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The Changing Nature of Probability Distribution of Daily Temperature: A Case of Coastal Zone of Tanzania

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Abstract: ***54 year datasets (1961 -2014) of recordings of the maximum and minimum daily (24 h) temperature in the coastal zone of Tanzania are analysed to test whether there is any significant (in statistical sense) trends in variability of daily temperature. In recent studies it has been reported that there are trends in mean temperature and other climate indices over Tanzania and many other countries worldwide. However, in Tanzania it is not clear whether there is also a trend in variability of daily temperature. In this study 3 meteorological stations (Dar es Salaam, Mtwara, Tanga) have been analysed for trends in variability using F-ratio test, least square method and Mann-Kendall trend test. The results indicate that the observed increasing/decreasing trends in variability of the maximum temperature are statistically non-significant at the level of 5% while the trends are statistically significant for minimum temperatures. Daily minimum temperatures for Dar es Salaam and Mtwara show an increasing trend in variability while a decreasing trend for Tanga station has been observed.***

Keywords: Variability, F-ratio test, Mann-Kendall trend test, Temperature, Tanzania

1. Introduction

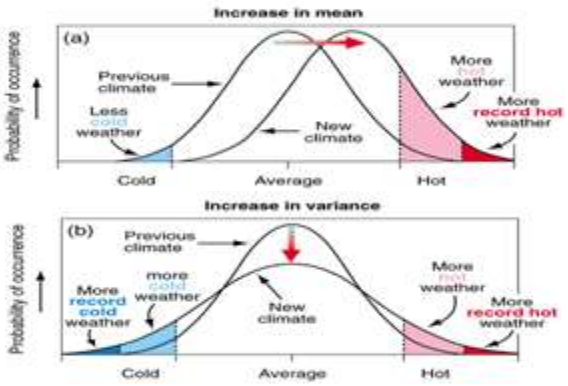
Extreme temperature events have impact on our society and economy. The increase in temperature (usually accompanied by decrease in rainfall)affects several sectors including agriculture, water resources, health, energy, industrial and transport sectors.

The primary impacts of climate change on society results from extreme events ([1], [2]). Changes in the frequency of extreme events have more impact than changes in mean climate ([2], [3]). Figure 1, panel (a), depicts the effect of an increase in the mean of a hypothetical symmetric distribution on the probabilities of extreme events (shaded).Figure 1, panel (b), shows the effect of an increase in variance of a hypothetical symmetric distribution on the probabilitiesof extremes (shaded). Figure 1, panel (c), shows the effect of increase in both mean and variance.Similar illustrations can be found in literature (e.g. in [2], [4] figure 1 respectively figure 3 in these article)Changes in the variance are considered more important than changes in the mean when assessing the frequency of climate extremes, with greater sensitivity the more extreme an event is ([1], [2], [5]).This result can be generalized to non-normal distributions, with the frequency of extreme events relatively more dependent on the scale parameter than the location parameter ([1], [2]).

Several studies, based in USA, former Soviet Union, Asia-Pacific region, have generally identified decrease in trend of temperature variability (variance). Others have identified increase in temperature variance [1]. With the observed and projected in the frequency of extreme warm temperature, many places in the world will face an increasing risk of extreme temperature events ([5], [6], [7]).Donat et al., [8] using a global observational dataset (1951-2010) of daily gridded maximum and minimum temperatures, investigate changes in the respective probability density functions. In this study, it is found that the distributions of both daily maximum and minimum temperatures have significantly shifted towards higher values with time, whereas changes in variance are spatially heterogeneous and mostly less significant.

Schematics have been developed, since the third report of Intergovernmental Panel on Climate Change (IPCC, 2001), to indicate how the distribution of temperature would shift associate with changes in mean, variance and skewness. However to the author's knowledge there arevery few studies which have actually shown the "real" shifts in the daily temperature in Tanzania which resemble any of the schematics proposed by IPCC.In the recent study by Chang'a et al., [9] it is concluded that on average the annual mean temperature anomaly has increased over Tanzania. It is also indicated that the mean percentage of warm days and warm nights has increased. However, it is not clear whether the increase in trend of extreme indices in Tanzania is due to increase in mean temperature alone or is also accompanied by change in variability of daily maximum and minimum temperature.

In this study, a dataset of daily maximum and minimum temperature recorded at stations in coastal zone of Tanzania is used to show if and/or how the distribution of temperatures have shifted over the past 54 years (1961-2014).



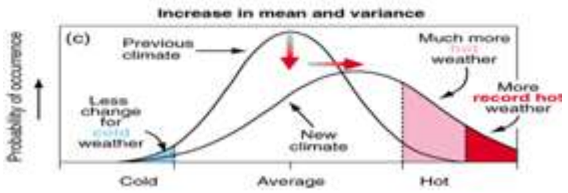


Figure 1: Three hypothetical forms of climate change are illustrated. In panel (a), the location parameter (in this case, the mean) of the distribution increases. In panel (b), the mean remains the same but the scale parameter (in this case, the variance) of the distribution decreases. In panel (c), both location and scale parameter are changing. Note how shifts in the location or scale parameter of the distribution change the probability of extreme events (shaded).Adapted from IPCC (2001) [6].

2. Study Area

The study area is a part of the United Republic of Tanzania. Tanzania is lying in the south of the equator between 1-12^0 S and 29-41^0 E. The study area is a coastal part of Tanzania along the western Indian Ocean as it is shown in figure 2.

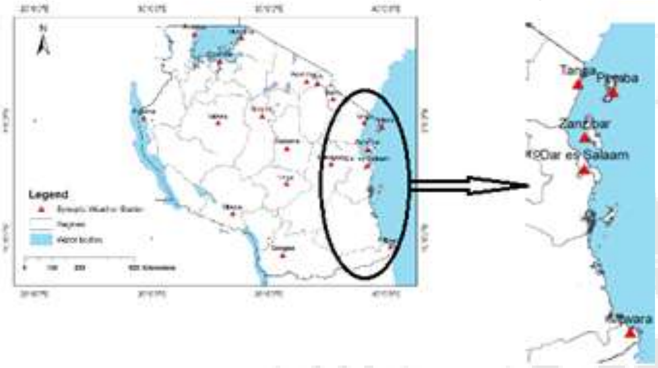


Figure 2: Location of the meteorological stations used in the study (Dar es Salaam, Mtwara, Tanga).

3. Data and Methodology

3.1 Data

Daily observed station data for maximum and minimum temperatures of 3 stations (figure 2) from coastal regions of Tanzania were employed in this analysis. These data sets were collected from Tanzania Meteorological Agency (TMA). These data were subjected to quality control using RClimDex software.

3.2 Methodology

Several studies have analysed several indices. Most of the analysed indices are those recommended by Expert Team on Climate Change Detection and Indices (ETCCDI). The study by Omodi et al. [9] on the changes in temperature and precipitation extremes over the greater horn of Africa region from 1961-2010 shows a significant decrease in total precipitation in wet days and increasing warm nights and decreasing cold extremes. A recent study by Chang'a et al. [10] on rainfall and temperature extreme indices in Tanzania (1961-2015) shows an overall increase in mean temperature, mean percentage of warm days, mean percentage of warm nights and decrease in mean percentage of cold days and nights. However, it is not clear if a trend in these indices is caused by distribution changes in both mean and variability or only change in mean.

To study if there is a change in variability, two approaches are used in this study. The first approach is to divide the temperature time series in two series and use F-test to test if there is a difference in variances of these two groups (by using ratio test). The second approach is to use linear regression on standard deviations. These approaches are discussed in the section 3.2.1 and 3.2.2 respectively.

3.2.1 F-test on variances

Temperature time series of 54 years (1961-2014) is divided into two time series of 27 years: 1961 to 1987 and 1988 to 2014.For Dar es Salaam region (for maximum temperature), the boxplot of these two periods is shown in Figure 2 panel (b)while corresponding densities are shown in Figure 3. The F-ratio tests, testing the null hypothesis: $\sigma_1^2 = \sigma_2^2$ against alternative hypothesis: $\sigma_1^2 \neq \sigma_2^2$ is used to test whether a change in variability of temperature time series is statistically significant. Here, σ_1^2 represents variance in the first group and σ_2^2 variance for the second group. Using respective sample variances s_1^2 and s_2^2 , the F-ratio test is given by

$$F = \frac{s_1^2}{s_2^2}. \qquad (1)$$

The more this (equation (1)) ratio deviates from 1, the stronger the evidence for unequal population variances hence change in variability in this case.

3.2.2. Linear regression on variance

The daily temperature time series are used to compute monthly and annual averages and variances of the maximum and minimum temperatures. Trend in these indices are calculated for each station by using linear regression. Let $y(t)$ be value of indices at time t (either month or year). The linear regression of $y(t)$ on t is expressed as

$$y(t) = \beta_0 + \beta_1 t. \qquad (2)$$

Trend analysis for climate change has been analysed in several studies using equation (1). If, on average, there are no changes, the value of $\beta_1 = 0$. If there are changes, on average, the value of $\beta_1 \neq 0$. Positive values of β_1 indicate increasing trend and negative values indicate decreasing trend. Trend analysis is essentially testing the hypothesis of whether $\beta_1 = 0$ or $\beta_1 \neq 0$ and the estimation of these coefficients in equation (2). The common methods for trend analysis are Mann-Kendall trend test, Sen's slope estimator and least square method. The first two are non-parametric methods and the last is a parametric method. Non-parametric methods are preferred because they do not assume any distribution (usually normal distribution).

4. Results

Results of the analysis on change in variance based on equation (1) are presented in section 4.1 and those based on equation (2) are presented in section 4.2.

4.1 Results based on F-test

The two groups of time series: 1961 to 1987 and 1988 to 2014 are applied in the equation (1). This results into

F(9775, 9821)=1.0086 with p-value= 0.7357 and 95% confidence interval of [0.97, 1.05] for Dar es Salam region (see Table 1 for other stations) using maximum temperature. This indicates that the two groups do not significantly differ in variances, hence implying that the variances have not significantly changed with time for maximum temperature over the period 1961-2014. This can also be noted from boxplot on Figure 2 panel (b). The boxes for the two periods have almost the same width. The same characteristics can be noted in the panel (a) of the same figure where boxplots of six periods of nine years are shown.The boxes are almost identical which implies equal variances (even if there is change in means). Similar results were obtained for Mtwara region for maximum temperature as shown in Table 1. Tanga region has a different scenario. For Tanga region, F=1.1232 with p-value<0.001 and 95% confidence interval of [1.08, 1.168]. This shows that the two periods have a significant difference in variances; the second interval has smaller variance compared to the first interval. This indicates that the variance decreases with time for the daily maximum temperature for records from Tanga station.

For minimum temperature, the results for all three stationsshow the variances to be significantly different for the two periods (see table 1). For Dar es Salaam and Mtwara stations, the results indicate the variances to be increasing while for Tanga station the variance is decreasing.

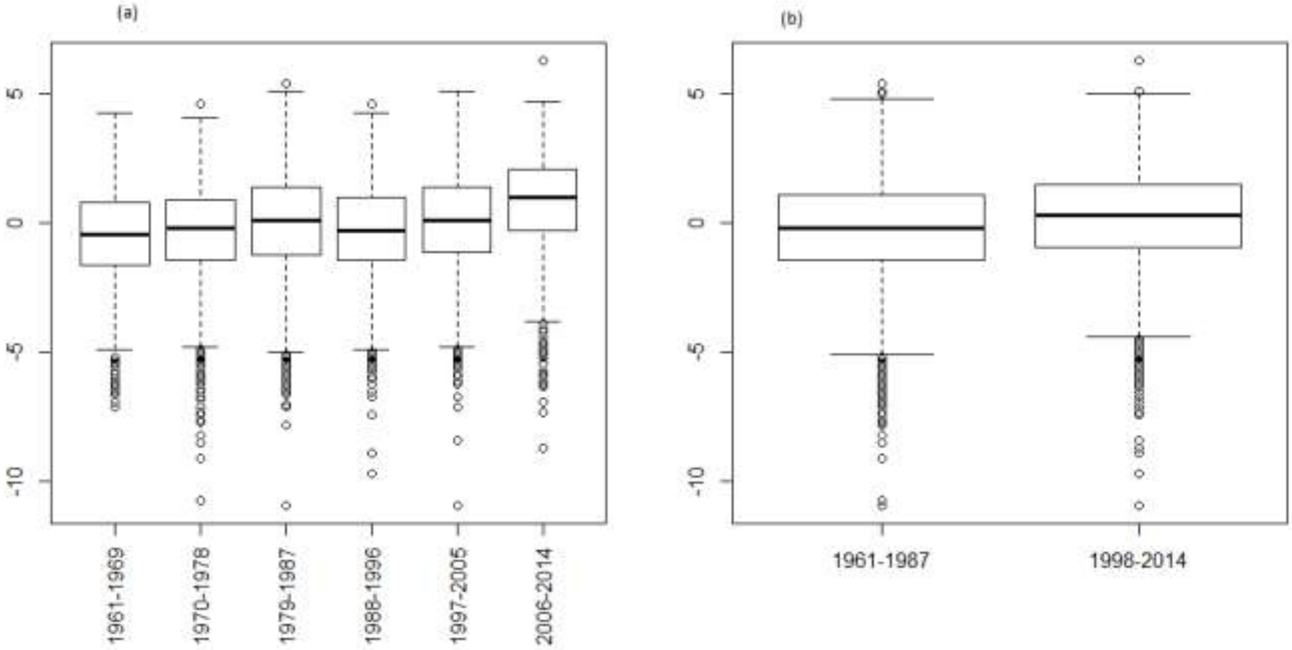


Figure 3: The panel (a) shows boxplots of six periods of nine years each.The panel (b) shows boxplots of two periods with twenty seven years each (1961-1987 and 1988-2014) of anomalies for daily maximum temperature for Dar es Salaam region.

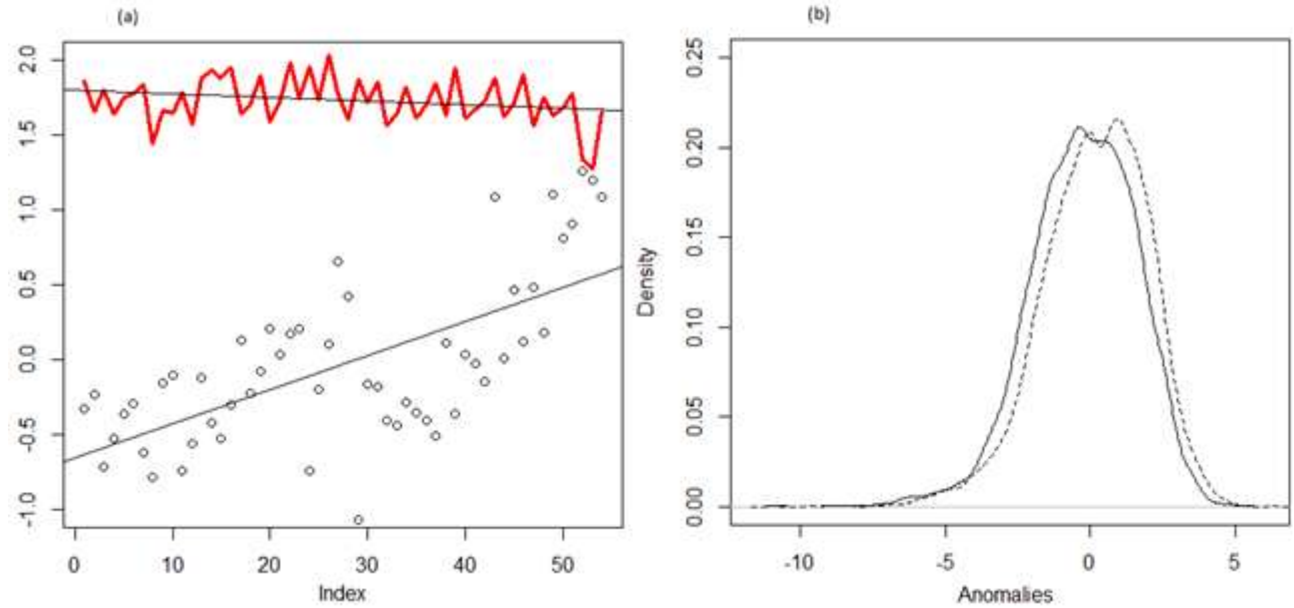


Figure 4: Panel (a) shows trend in maximum temperature (lower panel) and trend in standard deviation (upper penal). Penal (b) shows density plot of two temperatures time periods: 1961-1987 (solid line) and 1988-2014 (dashed line)for daily maximum temperature of Dar es Salaam

4.2 Results based on Linear Regression

Instead of using variances directly, the standard deviations (SDs) are used in equation (2) (SDshave the same units as measurement scale). In this study the SDson monthly and annual bases were calculated.Trend test in SDs is performed using Mann-Kendall test. The slope of linear trend is calculated using both Sen's slope estimator and least square method. The significance of the observed trend can be deduced, for instance, from the p-values of the associatedslope estimates or Mann-Kendall test.

Figure 4 panel (b) depicts densities of two periods: 1961-1987 (solid line) and 1988-2014 (dashed line) for daily maximum temperature of Dar es Salaam. It is clear that there is a shift in distribution towards warmer temperatures. However, there is no indication of change in variability. The shapes of two densities are almost similar. This is also observed in panel (a) of the same figure. In this panel there is a clear indication of increase in mean (lower panel) with a very slight decrease in variability (upper panel). Similar results (not shown) are obtained for Mtwara and Tanga stations.

Table 2 and Table 3 show the resulting estimates for the three stations along the coastal regions of Tanzania. Table 2 provides analysis results based on maximum temperature and table 3 presents analysis results based on minimum temperature. With exception of a very few cases (two cases), all the methods give consistent results which show that observed decreasing/increasing trends in SDs are/are not statistically significant.

Figure 5 panel (b) depicts trend in mean percentage of warm nights for the period 1961-2914 for Dar es Salaam region. Panel (a) of the same figure depicts densities of minimum daily temperature of two periods. On one hand the densities seem to have different variances- the first period (solid line) seems to have relatively small variance. However, the observed changes in variability and mean are significant at the level 5%. On the other hand there is a significant increasing trend in the mean percentage of the warm nights. One can conclude that the trend in the mean percentage of warm nights is associated with increase in both the mean and the variability daily temperature.

Table 1: Testing equality of variance based on equation (1)

Station	Temperature series					
	Maximum			Minimum		
	F	P-value	95% CI	F	P-value	95% CI
Dar es Salaam	1.0086	0.7357	[0.97, 01.05]	0.93	<0.001	[0.898, 0.972]
Mtwara	0.9727	0.1742	[0.93, 1.01]	0.938	0.002	[0.901, 0.976]
Tanga	1.1232	<0.001	[1.08, 1.168]	1.1232	<0.0001	[1.0796, 1.168]

Table 2: Testing change in variance of maximum temperature based on equation (2)

Station	Scale	Mann-Kendall test	Slope estimates			
			Sen's	P-value	LS	P-value
Dar es Salaam	Monthly	Not significant	-.00015	0.053	-0.0002	0.07
	Annually	Not significant	-0.002	0.14	-0.0024	0.07
Mtwara	Monthly	Not significant	-0.00046	0.52	-0.0001	0.29
	Annually	Not significant	-0.00062	0.51	0.0003	0.82
Tanga	Monthly	Significant	-0.00019	0.005	-0.0002	0.163
	Annually	Significant	-0.00514	<0.001	-0.0048	0.0015

Table 3: Testing change in variance of minimum temperature based on equation (2)

Station	Scale	Mann-Kendall test	Slope estimates			
			Sen's	P-value	LS	P-value
Dar es Salaam	Monthly	Significant	-0.00023	0.0009	-0.0002	0.0008
	Annually	Significant	0.0034	0.037	0.0029	0.049
Mtwara	Monthly	Significant	0.00016	0.0175	0.0002	0.0174
	Annually	Not significant	0.00185	0.156	0.0021	0.163
Tanga	Monthly	Significant	-0.00019	0.005	0.00019	0.0163
	Annually	Significant	-0.0051	<0.001	-0.0048	0.0015

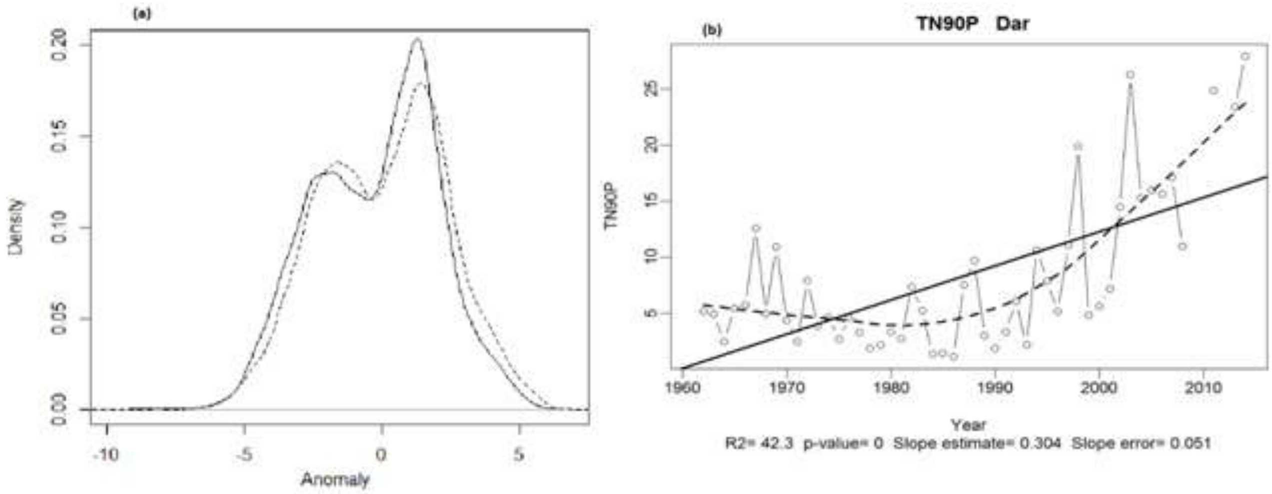


Figure 5: Panel (a) depicts densities of minimum temperature for the two periods: 1961-1987(solid line) and 1988-2014 (dashed line). Panel (b) depicts trend in mean percentage of warm nights over the period 1961-2014 for Dar es Salaam station

5. Discussion

Daily maximum and minimum temperature over the period 1961 to 2014 for Dar es Salaam, Mtwara and Tanga stations were analysedfor variability. Figure 6 depicts probability density functions (PDFs) of maximum (left) and minimum (right) of daily temperature anomalies (^{0}C) for Dar es Salaam(a), Mtwara (b) and Tanga (c) stations over the periods 1961-1987 (solid) and 1988-2014 (dashed). A comparison of PDFs over these two periods confirms that the distributions have shifted towards the warmer temperature. This is in agreement with other studies in Tanzania and other countries (e.g. [8], [9], [10], [11], [12], [13], [14], [15]). For maximum daily temperatures, the peaks of densities are almost equal for both periods except for Tanga station where the peak of the later period is higher. Equal peaks highlight equal variance of the distribution. This implies that the observed warming trends in extreme indices are likely to be associated with increase in both the mean and extremes with little change in the variability [15].

Both methods used in this study confirmed that there is no significant change in variability for maximum temperature except for Tanga station where variance is significantly decreasing. For Tanga station, F-test gives the ratio of 1.1232 with p-value less than 0.001 and 95% confidence interval of [1.08,1.168] (see Table 1). All Mann-Kendall, Sens and least squares estimates confirm the decrease (negative slope, see Table 2) in variance for Tanga station. For the minimum temperatures, the peaks of the PDFs are lower (except for Tanga station) for the later period. This highlights an increase in variances in daily minimum temperature over the period 1961-2014. This is confirmed with F-test (Table 1). However, the Mann-Kendall trend test, the Sens and the least squares methods gave inconsistent results for the two different measurement scales (monthly and annually). For instance, while the Sens and the least squaresestimates indicate increase in variance,for estimates based on annual scale, they indicate a decrease in variance when the estimates are based on monthly scale for Dar es Salaam station. Inconsistence is also observed for Tanga station when comparing two methods: the Sens and the least squares estimates based on monthly scale. The Sens estimate indicates decrease in variance while least squares based estimate indicates increase in variance (Table 2).However, generally all tests confirm the increase in variances for daily minimum temperatures with an exception of Tanga station where there is a decrease in variances.

The largest impact on warm extreme events would be in the case where variance increases [15]. It is therefore important to understand the changing nature of the probability distribution of daily temperatures.The observed increase in variances of the daily minimum temperature in this study is in agreement with other studies which have shown stronger warming trend for minimum temperature indices than indices of maximum temperatures [13]. The diurnal temperature range (DTR), for instance in Dar es Salaam station, shows decreasing trend which indicates that the maximum and minimum temperatures do not have the same trend. The study by New et al. [12] over southern and West Africa shows that 60% of the studied stations show a decrease in DTR although the neighbouring countries of Tanzania (Zambia, Mozambique) showed increasing trend in DTR showing that there is a rapid increase in maximum temperature than minimum temperature extremes.

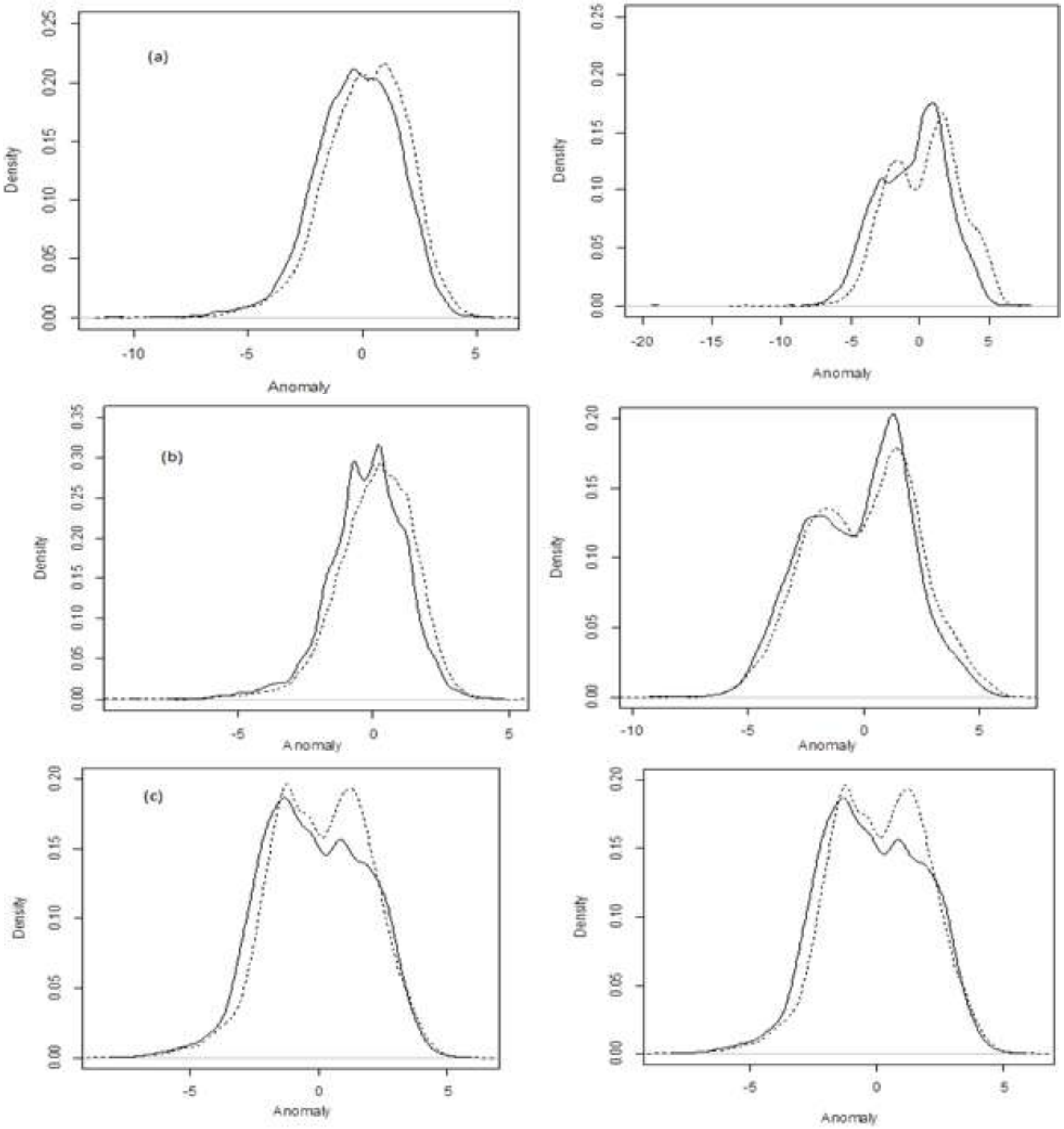


Figure 6: Probability density functions of maximum (left) and minimum (right) daily temperature anomalies (^{0}C) for Dar esSalaam(a), Mtwara (b) and Tanga (c) stations over the periods 1961-1987 (solid) and 19988-2014 (dashed).

6. Conclusion

This study presents variability of daily maximum and minimum temperature over the period 1961-2014 for coastal zone of Tanzania for Dar es Salaam, Mtwara and Tanga meteorological stations. F-ration test, Mann-Kendall trend test, Sens slope estimator and least squares method were used to test and estimate any significant changes in variance. For F-ratio test, time series were divided into two periods of 27 years (1961-1987 and 1988-2014).

The results show a significant increase/decrease in variability for daily minimum temperatures. However, the results do not show significant increase/decrease in variability for maximum daily temperature except for Tanga station where there is a significant decrease in the variability with time for maximum daily temperature.

There is a need to extend this study to cover the whole country in order to understand the changing nature of probability distribution of daily temperature on spatial and temporal bases. This will help in understanding the relationship between the observed trends in the climate change indices and the changing nature of probability distributions of daily temperature over time.

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Author Profile

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