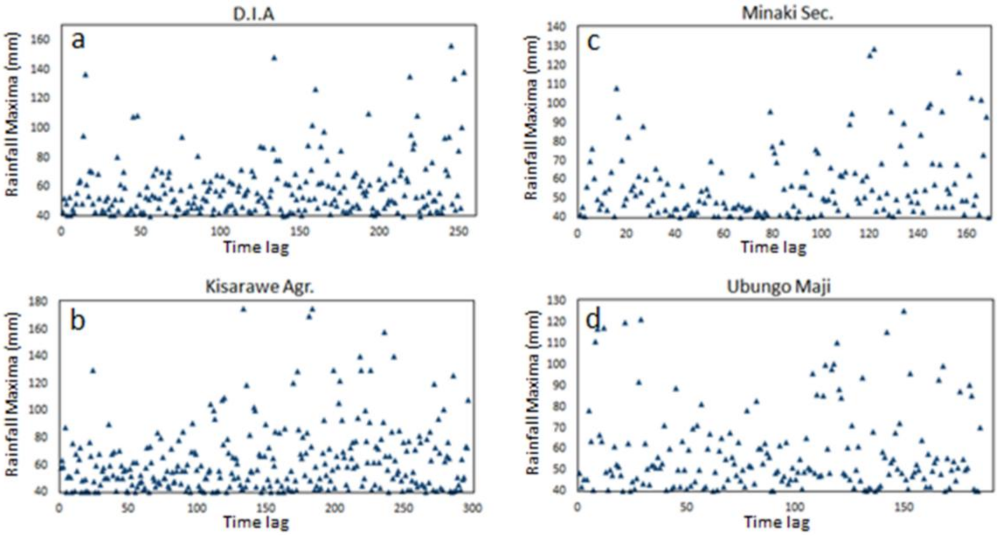

Figure 4: Extracted Extreme Maxima Samples (a) n = 253 (b) n = 297 (c) n = 169 (d) n = 185

Table 4: Estimates of the GP Distribution Parameters

Station	GP Parameters		
	γ	μ	σ
D.I.A	0.13	40	17.38
Kisarawe Agr.	0.15	40	22.14
Minaki Sec.	0.16	40	14.53
Ubungo Maji	0.16	40	15.39

A visual evaluation of the Quantile-Quantile (Q-Q) plots (Figure 5) reveal that in general, the GP model performed reasonably adequate in modelling extreme rainfall events in the four gauging stations used in the analysis. It can be observed from the Q-Q plots that the model performed exceptionally well for the lower values of extreme events; and performed satisfactorily for the events at the far right end of the tail (i.e., the most extreme values). Model performance was statistically ascertained by calculating the coefficients of determination (R^2) between the model results and the measured values. R^2 values were found to range between 0.95 and 0.98, which indicated a very good performance of the GP model.

Table 5 shows the estimated return periods of the extreme rainfall events in the study area, while Figure 6 shows the respective frequency curve. From the engineering design perspective, drainage structures (i.e., bridges, culverts, drainage channels, sewers, etc.) are usually designed using rainfall events with return periods of at least 25 years. Table 5 shows that in the study area, a rainfall event with an intensity of 100mm/day can be approximated as a 25-year event.

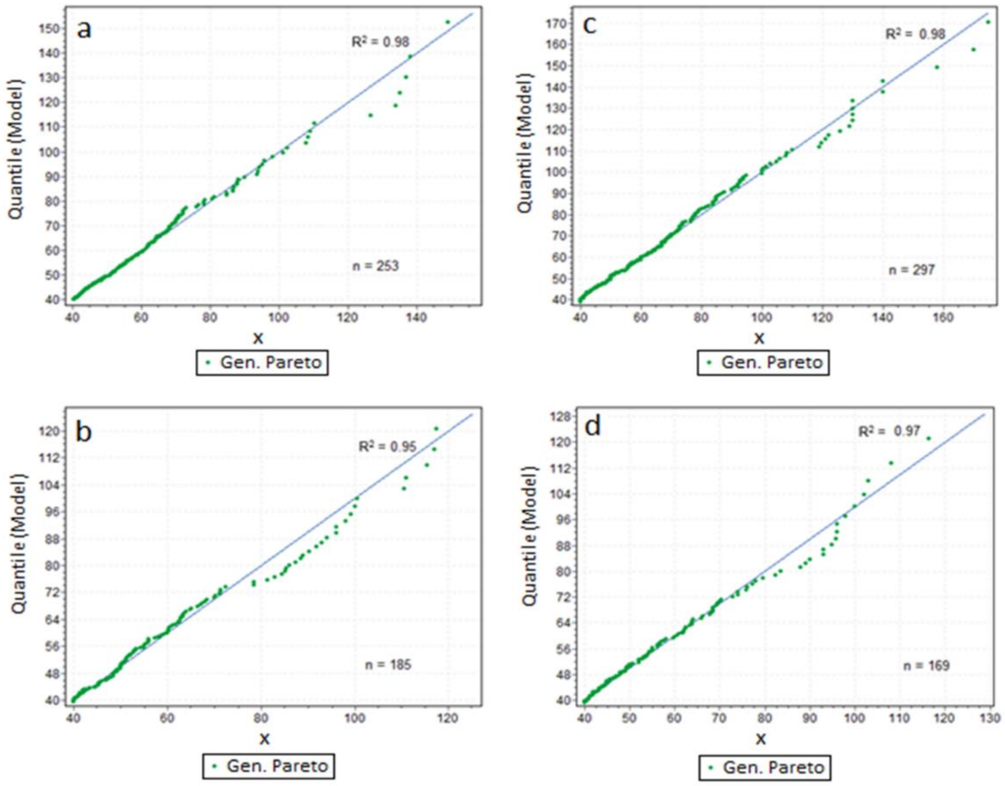

Figure 5: Q-Q Plots for the Fit of the GP Model to the Measured Rainfall Extreme Maxima Values (*line of equality indicates a perfect fit*) at (a) D.I.A (b) Ubungo Maji (c) Kisarawe Agr. (d) Minaki Sec.

Table 5: Return Periods of Extreme Rainfall Events

Station	Return Period (Years)						
	2	***5***	***10***	***25***	***50***	***100***	***200***
D.I.A	52.7	71.2	86.7	109.5	128.6	149.5	172.3
Kisarawe Agr.	56.2	80.4	101.1	132.1	158.6	188.0	220.7
Minaki Sec.	50.7	66.7	80.5	101.3	119.1	139.1	161.4
Ubungo Maji	51.3	68.3	82.8	104.8	123.7	144.8	168.3

Looking at the extracted rainfall maxima data (Figure 4), the number of rainfall events exceeding 100mm/day in the study area between 1967 and 2017 are 13/253 (5.1%) at D.I.A, 24/297, (8.1%) at Kisarawe Agr., 6/169 (3.6%) at Minaki Sec., and 9/185 (4.9%) at Ubungo Maji. Based on this observation and the actual experience with the study area, it is obvious that flooding has occurred from rainfall events with return periods of less than 25-years in the past. This could indicate a problem with the water carrying capacity of the drainage system currently in place in the study area.

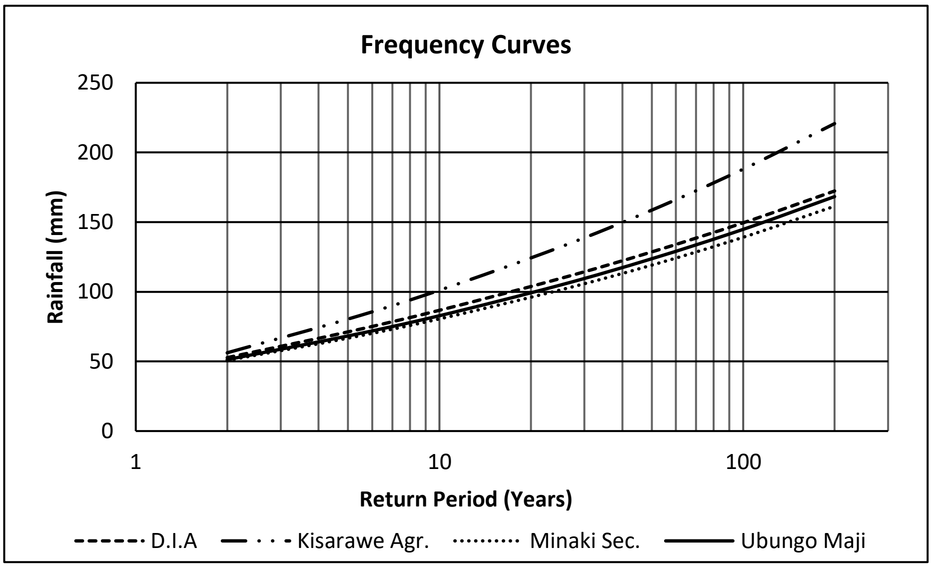

Figure 6: Extreme Rainfall Frequency Curves

The estimated magnitudes of rainfall trends and frequencies of maximum rainfall in this paper are based on historical rainfall records alone. Analysis of future rainfall scenarios based on climate change projections could provide a direction for future research opportunities in the study area. Luhunga et al. (2018) projected an increase of rainfall almost throughout Tanzania in the future. It is therefore important to quantify and understand the impacts of future climate change on extreme rainfall events at a more localized urban scale.

4. Conclusion

The findings of this paper show an indication of climate variability in the study area. It was found that total annual rainfall has a decreasing trend, but with statistically inconclusive significance. Annual maximum rainfall was observed to have a statistically significant increasing trend, while seasonal maximum rainfall showed a non-significant increasing trend. An increase in cases of urban flooding in Dar es Salaam can in one way be explained by the increase in annual and seasonal maximum rainfall found in this paper. The observed climate variability may constitute climate change in the long-run.

The peak over threshold method and the GP model provided reasonable results of the frequencies of extreme rainfall in the study area, based on the actual experience with the area. Based on this experience, and the findings of this paper, most of the pluvial and fluvial flooding in the study area are happening from rainfall events with return periods between 2 and 10 years; which are more in number relative to the 25-year and higher events. This is an indication of a problem with the drainage systems in the study area. The problem could either be in the designed sizes of the drainage structures, or their reduced water carrying capacity due to clogging by solid waste and sedimentation. Floodplain encroachment could also be another reason for the reduction in the water carrying capacity of natural drainage systems in the study area. These hypotheses require further research.

The findings of this paper can be used as a baseline in the long-term observation of extreme rainfall events; their magnitudes, trends, and frequencies in Dar es Salaam urban area, while trying to relate urban flooding to global climate change. Furthermore, the study results of the analysis of frequencies of extreme rainfall could be useful information in dealing with future flooding problems in the study area. That can be achieved by studying future scenarios of extreme rainfall events, compare the results with the current findings, and cater for the difference in the designs of stormwater infrastructures.

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