ASSESSING IMPACTS OF LAND USE CHANGES ON FLOOD OCCURENCE IN SOSIANI RIVER BASIN IN KENYA

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ABSTRACT

This study investigates the influences of land use changes on river peak discharge and its contribution to flash flood occurrence in Sosiani River basin in Kenya. A calibrated 2D Rainfall-Runoff Inundation model (RRI), was used to simulate the effects of land use change on river peak discharge and flood inundation. The model was calibrated against the observed stream flow data using four flood events (1970, 2006, 2010 and 2013) and then validated for the 2011 flood event. Landsat satellite images from 1973 to 2013 were obtained and classified. The results from this study indicated that discharge was sensitive to land use change, it increased with an increase in farmlands, urban and a reduction in forestland. When farmlands increased from 44% to 71% the peak discharge was increased from 128 m^3/s to 147 m^3/s. When the urban area was increased from 7% to 14% as a future scenario of 2025 the peak discharge increased from 185 m^3/s to 224 m^3/s. Reforestation of depleted forest in the (2013) land use was performed and the hydrological simulation results showed a decrease in peak discharge from 185 m^3/s to 103 m^3/s. In this research urban areas and farmlands were seen to cause sharp peak discharges in stream flow whereas the forest and grasslands had gradual peak discharges.

Keywords: Land use change, peak discharges, RRI model, GIS and remote sensing techniques

1. INTRODUCTION

Globally floods are regarded as the leading natural hazard with diverse impacts on human life, property and social-economic development. Prolonged high intensity rainfall coupled with reduced infiltration in buildup areas has greatly contributed to inundation in urban setting and areas adjacent to rivers (farmlands and houses). In the recent past, the severity and frequency of flash floods has been increasing in many parts of the world (Wiskow and van der ploeg, 2003). This increasing trend has been associated with wide spread of uncontrolled anthropogenic activities which negatively impact on the environment. Such activities include destruction of forest ranges, increased agricultural activities, draining of wetlands which are known to moderate floods and an increase in unplanned urbanization which contributes to high flood peak discharges. Climatic related disasters constitute over 70% of all registered disasters in Kenya (Otiende, 2009). Sosiani River basin covers approximately 647 km^2 and lies entirely within the Rift Valley of Kenya. Located in the Kenyan highlands it receives about 1600 mm annual rainfall (Sombroek, 1990). In recent past, Sosiani River basin has been prone to torrential pluvial and riverine flash floods. Eldoret town (**Figure 1**) which is the main town in the basin has been suffering frequent flash floods. The upstream catchment areas which were formerly characterized by forests have suffered widespread deforestation over the past decades. The forested land has gradually been converted into maize farming which constitutes the main crop grown in the area. There is a direct link between land use and floods and any change in land use may trigger a sequence of flood occurrences (Hadjimitsis, 2010). Therefore alterations in the usage of land such as clearing of forest ranges and replacing them with agricultural lands would significantly interfere with the hydrology of a river basin. The main objective of this study is to assess the land use changes in the Sosiani River basin and to analyze/investigate the effects of land use change on the river peak discharges and flash flood occurrences considering the land use changes in the basin.

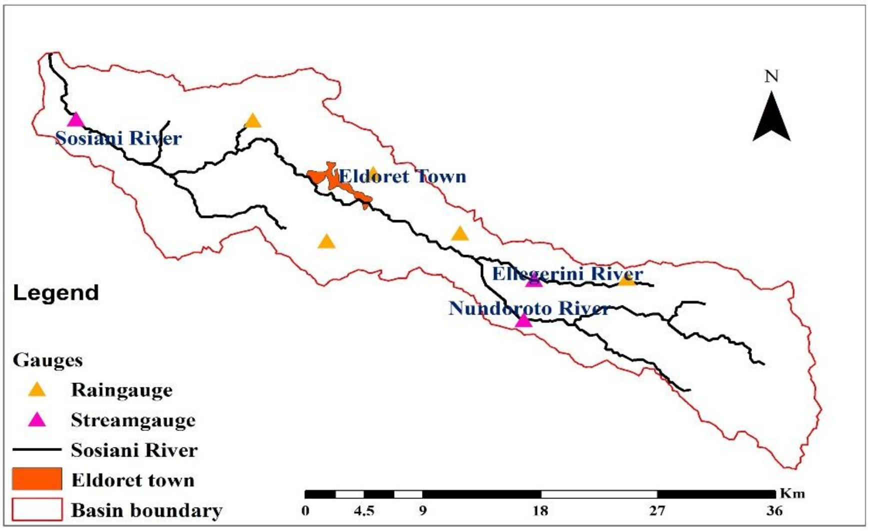


Figure 1: Sosiani River basin with gauge location

2. THEORY AND METHODOLOGY

The methodology used in this study involved extensive use of GIS and remote sensing techniques combined with hydrological simulations using different land use scenarios obtained from Landsat satellite imagery. The land use maps used in the study were derived from the historical Landsat MSS, TM and ETM+ time series imagery. Supervised classification was performed on each of the images using multispectral image analyst the basin area was then clipped out. The RRI model (Sayama *et al.,* 2012) which is integrated with GIS was used to analyze the influence of land use change on flood peak discharges in the deforested Sosiani River basin. The model was calibrated using different parameters it included adjusting manning's roughness for the river bed, soil depth, infiltration parameters, manning's roughness for different land uses.

3. DATA

The data requirement for the study can be divided into observed data and remotely sensed data. The remote sensed data included; land use maps, soil map and inundation maps from Modis. Digital Elevation Model (DEM), Flow Direction (FD) and Flow Accumulation (FA) were obtained from Hydrosheds 90m resolution data. The observed data sources include rainfall data, water level data and river discharge data. The river discharge data and water level data used in this study were available from three gauging stations in the Sosiani River basin. These gauging stations were 1CB05, 1CB08 and 1CB09 which are Sosiani, Nundoroto and Ellegerini respectively. The Sosiani River gauging station has its data ranging from 1959-2014 while Nundoroto and Ellegerini has its data ranging from 1960-2014. The location of gauges is indicated in **Figure 1.**

4. RESULTS AND DISCUSSION

4.1. Land use change detection analysis

The classification of land use maps was done for six different years. In order verify that the multispec classification performed on the Landsat imagery, another land use map was obtained from International Livestock Research Institute (ILRI) and International Steering Committee for Global Mapping (ISCGM) for comparison purposes. The land use were classified into five different classes namely; (1) forest, (2) farmland, (3) grassland, (4) urban and (5) water bodies. The absolute changes in land use were obtained from the difference in the cell count and the percentage change was computed as shown below;

$$\text{Percentage change} = \frac{Absoute\ change}{Total\ basin\ area} \times 100$$

The land use statistics for the Sosiani River basin revealed that there was change in all the land uses on the basin. This was achieved from the comparison that was done between the land use of 1973 and that of 2013 statistics. **Table 1** indicates the land use change analysis for 1973 and 2013 land uses. **Figure 2** shows the land use maps that were obtained after classification. The grassland type and forestland decreased more than half of the initial percentage (1973). The average rate of depletion in this land use type was 10 sq. km per annum. The buildup area were initially at 2. 52 sq. km in the 1973 land use as compared to the year 2013 which occupied 67.93 sq. km, the mean annual growth rate was 2.78 sq. km. Farmlands on the other hand were initially at 102.23 sq. km in the 1973 land use increased to 486.54 sq. km in the 2013 land use with a mean annual growth rate of 10.24 sq. km per annum. Assuming a constant growth rate of Eldoret town and its suburbs then by the year 2025 the urban area would occupy 95.3 sq. km which approximately 15% of the total basin area.

Table 1: Land use change analysis

Land use type	1973		2013		Change in area	
	Area in sq. km		Area in sq. km			
	%	km^2	%	km^2	%	km^2
Forest	16.9	109.34	6.8	43.99	-10.1	-65.35
Farmlands	15.3	102.23	75.2	486.54	+59.9	+384.31
Grasslands	66.6	430.91	7.2	46.58	-59.4	-384.33
Urban	0.4	2.52	10.5	67.93	10.1	+65.41
Waterbodies	0.3	2.00	0.3	1.96	-0.04	-0.04
Total	100%	647	100%	647	0.0	0.0

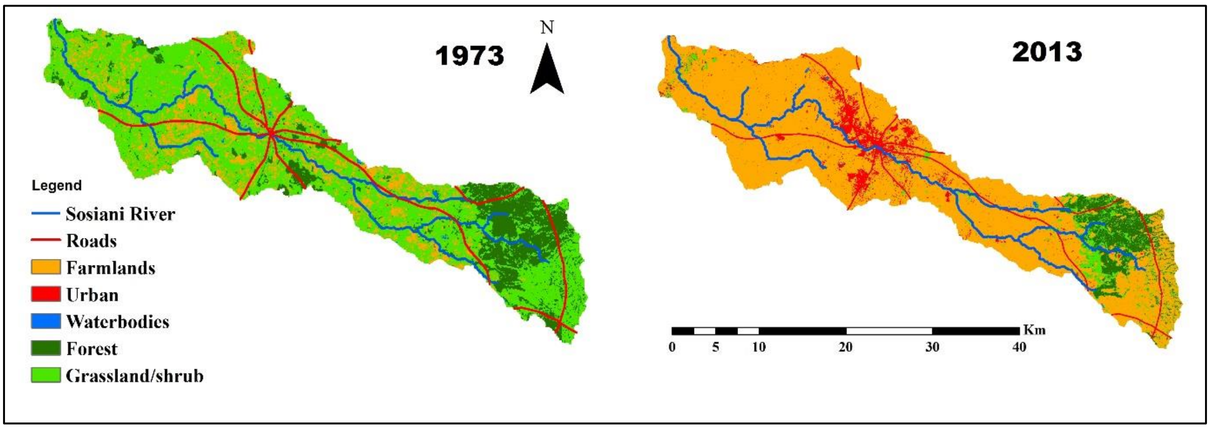


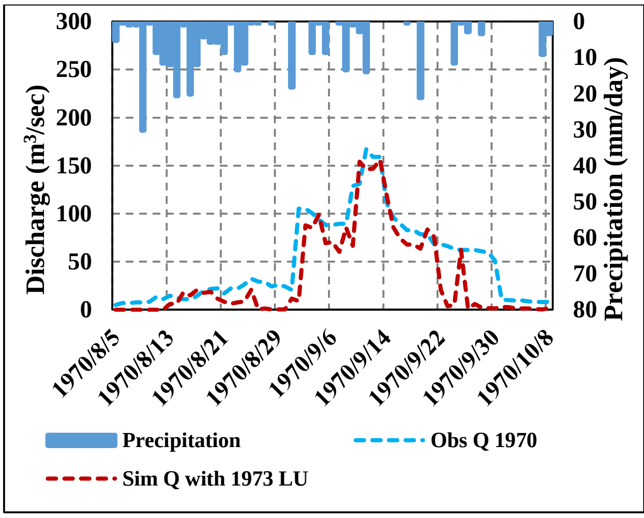
Figure 2: Land use map for Sosiani River basin 1973 and 2013

4.2. RRI model calibration and validation

The calibration results for one of the four different years are indicated in **Figure 3**. The chosen calibration periods had moderate damages. The 2011 flood event was chosen for the validation of the model this was because it had most damages reported on the basin **Figure 4.**The calibration and validation results gave good correlation as indicated in **Table 2.**

Table 2: Model efficiency parameters

Year	1970	2006	2010	2011	2013
1.Nash Sutcliffe efficiency(E)	0.60	0.85	0.71	0.74	0.74
2.Coefficient of determination(R^2)	0.78	0.92	0.91	0.82	0.91



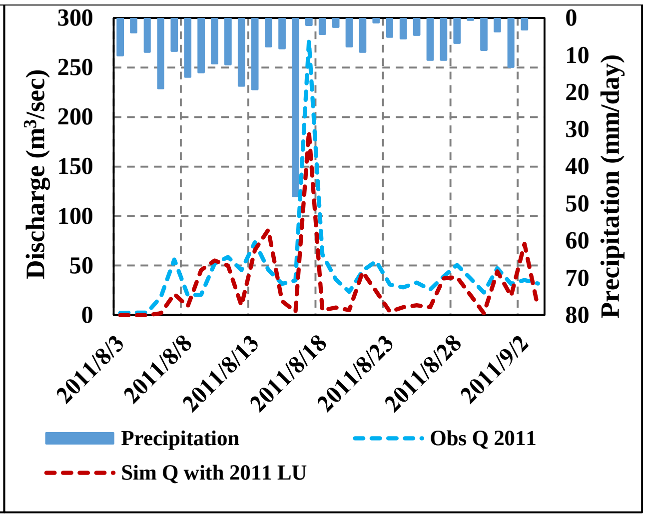


Figure 3: Calibration results for 1970 flood event

Figure 4: Validation results for 2011 flood event

4.3. Simulations with other land uses

According to the obtained results it is evident that a reduction in grassland/shrub would increase the peak discharge from 109 m^3/s to 119 m^3/s. Therefore grassland/shrubs are equally important in the control of the river discharge during a rainfall event. Vegetation (forests and shrubs) plays an important role in increasing concentration time and the general shape of the peak. A drainage basin with vegetation has its rising limb increasing gradually so is the falling limb on the other hand an urbanized drainage basin rises rapidly creating sharp peak and falls rapidly as indicated in **Figure 5** and **6**. This indicates that due to the reduction in storage on the basin and suppressed infiltration all the precipitation received in the basin is quickly converted into runoff which ends up in the river as stream flow during rainfall event. Increase in paved surfaces, build up areas hamper infiltration and the culverts and the side drains convey the rainfall water immediately into the river channels. Discharge was also seen to increase linearly with farmlands. 26% increase in farmlands which are mainly maize farming increased the peak discharge from 112 m^3/s to 154 m^3/s, the increase could be attributed to the interference with the soil structure, soil pores and creation of a hardpan below the soil surface thus hindering infiltration. In order to quantify the change in stream flow, the change in stream flow had to be categorized in terms of significance. To do this the land use of 1973 was assumed to be the most ideal land use for Sosiani River basin with minimum changes. The simulated stream flow discharge for different years was calculated as a ratio as indicated in **Table 3**. The change in river peak discharge ratio was then used to evaluate the temporal distribution of stream flow variation caused by the change in land use. The ratio was divided in three different groups (a) no river peak discharge change (ratio ≤ 1), (b) moderate river peak discharge change ($1.0 <$ ratio ≤ 2.5) and big change in river peak discharge (ratio > 2.5).

Table 3: Change ratio

Year	Ratio	Value
1973	-	-
1986	Qp_{86}/Qp_{73}	1.65
1995	Qp_{95}/Qp_{73}	2.26
2006	Qp_{06}/Qp_{73}	2.46
2011	Qp_{11}/Qp_{73}	2.73
2013	Qp_{13}/Qp_{73}	2.95
2025	Qp_{25}/Qp_{73}	3.29

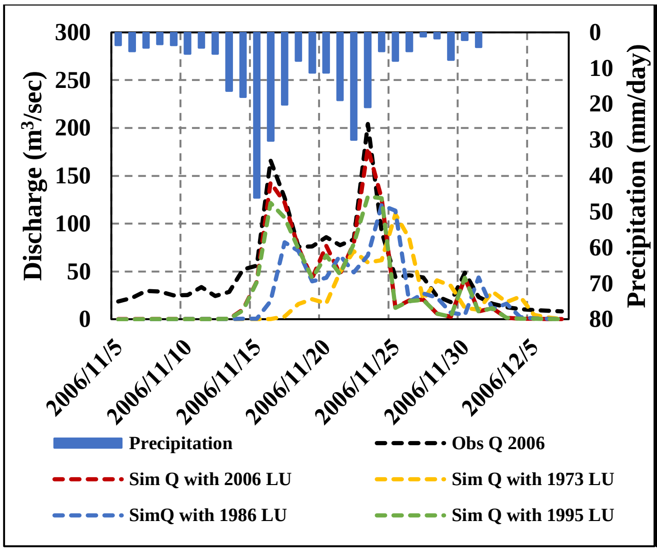


Figure 5: Simulation with all land uses using 2006 rainfall

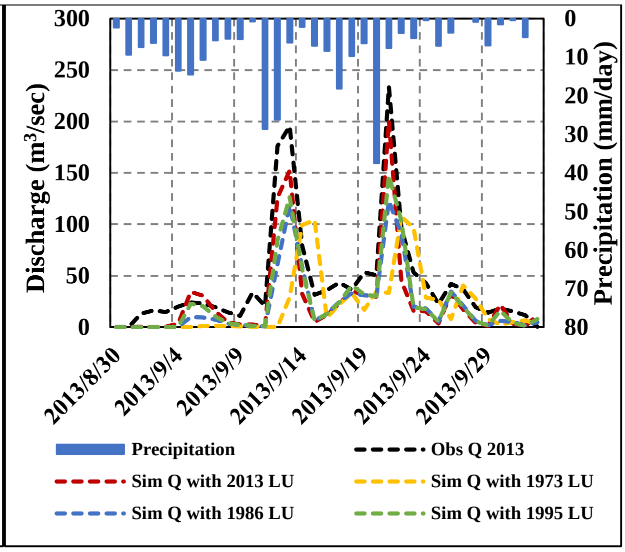


Figure 6: Simulation with all land uses using 2013 rainfall

The simulation results with the future land use scenario of the year 2025 by increasing urban area in the basin indicated a considerable increase in the river discharge using the 2006 and 2011 rainfall assuming there will be no change in the rainfall input in the basin. The peak discharge increased from 185 m^3/sec to 224 m^3/s **Figure 7**. This was a confirmation that build up areas increase surface runoff which in turn reached the river channel to form river discharge at the outlet of the basin. Increase in paved surfaces contributes to stream flow during a flood event this is because infiltration is suppressed and consequently surface runoff is increased.

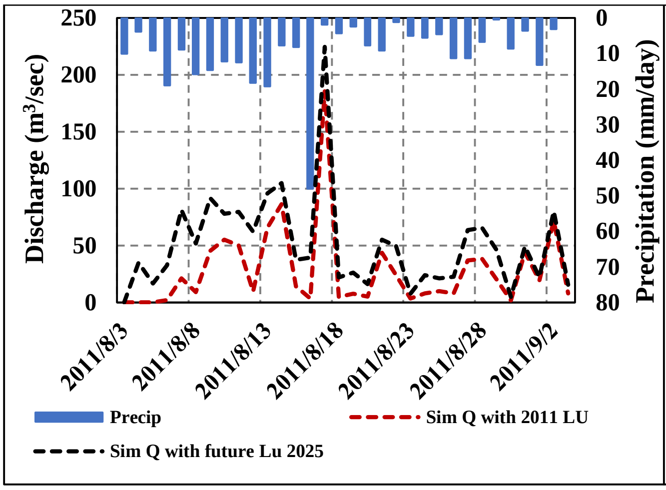


Figure 7: Urbanized 2025 land use peak discharge variation

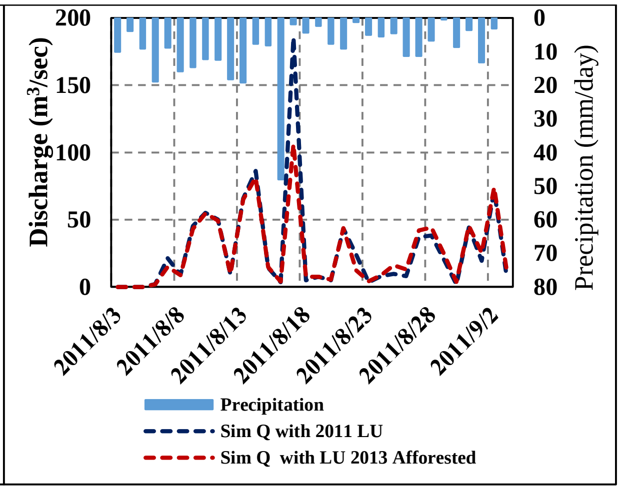


Figure 8: Reforested 2013 land use peak discharge variation

Reforestation was carried out in the 2013 land use. This was primarily done to assess the behavior of the flood peak discharge if reforestation was to be carried out as a non-structural counter measure. The simulation results indicated a reduction in the river peak discharge from 185 m^3/s to 105 m^3/s using the 2011 rainfall event as indicated in **Figure 8**. According to the results that were obtained, we were able to substantiate that forested land play a pivotal role in controlling river discharge during a rainfall event. Forestlands around the world are facing threats of being converted to other land uses most commonly agricultural land in order to bridge the food insecurity. As a consequent rivers are drying up during normal flows and extreme flood events during rainy season. To reverse the negative impacts of deforestation, Conservation of forests and tree planting should be embraced at global, regional and local level.

5. CONCLUSION AND RECOMMENTAIONS

The study of land use change is important to guide future developments in urbanizing basins. The land use data was effectively utilized during hydrological simulations this is evident from the representation of flood peak hydrographs variations, water level and flood discharges from the obtained results. The simulation results indicated that the discharge was very sensitive to land use changes and that any considerable change in land use would influence the behavior of river discharge during flood events.

This study has revealed that the land use change has negative effects on the river discharge, this changes could lead to floods occurrences in the basin downstream areas. The rapid land use changes that have occurred in the basin through the conversion of forests and grasslands to farmlands have profound effects on the runoff. In order to mitigate the land use changes, adoption of an integrated watershed management at the county level by in cooperating key stakeholders (forestry, land, water and environmental bodies) to work together in curbing the conversion of forests to others uses. Creation of public awareness on the importance of forest conservation would help in reduction of soil erosion and increase the lag time.

Formulation of laws and regulations related to flood management and mitigation should be given priority at the county level as this would guide future developments in the catchment and reduce the vulnerability to floods. Flood preparedness and response, Environmental Impact Assessment and proper legislation would reduce the damage to property and loss of life at basin level.

Adoption of sound agricultural practices and promotion of agroforestry at catchment level would reduce future flood occurrences.

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