Analysis of Spatio-temporal Characteristics of Rainfall on River Flow Variations in Mara River Basin, Kenya

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Abstract:-**Changes in rainfall and stream flows lead to increased uncertainty for the water investments. Assessment of river flows can warn impending stages during floods and assists in regulating reservoir outflow during low flows. The Mara River is the lifeline of the Mara River basin yet its value depreciating with significant reductions in river flows. 4 gauging stations have been operational in various periods since 1960 to date. Daily rainfall data were available for 58 stations established in different periods between 1920 and 1980. Data analysis to assess the quality of acquired data, make a selection of suitable data for statistical analysis and construct appropriate indices for spatio-temporal analyses was done. A seasonal pattern of rainfall indicated a bimodal rainfall regime with two rainy seasons. Change-point analysis indicated absence of discontinuities in the mean flows but the indices characterizing the high and low flows indicated a significant increase of both flows.**

Key Words**: Spatio-temporal, Seasonal, Inter-annual, Variability, Stream flow variations, Mara River, Flow Hydrological Extremes, Change-Point Analysis**

I. INTRODUCTION

Water is the most valuable resource for societies, an essential component of well-being and productivity. The world's agricultural, hydroelectric power production, industrial needs, inland navigation are dependent on the amount of water in the river systems. The planning and design of these water resources projects use the available historical records in which the current widely adopted procedure is to use the whole available data. River flows, however, are affected by variations of the driving force, rainfall, which in turn is influenced significantly by climatic variations. Since the climate is changing, the hydrological variables such as rainfall and stream flows are also changing and are therefore, in most cases, non-stationary hence the increased uncertainty for the water investments. An assessment of river flows provides important information that can give warning of impending stages during floods and assists in regulating reservoir outflow during low flows for water resources management [15].

The changes in the seasonal variability of stream flows and in the annual discharge of the stream flows may be caused by the land-use change ([9], [4], [7] – [16]) as well as the climate change ([6], [13], [1], [15], [19] –[2]). The change in land use causes the changes in the hydrology because each land use type has its own hydrological characteristics, in particular infiltration and surface runoff coefficient [3]. The climate change on the other hand can cause changes in the hydrology as it may alter the rainfall characteristics and evapotranspiration. According to [17], the changes in stream flow can have detrimental effects which include increased concentration of pollution due to the reduction of water for dilution, while an increase of high flows may increase risks of floods and sedimentation rates [18]. Better understanding of the stream flow patterns, their changes over time and the causes of such changes is beneficial in reducing the impacts associated with their extremes.

The value of the Mara River is depreciating. Extensive deforestation in its catchments, ever-growing population and the proliferation of tourist facilities within its riparian zone threaten to affect its flow regime and the quality of its water. Field reports indicated significant reductions of stream flows in the Mara River in the last 30 years [8]. Hypothetically, reduced infiltration rates and excessive run-off caused by loss of ground cover in its drainage basin have resulted in irregular flow regimes and flooding in the down-stream sections of the river. Silt loads carried by the river have increased and presumably, so have the nutrient and pesticide loadings. The Mau forests form very crucial water catchments for some of the large rivers in Kenya, which drain into Lakes Nakuru and Bogoria in Kenya as well as Lakes Victoria and Natron in Tanzania. Furthermore the Mara originates from these forests where it has crucial water catchments. The degazettement of the Mau forests to provide more agricultural land as proposed by the Government of Kenya will, therefore, adversely affect water volumes and flows of these rivers through denudation of their critical catchments around the Mau Hills. This may end up drying the river. It is of great importance to carry out spatio-temporal characteristics of rainfall and assess their influence on flow variations of Mara River since it is the only permanent flowing water of sufficient quantities in the whole of Mau catchment.For such an assessment, the study involved data selection and reconstruction of time series

II. MATERIALS AND METHODS

I. Study area and climate

The Mara River Basin is equally shared between the two East African countries of Kenya and Tanzania. This study was conducted in 2005 in the Mara River Basin, Kenya. The basin lies in the Equatorial East Africa, between latitudes 0˚21'S and 1˚ 54'S and longitudes 33˚42'E and 35˚54'E. The Mara River, which drains the basin, starts at an altitude of 2,920 meters in its upper basin, and ends at an altitude of 1,134 meters as it drains into the Lake, a 395km distance. A mean annual rainfall of 1,400mm represents precipitation regime of the Mara River Basin on the upper-forested parts of Mau escarpment, 900-1000mm in the middle rangelands and 700-850mm in the lower Loita hills and plains.The Mara River drains the Basin, with its primary tributaries in the upper and middle part of the basin being the Amala, Nyangores and Engare Ngobit. In the lower basin, the Talek and Sand Rivers, which originate from the Loita Hills and flow through the Loita plains, also constitute important tributaries of the Mara River.

II. Data acquisition, selection and time series reconstruction

The purpose of this process was to characterize the data to ensure that the data sets are temporarily homogeneous before carrying out other analyses.

A. Data acquisition and selection

The various sources of hydrological data identified during the review were contacted for the data. There was also a field visit to various parts of the basin to obtain the picture of the prevailing situation such as the changes in the river flows and the extent of deforestation. This was compared to the findings from the literature.

Since rainfall and stream flow data are often characterized by the presence of inconsistencies, statistical variability analysis aimed at verifying statistically the hypotheses that there is a significant reduction of flow volume in rivers in the Mara River basin and that there are significant modifications of the hydrological regimes of the rivers in the Mara River basin which are caused by changes in the characteristics of short-duration (e.g. hourly, daily) rainfall and consequently lead to amplifying frequency and severity of the hydrological extremes (floods and drought).

1) Rainfall data

The number of missing observations governs the calculation of annual series. The main objectives of the selection process were on having the longest and most continuous time series of both flow and rainfall indices for inter-annual variability analysis. The selection criteria were based mainly on record length, continuity of the records and spatial evenness of the distribution of rainfall stations. The criterion of less than 10% of missing monthly was used to screen out more stations for the purpose of inter-annual variability analysis.

2) River flow data

Similar to the rainfall data, flow data was selected based on the length and continuity of records. However, it was also necessary to check if the river flow was or was not regulated. The criterion of having rainfall stations within the catchment and around the gauging station was also used.

B. Time series reconstruction

1): Rainfall data

For rainfall data, filling of the missing values was done by segment average of the seasonal means. Since rainfall is highly spatially and temporally variable, correlation could not be used, otherwise the correlation coefficient would have to be too small to be able to fill. Outliers were left out during averaging.

2): Flow data

For flow data, Correlation analysis was used for time series reconstruction. The correlation coefficient expresses the degree of the association between two variables. Since most hydrological data are measured on a continuous scale, the Pearson product moment was used. The Pearson's correlation coefficient was estimated for two samples X and Y with N elements in the common period. It is represented as shown in equation 1 and ranges between +/-1[11].

$$r_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{\left(n\sum x_i^2 - \left(\sum x_i\right)^2\right)\left(n\sum y_i^2 - \left(\sum y_i\right)^2\right)}}$$

(Equation 1)

Filling of missing monthly values was done between individual monthly data at the particular gauging station as suggested in [17]. Using cross-correlations between different months, missing monthly flows were replaced by values computed as shown in equation 2[12]

$$X_j = \frac{S_j}{S_{j\pm k}} \times r_{XjXj\pm k} \times X_{j\pm k} \qquad \text{(Equation2)}$$

X_j and $X_{j\pm k}$ are monthly flows in month j and j±k. k is the time lead/lag between the two months that are highly correlated. $r_{xj,xj\pm k}$ is the coefficient of cross-correlation between X_j and $X_{j\pm k}$, Sx_j and $Sx_{j\pm k}$ are their respective standard deviations.

The cross-correlations were computed for months at the same site. If filling was not possible, the monthly flow was considered missing. The correlation coefficient was restricted to be at least 0.5.

III. Data Analysis

The main aims of data analysis were to assess the quality of acquired data, to make a selection of suitable data for statistical analysis and to construct appropriate indices for spatio-temporal analyses. This is because a hydrological time series is stationary if it is free of trends, shifts or periodicity. This implies that the statistical parameters of these series, such as the mean and variance, remain constant through time. However, the hydrological variables such as rainfall and stream flows are often non-stationary [14]. The inconsistencies related to non-stationarity of a time series due to the presence of discontinuities result into different parameter values between the two sub-periods of the available records [4]. Moreover, quasi-stationary series on average indices (for example average monthly flows) have been found to be highly non-stationary in relation to the indices defining the hydrological extremes. In such cases, the averaging of extremely low and high indices preserved the long-term averages of the series but not the variances ([5], [17] – [18].

A. Variability analysis of stream-flow and rainfall data

In variability analysis of a time series, three basic types of change can be distinguished [16]. These are discontinuity, a trend and a fluctuation. A discontinuity is an abrupt and permanent change in the average value of a time series. According to [12], a discontinuity at a given time represents a change in the probability law of a time series. A trend is a smooth increase or decrease, not necessarily linear, of the average value of a time series. A fluctuation in a time series refers to a regular or irregular change characterized by at least two maxima (or minima) or one minimum (or maximum). Where a variable progresses smoothly and gradually between the maxima and minima it is termed an oscillation and if the maxima and minima recur after approximately equal time intervals it is referred to as a periodicity. From the quality assessments suitable records for spatio-temporal analyses were selected.

B. Statistical analysis

This involved studying the variations of hydrological variables within the year (seasonal variations) and between the years (inter-annual variations). Seasonal patterns of variations were investigated using the average monthly indices of rainfall and flows and were used to highlight the seasonality of various hydro climatic variables such as rainfall and flows and their inter-relationships. Inter-annual variations of indices of rainfall and flow, on the other hand, were investigated using the change-point analysis and were used to indicate the presence of any inconsistencies in the hydro climatic data that would affect the model performance and whether or not the inconsistencies characterize all the related hydro climatic variables.

C. Shifts

The non-parametric test of Pettitt and the auto segmentation procedure of Hubert were used in the change-point analysis. The former test is referred to as the non-parametric data referring method and the latter as the non-parametric data dependent method. The Pettitt's test assigns values (-1, 0 and 1) for differences between the time series elements while Hubert's procedure uses exact values of the difference in the analysis and it is therefore more sensitive to outliers. However, the Pettitt's test provides only a single change-point and repeated series segmentation was performed to obtain other change-points. The results of this improved Pettitt's procedure and those of Hubert's auto segmentation procedure were used in determining series segmentation. It should be noted that segments which were at least 5 years long were accepted, while segments of less than 5 years were treated as grouped outliers and segments comprising single years as isolated outliers.

Shift analysis was done for the overall (unclassified) amounts and for different classes of rainfall. The rainfall was divided into six classes ranging between 0.1mm and over 40mm. Rainfalls amounts below 1mm(class 1) were not analyzed because many errors are involved in their estimation, and, they also don't have significant effect since most of the water evaporates immediately it falls on the ground. Class 2(1-9.9mm) and 3 (10-19.9mm) are the most common. They are well distributed light and moderate rainfall amounts and are important in recharging the groundwater table especially when falling on vegetated land. These rainfall amounts usually have less compaction effect on the ground surface which allows for infiltration. Classes 6 (above 40mm) are the most rear but have the biggest impact due to little time available for infiltration, hence result in voluminous direct runoff[10] and [13]. Thus there will be insufficient recharge of groundwater leading to a decrease of dry season flow. Classes 4 and 5 consisted of 20-29.9mm and 30-39.9mm respectively.

The average, minimum and maximum flows and the excess flow frequencies and volumes were used during inter-annual flow variability analysis. Persistence of low (high) flows was defined as the number of days in which flows are below (above) a predetermined flow threshold and is referred to herein as deficit (excess) flow frequency. Deficit and excess volumes are the cumulative flows below or above the same threshold values. Monthly excess flow and deficit flow volumes and frequencies were computed only for complete months. Otherwise a monthly value was considered missing.

III. RESULTS AND DISCUSSIONS

I. Data Acquired

Daily discharge data at Mara Mines were acquired from the Mara Region Hydrology Office (Tanzania). The rating curve and water levels at Mara Mines were obtained from the Lake Victoria Environmental Program (LVEMP). Daily discharge data of the Nyangores and Amala Rivers were acquired from the Ministry of Water (Kenya). Daily rainfall data were obtained from the Kenya Meteorological Department, Tanzania Meteorological Agency and the southern African FRIEND database at the Department of Water Resources Engineering of the University of Dar Es Salaam. The spatial distribution of these data is shown in Fig.1.

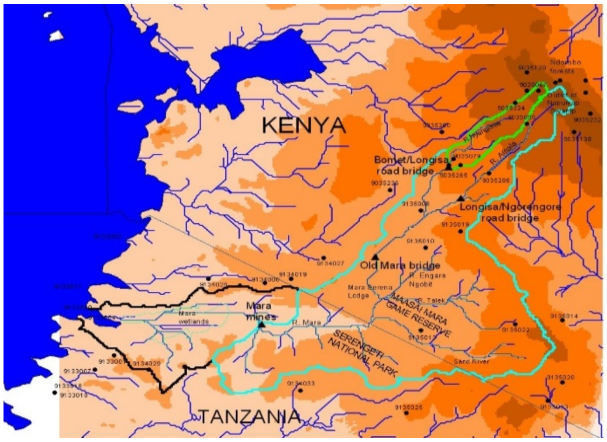


Fig.1: Details of the Mara River basin. Flow stations which are operational are shown in black triangles, and rainfall stations with available daily data are in black dots. The topography on the background was derived from a 1km×1km DEM of the USGS

According to the inventory of the availability of data in the basin, the 4 gauging stations, 1 in Tanzania at Mara Mines (River Mara) and 3 in Kenya at Bomet/Longisa road bridge (River Nyangores), Longisa/Ngorengore road bridge (River Amala) and at Old Mara bridge (Rivers Amala and Nyangores) have been operational in various periods since January 1960 to date. Since the vast central part of the basin lies within the controlled areas (the Maasai Mara Game Reserve and Serengeti National Park), most of these stations are therefore located upstream of the game reserve in Kenya and downstream of Serengeti in Musoma, Tanzania.Daily rainfall data were available for 58 stations, 15 in Tanzania and 43 in Kenya. These stations were established in different periods between early-1920s and early-1980s.

II. Data analysis, selection and time series reconstruction.

A. Data analysis

1): Rainfall data

Except for 6 Tanzania stations, daily data for all the stations was available since early-1960s to 2002. The earliest, latest and longest daily record at Musoma Meteorological Office starts in 1921 and continues through 1999 while the shortest record at Enangibere, Narok has data in 1964, 2001 and 2002. Most of the stations have 20-54 years of daily records spanning mainly the different sub-periods of the 1940-1999.

2): Flow data

Average daily flow data were available only at three gauging sites, Mara Mines (107081) in the main Mara River and in the main tributaries of Nyangores (1LA03) and Amala (1LB02). The available daily flow data mainly spans the sub-periods of the 1960-2000 period. Only 2 gauging stations have records in the 1970-1990 period in which the earliest and longest record of the Nyangores River at Bomet-Longisa Road Bridge is dated back to 1963 and extends to 2000. The station at Longisa/Ngorengore Road Bridge has the shortest record of gauge (1993-1995) with more than half of the observations missing. Practically, there is no reliable flow data in the basin since the early-1990s, except for the Nyangores River.

B. Data selection and time series reconstruction

1): Rainfall

Since the spatial distribution of rainfall stations is poor over the entire basin but moderately good around the Nyangores catchment, the analysis of rainfall data in relation to flow regime changes is concentrated in this catchment. The 22 stations within and around the catchment were thus selected. Rainfall records were further required to span the period encompassing that of flow record. Therefore only 17 stations were retained. The criterion of less than 10% of missing monthly values further screened out other stations to retain only 13 stations for the interannual variability analysis (Table I).

Table I: Records used for the Shift Analysis for Different Stations in each Season

Sno	WMO Code	JF	MAM	JJAS	OND
1	9035079	1960-1997	1961-2001	1960-1996	1960-1996
2	9035085	1960-2001	1961-2001	1960-1986	1960-1986
3	9035092	1960-2001	1960-2002	1959-1994	1959-1997
4	9035117	1960-2002	1959-2002	1960-2001	1959-2002
5	9035129	1960-1987	1959-1987		1959-1986
6	9035227	1962-1991	1960-1991	1961-1990	1960-1990
7	9035232	1960-1995	1960-1995	1960-1994	1960-1994
8	9035233	1962-1997	1961-1996	1961-1997	1960-1997
9	9035236	1962-2000	1961-2000	1961-2000	1961-1993
10	9035241		1962-1998	1962-1998	
11	9035260		1969-1998	1969-1998	1969-1998
12	9035265		1967-1995	1967-1992	1967-1992
13	9035008	1960-1985	1961-1985	1960-1982	1960-1982

2): Stream flow

For statistical analysis in the basin, only two gauging stations (107081 and 1LA03) were appropriate since data analysis rejected the third in the Amala River due to its short record. The two selected stations are not regulated and are therefore appropriate for the study of temporal flow variations under the influence of rainfall and land use/land cover changes. Consideration of continuity of monthly records indicated that the useful record in the Nyangores spans the period January 1963 - December 2000 while that at Mara Mines spans the period January 1970 - December 1991. It should be noted that mean monthly flows were computed only for months in which 90% of average daily flows were available. Monthly volumes and frequencies of excess and deficit flows were only determined for complete months. Otherwise, the monthly values were considered missing.

C. Flow variations

1): Flow seasonality

Mean monthly flows at the Mara Mines gauge, the most downstream gauge in the basin, display a main single peak centered in April (Fig. 2) due to the predominance of March-April-May peak in most parts of the basin.

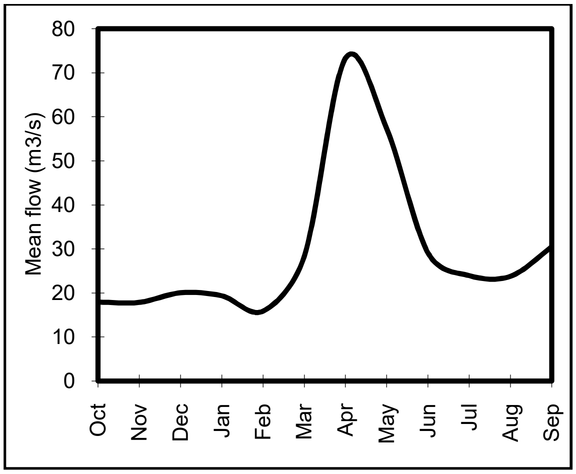


Fig. 2: Seasonal flow pattern at Mara Mines

Flows in April alone contribute about 20% of mean annual flow volume of 938Mm^3 while those during the March-April-May-June (MAMJ) period contribute about 53%. At 1LA03 gauge in the Nyangores River, there is a slight peak in May (Fig.3) while flows are persistently high from May through September due to the high rainfall amounts between April and August in the western Mau escarpment. The cumulative volume during this 5-month period contributes about 61% of the mean annual flow volume of 255Mm^3. The low flows are observed in January-February-March (JFM) at Nyangores, and in February and October at Mara Mines. This corresponds to declining overall amounts in November-December-January (NDJ) and February-March-April (FMA) seasonal rainfall amounts as explained by Valimba 2004.

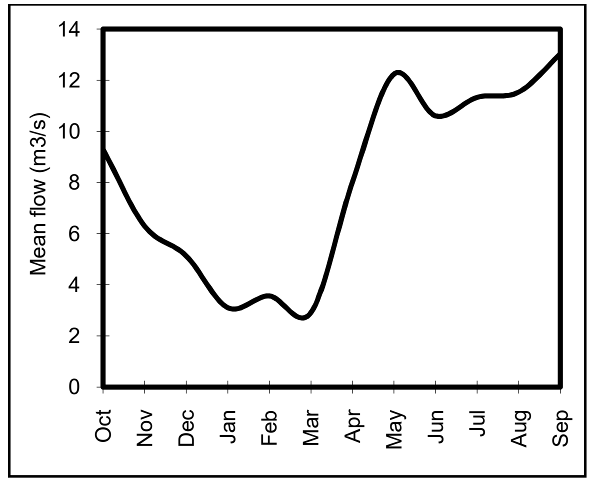


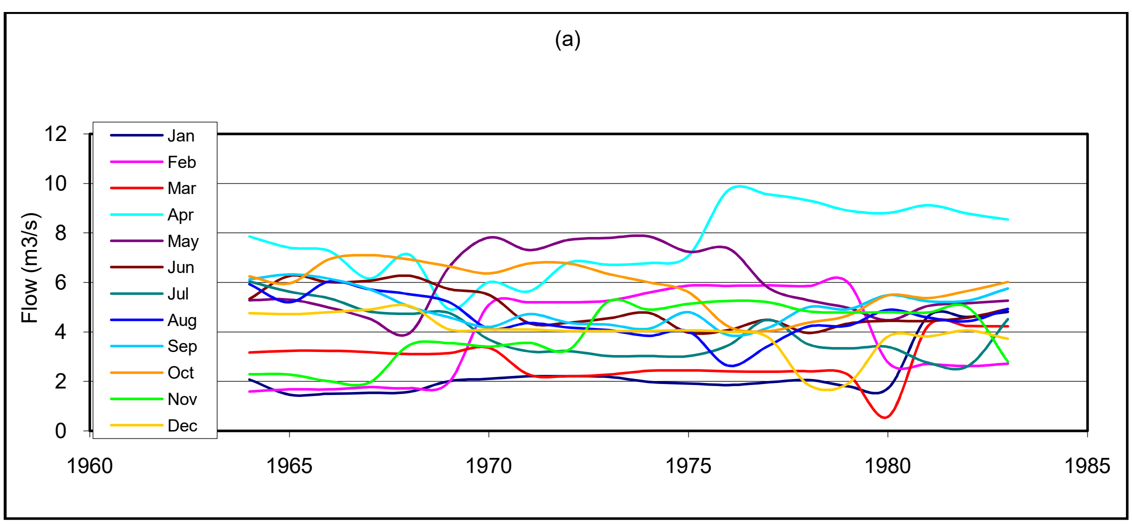
Fig. 3: Seasonal flow pattern at Nyangores

2): Inter-annual flow variability

The results of change-point analysis indicated absence of discontinuities in the annual mean flows. However, the results indicate significant discontinuities in the variance**.** According to the change-point analysis on monthly flow indices at the Mara Mines and Nyangores, the changes in the variance have occurred between 1970 and 1976.The months that were affected are February through May, particularly in April and May.

3): Average flows

The increase in the variance has been identified in April flows around 1975 at the upstream catchment of the Nyangores and around early-1970s at the downstream Mara Mines gauge. The variance of the May average flows at the Nyangores have increase around 1970 while decreasing at the Mara Mines. Except for a variance decrease at Mara Mines around 1977, mean monthly flows in the other months are quasi-stationary to the second moment (Fig.4a and b).



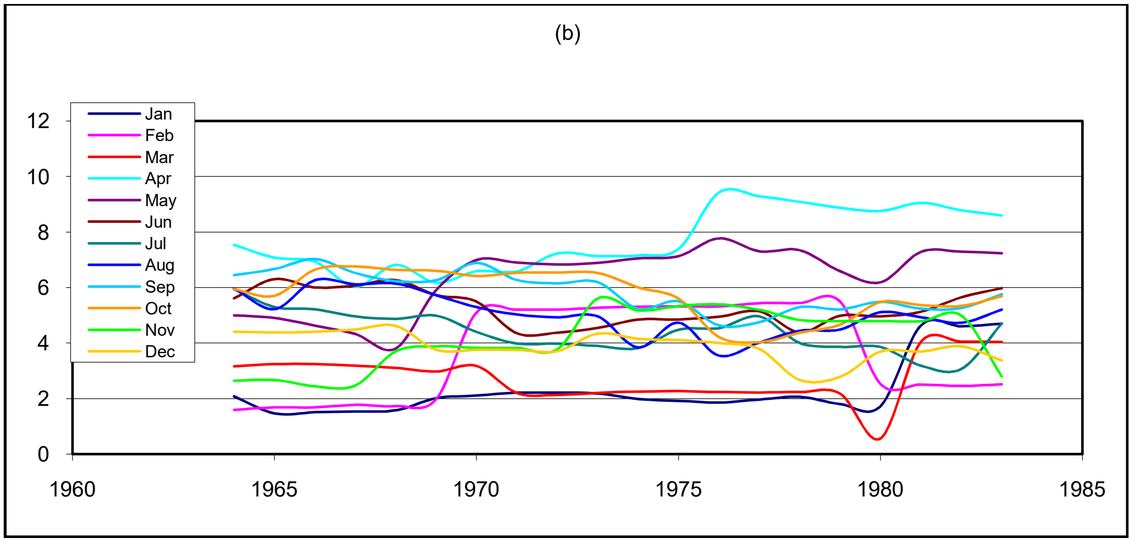


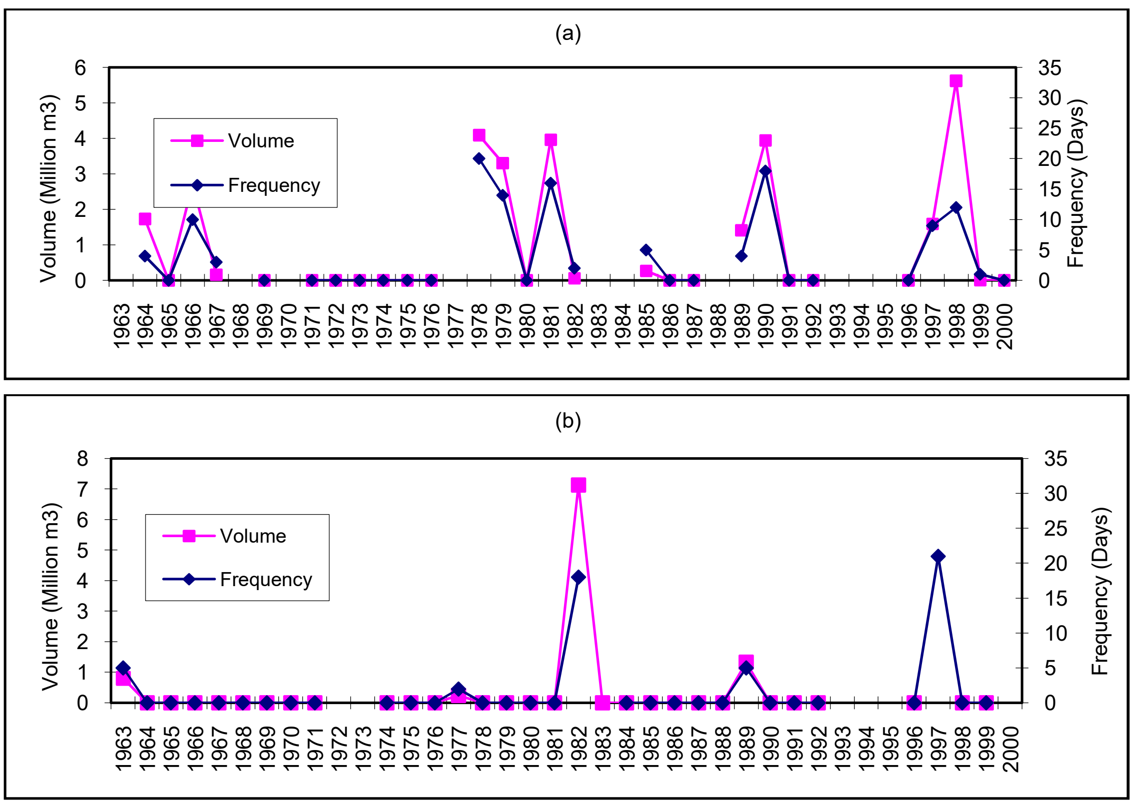
Fig. 4 a) mean and b) standard deviation flows at 1LA03 in the Nyangores

4): Maximum and Minimum flows

The analysis of maximum monthly flows indicated a significant increase of high flows in December and April and slightly in May around 1977. Changes of the minimum monthly flows were identified only in the upper catchment (Nyangores). The changes indicated increased persistence of low flows since the mid-1970s. No significant changes were identified in the Mara Mines catchment.

5): Excess flow volumes and frequencies

The excess flow frequencies and volumeindicated a significant increase of high flows in December and April and slightly in May around 1977/78 (Fig. 5).



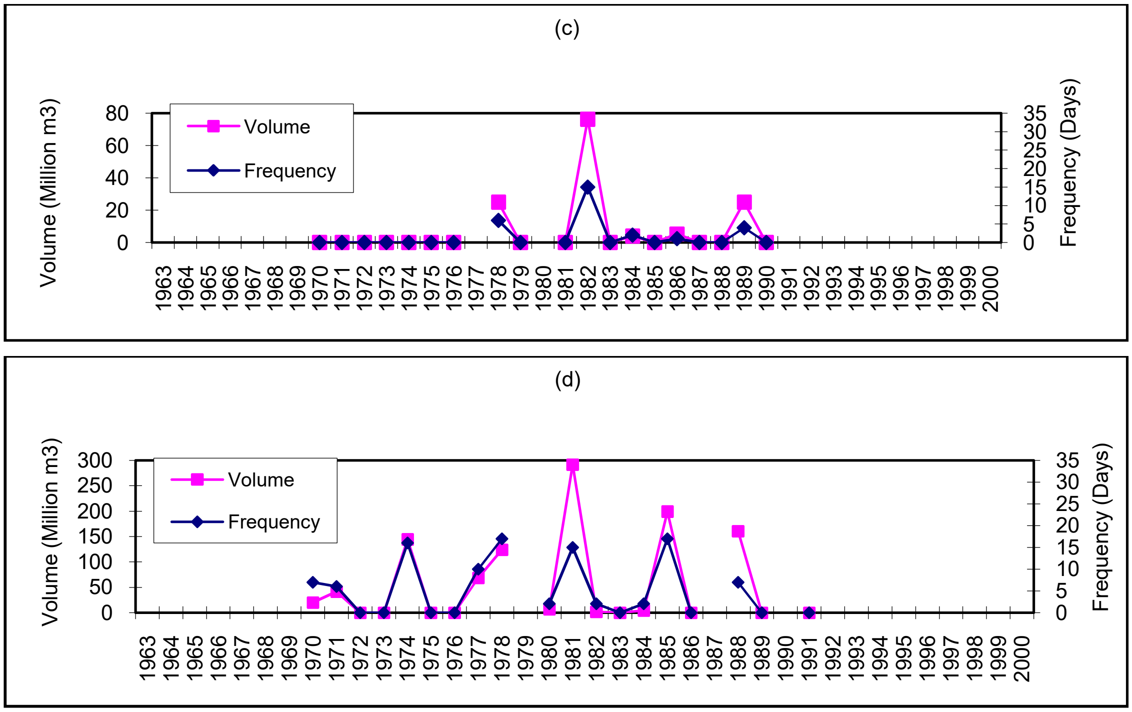


Fig. 5: Temporal evolution of flood flow frequencies and volumes in a) May and b) December at 1LA03 in the Nyangores River and in c) December and d) April at Mara Mines.

The increases characterize both averages and variances. In the post-1977, flows in April and May in the Nyangorescatchment frequently and abundantly exceeded the flood flow threshold in these two months, suggesting that floods were becoming more frequent and severe in the basin. The changes in the high flows suggested some modification of the characteristics of high flows. The disappearance of EFF in June since the late 1960s and the increase in EFF and EFV in May indicated that high flows were becoming less persistent in this catchment in recent decades. This further suggested a shortening of the duration of floods resulting rather into flashy-like floods.

6): Deficit flow volumes and frequencies

There was an indication of increased persistence of low flows in the small Nyangores catchment since the mid-1970s but no significant changes were identified in the Mara Mines catchment. The changes in the Nyangores led to increased frequency and volumes of flows below the drought flow threshold in March, the month of the lowest flows, and a decrease of the magnitude of minimum flows. These suggest an enhanced frequency and severity of droughts in this small catchment. Similar findings were from a study by [7] were revealed. These findings could be attributed to decrease in forested area especially Amala and Nyangores[8].

D. Seasonal and spatial patterns of rainfall

The seasonal pattern differs across the basin. In the upper part of the basin high monthly rainfall amounts are observed in the month of April through August (Fig. 6). High rainfall amounts occur during the month of April in the middle part of the basin. The lower part of the basin experiences high rainfall during the period March-April-May (MAM) and during October November December (OND). A bimodal rainfall regime is observed in the lower part of the basin with OND and MAM periods recording higher rainfall amounts than JF amounts. The rainfall amounts are higher in the upper and Western parts as compared to the South- East part of the basin. This could be attributed to the location of these parts within the basin. The areas on the Southeast are located away from the Lake and the mountains and so there is no influence of moisture from the Lake and the influence of mountains, as a physical boundary, that raises the moist air to form clouds hence precipitation.

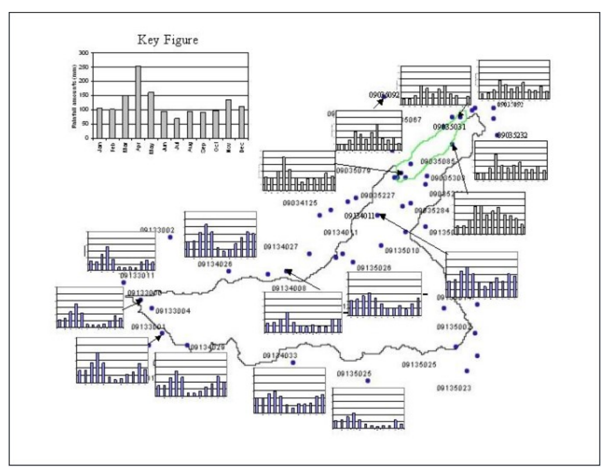


Fig. 6: Seasonal rainfall patterns

From the analysis of the seasonal means and the spatial pattern of the rainfall, the stations with the highest seasonal means are found on the downstream side of the catchment of the Nyangores River. The rainfall amounts near the catchment outlet are about twice those upstream values (Fig. 7). Therefore, the high flows recorded at the Bomet/Longisa Bridge gauging station could be significantly contributed by the lower part of the catchment. Most irrigation activities are practiced within the upstream side and this could explain the low flows within this region.

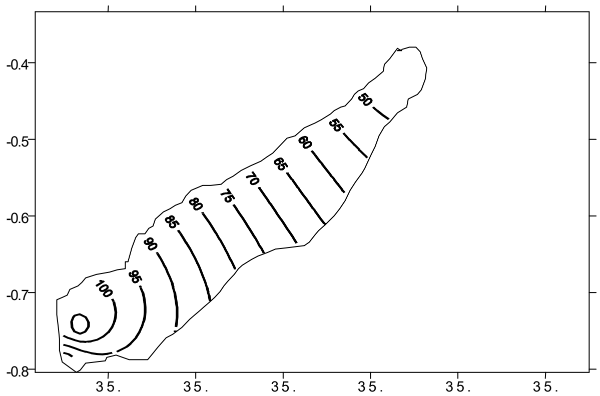


Fig. 7: General spatial rainfall patterns of the monthly means in mm.

E. Possible effects of rainfall changes

The results of change-point analysis indicated a general lack of shifts in total rainfall amounts in the basin. However, there was an indication of shifts in the amounts of rainfall due to different types of daily rainfall. The shifts characterized mostly the light rains and were generally decreasing. However, changes in heavy rainfalls identified in a few stations were generally increasing. Most of these shifts were observed during the MAM (1970-1991) and JJAS (1971-1979) seasons (Table II).

Table II: Dates on which shifts occurred for class two intensities

Sno	WMO Code	JF	MAM	JJAS	OND
1	9035079	1970(-)		1971(-)	
2	9035085				
3	9035092		1970(-)		
4	9035117	1991(-)	1991(-)		
5	9035129				
6	9035227			1971(+)	1975(+)
7	9035232				
8	9035233				
9	9035236		1983(-)	1979(-)	
10	9035241				
11	9035260				
12	9035265				
13	9035008		1980(-)		

However, these shifts were heterogeneous temporally and spatially. Temporal heterogeneity is due to shifts being identified in relatively different periods. This was the case of shifts in MAM in which shifts were identified in the early-1970s, 1980s and 1990s (Table 3.2), for the heavy rainfalls. While only one station underwent a shift for rainfall amounts above 30mm in 1974 (JF) and 1977 (MAM), two stations observed abrupt increases of the JJAS seasonal amounts in 1967-1975. None of these stations observed any shifts in seasonal amounts due to intensities more than 40mm[10] and [4]. Although dates of shifts were close to those in flow indices, these rainfall decreases during the JF and MAM seasons oppose the flood flow increases in April and May. The rainfall increases in JJAS period corresponded to an average increase of 1-2 events from zero and was mainly attributed to increases in August. Therefore given such a four-month lag between this rainfall increase in August and these flood flow increases in December, the rainfall increases could not be the cause of increasing flood flows in this small catchment. Fig. 8 is the general representation of shift occurrence.

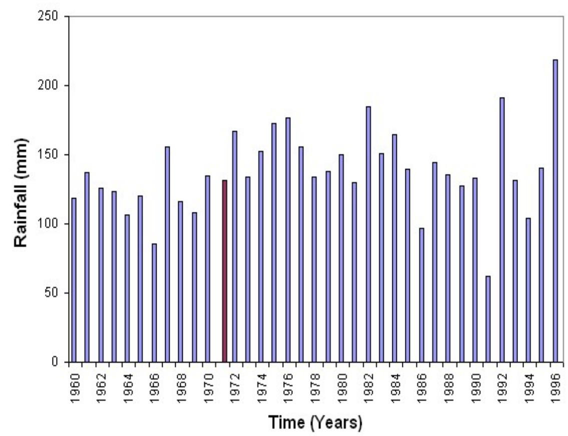


Fig. 8: Graph showing the occurrence of a shift in JJAS at 09035079 station. It is an example for the general occurrence of shifts.

IV. SUMMARY AND CONCLUSIONS

There were 4 gauging stations and 58 rainfall stations in the whole basin. Data analysis was done to obtain a homogeneous record for the model development. The analysis revealed lack of data and the quality of the available data was poor. Only 2 flow stations were used for inter-annual flow variability analysis. One flow gauging station is still operational and so 13 stations around and within Nyangores catchment were used for change-point analysis.

The results of change-point analysis indicated absence of discontinuities in the mean flows. Mean monthly flows at the Mara Mines display a main single peak centered in April which corresponds to the principal rainy season. At 1LA03 gauge in the Nyangores River, there is a slight peak in May while flows are persistently high from May through September due to the high rainfall amounts between April and August in the western Mau escarpment. Flow regimes have experienced significant changes since the mid-1970s. These changes were mainly attributed by changes of high flows and characterized the entire basin. Slight changes, which corresponded to the reduction of low flows, were identified in the upper catchment of the Nyangores River while no significant changes were identified in mean flows across the basin.

Similarly, there were no discontinuities in the overall rainfall amounts in the catchment, as per the change-point analysis. However, there was an indication of shifts in the amounts of rainfall due to different types of daily rainfall. The shifts characterized mostly the light rains and were generally decreasing. The shifts which occurred during the heavy rains were generally increasing. From the analysis of the seasonal means and the spatial pattern of the rainfall, the stations with the highest record of rainfall are found on the downstream side of the catchment. Similarly, the rainfall amounts increase downstream, the most downstream values being twice the upstream values. The general lack of changes in rainfall indices suggested an important role in of the artificial influences in the basin such as land cover in flow regime changes.

V. RECOMMENDATIONS

I. Data

A. Availability

The flow gauging stations are few and some do not have data records. The flow within the rivers is not therefore known. Records of flow on the tributaries and on the main Mara River as well as Mara Mines are needed. Evaporation stations are very far apart and most of them are located outside the study area. More of these stations should be installed in various parts of the catchment for better analysis hence performance of the models in future. Most of the rivers are ungauged. It is important for them to be gauged at their outlets, before and after their confluences, to be able to establish the flow contributions of adjoining rivers.

B. Quality

The spatial distribution of the available rainfall stations around flow gauging stations was poor, especially on the downstream side. The record length for some stations was very short. More rainfall stations should thus be installed and keeping of records of rainfall should be made. The data for most the flow and rainfall stations were not tallying even for long record lengths. The flow records were shorter and so not all the available rainfall data could be used. Only four evaporation stations were available in the entire Mara River basin and none was within Nyangores catchment. There should therefore be improved collection and processing of historical data with emphasis on their quality.

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