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Influence of Climate on Tea Yields in Mount Kenya Region

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Abstract
This study investigated the existence of a systematic relationship between tea yields and climatic parameters in the tea growing areas of Mount Kenya region. Both linear and multiple regression models were applied. The data used in this study were the daily mean minimum and maximum temperatures, daily mean relative humidity, radiation, total weekly rainfall, and total weekly tea yields. One week is taken to be seven days with the first day of July being the first day of the first week of the year. The results of applying these models using weekly data were found to be satisfactory and it was concluded that climatic parameters can indeed be used to predict tea yields in this region.

Key words: Aberdare Mountains, climatic parameters, Mt. Kenya, Photosynthetically active radiation, regression models, Rift Valley, Tea yield.

1. INTRODUCTION
Tea, botanically known as Camellia sinensis, is one of the leading cash crops in Kenya. Tea is a shrub, or straggling tree, which belongs to the family of Theaceae and grows wild to a height of 10 m or more. Tea is known to exist in three varieties, namely: China variety (C. s. sinensis), Cambodia variety (C. s. lasiocalyx) and Assam variety (C. s. assamia), all derived from their area of origin (Brown and Cocheme, 1973). However, none of these varieties is found in Kenya in its pure form but Assam variety is the predominant variety grown in Kenya due to its high yield potential(Kenya Tea Board website www.teaboard.or.ke), instead we have hybrids resulting from cross-pollination of the various varieties (Brown and Cocheme, 1973). These hybrids are known to respond well to climatic variables that are found in the tea growing areas in Kenya. Between
1997 and 2003 tea was Kenya’s leading foreign exchange earner except in 2003 when it was overtaken by horticulture (Kanyili, 2003). The processed dried leaves and buds of tea is prepared as a hot beverage and is consumed widely throughout the world. Kenya produces high quality tea with liquoring properties that range from good, medium to very fine.

Tea originated from the forest source near river Irrawaddy, Burma (Onwueme and Sinha, 1991). Commercially, planting of tea is hardly 200 years old. In Africa, tea was first planted in Durban, Bontane Garden, in 1850. It was brought to Kenya and first planted at Limuru; latitude 1.1°S, longitude 36.7°E and altitude 2000m above mean sea level, at the turn of the 19th century (Wilson, 1969). Limuru has a mean annual rainfall of about 1300 mm, a mean maximum temperature of about 20 °C and a mean minimum temperature of about 10 °C.

Cultivation of tea in the world is confined to the subtropics and the mountainous regions of the tropics at altitudes of about 1200 m to 2200 m above mean sea level. Tea yield is highly influenced by the seasonal fluctuations in climatic variables such as rainfall, temperature, solar radiation and humidity. Cultivation of tea is favoured by a temperature range of not more than 10 °C. The tea plant undergoes a dormant period in the cold months when the daily temperature ranges are more than 11 °C, and harvesting ceases to be economical (Etherington, 1973). Rainfall ranges of between 1250 mm to 1750 mm per annum and a relative humidity of about 80% are favourable for commercial cultivation of tea. Agricultural land derived from forest or treated in such a manner as to simulate forest environment is ideal for the growth and development of tea (Aclad, 1971). These tropical forest climatic conditions must of necessity be annual rainfall ranging between 1,200 mm and 1,400 mm, temperatures that are well above freezing point, solar radiation that is well distributed throughout the year, high relative humidity and soils that are deep and well drained (Brown and Cocheme, 1973). These tropical forest conditions are found between altitudes 1500 m and 2700 m and include the area in Kenya between Mt. Kenya and Lake Victoria on either side of the Rift Valley (Kenya Tea Board, 1998). These conditions favour the growth rate of the tender shoots consisting of two leaves and a bud, which are the harvestable products in tea.

This paper investigates the relationship between climate variability and tea production, and presents the optimal climatic variables that are best suited for improvement of tea yields in Kenya. The paper further develops and discusses climate advisories that would assist the farmers to improve on their tea production and productivity.

2. MATERIALS AND METHODS

The climate data used in this study were obtained from Kenya Meteorological Department (K.M.D) and cover the period June 24, 1995 to June 23, 1996. The tea yield data covering the period between July 1, 1995 and June 30, 1996 respectively came from Kenya Tea Development Agency (K.T.D.A), which manages a network of tea factories in Kenya tea growing zones. The climatic parameters which were obtained from Kenya Meteorological Department (KMD) are within the range considered conducive for cultivation of tea.

Tea growing area which is covered by this study, lies within the latitudes 0.4° N and 1.3° S and longitudes 36.5° E and 37.7° E. This area comprises four localities in Kiambu, Meru, Kirinyaga and Nyeri regions. All the four areas experience a mean maximum temperature of about 24 °C and a mean minimum temperature of about 13 °C except Nyeri which has a mean minimum temperature of about 12 °C. These areas are located at altitudes between 1500 m and 2000 m above mean sea level. Preceding weekly climatic parameters influence yields more than those of the current period. Hence, the climatic data that were obtained for this study were weekly totals of rainfall, mean daily temperatures, mean daily relative humidity and mean daily radiation. Weekly tea yield totals and climatic data were matched by plotting them on a time series (Figures 1a and 1b).

Scatter plots of yields on various climatic parameters were made and the regression lines (Equation 1) obtained for each parameter shown in Figures 2a –2e.

\[ y = a + bx + \varepsilon \]  

where, the response variable \( y \) is the weekly tea yield (kg/ha/wk), the explanatory variable \( x \) is any of the climatic parameters for the previous week, \( a \) is the y-intercept or the yield when no contribution of climate is considered, \( b \) is the slope of the regression line and the random variable \( \varepsilon \) is the residual. From the slope of Equation 1, the effect of any one of the climatic parameters on the weekly tea yield was evaluated.

In order to incorporate more than one climatic parameter in the determination of weekly tea yields, we used a multivariate regression model in which tea yield was regressed on different climatic parameters (Equation 2).

\[ y = a_0 + \sum_{i=1}^{5} a_i x_i + \varepsilon \]

In Equation 2 the response variable \( y \) was tea yield while the explanatory variables \( x_i \) were climatic parameters.
Equation 2 was used to determine the total contribution of the five climatic parameters to the weekly tea yields. The magnitudes of coefficients $a_i$ of the climatic parameters in the model determined the amount of contribution of climatic parameters to tea growth and development; hence the yield. A comparison was made of predicted versus observed yields using Chi-square parameter (Table 1) under the following null and alternative hypothesis:

$H_0$: The observed and predicted yields are independent.

$H_1$: The observed and predicted yields are dependent.

The regression of predicted yields on observed yields is shown in Figure 3.
Table 1: Chi-Square parameters of predicted (Pr) versus observed yields for Kiambu, Kirinyaga, Meru and Nyeri

<table>
<thead>
<tr>
<th>Week</th>
<th>Kiambu</th>
<th>Kirinyaga</th>
<th>Meru</th>
<th>Nyeri</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\frac{(Ob - Pr)^2}{Ob})</td>
<td>(\frac{(Ob - Pr)^2}{Ob})</td>
<td>(\frac{(Ob - Pr)^2}{Ob})</td>
<td>(\frac{(Ob - Pr)^2}{Ob})</td>
</tr>
<tr>
<td>47</td>
<td>3.311</td>
<td>0.462</td>
<td>0.955</td>
<td>0.061</td>
</tr>
<tr>
<td>48</td>
<td>7.511</td>
<td>1.729</td>
<td>11.985</td>
<td>0.172</td>
</tr>
<tr>
<td>49</td>
<td>0.047</td>
<td>10.390</td>
<td>3.640</td>
<td>2.201</td>
</tr>
<tr>
<td>50</td>
<td>0.347</td>
<td>2.415</td>
<td>20.532</td>
<td>0.565</td>
</tr>
<tr>
<td>51</td>
<td>2.853</td>
<td>0.003</td>
<td>0.675</td>
<td>4.829</td>
</tr>
<tr>
<td>52</td>
<td>0.094</td>
<td>0.742</td>
<td>12.956</td>
<td>0.146</td>
</tr>
</tbody>
</table>

\[
\chi^2 = \frac{(Ob - Pr)^2}{Ob}
\]

14.165 15.741 50.743 7.974

Figure 2a: Regression relationship between weekly tea yields and mean minimum temperature at 95% confidence level for Kiambu, Kambaa Tea Factory.

Figure 2b: Regression relationship between tea yields and mean maximum temperature at 95% confidence level for Kiambu, Kambaa Tea Factory.
Figure 2c: Regression relationship between weekly tea yields and total weekly radiation at 95% confidence level for Kiambu, Kambaa Tea Factory.

Figure 2d: Regression relationship between weekly tea yields and total weekly rainfall at 95% confidence level for Kiambu, Kambaa Tea Factory.

Figure 2e: Regression relationship between weekly tea yields and mean relative humidity at 95% confidence level for Kiambu, Kambaa Tea Factory.
3. RESULTS AND DISCUSSION

Results obtained from the study are presented in both tabular and graphical form together with a brief discussion.

3.1 Relationship between Weekly Tea Yields and Climatic Parameters.

Plots of tea yields and climatic data against time, where the first week of July was considered as week 1 and the last week of June as week 52; were obtained for the four locations namely: Kiambu, Meru, Kirinyaga and Nyeri. Figures 2a and 2b show the plots for Kiambu. Similar plots were obtained for the other locations. Three peak yields were observed in weeks 13-17 corresponding to the months of October to early November, weeks 22-24 corresponding to the second half of December and weeks 34-39 corresponding to late March to mid May. These peaks closely lag the short rains (September – November), between weeks 11 and 29, and the long rains (March – May), between weeks 33 and 48. These were the periods when higher temperatures were also experienced. The results showed that the weekly tea yields are lowest when temperatures are also lowest particularly during cold dry season (June – August), that is between weeks 50 and 10. On the other hand yields are highest when both temperatures and radiation are highest during the short rains season (September – November), that is between weeks 11 and 30, and during the long rains season (March – May), between weeks 33 and 48. In both cases the yield lags climatic variables by a week or two.

High weekly tea yields are observed when high solar radiation values (W/m²) and high rainfall values (mm) occur in the same period. This is probably because photosynthetically active radiation, (0.41-0.7µ), and moisture are abundantly available for dry matter production during assimilatory processes.

This leads to an increase in weekly tea yields. Transpiration aids the metabolic activities of the tea plant. Increased atmospheric humidity (%) results in reduced transpiration hence reduced water use efficiency and therefore reduced yields. Low mean minimum temperatures retard metabolic activities of the tea plant resulting in low tea yields observed during cold seasons of weeks 1 to 12 (July - September). High weekly tea yields coincide with warmer periods of the year because of the increased metabolic activities within the tea plant.

Figures 2a to 2e show the linear relationships between weekly tea yields and the various climatic parameters at Kiambu. Results obtained from the scatter plots of these sites are summarised in Tables 1 and 2 in columns 2 to 11. Table 2 shows the intercepts and slopes of linear regression models (Equation 1) of weekly tea yields on individual climatic parameters in the four sites and their averages. The intercepts are the values of the weekly tea yields when each climatic parameter is zero. We observe in Table 2 that weekly tea yields are relatively more sensitive to maximum and minimum temperatures but less sensitive to the relative humidity. Physiologically high minimum temperatures promote dry matter destruction by respiration. High maximum temperatures promote accumulation of dry matter through photosynthesis. The yields are low for high relative humidity which retards water use efficiency. High maximum temperatures occur during day-time when the tea plant leaves are not subjected to mutual canopy shading of harvestable parts.
On the other hand, minimum temperatures occur in the early part of the morning when the leaves generally undergo mutual shading. The slopes of the regression lines indicate change in tea yields per unit change in the climatic variable, which is a growth rate per unit increase in the variable. The growth rate of tea is highly sensitive to changes in minimum temperature since the slopes are above 17.83 in all the sites studied except at Nyeri where it was 4.96. Any unit increase in minimum temperature resulted in increase in weekly tea yields of about 4.96 kg/ha/wk. Similar observations were made for maximum temperature where all the sites showed over 15.29 kg/ha/wk increase in weekly tea yields for every unit increase in maximum temperature. Rainfall, radiation and relative humidity have relatively little effect on the yield possibly due to the tea canopy that completely covers the ground resulting in mutual shading of the leaves when the canopy is fully developed and plucking table is formed. The slopes for these parameters range between –4.72 and 1.33.

Table 2: Intercepts (Int) and slopes (Slo.) of regression lines for all the four sites and their average

<table>
<thead>
<tr>
<th>Weekly climatic factor</th>
<th>Kiambu</th>
<th>Kirinyaga</th>
<th>Meru</th>
<th>Nyeri</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Int</td>
<td>Slo</td>
<td>Int</td>
<td>Slo</td>
<td>Int</td>
</tr>
<tr>
<td>Radiation (Q) W/m²</td>
<td>28.0</td>
<td>1.03</td>
<td>155.7</td>
<td>0.82</td>
<td>61.5</td>
</tr>
<tr>
<td>Total rainfall (Rf) mm</td>
<td>139.1</td>
<td>0.17</td>
<td>230.6</td>
<td>0.37</td>
<td>233.7</td>
</tr>
<tr>
<td>Mean maximum temperature (Tx) ºC</td>
<td>-209.3</td>
<td>15.29</td>
<td>-254.7</td>
<td>20.76</td>
<td>-221.2</td>
</tr>
<tr>
<td>Mean minimum temperature (Tn) ºC</td>
<td>-183.3</td>
<td>24.40</td>
<td>-46.3</td>
<td>20.55</td>
<td>-42.3</td>
</tr>
<tr>
<td>Mean relative humidity (H) %</td>
<td>305.7</td>
<td>-2.30</td>
<td>517.3</td>
<td>-3.91</td>
<td>375.6</td>
</tr>
</tbody>
</table>

Table 3: Coefficients of Correlation (r %) and determination (R² %) for all the four sites and their average

<table>
<thead>
<tr>
<th>Weekly climatic factor</th>
<th>Kiambu</th>
<th>Kirinyaga</th>
<th>Meru</th>
<th>Nyeri</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r %</td>
<td>R² %</td>
<td>r %</td>
<td>R² %</td>
<td>r %</td>
</tr>
<tr>
<td>Radiation (Q) W/m²</td>
<td>50</td>
<td>25</td>
<td>34</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>Total rainfall (Rf) mm</td>
<td>9</td>
<td>1</td>
<td>21</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>Mean maximum temperature (Tx) ºC</td>
<td>56</td>
<td>32</td>
<td>54</td>
<td>29</td>
<td>45</td>
</tr>
<tr>
<td>Mean minimum temperature (Tn) ºC</td>
<td>63</td>
<td>40</td>
<td>33</td>
<td>11</td>
<td>31</td>
</tr>
<tr>
<td>Mean relative humidity (H) %</td>
<td>-35</td>
<td>12</td>
<td>-34</td>
<td>11</td>
<td>-14</td>
</tr>
</tbody>
</table>

On the other hand, minimum temperatures occur in the early part of the morning when the leaves generally undergo mutual shading.

The slopes of the regression lines indicate change in tea yields per unit change in the climatic variable, which is a growth rate per unit increase in the variable. The growth rate of tea is highly sensitive to changes in minimum temperature since the slopes are above 17.83 in all the sites studied except at Nyeri where it was 4.96. Any unit increase in minimum temperature resulted in increase in weekly tea yields of about 4.96 kg/ha/wk. Similar observations were made for maximum temperature where all the sites showed over 15.29 kg/ha/wk increase in weekly tea yields for every unit increase in maximum temperature. Rainfall, radiation and relative humidity have relatively little effect on the yield possibly due to the tea canopy that completely covers the ground resulting in mutual shading of the leaves when the canopy is fully developed and plucking table is formed. The slopes for these parameters range between –4.72 and 1.33.

Table 3 shows the coefficients of correlation (r) and coefficients of determination (R²) of yield with climatic parameters for all the four sites and their averages. The coefficients of correlation were observed to be positive for all the climatic parameters except relative humidity. The maximum temperatures were observed to be most highly and positively correlated to tea yields.
soil moisture and the rainfall may not show immediate effect. Radiation explains more than 20% of variations in the weekly tea yields with the exception of Kirinyaga. The hypotheses $H_0: b = 0$ (null) $H_1: b \neq 0$ (alternative) were tested by the F statistic, $F = \frac{MSS}{MSE}$, with (3, 12) degrees of freedom at 5% level of significance.

The null hypothesis $H_0: b = 0$, is that tea yields in this region are significantly influenced by all the five climatic parameters considered in this study. The alternative hypothesis $H_1: b \neq 0$ is that at least one of the climatic parameters has no significant influence on the tea yields in this region.

Table 4 shows the single factor ANOVA table for slopes of all the regression lines at 5% level of significance. The computed F-value (1.23) is less than the tabulated critical F-value (3.06). We therefore accept the null hypothesis and conclude that tea yields in this region are significantly influenced by all the five climatic parameters considered in this study.

Table 5 shows the observed and predicted yields together with the percentage absolute error (%Er) between observed and predicted weekly yields. Hence climatic parameters

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-Value</th>
<th>F-Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2633.99</td>
<td>4</td>
<td>658.25</td>
<td>1.23</td>
<td>0.34</td>
<td>3.06</td>
</tr>
<tr>
<td>Within Groups</td>
<td>8040.24</td>
<td>15</td>
<td>536.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10673.22</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Observed (Obs) and predicted (Prd) weekly tea yields (kg/ha) in Kiambu, Kirinyaga, Meru and Nyeri for weeks 47 to 52 and the percentage absolute error (%Er) between observed and predicted weekly yields.
3.2. Multiple Regression Models

Multiple regressions (Equation 2) of tea yields on the five climatic parameters were performed for the five sites and the results were displayed in Table 6. The differences in climate among the sites are reflected in their coefficients (slopes, Equation 2). The highest coefficient for maximum temperature (\(T_x\)) was found at Kirinyaga (41.2) while the lowest coefficient was Meru (0.02). This indicates that for every unit increase in \(T_x\), there is a corresponding increase in yields of 41.2 Kg/ha/wk. The highest coefficient for minimum temperature (\(T_n\)) was at Kiambu (17.3) and lowest at Meru (0.10). However, at Kirinyaga any increase in \(T_n\) results in a loss of yield by 7.5 (that is -7.5). The influence of radiation (Q) is minimal but positive for Kiambu (0.5) and Nyeri (0.4). The negative influences were found at Kirinyaga (-1.2) and Meru (-0.1). There was dry matter loss through respiration for every increase in Q at the latter sites. Unlike the case with linear regression model (Equation 1), the multiple regression models show positive increase of yield with unit increase in relative humidity, in which Kiambu has the highest value (1.3) followed by Meru (1.28) while Nyeri had the lowest (0.2). The highest coefficient for rainfall (\(R_x\)) was found at Meru (5.07) and the lowest at (Kiambu -0.1). The inter-comparisons of the coefficients of the multiple regression model display spatial differences that reflect the influence of the climatic variables on the weekly tea yields in the sites studied. In the unlikely hypothetical situation when all the climatic parameters reduce to zero, the dry matter destruction will quickly take place in Kirinyaga where the intercept is -565.6. Meru would experience the least dry matter destruction maximum temperature, mean minimum temperature, total weekly radiation, relative humidity and total weekly rainfall and the peaks of weekly tea yields.

The results of the study indicate that temperatures, both the mean minimum and the mean maximum, highly influence tea yield in this region. Both temperatures have the highest slopes, indicating highest contribution to unit yield and lowest when they decline to zero. It was observed that maximum temperature, weekly radiations and minimum temperatures appear to influence tea yields in this region more than the other climatic variables in that order. They have the highest average percentage correlation coefficient as well as the highest average percentage coefficients of determination.

Tea yields in this region are significantly influenced by all the five climatic parameters considered in this study as the computed F-value (1.23) is less than the critical F-value (3.06). Since the calculated values of Chi-square parameter at 5% level of significance and 5 degrees of freedom were all greater than the tabulated critical value (11.070), except for Nyeri, we rejected the null hypothesis and concluded that there is actually a strong connection between observed and predicted yield values.

From the results of the study it was clear that three most important climatic parameters for tea yields in Kiambu are the mean minimum, mean maximum temperature and the terrestrial radiation which together account for about 97% of variations in the weekly tea yields. The results of multiple regressions show that the model can be used to predict weekly tea yields in this region accurately. Hence information on climatic parameters, which can be obtained from the local tea factories can help farmers and the

Table 6: Constants of multiple regression models of yield on individual climatic parameters for Kiambu, Kirinyaga, Meru and Nyeri. (Note \(T_x\)=maximum temperature, \(T_n\)=minimum temperature, \(Q\)=solar radiation, \(H\)=relative humidity and \(R_x\)=rainfall)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Coefficients (slopes) of climatic parameters</th>
<th>Intercepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(T_x)</td>
<td>(T_n)</td>
</tr>
<tr>
<td>Kiambu</td>
<td>8.7</td>
<td>17.3</td>
</tr>
<tr>
<td>Kirinyaga</td>
<td>41.2</td>
<td>-7.5</td>
</tr>
<tr>
<td>Meru</td>
<td>0.02</td>
<td>0.10</td>
</tr>
<tr>
<td>Nyeri</td>
<td>16.5</td>
<td>7.2</td>
</tr>
</tbody>
</table>

4. CONCLUSION

These results show that weekly tea yields depended strongly on relative humidity and mean minimum temperature. From the results of the study, it is clear that there is good agreement between the magnitudes of the five climatic parameters namely the mean management of various Tea factories in making informed decisions well in advance in order to achieve maximum returns from the produce.

5. ADVISORY AND RECOMMENDATION

The study has shown that temperatures, both
maximum and minimum, together with terrestrial radiation account for over 97\% of tea yields. Accurate weekly forecasts of these climatic parameters together with rainfall would result in accurate yield forecasts in the subsequent week. Therefore weekly updates of climate forecasts should be made available to tea farmers on a regular basis. Farmers should use these forecasts to plan for the subsequent week’s labour. Local tea factories should liaise with the Kenya Meteorological Department for provision of the climatic forecasts. The factories should also arrange to have a weather advisor attached to various factories to advise tea farmers on the implications of various climatic forecasts. Using these forecasts the factories would also be able to assess the expected green leaf deliveries and plan accordingly. The forecasts will also be used as reliable advisory tools to advise farmers on the best times to apply fertilizers as well as the period within which to prune the tea in order achieve maximum benefit. Delay in any of the two activities translates into loss in tea yields.

REFERENCES
ABSTRACT

Regional flood frequency analysis deals with the identification of homogeneous regions of which the distribution of peak flows from sites from in such a region are similar. Once a homogenous region is identified, standardized data from different sites within the region can be pooled together and a single frequency curve applicable to the region can be derived.

The data used in this study includes Annual Maximum Annual Flood (MAF) series of daily discharges from 28 river gauging stations located in the Nile Equatorial Basin. These data were quality controlled using single mass analysis, and time series plots to check any inconsistencies before the MAF series were extracted. The regional homogeneity testing was done independently for stations in Kenya and Tanzania because of the large variations in the length of records.

The methods used for regional homogeneity testing are the heterogeneity measure statistics, the use of L-moments diagrams and at-site regional analysis. L-moments are defined as linear combinations of probability weighted moments (PWM). L-moment ratio diagrams are based on simple measure of the dispersion of the sample L-moments such as linear combination of; the coefficient of variation (L-CV), the skewness (L-CS) and kurtosis (L-CK). In this case the method of assessing heterogeneity is based on visual assessment of the dispersion of the at-site L-moments of the observed and simulated region. Heterogeneity statistics are also computed on the basis of L-moment ratios.

The regional analysis approach, used with Tanzanian data, is based on the empirical distributions determined for all the sites within the region. The average of the empirical distributions is determined to represent the frequency curve for the region. Based on the Quantile-Quantile (Q-Q) plots, Extreme Value Type I (EV1) was the selected theoretical distribution used to derive the regional frequency curve for the Tanzania data using the method of PWM to estimate the parameters. The regional frequency curve in this case is derived by regional averaging of dimensionless at-site order statistics.

The results of the study indicated that the stations in the Kenyan part of the basin can be considered to be moderately heterogeneous and cannot entirely be represented by a single distribution in regional analysis. The L-moment ratio diagrams for the observed and simulated data show some dissimilarity while the absolute value of the heterogeneity measure statistics is 1.25. The result of regional analysis based on empirical distributions grouped together the Tanzanian stations into relatively homogeneous region.

Keywords: L-moment ratios, homogeneity grouping, discordancy measure, heterogeneity measure, Quantile-Quantile (Q-Q) plots
1. INTRODUCTION

In many water-engineering applications, the available time series are too short for a reliable estimation of extreme events. The difficulties are related to the uncertainty in the calibration of the appropriate extreme value distribution. Regionalization provides a means to cope with this problem by assisting in the identification of the shape of the extreme value distribution, leaving only a measure of scale (or more general, an ‘index’) to be estimated from the at-site data.

Identification of homogeneous regions where the distribution of peak flows is similar is important for regional flood frequency analysis. Once a homogenous region is identified, standardized data from different sites within the region can be pooled together and a single frequency curve applicable to the region can be derived. In cases where adequate rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists and engineers to derive reliable flood estimates directly and regional studies can be useful.

This paper focuses on the application and comparison of techniques for homogeneity testing. Discharge data from the Nile Equatorial basins in Kenya and Tanzania were considered.

1.1 DATA AND STUDY AREA

Data Available

The data that have been used to carry out the homogeneity testing includes Maximum Annual Flood (MAF) series of daily discharges from 28 river gauging stations located in the Nile Equatorial Basin (9 stations located on the Tanzanian side and 19 stations located on the Kenyan side). The list of river gauging stations used in the study is presented in Table 1. From the table, it can be observed that stream flow records from the Tanzanian side are only available for the period from 1970 to 1982 and the record length of available data varies from 9 to 11 years. Record lengths on the Kenyan side range between 32 and 47 years. These data were quality controlled using mass curve, double mass curve methods, and time series plots to check any inconsistencies before the MAF series were extracted.

For the purpose of flood frequency analysis two methods of sampling are of relevancy i.e. Maximum Annual Flood (MAF) series or Partial Duration (PD) series. The MAF series consist of the maximum flows for each year, and is the most frequent sampling method used among the two common series. One of the aspects in favor of the MAF series is the reasonable assumption that the data series is not serially correlated, i.e., successive values are independent. This property is an important prerequisite for the subsequent statistical treatment of data. A disadvantage of MAF series is that the second or third, etc, highest events in a particular year may be higher than the maximum event in another year and yet they are totally disregarded.

The PD series, on the other hand, consists of flood peak events above a certain threshold magnitude. The threshold is generally selected low enough so that at least one event in each year is included in the series. It is important that each event that is included in the PD series must be separate and distinct so that the sampled events are independent.

The regional homogeneity testing was done for Kenya and Tanzania stations independently because of the large variations in the length of records. However, MAF populations at several sites are assumed not to be dependent on catchment size, Cunnane (1989). Table 1 gives an overview of the stations considered in the study while figure 1 shows the distribution of the stations within the Nile equatorial basin.

Figure 1: Map of the study area and the location of river gauging stations for the study.

2. METHODS FOR HOMOGENEITY TESTING

Sites are grouped when they have similar catchment characteristics, e.g. flood response, when a regionalized flood frequency analysis is conducted, Cunnane (1989). Hosking and Wallis (1993) developed several tests for use in regional studies. They gave guidelines for judging the degree of homogeneity of a group of sites, and for choosing and estimating a regional distribution. The three regional homogeneity measures selected for this study are the heterogeneity measure statistics, and the use of L-moment ratio diagrams and at-site regional analysis. L-moment ratio diagrams as a tool for identifying a regional distribution have been used in many studies, including Chowdhury et al. (1989), Pilon & Adamowski (1992), Vogel & Fennessey (1993), and Vogel et al. (1993a, 1993b). Another method for homogeneity test is based on estimated dimensionless 10-year floods developed by Lu & Stedinger (1992).
Table 1: List of discharge stations used in the analysis

<table>
<thead>
<tr>
<th>Serial no.</th>
<th>River</th>
<th>Station</th>
<th>Area (km²)</th>
<th>Country</th>
<th>Period of record</th>
<th>Years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ngono</td>
<td>Muhutwe</td>
<td>780</td>
<td>Tanzania</td>
<td>1971-1982</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Ngono</td>
<td>Kalebe brg</td>
<td>1185</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Ngono</td>
<td>Kyaka rd brg</td>
<td>2608</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Ruvuma</td>
<td>Mwendo ferry</td>
<td>-</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Kagera</td>
<td>Nyakanyasi</td>
<td>48228</td>
<td>Tanzania</td>
<td>1970-1978</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>Moame</td>
<td>Mabuki brg</td>
<td>1410</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Magogo</td>
<td>Shinyanga rd</td>
<td>1212</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Simiyu</td>
<td>Road crossing</td>
<td>10659</td>
<td>Tanzania</td>
<td>1970-1978</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>Simiyu</td>
<td>Ndagalu</td>
<td>10560</td>
<td>Tanzania</td>
<td>1970-1982</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>Kwoittobos</td>
<td>1be06</td>
<td>808</td>
<td>Kenya</td>
<td>1956-1984</td>
<td>29</td>
</tr>
<tr>
<td>11</td>
<td>Kwoittobos</td>
<td>1be01</td>
<td>715</td>
<td>Kenya</td>
<td>1956–1975</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>Noigameget</td>
<td>1bc01</td>
<td>681</td>
<td>Kenya</td>
<td>1950–1985</td>
<td>36</td>
</tr>
<tr>
<td>13</td>
<td>Nundoro</td>
<td>1cb08</td>
<td>167</td>
<td>Kenya</td>
<td>1964-1984</td>
<td>21</td>
</tr>
<tr>
<td>14</td>
<td>Sergoit</td>
<td>1ca02</td>
<td>717</td>
<td>Kenya</td>
<td>1960 – 1985</td>
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<tr>
<td>15</td>
<td>Sosiani</td>
<td>1cb05</td>
<td>697</td>
<td>Kenya</td>
<td>1960 – 1989</td>
<td>30</td>
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<tr>
<td>16</td>
<td>Miriu</td>
<td>1jf06</td>
<td>394</td>
<td>Kenya</td>
<td>1964-1988</td>
<td>25</td>
</tr>
<tr>
<td>17</td>
<td>Yala</td>
<td>1fg02</td>
<td>2864</td>
<td>Kenya</td>
<td>1959 – 1985</td>
<td>27</td>
</tr>
<tr>
<td>18</td>
<td>Nzoia</td>
<td>1ee01</td>
<td>11849</td>
<td>Kenya</td>
<td>1963-1994</td>
<td>32</td>
</tr>
<tr>
<td>19</td>
<td>Yala</td>
<td>1fg01</td>
<td>2388</td>
<td>Kenya</td>
<td>1950-1985</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>Nzoia</td>
<td>1da02</td>
<td>8417</td>
<td>Kenya</td>
<td>1950-1988</td>
<td>39</td>
</tr>
<tr>
<td>21</td>
<td>Yala</td>
<td>1fe02</td>
<td>1577</td>
<td>Kenya</td>
<td>1962-1985</td>
<td>24</td>
</tr>
<tr>
<td>22</td>
<td>Kipkarren</td>
<td>1ce01</td>
<td>2440</td>
<td>Kenya</td>
<td>1950-1987</td>
<td>38</td>
</tr>
<tr>
<td>23</td>
<td>Kipwen</td>
<td>1cb09</td>
<td>80</td>
<td>Kenya</td>
<td>1964-1984</td>
<td>21</td>
</tr>
<tr>
<td>24</td>
<td>Little nzoia</td>
<td>1bb01</td>
<td>1474</td>
<td>Kenya</td>
<td>1957-1985</td>
<td>29</td>
</tr>
<tr>
<td>25</td>
<td>Rongit</td>
<td>1bg07</td>
<td>684</td>
<td>Kenya</td>
<td>1961-1984</td>
<td>24</td>
</tr>
<tr>
<td>26</td>
<td>Nyando</td>
<td>1gd04</td>
<td>2520</td>
<td>Kenya</td>
<td>1956-1988</td>
<td>33</td>
</tr>
<tr>
<td>27</td>
<td>Kuja Migori</td>
<td>1kc03</td>
<td>3046</td>
<td>Kenya</td>
<td>1951-1985</td>
<td>35</td>
</tr>
<tr>
<td>28</td>
<td>Kipkarren</td>
<td>1cd01</td>
<td>67</td>
<td>Kenya</td>
<td>1932-1987</td>
<td>56</td>
</tr>
</tbody>
</table>

compared several goodness-of-fit tests for the regional Generalized Extreme value (GEV) distribution and found that a new chi-square test based on the L-coefficient of variation and the L-skewness outperformed other classical tests. The heterogeneity measure, and the L-moment ratio methods for identification of homogeneous regions are briefly discussed below.

2.1 Heterogeneity measure statistics

The statistics of the standardized flood data such as the coefficient of variation (Cv), coefficient of skewness (Cs), coefficient of kurtosis (Ck) and the index flood $Q_{max}/\bar{Q}$; where $Q_{max}$ are the flood series or annual maximum series and $\bar{Q}$ is the mean flood) are considered to be constant across a homogeneous region, Hosking(1986, 1990). Departures from such assumptions could lead to a bias in the flood estimates at some sites. Those catchments whose Cv, Cs, Ck, and $Q_{max}/\bar{Q}$ values happen to coincide with the regional mean values would not suffer such bias. Under this method, the hydrologic homogeneity can
Cs, Ck, and $Q_{max}/Q$ values happen to coincide with the regional mean value.

Furthermore statistics such as the linear combination of PWM (L-moments) can be used to estimate the degree of heterogeneity in a group of sites and to assess whether they might reasonably be treated as a homogeneous region, Hosking et al. (1993). The method of heterogeneity measure statistics was based on the L-moments which are defined below:

**L-moments**

For a random variable $X$ with cumulative distribution function $F$, the following quantiles:

$$
\beta_r = E\{X[F(X)]^r\}
$$

are the Probability-Weighted Moments (PWMs), defined by Greenwood et al. (1979) and used to estimate the parameters of the probability distributions. Hosking (1986, 1990) defined L-moments to be linear combinations of PWMs:

$$
L_{r+1} = \sum_{k=0}^{r} P_{r,k}^* b_k
$$

such that the first sample L-moment would be $L_1$ for $r=0$

and $b_k$ is given by $b_k = \frac{1}{n-k(n-2)(n-r)} Q_{k,r}$

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and $b_k$ is given by $b_k = \frac{1}{n-k(n-2)(n-r)} Q_{k,r}$

where: $\beta_k$ are the PWMs with $k=0, 1, 2, \ldots, r$

$L_{r+1}$ are the L-moments with $r=0, 1, 2, \ldots, k$

and for $r, k$ $P_{r,k}$ is given by

$$
P_{r,k}^* = (-1)^{r-k} \binom{r}{k} \binom{r+k}{k}
$$

In particular the first four L-moments are given as:

$$
l_1 = b_0, l_2 = 2 b_1, l_3 = 6 b_2 - 6 b_1, l_4 = 20 b_3 - 30 b_2 + 12 b_1 - b_0
$$

L-moment ratios are the quantiles $t = l_2/l_1$ and $t_r = l_r/l_2$, $r = 3, 4, \ldots$

Figures 2 and 3 are examples of L-moment ratio diagrams.

L-moments are similar to but more convenient than PWMs because they are more easily interpretable as measures of distribution shape. In particular, $l_1$ is the mean of the distribution, a measure of location; $l_2$ is a measure of scale; $t_3$ and $t_4$ are measures of skewness and kurtosis, respectively. The L-CV, $t_2 = l_2/l_1$, is analogous to the usual coefficient of variation.

Heterogeneity measure statistic by means of L-moments

$\beta_r = E\{X[F(X)]^r\}$

---------------------------(1)

For a random variable $X$ with cumulative distribution function $F$, the following quantiles:

$\beta_r = E\{X[F(X)]^r\}$

---------------------------(1)

are the Probability-Weighted Moments (PWMs), defined by Greenwood et al. (1979) and used to estimate the parameters of the probability distributions. Hosking (1986, 1990) defined L-moments to be linear combinations of PWMs:

$L_{r+1} = \sum_{k=0}^{r} P_{r,k}^* b_k$

---------------------------(5)

such that the first sample L-moment would be $L_1$ for $r=0$

and $b_k$ is given by $b_k = \frac{1}{n-k(n-2)(n-r)} Q_{k,r}$

---------------------------(5)

Then $l_r$ is an unbiased sample-based estimator of $l_r$. The estimators $t_2 = l_2/l_1$ of $t_r$ are consistent but not unbiased. The quantiles $l_1$, $l_2$, $l_3$, $t_3$ and $t_4$ are useful summary statistics for data samples. They can be used to judge which distributions are consistent with a given data sample (Hosking, 1990). Details can be found in Hosking et al. (1993) among others.
In a homogeneous region, all sites have the same population L-moment ratios. Their sample L-moment ratios will, however, be different owing to sampling variability.

The easiest, but subjective, method of assessing heterogeneity is by visual assessment of the dispersion of the at-site L-moments such as the L-moment coefficient of variation (L-CV), the L-skewness (L-CS) or the L-kurtosis (L-CK). This can be done based on a plot of L-CS versus L-CV or L-CK, commonly referred to as L-moment diagrams, Hosking et al. (1993).

An alternative and more objective simple measure of the dispersion of the sample L-moments is the standard deviation of at-site L-CVs. L-CVs are used in this study because between-site variation in L-CV has a much larger effect than variation in the L-CS or L-CK on the variance of the estimates of quantiles, except those in the far tail of the distribution (Hosking et al., 1985a). Simulation can be used in order to establish the kind of dispersion that would be expected. By repeated simulation of a homogeneous region with sites having record lengths the same as those of the observed data, the mean and the standard deviation of the chosen dispersion measure can be obtained (Madsen et al., 1997b). The level of homogeneity or heterogeneity measure, \( H \), of a region then can be expressed as:

\[
H = \frac{Y - \hat{Y}}{\sigma}
\]  

where \( Y \) is the statistic or variable considered to test the homogeneity, \( \hat{Y} \) the mean of the simulated values for this variable and \( \sigma \) is the standard deviation of the simulated values, Hosking et al. (1993) and Burn (1997).

However, a more appropriate statistic compares the observed and the simulated dispersion, through the weighted standard deviation \( (V) \) of the at-site L-CVs, Burn (1997). This expressed as:

\[
V = \sum_{i=1}^{N} \frac{n_i (t_i' - \bar{t})^2}{\sum_{i=1}^{N} n_i}
\]  

where \( t_i' \) and \( \bar{t} \) are the sample L-CVs at each site \( i \) and the regional mean L-CV respectively, while \( n_i \) are the sample record lengths at each site \( i \) and \( N \) the number of sites.

Group average L-moment ratios, with sites weighted proportionally to their record lengths are:

\[
\bar{t}_i = \frac{1}{N} \sum_{i=1}^{N} n_i t_i'
\]

where the sample L-moment ratios at site \( i \) are denoted by \( t_2, t_3, t_4, \ldots \).

Then a Gumbel distribution is fitted to the regional average L-moment \( \bar{t}_1, \bar{t}_3, \bar{t}_4, \ldots \), which are the mean sample L-moment ratios obtained from a finite sample. The regional average L-moment ratio is computed from the site values which are weighted proportionally to their record lengths as shown in Equation 9.

Finally, a similar number of regions as the observed \( (N_{sim}) \) is to be simulated from the Gumbel distribution; the regions are homogeneous and have no cross correlation or serial correlation, and sites have the same record lengths as the observed data. For each simulated region calculate \( V \) and from the simulations determine the mean and standard deviation of the \( N_{sim} \) values of \( V \) and call these \( \mu_V \) and \( \sigma_V \).

Mathematically, equation 6 can be written as:

\[
H = \frac{V - \mu_V}{\sigma_V}
\]

\[\text{(10)}\]

in which \( H \) is the heterogeneity measure statistic.

The region is regarded as “acceptably homogeneous” if \( |H| < 1 \), “possibly heterogeneous” if \( 1 < |H| < 2 \), and “definitely heterogeneous” if \( |H| \geq 2 \) (Hosking and Wallis, 1993).

2.2 Regional distribution analysis

This approach is based on the empirical distributions determined for all the sites within the region. The average of the empirical distributions is determined to represent the frequency curve for the region. Empirical distributions are determined for each site by ranking the standardized data (after dividing by the scale parameter) in ascending order and then assigning to each of the ranked standardised flow magnitudes the probability of non-exceedance by using the Gringorten plotting position formula. This plotting probability is unbiased and suitable for Gumbel and exponential paper.

The Gringorten formula is expressed as:

\[
F_i = \frac{i - 0.44}{N + 0.12}
\]

\[\text{(11)}\]
sample member. The results of using an empirical approach are presented in section 3.

Regional flood frequency analysis can also be based on the L-moments: The L-moment ratios $l_1$, $l_2$, $l_3$, …, $l_p$ are estimated by the corresponding sample L-moments of the at-site statistics. Hosking et al. (1985a), Lettenmaier and Potter (1985), Wallis and Wood (1985), Lettenmaier et al. (1987), Hosking and Wallis (1988), and Potter and Lettenmaier (1990) have shown that index flood procedures based on PWSs or L-moments yield robust and accurate quantile estimates.

In this study, the Q-Q plots were used to select the best theoretical distributions using the 9 locations in Tanzania. The method of Q-Q plots has been discussed by Opere et al. (2006). The regional frequency curve is derived by regional averaging of dimensionless at-site order statistics such as obtained by division of MAF series, $Q$, by the mean MAF, $\bar{Q}$, at each site and fitting a distribution, Cunnane (1989).

It should be noted that the equation of the regional frequency curve is given by:

$$Q(T) = 0.801 + 0.3451 \ln(-\ln(F(Q)))$$

3. RESULTS AND DISCUSSIONS

Results from the methods that were used to determine regional homogeneity are presented in this section. The discharge data were subjected to various statistical tests for homogeneity. One of these methods is based on visual assessment of the L-moment statistics while the other involves the computation of homogeneity measure statistics as presented in section 2.

3.1 Homogeneity measure statistic

The method of Homogeneity measure statistic involves the computation of a heterogeneity measure statistics based on the observed and simulated data and governed by equation 9. The 19 regions on the Kenyan side were simulated using Gumbel (EV1) distribution. This distribution has been selected in a previous study to fit the annual maximum series for this region, Opere et al. (2006).

Based on the methods described under section 2.1, the computed H statistic was -1.25 and since $|H| <2$, the region is possibly heterogeneous.

3.2 L-moment ratio diagrams

The L-moment ratio diagrams (Figure 2) shows the results of the visual assessment of the dispersion of the at-site L-moments obtained by plotting L-CV versus both L-CS. Figure 3 on the other hand is a plot of L-CK versus L-CS.

![Figure 2: L-moment ratio diagrams for L-kurtosis (L-CK) and L-skewness (L-CS) for 19 locations in Kenya](image-url)

The results in Figure 2 show dissimilarity in the spread of the observed and simulated statistics (L-CV and L-CS). Figure 3 depicts a similar spread of the observed and simulated statistics (L-CK and L-CS). This is an indication that the stations belong to a moderately heterogeneous region and cannot entirely be represented by a single distribution in regional analysis.

3.3 Results of regional analysis based on EV1 as a theoretical distribution

For each of the 9 stations in Tanzanian, empirical distributions were plotted to each site. A regional flood frequency distribution was then derived. Example of the results based on empirical distributions is shown in Figure 4 for the Tanzanian stations. Plots of empirical distributions for all the stations, i.e. plots of ranked standardized flow versus non-exceedance probability, were plotted on the same graph.

From Figure 3 it is observed that the empirical distributions for the different sites plot relatively
4. CONCLUSION

The results indicated that the 19 locations on the Kenyan side of the Lake Victoria basin could be grouped into a moderate heterogeneous hydrological region and therefore only at-site flood frequency analysis could be recommended. Further test would be required to investigate the level of heterogeneity and ascertain whether the region could be divided into two or more homogeneous regions.

On the other hand, observations from the sites on the Tanzanian side of the basin, based on empirical distributions fitting, indicated that the stations in the region constitute a single homogenous region which suggests that a single theoretical extreme value distribution can be used to derive a regional frequency curve for the Lake Victoria sub-basin in Tanzania. Referring to the calibration results reported in Opere et al. (2006), the selected distribution to fit the Maximum Annual Flood (MAF) series was the EV1/Gumbel distribution for the 9 Tanzanian sites. On this basis the EV1/Gumbel distribution was used to derive the regional frequency curve for the region. The derived curve is shown in Figure 4. It can be observed from Figure 4 that EV1/Gumbel distribution fitted by PWM method gives a good fit to the observed data.

On this basis of Q-Q plots, EV1 was chosen and parameters estimated using the method of PWM (Table 2). This distribution was further used to derive the regional frequency curve for the region presented in figure 4.

4. CONCLUSION

The results indicated that the 19 locations on the Kenyan side of the Lake Victoria basin could be grouped into a moderate heterogeneous hydrological region and therefore only at-site flood frequency analysis could be recommended. Further test would be required to investigate the level of heterogeneity and ascertain whether the region could be divided into two or more homogeneous regions.

On the other hand, observations from the sites on the Tanzanian side of the basin, based on empirical distributions fitting, indicated that the stations in the region constitute a single homogenous region which suggests that a single theoretical extreme value distribution can be used for each of the sites to derive...
regional frequency curves for the Tanzanian side. The homogeneity grouping in Tanzania formed the fundamental base for regional modeling. On this basis the EV1/Gumbel distribution using the PWM method of parameter estimation was used to derive the regional frequency curves for the Tanzanian side of the basin. This observation was different from the 19 Kenyan locations which could be fitted to different alternative distributions. Therefore no single distribution could be recommended for regional analysis for the Kenyan locations.

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The Atlantic-Indian Ocean Dipole and Its Influence on East African Seasonal Rainfall

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ABSTRACT
This study has used principal component analysis, composite analysis and correlation analysis to establish the sea surface temperature modes that could represent the combined influence of the Atlantic and Indian Oceans on the seasonal rainfall over East Africa. The results from principal component analysis indicated that sixteen, sixteen, fifteen, and fourteen modes, accounting for about 93%, 94%, 93%, and 93% of the total seasonal sea surface temperature variance, were significant for the December-February, March-May, June-August and September-December periods, respectively. Most of the first four modes represented sea surface temperature variability associated with the individual oceans such as basin wide warming/cooling associated with El Niño/Southern Oscillation, inter-hemispheric SST variability over the Atlantic Ocean, and Indian Ocean Dipole. The decadal and inter-decadal variability were observed with the time coefficients associated with the modes.

The results from correlation analysis indicated that the mode representing Atlantic-Indian Ocean Dipole together with the associated gradient has significant relationships with rainfall for March-May and September-December periods. The gradient mode accounted for the highest rainfall variance with September-December rainfall. The use of the gradient mode improved the values of correlation compared to those observed with the sea surface temperatures of the centres used to develop the mode indicating the ability of the gradient modes to improve relationships with rainfall.

The results from composite analysis indicated that the gradient associated with the mode delineated the March-May and September-December rainfall associated with its opposite phases. The opposite phases of the mode were associated with opposite patterns of seasonal rainfall and wind currents confirming that the observed relationships are realistic.

These results have documented a mode together with the associated gradient that can be used to represent the combined influence of the Indian and Atlantic oceans on the rainfall over the region, and improve the monitoring and prediction of seasonal rainfall over the region. However, more studies need to be done to understand further the dynamics of this mode and its association with rainfall over the region.
1.0 INTRODUCTION

The Atlantic and Indian oceans are major sources of moisture for the East African region. The oceans do not influence the regional climate independently but in some integrated manner through the interactions associated with the oceanic and atmospheric circulations (Wolter 1987). The El Niño/Southern Oscillation (ENSO) and Walker circulation (Chervin and Druyan 1984), and the Great Ocean Conveyor(GOC) (Gross 1972; Saenko et al. 2002) are some examples of the atmospheric and oceanic processes that may be associated with the combined influence of the global oceans on global climate. The low-level circulation patterns associated with the above-normal rainfall over the region is dominated by easterly inflow from the Indian Ocean and westerly inflow from the Congo tropical rain forest into the positive rainfall region (Anyah and Semazzi 2006; Schreck and Semazzi 2004). Goddard and Graham(1999) observed significant influence of the Indian Ocean on seasonal rainfall over the region. Okoila(1996) observed that the cooling over the eastern Atlantic Ocean together with the warming over the Indian Ocean are associated with enhanced rainfall over the region.

The GOC transports warm and low salinity water from the tropical Pacific and Indian oceans round South Africa to north Atlantic near Iceland (Burroughs 1999). The GOC and the associated currents influence the global climate patterns through ocean-atmosphere interactions and any change in the path or strength of the GOC may influence the climate around the world (Burroughs 1999; Dong and Kelly 2004; Stouffer et al. 2007). The amount of heat transported around by atmospheric and oceanic currents plays an important role in determining the mean climate of any region on earth (Shukla 1991; Wunsch and Heimbach 2006) and the ocean waves have significant influence on Sea Surface Temperatures (SST) (Hasizume et al. 2003; Jochum et al. 2007; Qiao et al. 2004; Valsala and Ikeda 2007 ; Zang and Gottschalk 2002).

Most studies in the region established the major Principal Component Analysis modes associated with the influence of the Atlantic and Indian Oceans as independent fields( Omondi 2005 ; Owiti 2005). Such approaches may not reveal the modes representing the combined influence of the two oceans on the rainfall over the region. In this study the two oceans are analysed as a single SST field to establish their combined influence on the seasonal rainfall over the region and develop an index that would be used as a for regional rainfall.

This study recognizes that the SST gradient modes together with the associated pressure gradients have a strong influence on the atmospheric and oceanic circulation( Barry and Chorley 1968; Lindzen and Nigam 1987; Shukla 1991). The SST gradient modes influence the Walker circulation together with the intensities of the individual cells( Lindzen and Nigam 1987). The temperature gradients and the associated pressure gradients are key factors in determining pressure gradients, wind patterns, moisture transport, moisture convergence and divergence patterns, and many other regional circulation patterns that determine rainfall anomalies (Goddard et al 2000; Lindzen and Nigam 1987). In developing the SST gradient mode to represent the influence of the two oceans in climate prediction models, it is assumed that horizontal atmospheric motions in response to meridional and zonal temperature gradients, which are stronger than the vertical motions(Byers 1959), would account for most of the influence of the general circulation on seasonal rainfall over the region. These assumptions are motivated by the findings of the previous studies, which have shown that meridional and zonal gradients have the highest influence on the general circulation in the tropics (Lindzen and Nigam 1987; Ward 1998). A more detailed discussion of the properties of SST gradient modes that motivated this study is presented in Nyakwada(2009). The SST index is based on the centres of major PCA mode representing their combined variability.

The methods and data used in this study are presented in Chapter two, Chapter three presents the results from this study. The conclusions from this study are presented in Chapter 4.

2.0 DATA AND METHODOLOGY

2.1 Data Sources

The data used in this study are rainfall from 59 stations, distributed over East Africa, available at the IGAD Climate Prediction and Application Centre (ICPAC) formerly known as the Drought Monitoring Centre (DMC), Nairobi obtained from the Kenya Meteorological Department (KMD), Tanzania Meteorological Agency (TMA) and Uganda Meteorological Department (UMD) for the period 1960-2006. The homogeneous climate zones used in this study are those developed over the years by ICPAC through pre-season capacity building workshops from principal component analysis (PCA) using the same data(ICPAC 1999). The same zones are used for operational purposes and capacity building workshops at ICPAC (ICPAC. 1999). Many recent studies including Nyakwada(2009), Komutunga (2006); Njau (2006); Omondi (2005) and Owiti (2005) used the same homogenous zones in order to reduce the number of rainfall stations used in examining teleconnections between regional rainfall and global scale circulation variables.

The other data used are the SST for 10° x 10°
2.2 Methodology

The methods used in this study included principal component analysis (PCA), Correlation Analysis and composite analysis. Principal Component analysis (PCA) is a frequently used multivariate technique in atmospheric sciences to reduce data sets while retaining maximum variability contained in the original data, establish similarities in spatial and temporal climate variability, and identify the dominant modes of variability in statistical fields (Barnston and Livezy 1987; Wilks 2006; von Storch and Zwiers 1999). Kaiser criterion (Kaiser 1959; 1960) and Scree test (Craddock and Flood 1969; Craddock and Flintoff 1970) were used to establish significant PCA modes. The PCA was used to establish the major modes of variability that dominate SST for the combined oceans. The core centres of the modes representing opposite phases of SST variability are used to develop the SST gradient modes associated with the combined influence of the two oceans.

The correlation analysis is used to quantify the relationships between rainfall, and SST PCA and gradient modes representing a combined influence of the Atlantic and Indian Oceans. The Student t - test was used to determine the significance of the values of correlation (Wannacott and Wannacott 1985).

Composite analysis, which is a simple method used to study atmospheric processes influencing specific phenomena, was used to establish relationships that could not be revealed by the correlation method. The method was also used to infer the physical processes that may be associated with the observed relationships. The first step of the method involves the choice of a basis for developing composites. The second step involves the selection of the cases that meet a specific category of the decided base. The selected cases are then averaged to set a mean pattern of the element in response to the behaviour of the selected base (Drbohlav et al. 2007; Kayano et al. 2007; Nobre and Shukla 1996; Krishnamurthy and Shukla 2007; Maloney and Shaman 2008). This approach was used in this study. The SST gradient mode associated with the PCA modes representing the combined influence of the Atlantic and Indian Oceans formed the basis for composite analysis.

3.0 RESULTS AND DISCUSSIONS

3.1 Principal Component Analysis

A total of one hundred 10° x 10° latitude/longitude SST grid points were used to represent the two oceans. It should be noted that, since the total sum of eigenvalues was one hundred, the portion of the variance accounted for by the PC modes was equal to the eigenvalue associated with each mode in agreement with the equation used to calculate the variance accounted for by the PC modes (Murakami 1980). The PCA results are presented for the December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON) periods.

The SST for the period December-February (DJF) season are often used to predict the MAM seasonal rainfall over the region. The MAM seasonal rainfall remains the most difficult to predict. The understanding of the modes that dominate SST variability when the oceans operate as a single field would help reduce the number of predictors. Figure 1 and Table 1 indicate that sixteen PCA modes, accounting for about 93% of the total DJF SST variance, were significant for the DJF SSTs. The first four modes accounted for about 61% of the total SST variance. The first, second, third and fourth mode accounted for about 36%, 10%, 8% and 7% of the total SST variance, respectively. The large number of significant PCA modes and the low variance that they explain may be a reflection of the complexity of the shared Indian and Atlantic oceans SST variances. Each of the oceans has its own circulation systems, but some persistence in anomaly patterns are common during some periods and seasons, especially during major ENSO years (Chambers et al. 1999; Colberg and Reason 2004; Terray and Dominiak 2005). Only the spatial and temporal characteristics of the first three modes that accounted for most of the variance are discussed.
Table 1: The significant principal component analysis modes of December-February sea surface temperatures for the combined Indian-Atlantic Ocean and the associated variance

<table>
<thead>
<tr>
<th>PCA Mode Number</th>
<th>Eigenvalues</th>
<th>% of Total Variance</th>
<th>Cumulative % of Total Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35.61</td>
<td>35.61</td>
<td>35.61</td>
</tr>
<tr>
<td>2</td>
<td>10.08</td>
<td>10.08</td>
<td>45.69</td>
</tr>
<tr>
<td>3</td>
<td>8.25</td>
<td>8.25</td>
<td>53.94</td>
</tr>
<tr>
<td>4</td>
<td>6.71</td>
<td>6.71</td>
<td>60.65</td>
</tr>
<tr>
<td>5</td>
<td>6.47</td>
<td>6.47</td>
<td>67.12</td>
</tr>
<tr>
<td>6</td>
<td>5.13</td>
<td>5.13</td>
<td>72.25</td>
</tr>
<tr>
<td>7</td>
<td>3.80</td>
<td>3.80</td>
<td>76.05</td>
</tr>
<tr>
<td>8</td>
<td>3.47</td>
<td>3.47</td>
<td>79.52</td>
</tr>
<tr>
<td>9</td>
<td>2.88</td>
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<td>84.73</td>
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<td>15</td>
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<td>1.16</td>
<td>91.98</td>
</tr>
<tr>
<td>16</td>
<td>1.10</td>
<td>1.10</td>
<td>93.08</td>
</tr>
<tr>
<td>17</td>
<td>0.96</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Atlantic Ocean representing inter-hemispheric SST variability (Nyakwada 2009; Omondi 2005). The third mode (Figure 2c) represented meridional and zonal SST variability similar to the third mode for the Atlantic Ocean (Nyakwada 2009).

Figure 2a: The spatial patterns of the loadings of the first PCA mode observed with the December-February SST for the joint Indian-Atlantic Ocean.

The second PCA mode of the DJF SST (Figure 2b) was similar to the second PCA mode for the joint Indian-Atlantic Ocean. Figure 2b: The spatial patterns of the loadings of the second PCA mode observed with the December-February SST for the joint Indian-Atlantic Ocean.

The temporal characteristics of the modes observed with the DJF SST (Figure 3) indicated that they represented inter-decadal and decadal variability. Decadal and multidecadal variability associated with the variation of thermohaline circulation have been observed in the Atlantic Ocean (Latif et al. 2006). The first mode represented a trend similar to what was observed with the first DJF modes for the Indian and Atlantic Oceans (Nyakwada 2009). The years of large positive and negative values of the time coefficients correspond to some of the major wet and dry years over parts of central, eastern and western Africa associated with ENSO and inter-hemispheric SST gradient in the Atlantic (Nicholson and Entekhabi 1987; Nicholson and Kim 1997; Schreck and Semazzi 2004; Wu et al. 2007).

The PCA of MAM SST indicated that sixteen PCA modes, accounting for about 94% of the total SST variance, were significant. The first four modes accounted for 68% of the total SST variance compared to 61% for DJF. The first, second, third and fourth modes accounted for about 39%, 13%, 10%
and 6% of the total SST variance, respectively and their spatial and temporal characteristics were similar to those of the modes observed with DJF SSTs, which represented the PCA modes observed with the Individual oceans. The only differences were the levels of the explained variances and areas dominated by specific modes.

Figure 3a: The graphical plot of the time coefficients of the first joint Indian-Atlantic Ocean SST PC mode for December-February.

Figure 3b: The graphical plot of the time coefficients of the second joint Indian-Atlantic Ocean SST PCA mode for December-February.

Figure 3c: The graphical plot of the time coefficients of the third joint Indian-Atlantic Ocean SST PC mode for December-January-February

The period JJA is often used to predict the October-December (OND) seasonal rainfall over the region. The OND rainfall season is the most studied due to high potential of its predictability (Behera et al. 2005; Black et al. 2003; Omondi 2005; Owiti 2005). The PCA for this season indicated that fifteen PCA modes, accounting for about 93% of the total JJA SST variance, were significant. The first four modes in this season accounted for about 64% of the total JJA SST variance. The first, second, third and fourth mode accounted for about 37%, 13%, 8% and 6% of the total JJA SST variance, respectively. The spatial and temporal characteristics of the first and third PCA modes were similar to those observed with DJF and MAM SST, and represented SST variability in the individual Indian and Atlantic Oceans. The second mode was, however, unique for the season and represent a dipole with a positive pole in the western Indian Ocean located in the region (20°N-20°S, 40°E-90°E) and a negative pole over the eastern Atlantic Ocean located in the region (10°N-10°S, 40°W-20°E)(Figure 4). This dipole, which shall be referred to as Atlantic-Indian Ocean Dipole (AIOD), may be associated with the atmospheric and oceanic circulations linking the two oceans resulting from the Great Ocean Conveyor and the Walker cell across the continent of Africa linking the Western Indian Ocean and the Congo Basin (Hastenrath and Polzin 2004; Tanaka et al. 2004; Wang 2002). El Niño/La Nina have been associated with the cooling/warming off the western coast of Southern Africa and in the Gulf of Guinea during the period February –July (Frankignoul and Kestenare 2005) and warming/cooling in the western Indian Ocean (Chambers et al. 1999; Kug and Kang 2006; Kug et al. 2007). The opposite phases in the cooling/ warming of the Atlantic/Indian Oceans have been associated with wet conditions over the region (Okoola 1996) resulting from the convergence of moist air masses from the Congo basin and Indian Ocean over the region ((Anyah and Semazzi 2006). Figure 4 indicates further a less prominent negative pole over the eastern Indian Ocean located in the region (0°-20°S, 100°E-130°E), which is often used to represent the eastern pole of the Indian Ocean Dipole mode (Behera et al. 2005; Saji et al. 1999). The less prominence of the eastern pole over the Indian Ocean in this season may imply that when the two oceans interact, the dipole linking the Atlantic and Indian Ocean is stronger than IOD.

years have been associated with ENSO and IOD events as defined by Behera et al. (2005); Owiti (2005); and Saji et al. (1999) among many other authors. It can be observed that most of the extreme wet/dry conditions over the region associated with El Nino/La Nina and positive/negative IOD correspond to negative/positive coefficients of this mode. The capability of this mode to separate the dry and wet years by JJA season makes it a more powerful tool than the classical IOD that has a maximum influence in SON as was observed for the PCA of the Individual oceans (Nyakwada 2009). This is the first time this mode representing Atlantic-Indian Ocean Dipole sea surface temperatures for the combined Indian-Atlantic oceans representing Atlantic-Indian Ocean Dipole was observed over the northern parts of Kenya and Uganda. These results indicate that this mode could be used to predict the rainfall for the season. However, the variance accounted for by the mode is relatively low necessitating the need to establish related indices that could provide more powerful tools for predicting rainfall over the region.

3.2 Correlation Analysis

3.2.1 Correlation with the PCA Mode

The correlation analysis is used to quantify the relationships between the SST modes and rainfall. The correlation analysis is also used to assess the potential to improve the relationships between regional rainfall and SST based predictors. The results for correlation analysis of rainfall and PCA modes are presented for the September-December period that showed the highest relationships with the PCA mode representing the AIOD. The results from t-test indicated that a correlation of 0.25 was significant. These results indicate that this mode could be used to improve an SST gradient mode to represent the influence of this mode on rainfall over the region. The correlation analysis is also used to assess the potential to improve the relationships between regional rainfall and SST modes accounting for 93% of SST variance were significant. The PCA modes observed in DJF, MAM, and JJA were still discernable in SON. The extensively documented Indian Ocean Dipole was the second mode in SON SST and accounted for 11.53% of SST variance. These results indicate that IOD reaches its peak in a combined ocean field in SON compared to AIOD which has the peak in JJA.

3.2.2 Correlation with the Sea Surface Temperature Gradient Mode Associated with the Atlantic-Indian Ocean Dipole

The results from correlation analysis are presented for the core centres used to compute the SST gradient mode and for the related gradient mode to establish improvements in relationships when the gradient modes are used. Figures 7a and 7b give the
spatial patterns of the values of correlations between SOND rainfall and the July SST representing the centres over the equatorial western Indian and eastern Atlantic Ocean used to compute the SST Gradient mode. Figure 7a indicates that SOND rainfall over the northern parts of the region was negatively correlated to the July SST over the eastern equatorial Atlantic Ocean. The largest value of correlation was 0.39 indicating that the July SST over the eastern equatorial Atlantic Ocean accounted for about 15.21% of SOND rainfall variance.

Figure 7b indicates that SOND rainfall was positively correlated to the July SST for the centre over the equatorial western Indian Ocean. The largest value of correlation was 0.54 indicating that the SST over this centre for the month of July accounted for about 29.16% of SOND rainfall variance.

Figure 7c indicates marked improvements in the values of correlation when SST gradient mode computed from the two centres is used. Figure 7c indicates that SOND rainfall over most parts of the region was significantly and negatively correlated to the SST gradient mode associated with AIOD for the month of July. The highest value of correlation of 0.63 indicated that the SSTG mode accounted for about 39.69% of SOND rainfall variance which is higher than the variance accounted for by the PCA mode and SST for the core centres of the PCA. The lowest correlations were concentrated in the coastal region. The Atlantic Ocean influences rainfall over the region through moisture incursions by the westerly wind currents over the western parts of the region (Anyah and Semazzi 2006; Indeje and Semazzi 2000; Schreck and Semazzi 2000, Schreck and Semazzi 2000).

The improvement in relationships when the gradient mode are used as indicated in Figures 7a-7c confirm the advantages this SST gradient mode could have in the prediction of seasonal rainfall over the grid point SSTs. The results also indicate the AIOD has significant influence on rainfall over the region.

The negative/positive correlation observed with the SST over the equatorial eastern Atlantic / western Indian Ocean is reaffirms the existence of the dipole observed in the second JJA PCA mode (Figure 4). The influence of this mode on the rainfall over the region may be in cognizance of the fact that the oceans and the atmosphere act as a single field through the associated wind and water currents (Shukla 1991; Stouffer et al 2007; Wunsch and Heimbach 2006).

The negative relationships observed with the gradient associated with AIOD indicate that the warming /cooling over the equatorial western Indian /eastern Atlantic Ocean favour enhanced SOND seasonal rainfall over most parts of the region in agreement with the observations of Nicholson and Entekhabi (1987); and Okoola (1996). This pattern of SST variations is likely to influence the Walker circulation cell linking the western Indian Ocean and the Congo Basin. The negative values of the SST gradient could be associated with the warm equatorial western Indian Ocean and a relatively cold equatorial eastern Atlantic Ocean that would imply the reverse of the Walker circulation favouring enhanced influx of moisture into the region from the Congo Basin and Indian Ocean as has been observed for wet years (Anyah and Semazzi 2006; Indeje and Semazzi 2000, Schreck and Semazzi 2000).
These relationships also reveal the importance of the combined role of the Atlantic and Indian Ocean as influences seasonal rainfall over the region. The spatial patterns of the values of correlation also reveal that the responses of SOND rainfall over western parts of the region and Kenyan coast to the SST gradient mode associated with AIOD are in agreement with the responses of seasonal rainfall over the respective regions to SST variability. The improvements in the values of correlation between rainfall and SST based predictors when the SST gradient mode is used indicate that the use of this zonal SST gradient mode improves the relationships between SOND rainfall and SST based predictors compared to grid point SSTs.

The spatial patterns of the values of correlation observed between the SST gradient mode associated with AIOD together with the SST for the core centres and MAM rainfall are presented in Figures 8a-8d. The predictability for the MAM period has always proved difficult for most models and these difficulties have been referred to as spring predictability barrier (Annamalai et al. 2007; Barnston et al 1996; Korecha and Barnston 2007; Ogallo 1988) and predictability gap (Godfrey et al. 1995). The drop in the predictive skill in April has been attributed to weak organization of the tropical atmosphere in the month (Godfrey et al. 1995).

Figures 8a and 8b give the spatial patterns of the values of correlation observed between MAM rainfall and SST representing the centres over the western Indian Ocean and eastern Atlantic Oceans associated with the AIOD. Figure 8a indicates that MAM rainfall over parts of Lake Victoria Basin and northern coast was positively correlated to the March SST representing the centre over the western Indian Ocean. However, rainfall over southern Tanzania was negatively correlated to SST representing the centre over western Indian Ocean.

These results indicate that the response of MAM rainfall over parts of the region to SST over the equatorial western Indian Ocean was not uniform. The largest value of correlation observed with SST over the western Indian Ocean for the month of March was 0.51 indicating that they accounted for about 26.01% of the MAM rainfall variance.

Figure 8b indicates that MAM rainfall over parts of the region was negatively correlated to the March SST over the equatorial eastern Atlantic Ocean. The negative relationships observed between SST over the equatorial eastern Atlantic Ocean and MAM rainfall is in agreement with the findings of Nicholson and Entekhabi (1987); and Okoola (1996) among other authors.

Figure 8: The spatial patterns of the values of correlation between March-May rainfall and the March Sea surface temperature for the centre in the equatorial (a) western Indian (b) eastern Atlantic Ocean associated with the Atlantic-Indian Ocean Dipole.
These results indicate that MAM rainfall over parts of the region is likely to be enhanced by the cooling over the equatorial eastern Atlantic Ocean. The largest value of correlation observed with the SST over eastern Atlantic was 0.48 indicating that they accounted for about 23.04% of the MAM rainfall variance.

Figures 8c and 8d give the spatial patterns of the values of correlations between MAM rainfall and the SST gradient mode associated with AIOD. Figures 8a-8c indicate some improvement in the relationships when SST gradient mode is used compared to those observed with the SST representing individual centres. The MAM rainfall over most parts of the region is negatively correlated to the SST gradient mode for the month of March and the largest value of correlation was 0.56 indicating that this mode accounted for about 31.26% of MAM rainfall variance. Similar relationships were observed with the SST gradient mode for the months of February, April and May. However, Figure 8d indicates a change in the relationships in the month of January when this mode was positively correlated to MAM rainfall over parts of the region. Such changes in the sign of relationships need to be taken into consideration when using this mode as a tool for monitoring and advising on expected seasonal rainfall performance.

The peak relationships observed with SST gradient mode associated with AIOD were observed in the months of March and April suggesting that the inclusion of this SST gradient mode for these months may improve the skill in the prediction of MAM seasonal rainfall. This would require the prediction of SST for the months of March and April. It is possible to predict SSTs and the predicted SSTs may lead to improvements in the skills of the models (Mauget and Ko 2008).

3.3 Composite Analysis

The results from correlation analysis do not reveal the dynamics associated with the observed relationships. The composite analysis may reveal the physical basis and other forms of relationships not established with correlation analysis. The basis of composite analysis in this study was mapping mean rainfall, and wind anomalies for years of similar sea surface temperature gradient values for specific seasons. The categories for composite analysis are the extreme negative (EN) referring to values of SSTG < -s/2, moderate negative (MN) referring to values -s/2 £ SSTG<0, moderate positive (MP) referring to 0 < SSTG £ s/2 and extreme positive (EP) referring to SSTG >s/2. Only the results for extreme negative and positive phases of the SST gradient mode are presented.

3.3.1 September-December Rainfall

The years with similar categories for the gradient mode on which the composite analysis of SOND was based are given in Table 2.

Figures 9a and 9b give the spatial patterns of the values of the composites of SOND rainfall anomalies associated with the extreme negative and positive phases of the SST gradient associated with AIOD. The clear shifts in the signs of the rainfall anomalies map patterns for extremely positive and negative
values of the gradient mode are quite evident. It can be observed from Figures 9a and 9b that the values of SOND rainfall composite anomalies associated with the positive/negative phases of SST gradient mode were negative/positive. This spatial pattern of the values of SOND rainfall composite anomalies indicates that the positive/negative phases of the SST gradient mode favour deficient/enhanced SOND rainfall over most parts of the region. This is in agreement with the negative correlation observed between the SST gradient mode and SOND rainfall. These results indicate that AIOD has significant influence on SOND rainfall over most parts of the region.

Table 2: The years during the period 1961 to 2006 associated with the various categories of the phases of the zonal sea surface temperature gradient modes.

<table>
<thead>
<tr>
<th>G R A D I E N T</th>
<th>Extreme Negative</th>
<th>Extreme positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSTG AEs/2</td>
<td>SSTGGs/2</td>
<td></td>
</tr>
<tr>
<td>A I O D (July)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3.2 March-May Rainfall

The composite analysis of MAM rainfall was based on the years listed in Table 3 when the mode was extremely positive or negative.

Figures 10a and 10b give the spatial patterns of the values of composites of MAM rainfall anomalies associated with the extreme negative and positive categories of the SST gradient mode for the zero-lagged month of March. Figure 10a indicates that the MAM rainfall composites associated with the extreme negative values of the SST gradient mode for the month of March coinciding with season were

Table 3: The years during the period 1961 to 2006 associated with the various categories of the phases of the sea surface temperature gradient mode associated with Atlantic-Indian Ocean Dipole for the month of March.

<table>
<thead>
<tr>
<th>G R A D I E N T</th>
<th>Extreme Negative</th>
<th>Extreme Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSTG AEs/2</td>
<td>SSTGs/2</td>
<td></td>
</tr>
<tr>
<td>A I O D (March)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9a
Figure 9a: The spatial patterns of the values of composite of September-December rainfall anomalies associated with extreme (a) negative (b) positive categories of sea surface temperature gradient mode based on Atlantic-Indian Ocean Dipole for the month of July.
positive over most parts of the region indicating that the extreme negative phase of this mode favour enhanced MAM rainfall over most parts of the region.

Figures 10b indicate that MAM rainfall associated with the extreme positive values of the SST gradient mode for the month of March coinciding with the season were negative over most parts of the region indicating that the extreme positive phase of this mode favour deficient MAM rainfall over most parts of the region. These results from composite analysis of MAM rainfall and the SST gradient mode for the zero-lagged month of March indicates further that the correlations observed between MAM rainfall and the SST gradient mode were realistic since the mode was able to delineate cases associated with each phase. These results also indicate that this SST gradient mode could be useful in the monitoring and prediction of MAM seasonal rainfall. However, since the peak relationship is achieved in the season, the use of this gradient requires that it be predicted.

The results of composite analysis of seasonal rainfall and the SST gradient mode have indicated significant linkages amongst some of the extreme phases of the SSTG mode and seasonal rainfall. The results confirmed that the observed relationships between the seasonal rainfall and SST gradient mode were realistic. The mode provides a useful tool for seasonal climate prediction.

### 3.3.3 Wind Composites

The wind currents represent the vehicles for the transport of moisture and dictate areas of convergence influenced by the strengths, tracks, sources and direction of wind currents. The pattern of the values of composite for wind would help in understanding the physical dynamics of the SSTG mode. The basis of the composite are the categories of the gradient as indicated in Table 2. Figures 11a and 11b give the spatial patterns of the SON zonal surface wind composite anomalies associated with the extreme positive and negative categories of the SST gradient mode, for the lagged month of July. Figure 11a indicates that the extreme negative values of the SST gradient mode are associated with westerly wind anomaly over the region 40°N-35°S, 20W-140E and easterly wind anomaly in equatorial central Indian Ocean. This pattern may favour enhanced rainfall over the region through the influence of the penetration of the Congo air-mass that interacts with enhanced dominant easterly wind current from the Indian Ocean. The largest values of the westerly and easterly anomalies were 0.6 and –1.4, respectively.

Figure 11b indicates that SON wind composite anomalies associated with the extreme positive values of the SST gradient mode for the lagged month of July were dominated with easterly wind anomalies, which would be associated with the acceleration of surface wind speeds and divergence. In the equatorial Indian Ocean, the easterly anomalies are replaced by westerly anomalies, which would be associated with the deceleration of the easterlies over the ocean and reduced moisture incursion into the region. The highest westerly anomaly was 1.2 and easterly anomaly was –0.8.
These results indicate that the two extreme phases of the SST gradient mode for the month of July are associated with the opposite patterns of the SON wind composite anomalies confirming that the influence of the mode on rainfall may be associated with the changes in the wind currents, moisture transport and convergence. These results confirm that the AIOD has significant and realistic influence on the rainfall over the region. The SST gradient mode associated with AIOD would provide new and realistic tools for predicting seasonal rainfall over the region.

Figures 12a and 12b gives the spatial patterns of the SON meridional surface wind composite anomalies associated with the extreme negative and positive phases of the SST gradient mode for the lagged month of July. Figure 12a indicates that the extreme negative values of the SST gradient mode are associated with enhanced SON southerly surface winds over the southern and western Indian Ocean, and south-eastern Atlantic Ocean. These are the major sources of moisture for the region. The enhanced meridional component in these areas would lead to improvements in the moisture incursion. The largest positive anomaly was 10. A negative anomaly was observed over the northern Atlantic. The negative anomaly would imply enhanced northerly flow associated with the Azores high-pressure system. The largest negative anomaly was –8.

Figure 12b indicates that the values of SON meridional surface wind composite anomalies associated with the extreme positive phase of the SST gradient mode for the lagged month of July were generally weaker than those associated with the extreme negative phase especially over the western Indian Ocean and were positive over the southern Indian Ocean and southern Atlantic Ocean. A marked difference is observed over the western Indian Ocean where the positive anomalies observed with the negative phase are replaced with the negative anomalies. The largest positive anomaly was 7.
compared to 10 observed with the negative phase of the SSTG mode. The negative anomalies were still observed over the northern Atlantic Ocean. The largest negative anomaly was –4 compared to –8 observed with the negative phase.

It should be observed that the anomalies were relatively weaker for the extreme positive phase compared to the negative phase of the mode. These results continue to indicate that the influence of AIOD on rainfall may be associated with the changes in the wind currents, moisture transport and convergence.

These results indicate that the influence of the SST gradient mode associated with AIOD is discernible from both the zonal and meridional surface wind currents and rainfall for both seasons. The mode was able to delineate the opposite phases of the zonal surface and meridional surface wind currents associated with opposite phases of the mode, and rainfall for both seasons. The results confirm further that the observed correlations between SOND rainfall and SST gradient modes are realistic and may be associated with the influence of the SSTG mode on atmospheric circulation, moisture transport and convergence. These results indicate further that the SSTG mode based on AIOD provide new and realistic tools for improving the prediction of seasonal rainfall over the region.

4.0 CONCLUSIONS

This study has established a mode that could be used to represent a combined influence of the Atlantic and Indian Oceans. The Atlantic-Indian Ocean Dipole (AIOD), which is documented for the first time, has significant influence on regional rainfall for both seasons. The sea surface temperature gradient mode associated with the AIOD had significant relationships with both March-May and September-December rainfall. The mode, however, accounted for the highest rainfall variance with the September-December rainfall.

Results from composite analysis of rainfall and wind confirmed significant linkages between the AIOD and rainfall through the influence on wind currents with the negative phase of the mode favouring enhanced rainfall during both MAM and SOND seasons. The SST gradient mode associated with AIOD effectively delineated rainfall and wind associated with the opposite phases of the mode. The extreme positive and negative phases of the SST modes influenced both the zonal and meridional wind circulation. For example the extremely negative phase of the SSTG mode associated with AIOD corresponded to mainly westerly wind anomaly with an easterly wind anomaly over the eastern Indian Ocean together with a southerly anomaly in the Indian and Southern Atlantic phase of the same mode was associated with mainly easterly wind anomaly with a westerly wind anomaly over the eastern and central Indian Ocean together with a relatively weaker southerly wind anomaly over the Indian and southern Atlantic Ocean. These wind patterns favour opposite rainfall performance confirming that the relationships observed with AIOD together with the associated SST gradient mode are realistic.

These results provide a useful tool that could be included in the monitoring and prediction of both MAM and SOND rainfall season

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Decadal Rainfall Variability Modes in observed Rainfall Records over East Africa and their Predictability using Sea Surface Temperature

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ABSTRACT

The space-time patterns of decadal rainfall variability modes over East Africa and their predictability potentials using Sea Surface Temperatures (SST) are investigated. The analysis includes observed rainfall data from 1920-2004 and global sea surface temperatures (SSTs) for the period 1950-2004. Simple correlation, trend and cyclical analyses, Principal Component Analysis (PCA) and Canonical Correlation Analysis (CCA) methods are employed. The results show decadal signals in filtered observed rainfall record with 10 years period during March – May (MAM) and October – December (OND) seasons. During June – August (JJA), however, cycles with 20 years period are common. Too much / little rainfall received in one or two years determines the general trend of the decadal mean rainfall. PCA results showed six, five and four modes of variability accounting for 80%, 81.3% and 65.1% during MAM, OND and JJA seasons respectively. CCA results for MAM showed significant positive correlations are observed between the sea surface temperatures and the canonical component time series over the central equatorial Indian Ocean. Positive loadings are spread over the coastal and Lake Victoria regions while negative loadings over the rest of the region with significant canonical correlation skills. For the June – August season, Atlantic SSTs had negative loadings centred on the tropical western Atlantic Ocean associated with the wet / dry regimes over western/eastern sectors. The highest canonical correlation skill between OND rainfall and the Pacific SSTs showed that ENSO/La Nina phases are associated with wet/dry decades over the region.

1.0 INTRODUCTION

Over the region, much attention has been devoted to how and why precipitation varies in association with the El Niño-Southern Oscillation (Mutemi 2003; Indeje et. al.2000, Ogallo 1988) at diurnal, seasonal and interannual time-scales. The impacts of persistent decadal climate anomalies have far reaching socio-economic implications due to persistent climate stress that they would impose on the regional socio-economic systems.

Decadal scale fluctuations are crucial to human welfare because they control water supplies,
affect biota, and may modulate higher-frequency events such as floods and droughts. Also, low frequency natural variability is important in global climate change issues because it may obscure human influences on hydrologic variations.

Decadal variability signals have been observed in many climate parameters worldwide (Ryan and Bromwich, 2006; Wu and Liu, 2005). Examples of such variability include Northern Atlantic Oscillations (NAO) indices; drought in California, Australia, or the Sahel and eastern Africa. It has been observed in lake level fluctuations and interannual rainfall records.


Impacts of such decadal variability of extreme climate events would generally require more challenging mitigation strategies. Mitigation and adaptation to any of the climate anomalies would depend on the magnitude and duration of the persistence of the anomalies. Mitigation and/or adaptation measures are likely to involve investment in infrastructure and changes in policy due to the potentially large magnitude of their effects.

In this paper, decadal trend modes in observed East African rainfall records are examined and their possible linkage to decadal mode patterns in the global Sea Surface Temperatures.

2.0 DATA AND METHODS

In the analysis monthly observed rainfall data obtained from the Kenya Meteorological Department (KMD) for the period 1920 – 2004 were used.

Also used in the study was the reconstructed Reynolds SST data for the period 1950 – 2004 obtained from NOAA / CDC Optimum Interpolation (OI) global Sea Surface Temperature (SST) Version 2 downloaded from the website. The SSTs data are on 1.0° x 1.0° grid point resolutions. The analysis uses in situ and satellite SSTs plus SSTs simulated by sea-ice cover (Reynolds and Marsico 1993, Reynolds and Smith 1994, Reynolds et al., 2002).

Attention in this study is primarily on the lower frequency variability and thus a 9-point binomial coefficient filter is employed to filter both the rainfall and sea surface temperature series so that all fluctuations of period shorter than 10 years are con-

Graphical methods are used to examine decadal trend modes while statistical methods based on rank statistics such as Mann-Kendall and the Spearman rank tests (Kendall 1938, 1945, 1948; Kendall and Stuart 1961; WMO 1966) are employed to test the significance of the observed trends.

Empirical Orthogonal Functions (EOF) analysis based on covariance matrix (Wilks, 1995) was applied to define dominant modes of variability of the low pass rainfall and SST series. To define the dominant modes of decadal variability and ascertain their relationship to SST variations in the global oceans, Canonical Correlation Analysis (CCA) technique is adopted (Barnett and Preisendorfer 1987; Graham et al. 1987a, 1987b; Barnston and Ropelewski 1992; Barnston 1994; Wilks, 1995; Barnston and He 1996; Von Storch and Zwiers, 1999 and Livezey and Smith, 1999; Mutemi 2003).

3.0 RESULTS FROM THE DECADAL TREND MODES

The patterns of the decadal trend mode for both the smoothed (filtered) and unsmoothed time series are shown in Figures 1a and 1b for both the long rainy season of March – May (MAM) and the short rainy season of October – December (OND). The ten year cycles are clearly discernible in the smoothed series. These modes are clearly observed when the time series of smoothed series are plotted as anomalies in Figure 2a and 2b. The trend mode of a third minor season of June-August (JJA), when western and coastal parts of the region receive substantial amount of rainfall, are however dominated by twenty year cycles (Figure 2b).


There were significant spatial variations in the observed decadal trend signals. There is no decade when the whole region was dominated by one specific trend signals in this season. This could be attributed to the influence of the regional and local factors including the existence of many large inland water bodies and complexity in the East Africa topography.

The short rainfall season of October-December is the second major season for the region. The extreme events in one or two years within a decade influenced the general trend of the decadal mean rainfall. Example is the 1997/98 El Niño related floods that made 1991-2000 be a wet decade in most zones.

The 1961 – 1970 decade was wet due to the heavy rainfall that was received over most parts of the region in 1961/1962 that resulted into the rise of Lake Victoria level by over 2.5 metres (Yin and Nicholson, 1998, Nicholson, 1998, Phoon et al., 2004).


In order to establish whether the observed decadal trend modes are significant, statistical tests such as the differences amongst some decadal means and the Spearman rank were carried out. A comparison of decadal means and
also with the long term seasonal rainfall means showed that the decades of 1921-1930 and 1961-1970 were generally wet while 1931-1940, 1951-1960 and 1991-2000 were generally dry during the long rainfall (March-May) season of the study period.

In order to establish whether there was existence of any spatially coherent decadal differences, the spatial patterns of the various means were plotted (Figure 3). Large scale wet/dry cases were however evident for a few specific years. This could have been due to the influence of the regional and local factors including the existence of many large inland water bodies and topographical complexity in the region (Mukabana and Pielke 1996; Anyah 2004)

### 4.0 RESULTS FROM PCA ANALYSIS OF RAINFALL

#### 4.1 October - December rainfall

Table 4 gives results that were obtained from rotated varimax solutions for OND season.

Table 1: Eigenvalues, variance and accumulated variance extracted by each mode of the decadal October - December rainfall

<table>
<thead>
<tr>
<th>Period</th>
<th>Factor</th>
<th>Eigenvalues</th>
<th>Variance Extracted (%)</th>
<th>Cumulative Variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OND</td>
<td>1</td>
<td>15.9</td>
<td>42.9</td>
<td>42.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5.3</td>
<td>14.2</td>
<td>57.1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.9</td>
<td>10.5</td>
<td>67.6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2.7</td>
<td>7.2</td>
<td>74.8</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2.4</td>
<td>6.5</td>
<td>81.3</td>
</tr>
</tbody>
</table>

The results show that six PCA modes were significant (Table 1, Figure 4) These accounted for 81.3% of total October – December smoothed rainfall variance and thus was used for further analyses.
4.2 March - May rainfall

Table 2 and Figure 6 give results that were obtained from rotated varimax solutions for MAM season. Results show eight modes accounting for 80% of March – May seasonal rainfall dominant.

Table 2: Eigenvalues, variance and accumulated variance extracted by each mode of the decadal March - May rainfall

<table>
<thead>
<tr>
<th>Period</th>
<th>Factor</th>
<th>Eigenvalues</th>
<th>Variance Extracted (%)</th>
<th>Cumulative Variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAM</td>
<td>1</td>
<td>7.3</td>
<td>19.7</td>
<td>19.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6.9</td>
<td>18.6</td>
<td>38.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5.9</td>
<td>15.9</td>
<td>54.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4.2</td>
<td>11.4</td>
<td>65.6</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.0</td>
<td>8.1</td>
<td>73.6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2.3</td>
<td>6.3</td>
<td>80.0</td>
</tr>
</tbody>
</table>

The spatial patterns of the first 3 dominant modes are shown in Figure 7.
5.0 RESULTS FOR S-MODE PCA ANALYSIS FOR THE SPECIFIC BASINS SEA SURFACE TEMPERATURE ANOMALIES

This section presents the results that were obtained when the specific basin SST records for October – December, June – August and March - May were independently subjected to PCA. The results from rotated varimax solutions are summarized in Table 3 and spatial patterns Figure 8 for the specific ocean basins.

Table 3: Percentage variance extracted by the first 4 Rotated Principle Components for the Sea Surface Temperature anomalies

<table>
<thead>
<tr>
<th></th>
<th>OND</th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indian Ocean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1</td>
<td>38.0</td>
<td>40.5</td>
<td>45.4</td>
<td>35.2</td>
</tr>
<tr>
<td>PC2</td>
<td>26.0</td>
<td>15.8</td>
<td>41.4</td>
<td>32.5</td>
</tr>
<tr>
<td>PC3</td>
<td>20.1</td>
<td>15.7</td>
<td>24.9</td>
<td>24.9</td>
</tr>
<tr>
<td>PC4</td>
<td>11.3</td>
<td>8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>95.4</td>
<td>80.5</td>
<td>89.8</td>
<td>92.6</td>
</tr>
<tr>
<td>Atlantic Ocean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1</td>
<td>64.1</td>
<td>39.1</td>
<td>32.5</td>
<td>39.7</td>
</tr>
<tr>
<td>PC2</td>
<td>34.9</td>
<td>30.6</td>
<td>31.5</td>
<td>34.9</td>
</tr>
<tr>
<td>PC3</td>
<td>13.7</td>
<td>21.8</td>
<td>13.5</td>
<td>13.5</td>
</tr>
<tr>
<td>PC4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.0</td>
<td>83.4</td>
<td>85.8</td>
<td>88.1</td>
</tr>
<tr>
<td>Pacific Ocean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1</td>
<td>31.0</td>
<td>40.1</td>
<td>40.9</td>
<td>32.0</td>
</tr>
<tr>
<td>PC2</td>
<td>23.4</td>
<td>30.0</td>
<td>28.2</td>
<td>23.7</td>
</tr>
<tr>
<td>PC3</td>
<td>22.9</td>
<td>11.5</td>
<td>9.6</td>
<td>23.5</td>
</tr>
<tr>
<td>PC4</td>
<td>10.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>76.6</td>
<td>81.6</td>
<td>78.7</td>
<td>79.2</td>
</tr>
</tbody>
</table>

The PCA1 mode for Indian Ocean decadal SST during October - December season accounts for 38% of the total variance. The positive loading is centered on tropical equatorial Indian Ocean and the negative centre is located in the southwestern Indian Ocean (Figure 8a).

Figure 8b shows the spatial patterns for Atlantic Ocean October-December PC1. The southern basin of the ocean has negative loadings while northern positive with the highest variance of 64.1%. The Pacific Ocean PC1 however, had dipole like pattern of SSTs with positive centre near the Indo-Pacific area while negative centre located near the southwestern Indian Ocean. The total variance accounted for this mode is 31% (Figure 8c). PCA1 mode (35.2%) for June – August season had positive loading spread along the central equatorial Indian Ocean while negative loading to the southeastern Madagascar area (Figure 8d).

In the Pacific Ocean, the first dominant mode for the four seasons seemed to have positive / negative loadings over equatorial eastern / western ocean basin regions (Figure 9) that seem to reflect El Niño Southern Oscillation (ENSO) / La Nina variability mode (Tanimoto et al, 1993; Trenberth and Hurrel 1994; Mantua et al, 1997). The PCA2 showed spatial loading opposite that of the PCA1 i.e., negative/positive loading over equatorial eastern/western Pacific Ocean.

6.0 RESULTS FROM CANONICAL CORRELATION ANALYSIS

In this section 6, the strength and the sign of the corresponding patterns are described by the canonical correlation coordinates. The Canonical Correlation Analysis (CCA) takes into account analysis of the full space and time dimensions of the two fields and this is an exceptional skill better than the correlation analysis.

6.1 Results for March - May rainfall season

The average December-February (DJF), June – August (JJA) and March-May (MAM) SSTs from the various ocean basins were independently correlated with March - May rainfall. Three significant modes were discernible for the Indian Ocean basin with December-February and March-May SSTs. The canonical modes accounting for about 72% and 86.8% respectively of the total variance were selected as inputs into the CCA model.

Figure 10 and 11 give examples of the CCA loading patterns for the December-February and March-May Indian Ocean SSTs. An area of high significant positive correlation between the sea surface temperatures and the canonical component time series was evident over the central equatorial Indian Ocean (Figure 10a). Similarly, there was significant correlation at most locations with positive loadings over the coastal and Lake Victoria regions and negative loading over the rest of the region (Figure 10b). The canonical correlation skill between rainfall and the predictor SST modes was about -0.79. The canonical correlation score between rainfall and the predictor SST modes was 0.72 and 0.96 for one and zero lags respectively. The canonical scores of the pattern with warm SST in the Indian Ocean are increasing since the mid 1970s whereas the negative coupling is decreasing.
8(a) Indian Ocean October - December PC1

8(b) Atlantic Ocean October-December PC1
Figure 8: The spatial patterns of the first 9-term binomial coefficient filter of SST PCA modes for Indian Ocean.

(8d) Indian Ocean June – August PC1
(8c) Pacific Ocean October - December
9(a) Pacific Ocean October - December PC1

9(b) Pacific Ocean December - February PC1
Figure 9: The spatial patterns of the first 9-term binomial coefficient filtered SST PCA modes for Pacific Ocean basin.

9(c) Pacific Ocean March-May PC1

9(d) Pacific Ocean June-August PC1
Power et al., (1998) in his analysis of decadal climate variability showed that decadal variability in Indian Ocean SST south of 40°S is associated with rainfall variability over eastern Australia.

6.2 Results for June–August rainfall season

The average March-May (MAM) and June-August (JJA) SSTs from the various ocean basins were independently correlated with June-August rainfall. Figures 12 and 13 depict loading patterns for the March-May and June-August Atlantic Ocean SSTs with June-August seasonal rainfall modes together with the corresponding temporal functions. The negative loadings over the equatorial north-western and central Atlantic Ocean regions (Figure 12a) are associated with the wet/dry regimes over western / eastern sectors of eastern Africa (Figure 12b). The canonical correlation score between rainfall and the predictor SST modes was about 0.72 for lag one and 0.87 for zero lag. Lag zero that had maximum weights over the Atlantic Ocean basin and was positively correlated with JJA over the whole of western and coastal regions of Kenya together with Uganda (Figure 13b).

Similar observation have been observed by past studies including over the Indian Ocean and South Africa rainfall by Preston (2005), Washington et al., (2003), Reason et al., (2004) among others.
Figure 10: The first spatial pattern pair for canonical correlation between decadal DJF Indian SST and MAM rainfall (a) correlation between the predictor (SST) and the canonical vector (u), (b) correlation between the predictant (rainfall) and canonical vector (v) and, (c) normalized temporal functions (u and v) of the first CCA patterns for rainfall and SST.

11 (a) CCA-1 March – May SST

11 (b) CCA Model (Correlation 0.96)
11 (c) CCA-1 March – May Rainfall

Figure 11: Same as Figure 10 but for March - May Indian Ocean SST (lag zero).

12 (b) CCA-1 October-December Rainfall

12 (a) CCA-1 March-May SST
Figure 12: The first spatial pattern pair for canonical correlation between decadal MAM Atlantic SST and JJA rainfall (a) correlation between the predictor (SST) and the canonical vector (u), (b) correlation between the predictant (rainfall) and canonical vector (v) and, (c) normalized temporal functions (u and v) of the first CCA patterns for rainfall and SST.

13 (a) CCA-1 June – August Atlantic Ocean SST

13 (b) CCA Model (Correlation = 0.87)
6.3 Results for October - December rainfall season

The average June-August (JJA) and October-December (OND) SSTs from the various ocean basins were independently correlated with October-December rainfall. Figures 14 and 15 represent CCA loading patterns for the June-August and October-December Pacific Ocean SSTs and October-December rainfall. The highly negative loading over the equatorial eastern Pacific Ocean seems to be the major mode associated with the dry spell in nearly the whole of the region with wet conditions over the southern parts that generally have unimodal rainfall regimes. The canonical correlation skill between October-December rainfall and the predictor SST modes is 0.88. Figure 15 shows the CCA loading patterns for the predictant October-December rainfall and predictor Pacific Ocean SST modes at zero lag. The negative SST loading over the equatorial eastern Pacific Ocean is linked to the generally dry conditions in the region. The canonical correlation skill between October-December decadal rainfall and the predictor SST modes is 0.97. Thus cold ENSO phase would be associated with depressed rainfall season over the whole region, while warm phase (El Nino) would be associated with enhanced decadal rainfall over most parts of the region.
14 (c) CCA MODE1 (CORRELATION=0.88)

Figure 14: The first spatial pattern pair for canonical correlation between decadal JJA Pacific SST and OND rainfall (a) correlation between the predictor (SST) and the canonical vector (u), (b) correlation between the predictant (rainfall) and canonical vector (v) and, (c) normalized temporal functions (u and v) of the first CCA patterns for rainfall and SST.

15 (a) CCA-I October-December SST

15 (b) CCA-I OND Rainfall

15 (c) CCA Model (Correlation = 0.97)

Figure 15: Same as Figure 14 but for OND SST (lag zero).
7.0 SUMMARY

Trend analysis results showed that although no significant trend in the interannual patterns were discernible at many locations, too much or too little rainfall received in one or two years influenced the general trend of the decadal mean rainfall. Eight and one zones in October-December and March-May respectively showed significant positive trends during this period of study. For the June-August (JJA) season when only the western and coastal parts of the region receive substantial amount of rainfall, no significant trends were observed although the decades after 1961 were wetter than before in these western region but drier along the coastal region. No decade was observed to have the whole region dominated by one specific trend mode for whole study region except 1931-1940 and 1961-1970 during October – December season.

Results from canonical correlation analysis (CCA), indicated that when the average December-February (DJF) and March-May (MAM) SSTs from the various ocean basins were independently correlated with March-May rainfall, three significant modes were discernible. One area of high significant positive correlation between the sea surface temperatures and the canonical component time series was evident over the central equatorial Indian Ocean. Similarly, there was significant correlation resulting into wet coastal and Lake Victoria regions with the rest of the region dry.

The results from the average March-May (MAM) and June-August (JJA) SSTs correlated with June-August rainfall had negative loadings centred on the equatorial western and central Atlantic Ocean regions which were associated with the wet / dry regimes over western / eastern sectors of the region. Linkages between Atlantic Ocean basin and Eastern Africa during June-August are largely influenced by the space-time pattern of both zonal and meridional arms of the ITCZ.

The average June-August (JJA) and October-December (OND) with October - December rainfall produced highly negative loading over the equatorial eastern Pacific Ocean that were associated with rainfall deficit in nearly the whole region but wet conditions over the southern parts of the region. The positive centre over the eastern equatorial Pacific Ocean however was associated with wet conditions in nearly all the region.

8.0 CONCLUSION

This study has provided some evidence of decadal variability in the interannual patterns of east Africa rainfall. The March – May and October – December seasonal rainfall are dominated with 10 year season showed 20 years cycles of wet and dry phases. Some teleconnections were also evident between the observed decadal rainfall variability patterns and SST variability modes over parts of the global oceans. The significant correlations between the rainfall and SSTs offered useful skill in predicting rainfall of the region at decadal time scale.

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1). Title, name and affiliation of each author, dateline, any current or additional affiliations, and corresponding author address and e-mail. These items should appear on the first page by themselves, with the abstract beginning on page 2. The date of receipt of the manuscript will be supplied by the Editors.

2). Abstract. A concise (250 words) abstract is required at the beginning of each article and, at the discretion of the chief Editors, at the beginning of appropriate shorter contributions. Authors should summarize their conclusions and methods in the abstract. First person construction should not be used in the abstract, and references should be omitted because they are not available per se to abstracting services.

3). Text. The text should be divided into sections, each with a separate heading and numbered consecutively. The section/subsection headings should be typed on a separate line [e.g., 1. Introduction, a. Data, 1) RADIOSONDE, and (i) Experiment 1].

4). Acknowledgments. Omit the word "number" from grant or contract acknowledgments.

5). Appendix. Lengthy, mathematical analyses whose details are subordinate to the main theme of the paper should normally appear in an appendix. Each appendix should have a title.

6). References. References should be arranged alphabetically without numbering. The text citation should consist of the author’s name and year of publication, [e.g., “according to Rossby (1945),” or “as shown by an earlier study (Rossby 1945)”]. When there are two or more papers by the same author in the same year, the distinguishing suffix (a, b, etc.) should be added. More information on preparing and arranging references is provided in section 3d of this document.

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The print-quality original electronic figure files must be in EPS. Authors should attempt to visualize mathematical expressions as they will appear in print. Avoid built-up fractions and other complicated equation structures in text. Instead, have complicated expressions appear as display equations, that is, as equations centered on their own line. Display equations are usually numbered consecutively to facilitate their citation in text, which is done by using the equation number in parentheses set flush right.

Because of KMS typesetting requirements, authors who use Microsoft Word to prepare their manuscripts are asked to use MathType version 5 to prepare their display equations, rather than making entries from the keyboard, and to avoid the use of MathType entirely in running text, using the keyboard exclusively except to create overbarred variables or variables with stacked super/subscripts that cannot be easily created from the keyboard. Following this practice will greatly reduce production time for mathematics-heavy papers.

Authors can facilitate the correct typesetting of their equations by using the correct typeface for variables. Scalar variables are set as italic (with S, TIF or MS word format).

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c. Mathematical formulas, units, and time and date

The exception of multiple character variables, e.g., RH or SST), vectors are set as boldface roman (e.g., V), and matrices and tensors are set as boldface sans serif (e.g., A). If the author cannot reproduce these typefaces, he or she should indicate vectors with a single wavy line under the character and matrices in print versions or provide a list of variable types (if submitting electronically).

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d. References

A complete “Guidelines for Preparing References” may be obtained from KMS Headquarters or online in the AG. A few of the most common reference types are shown here. In order for the cross-reference linking now possible through the KMS Journals Online to work properly, references must be complete and properly formatted. Authors are encouraged to invest the time needed to prepare the references according to KMS style.
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Reference must consist of last name and initials of author(s), year of publication of book, title of book (italicized or underlined), publisher’s name, and total pages. For example:


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For a book or monograph that is a collection of papers written by independent authors, the reference must be made to the authors of a particular chapter and consist of last name and initials of author(s), year of publication of book, title of the chapter, title of book (italicized or underlined), name of editor(s), publisher’s name, and inclusive pages for the chapter. For example:


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Technical reports, conference proceedings, and other “gray literature” should be referenced only when no other source of the material is available, and an “available at” address should be provided for reports and dissertations.

4. **Manuscript submission**
All articles in meteorology and its applications are welcome for submission and authors are encouraged to study carefully the sections on manuscript preparation.

The manuscript should be submitted to KMS through online submission at the KMS Editor’s e-mail ([rokoola@uonbi.ac.ke](mailto:rokoola@uonbi.ac.ke) or [kmsmails@yahoo.com](mailto:kmsmails@yahoo.com)). Note that hard copy manuscripts and related material for all journals are now submitted directly to KMS Editor. If a manuscript meets the KMS submission qualifications (described in the table below), it will be turned over to the chief editor’s office to begin peer review. The chief editor and the journal’s editorial board will oversee the peer review of the manuscript and will correspond directly with the author concerning the disposition of the submission.

The submission must include the following components:

1) a cover letter that includes the manuscript title and full contact information, including mailing address, phone and fax numbers, and e-mail address, for one of the authors (usually the lead author), as well as any additional information required for the manuscript,(see section 2);

2) the copyright transfer for signed by all authors (see section 2), and, 3) if submission is by hard copy rather than online, five complete copies of the manuscript and figures with captions below (three for *J. Phys. Oceanogr.*). In addition, KMS still requires at least one set (two if electronic files are not available) of original hard copy figures, preferably without captions, by the time the paper is accepted. A summary of requirements for successful qualification of manuscripts is given at the end of this document. For online submission requirements, see the next section.
5. **Online manuscript submission**

The KMS journal now accepts manuscripts in electronic form through an online submission process. There are constraints that must be met before a manuscript can be submitted online. These constraints and the submission process itself are discussed in this document. Authors may submit a soft copy as an attachment in ms word.

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6. **Publications charges**

KMS has not developed a page charge policy. These page charges are designed to cover the cost of editorial, composition, and related work needed to prepare an article for publication. Reproduction of color figures is significantly more expensive and results in higher publication charges. Payment of publication charges may be expected by the Society in the near future in view of the color printing that is necessary.
A BRIEF GUIDE FOR AUTHORS

Qualification of Manuscripts

Items that must be in place before a submitted manuscript package can begin the peer-review process:

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4) Abstract, references, and figure caption list begin on new pages.

5) Double-spaced abstract, main text, appendixes, references, figure caption list, and table captions and body text.

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The Kenya Meteorological Society

BRIEF HISTORY

The Kenya Meteorological Society (KMS) was registered in 1987, as a non-profit making professional/scientific society, in a bid to promote the understanding of meteorology and its applications, among other functions, in Kenya and beyond. During its short span of existence, the Society has undertaken its duties with dedication.

The objectives of the Society include the advancement of meteorology in Kenya. In this respect, the role of the KMS is, therefore, to enhance the services of the Kenya Meteorological Department (KMD) in the promotion of meteorology.

MEMBERSHIP

The KMS draws its membership from meteorologists, environmentalists, agriculturalists and other scientists from related disciplines in Kenya and from renowned institutions the world over.

Member: Any Kenyan who holds at least a post-secondary education diploma in Meteorology or related sciences from a recognized institution of higher learning.

Associate Member: Any person who is distinguished by his/her work in Meteorology or a distinguished person whom the Society may choose to honor for his/her services to the Society.

Fellow: Any member who has been elected to the fellowship by the Committee.

Foreign Member: Any non-Kenyan who has been elected to the membership of the Society by the Committee.

Corporate Member: Any school, college, university or department of a school, college or university, research institution, company, national meteorological services or any other organization with interest in meteorology.

Student Member: Any person enrolled in a recognized post-secondary institution of learning.

Membership fees: Membership fees in the various categories are minimal and are only meant to indicate commitment of a given member.

ACTIVITIES

The Society is set to attain its goals by facilitating communication of important findings, which contribute towards the advancement of meteorological knowledge to Kenyans and the global community at large. In this regard it is the policy of the Society to encourage research in Meteorology and other related sciences; organize local and international Meteorological workshops, conferences, symposia; introduce public education; and, sensitize the public on the important aspects of Meteorology such as drought, desertification and climate change.

Activities in Progress: The Kenya Meteorological Society (KMS), in conjunction with the Kenya Meteorological Department (KMD), the University of Nairobi (UON), and the Kenya Agricultural Research Institute (KARI), has organized Workshops on Meteorological Research, Applications and Services. In addition to dealing with pressing global issues, it is also intended to facilitate sustained interaction of Meteorologists and users of Meteorological products. This will eventually enable Meteorologists to better tailor their products to the needs of the users.

Among the on-going projects by KMS is the publication of ‘The KMS Bulletin’, a quarterly newsletter, which seeks to inform scientists and the general public on what is happening in the field of weather and climate. This Newsletter, whose aim is the promotion of public education, is distributed to schools, other institutions and individuals in Kenya and abroad. In addition, the Society sponsors lectures by experts in schools and community-based groups on weather and other meteorological topics of current interest.

The KMS launched a-half-yearly publication, Journal of the Kenya Meteorological Society, in September 2007 in a bid to facilitate dissemination of research findings by scientists within Kenya and beyond.
Journal of Kenya Meteorological Society

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