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Effects of Watershed Land Use Change on Streamflow of Motoine/Ngong River, Nairobi River Basin, Kenya

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Abstract: **An important aspect of understanding discharge of a river is to examine the influences to which the river responds. Understanding the interaction between human activities and hydrologic processes is fundamental in addressing environmental degradation. This study examined streamflow in relation to land use changes. The study was based on Motoine/Ngong River sub-catchment, Nairobi River Basin, Kenya. Analysis of spatial and temporal land use change was done for the whole sub-catchment for five land use classes namely: bare ground, built up area and road, grassland, forest and other vegetation. Four representative sampling points along the course of the river: at the Motoine swamp outlet, Ngong Road Bridge, Nairobi dam inlet and at Kangundo Road Bridge were used to carry out flow measurements. The findings indicate spatial change in land use from 1976 to 2012, with built up area and road pattern of land use being the highest at 50.98% of the catchment, thereby forming a large area of impermeable surface cover. Flow of Motoine/Ngong River shows a marked variation between seasons and also from 1976 to 2012. This variability is attributed to increase in impermeable surface cover. Very high direct flow was noted from flood marks.**

Keywords: **Catchment, land use, streamflow, Motoine/Ngong River.**

1. INTRODUCTION

The effect of land use change on river flow, and the consequent land degradation through erosion, is one of the most important environmental problems of our time. It is necessary to understand streamflow responses of Motoine/Ngong River to changes in land use in the catchment. This study examines streamflow of Motoine/Ngong River in relation to land use changes particularly conversion of forest and other vegetation cover to farmland and urbanization. Increase in stream discharge is attributed to clearing of forest and other vegetation cover for other land uses (Baldyga, 2007; Kathumo, 2011). Kenya lost 6.5% of its forest cover between 1990 and 2010 (FAO, 2011). Greatest land use change from vegetation cover to bare surfaces and built-up areas in the sub-catchment occurred from the year 1976 (Tibaijuka, 2007). Clearing of vegetation has altered hydrological and geomorphologic states of streams by decreasing evapotranspiration and increasing overland flow and river discharge (Coe et al, 2010). The replacement of forest cover with paved surfaces or other land use types increases water yield from the catchment due to reduction in water losses as a result of compaction of soil (Mansell, 2003). Mati et al (2008) found sharp increases in flood peak flows coupled with increase in soil erosion in the upper catchments of the Mara River because of clearing of forest, scrubland and grassland in favour of agriculture. A section of Motoine/Ngong River flows through the city of Nairobi whose growth is estimated by Olima (2001) to be 7.2% p.a. Changes in land use and land cover are the most significant causes of long-term variation in streamflow in river basins (Costa et al, 2003). The challenges of water quality in Nairobi River basin due to land use change and sediment production have been studied (Kithiia, 2012), however the effect of land use change on river discharge for Motoine/Ngong River has not been investigated before. Flooding and high surface runoff increase stream discharge, an important element in fluvial processes of erosion and sediment transport (Christopherson, 2010) and affects engineering works such as drainage systems and bridges. The current study examines the effect of watershed land use change on streamflow of Motoine/Ngong River, Nairobi River basin, Kenya.

2. LITERATURE REVIEW

Land use is an important factor influencing streamflow. Worldwide changes to forests, farmlands, waterways and air are being driven by the need to provide food, shelter and clothing (Foley et al, 2005). Coe et al (2010) says that these changes have altered hydrological and geomorphologic states of streams by decreasing evapotranspiration on the land surface and increasing overland flow, river discharge, erosion and sediment fluxes.

Studies on changes in land cover with changes in river discharge generally indicate that deforestation causes an increase in the annual mean discharge (Costa et al, 2003). Tall forests have greater evapotranspiration rates than other vegetation or other land use type, because of greater canopy roughness and deeper root systems which draw on soil moisture. When they are cut the water pathways are reduced from the watershed and there is a greater total streamflow from the catchment (Miller and Miller, 2007).

Mutie et al (2006), in evaluating land use change effects on river flow in the Mara river basin Kenya, found that forests, shrub land, savannah, water bodies and grassland had reduced at the expense of increase in agricultural land, tea, open forests and wetlands. Mati et al (2008) reports that the hydrology of the Mara River has changed and records sharp increases in flood peak flows coupled with increase in soil erosion in the upper catchments, with silt build-up in the downstream flood plains.

Baldyga (2007) found increased downstream flooding of River Njoro that is attributed to land use change in its catchment. Kathumo (2011) reports the same for river Gucha catchment: that forest cover decreased by 62.94 and 68.49% as agricultural land and residential area increased by 30.36 and 7.53% for the period between 1976-1993 and 1993-2010 respectively. Total annual streamflow also increased by 3468.51 and 670.06 cumecs in the same period. Further reports by Baldyga indicate that base flow reduced by 4.0 and 4.1%, while peak flow increased by 30.4 and 7.36% respectively for the same period.

Modification of the land surface during urbanization changes the type and magnitude of runoff processes. Konrad (2002) found that annual maximum discharge in a stream increases as urban development occurs. Konrad adds that urbanization also affects other elements of the drainage system; gutters, drains, and storm sewers are laid in the urbanized area to convey runoff rapidly to stream channels, while straightening, deepening or lining of channels with concrete is done to make them hydraulically smoother. These result to transmission of the flood wave downstream more quickly and with less storage in the channel. Higher downstream flood peaks result. Consequently, the peak discharge, volume, and frequency of floods increase in nearby streams. Runoff volume also affects low flows because in any series of storms the larger the percentage of direct runoff, the smaller the amount of water available for soil moisture replenishment and for groundwater storage (Booth and Bledsoe, 2011).

Im et al (2007) found that a 10% increase in urban area increased total runoff by 5.5% and overland flow by 24.8%. Paul and Meyer (2008) report that urbanization affects both sediment supply and bankfull discharge. High impervious surface cover (ISC) associated with urbanization increases the frequency of bankfull floods. As a result, increased flows begin eroding the channel and a general deepening and widening of the channel occurs to accommodate the increased bankfull discharge. Urban watersheds with bare/paved surfaces have zero infiltration capacity, resulting to high overland and streamflow.

3. METHODOLOGY

Catchment Characteristics of the Study Area:

The study area was Motoine/Ngong river sub-catchment (Fig.1) extending from latitude 1° 17´ N to 1° 18´ N and longitude 36° 40´ E to 36° 55´ E and covering an area of 127 km^2 (Monene, 2014). The river is called Motoine upstream of Nairobi dam and flows out of the dam as Ngong River before joining the larger Nairobi River. The basin experiences a double maxima rainfall regime with a mean annual ranging between 1000 and 1200 mm (UNEP, 2003). The basin has daily maximum temperatures ranging from 21.4° C in August to 25.6° C in the month of March. Daily evaporation ranges from 89 mm in the month of July to 191 mm in the month of March (FAO, CLIMWAT Database).

Motoine River has its source at Motoine swamp where water issues from three permanent springs at the margin of Thogoto forest. From the swamp the river flows across the Karen-Dagoretti market road through a culvert and disappears into nearby farms in what was formerly Dagoretti forest. From here the river maintains a sub-surface flow through the Dagoretti Forest up to the Ngong road forest (Monene, 2014). Runoff is slow due to the undulating nature of its water head, and discharge of the river varies from one point to another along its course (UNEP, 2003). Ngong stream rises from just above Jamhuri International Trade Fair grounds at about 1,850 m a.s.l and drains into the Jamhuri Dam (Kahara, 2002). Other five streams namely: Gatwereka, Olympic, Banker, Golf Course and Undugu flow into the Nairobi Dam through the Kibera slums (Primoz, 2010). Numerous natural springs also contribute significant quantities of water into the dam. Man-made dams namely: Upper and Lower dams, have been constructed along the Motoine valley to detain surface flow (Kahara, 2002).

The catchment occurs in an area of three geological formations: the upper catchment overlies the Upper Athi volcanics which are porous and permeable, the Lower Athi volcanics that are weathered down to clayey materials and the Kirichwa valley tuffs. At the lower catchment the main top formation are the deeply weathered Nairobi phonolites (Krhoda and Kwamboka, 2016). The catchment is generally gently sloping at 1.01% except along river valleys where slopes range from about 7% to 19% (Monene, 2014).

Land use in Nairobi River basin has changed due to the expansion of agriculture and urbanization since the early 1900s (UNEP, 2001). The increase in human population from 0.7 million in 1975 to 2 million in 1999 resulted in the reduction of pristine land (UNEP, 2003). Various activities such as car washing, small-scale industry and urban farming are undertaken in the basin. The Motoine/Ngong River is used in Dagoretti area for irrigation agriculture and several other domestic uses (Krhoda, 2002).

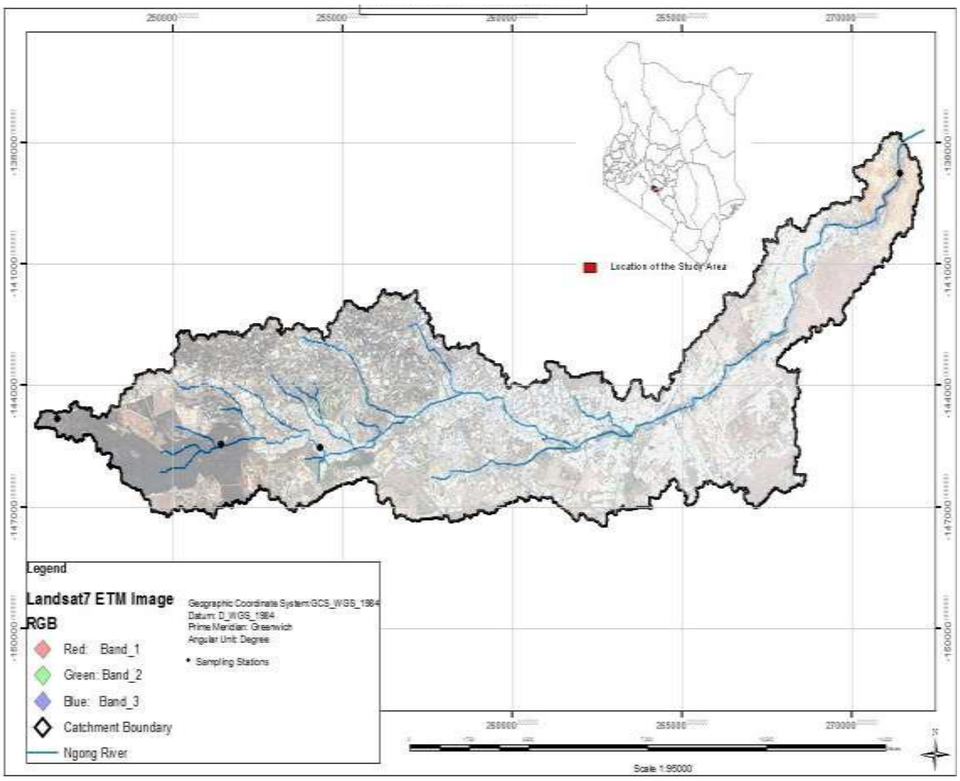


Fig. 1: Map of the Study Area – Ngong/Motoine River Catchment

Data Collection:

Primary data was obtained using structured questionnaires administered to a representative sample of farmers in the sub-catchment to get historical data on land use and land use change. The sample size was determined using the equation adopted from UNICEF (1995):-

$$n = \frac{t^2 \times p\,(1-p)}{m^2}$$

Where:

n is required sample size, *t* is the confidence level at 95%, *p* is the estimated number of farmers in the catchment and *m* is the margin of error at 5%.

Data on forest cover change was obtained by interviewing the forest officer at Ngong Road forest office. Field observations and Photography were also done at different sites to reveal key land use types. Data on discharge of the river was obtained by taking measurements using velocity-area method and an OTT C2 small current meter at four gauging stations along the River course: at Motoine swamp outlet (37M 0242157 UTM 9857007), Ngong Road Bridge (37M 0271397 UTM 9861770), Nairobi dam inlet (37M 025450 UTM 9854120) and at Kangundo Road Bridge (37M 0271396 UTM 9861765).

The equation used was;

$$\mathrm{Qr} = \sum_{i=1}^{n} \mathrm{A}\, c_i\, V_i$$

Where:

Qr is the river discharge (m^3/s), Ac_i is the river cross-sectional area (m^2) (*i* denotes any one measurement in a series), V_i is the sectional flow velocity (m/s) and *n* is the number of measurements made. Measurements of discharge were done twice for each of the four sampling points: once each during the rainy season and dry season. Field observations and photography of flood marks were also done to estimate the level of direct flow.

Secondary data on historical changes in land use was obtained from satellite imageries for 1976, 1984, 1995, 2002 and 2013 sought from Department of Resource surveys and Remote Sensing (DRSRS). Additional data on forest cover change was collected from the Kenya Forest Service and river discharge from the Water Resources Management Authority (WRMA) Sub-regional office in Nairobi, Ministry of Environment, Water and Natural Resources.

Data Analysis:

Data analysis was enabled using statistical measures of central tendencies, calculation of percentages and correlation to determine the relationship between land use and streamflow. Land use change pattern from 1976 to 2012 was assessed from satellite images. This was followed by mosaicing of images, clipping of the study area by use of ArcGIS tool, classification and vectorization to enable computation of the area covered by each pattern of land use.

4. RESULTS AND DISCUSSION

Changes in Land Use between 1976 and 2013:

The findings of the study indicate that there has been spatial change in land use over the years in Motoine/Ngong River sub-catchment. Five land use classes were identified within the catchment, namely: bare ground, built up area and road, grassland, forest and other vegetation (Fig. 2 and 3).

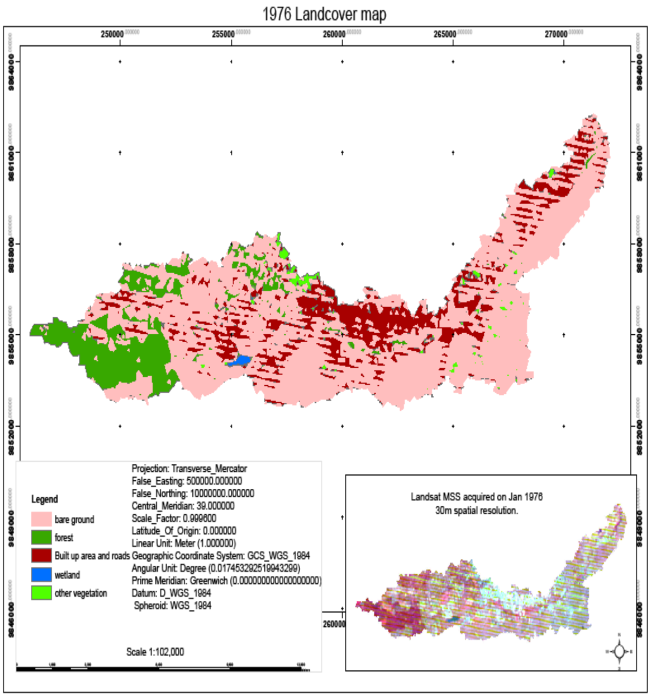


Figure 2: Satellite Image for 1976.

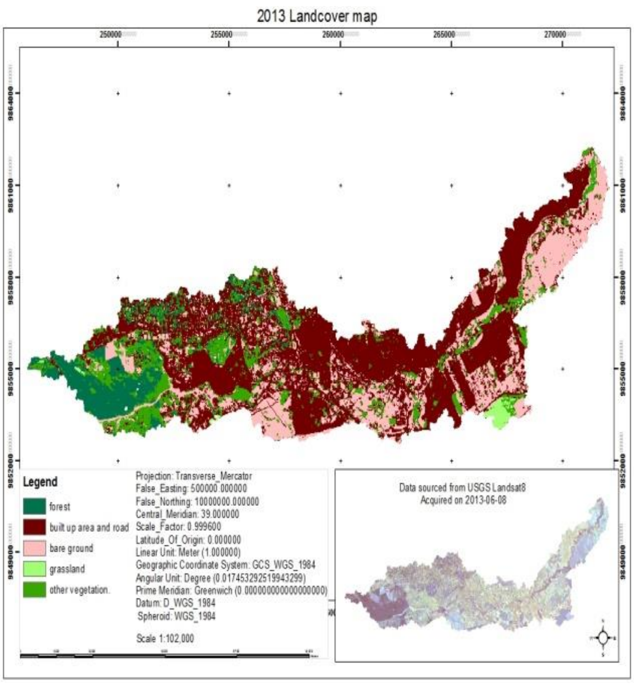


Figure 3: Satellite Image for 2013.

Built-up area and Road pattern increased from 22.78% in 1976 to 50.98% in 2013, an increase of 124%. This formed the main pattern of land use covering more than half of the catchment. Mundia and Aniya (2006) attribute this change in land use to increasing and rapid economic developments in Nairobi city. Increase in built-up area and reduction of grassland and other vegetation increase surface runoff and streamflow. Other vegetation pattern of land use registered an increase of 600% from 2.17% in 1976 to 15.18% in 2013.

Bare ground registered the greatest reduction of 58% from 57.48% in 1976 to 23.86% in 2013 because of improved land management and a simultaneous increase in built-up area and road surfaces. Other patterns that reduced were forest by 43% and grassland by 39%. Information from interviews conducted on sampled residents within the catchment indicated that the area of Njiru was formerly a ranch before it was sub-divided and settlements started. Those that moved to the area before the year 2000 reported that the land cover was grass and bush. This explains the marked reduction in grassland and other vegetation between 1995 and 2002. Increase in built-up area and road and other vegetation increased streamflow in the sub-catchment due to increase in impermeable surface cover.

The main forest cover in the sub-catchment is the Ngong Road forest which was gazetted 1932, and covered an area of 2929.6 ha at that time. Excisions have been made over the years to provide land for road construction, development of schools, churches, public cemeteries and other social facilities. The current cover of 1224.4 ha is only 41.8% of the original cover. The latest excision was made in the year 2013 for 56 ha for construction of the southern by-pass interchange road. Reduction in cover of forest and grassland increased impermeable surface cover in the sub-catchment which reduced infiltration and increased streamflow.

Streamflow:

The flow of Motoine/Ngong River is variable between seasons and from 1976 to 2012. Average flow at Motoine swamp outlet was $78m^3$/day (Table 1.0) and forms the source of Motoine River. The water issues from three permanent springs at the margin of Thogoto forest. The river flows across the Karen-Dagoretti market road through a culvert and disappears into nearby farms in what was formerly Dagoretti forest.

Ngong Road Bridge had no flow during the dry season because of impounding of the Motoine stream by the Upper and Lower dams located in the Ngong Road forest. Payet and Obura (2004) found that depletion of water resources was caused by drawing it through boreholes and wells causing perennial rivers to dry up. Wet season flow was $889.92m^3/s$ or 445 m^3/ day (Table 1.0). Flood marks were observed measuring about one meter high on the plants along the river banks. No flood marks were observed outside the banks, an indication that the river does not overflow its banks mainly because of abstraction by the Upper and Lower dams and also because this part of the catchment is within the Ngong Road forest cover which has a high infiltration capacity.

Average flow at Nairobi dam inlet was 0.0888 m^3/s or 7,672 m^3/ day (Table 1.0). The river at this section has cut a deep channel able to contain the flow even during the rainy season as indicated by absence of flood marks outside the river channel.

Average flow of Ngong River at kangundo Road Bridge was $0.96m^3/s$ or $82{,}944m^3$/day (Table 1.0). The water overflows its banks of about 10.5m wide to cover a wide area of the valley up to 58.5m as indicated by flood marks. The height of floods reaches 1.4m on tree trunks and banana stems.

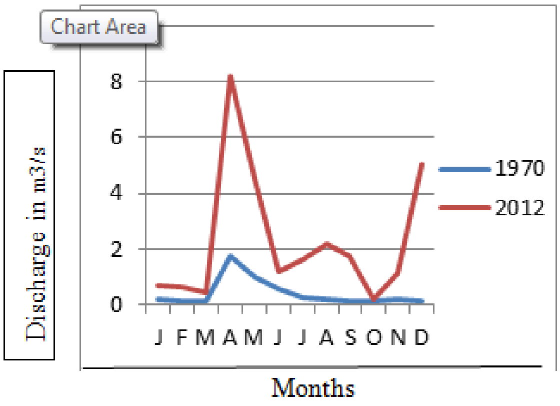
Data on discharge for Motoine/Ngong River was limited to only that on which measurements have been made because it does not have gauge stations. For this reason data on discharge for Mbagathi and Nairobi Rivers, which are within the same catchment, was interpolated to relate land use change and streamflow. Discharge for 1970 compared to that for 2012, showed that the mean monthly discharge has generally increased over time (Fig. 4 and 5). Discharge for Nairobi River in the month of April 1970 was $1.72m^3/s$ and $8.18m^3/s$ for the same month in 2012 (Fig.4). This indicates that rain season flow was quite high in 2012 compared to 1970. Recorded rainfall in the months of April was 469.1mm for 2012 and 347.3mm for 1970, an increase of 35%. Discharge for Nairobi River for this same month was $8.18m^3/s$ for 2012 and $1.72m^3/s$ for 1970, an increase in discharge of 375.58%. In spite of higher rainfall recorded in the months of April 2012 than 1970, streamflow was several times higher in 2012 than in 1970. This is attributed to increase in impermeable surface cover in the catchment due to increase in built up area and road pattern of land use.

TABLE 1: DISCHARGE FOR MOTOINE/NGONG RIVER (DRAINAGE AREA 3BA) AT FOUR GAUGING STATIONS

Station	**Dry Season Discharge (m^3/day) on 5/9/2013**	**Wet Season Discharge (m^3/day) on 17/12/2013**	**Mean Discharge (m^3/day)**
Motoine Swamp Outlet	89	66	78
Ngong Road Bridge	0	890	445
Nairobi Dam Inlet	6,955	8,389	7,672
Kangundo Road Bridge	46,604	119,283	82,944

The same trend was evident for Mbagathi River (Fig. 5) for the month of September 1970 and 2012; an increase in rainfall by 156% and an even higher increase in discharge by 243%. Information from the questionnaire indicated that flow filled the channel during the wet season and the water level was very low during the dry season.

Correlation between built-up area and streamflow yielded a value of 0.8 ($r = 0.8$), an indication of a strong positive relationship between increase in built-up area and streamflow. Coefficient of determination (r^2) was 64%, representing the proportion of variance in streamflow for Motoine/Ngong River that is accounted for by increase in built-up area and road surfaces in the sub-catchment.



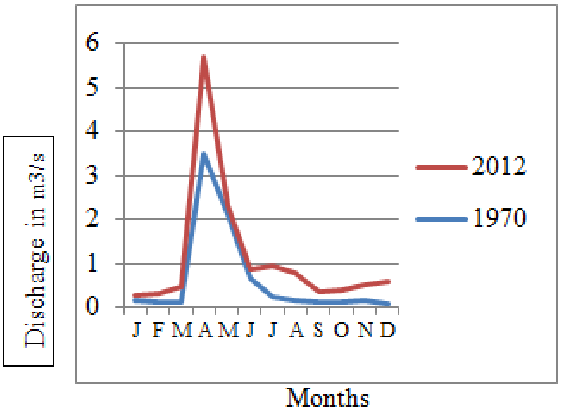


Fig. 4: Discharge in m3/s for Nairobi River for 1970 and 2012. Fig. 5: Discharge in m3/s for Mbagathi River for 1970 and 2012

Summary:

The findings of the study indicate that there has been spatial change in land use over the years in Motoine/Ngong river sub-catchment. Five land use classes were identified within the catchment, namely: bare ground, built up area and road, grassland, forest and other vegetation. These patterns showed both increase and decrease in extent of coverage between 1976 and 2012. Overall built-up area and Road and other vegetation pattern of land use registered an increase over the study period, while forest, grassland and bare ground reduced. Built-up area and road pattern of land use showed a steady increase over the period under study, increasing from 22.78% in 1976 to 50.98% in 2012. Other vegetation land use pattern also increased from 2.17% in 1976 to 15.18% in 2012. Increase in built-up area and road and other vegetation have resulted to increased streamflow in the sub-catchment.

Grassland pattern of land use reduced from 2.14% in 1976 to 1.30 % in 2012. Forest cover pattern of land use also reduced by 56% from 15.18% in 1976 to 8.68% in 2012. This reduction in cover of forest and grassland in the sub-catchment reduced infiltration and increased streamflow. Bare ground reduced from 57.48% in 1976 to 23.86% in 2012.

The flow of Motoine/Ngong River is variable between seasons and from 1976 to 2012. The dry season flow was low; recording zero at the Ngong Road Bridge sampling point, while wet season flow was high measuring 82,944 m^3/day at the kangundo Road Bridge gauging station and evidently overflows its banks of about 10.5m wide to cover a wide area of the valley up to 58.5m. The height of floods reaches 1.4m as shown by flood marks on tree trunks and banana stems.

5. CONCLUSION

The analysis shows that there has been spatial change in land use over the years at the Motoine/Ngong River sub-catchment. This change was characterized by both increase and decrease over the years in the area of coverage of forest, grassland and bare ground land use patterns. Overall each of these patterns' coverage was lower in 2012 than in 1976, and together they cover 49.02% of the catchment. Built up area and road surfaces was the only pattern that recorded a steady increase from 1976 to 2012 and covers the remaining 50.98% of the catchment. This has increased the impervious surface cover in the catchment, which has caused a reduction in infiltration capacity while increasing surface run-off and streamflow. Reduction in infiltration capacity translates to reduced ground water recharge. This results to a reduction in baseflow and a high seasonal flow variability as observed at the Motoine/Ngong River. Data from this research will be used to design urban infrastructure such as bridges, culverts, drainage channels and rain water detention structures as well in the management of the river and its catchment.

REFERENCES

[1] Baldyga, T. J., Miller, S. N., Maina G. C., & Shivoga, W. (2007). Suitability of the Automated Geospatial Watershed Assessment (AGWA) Tool in Assessing Hydrological Response and Land Cover Change in River Njoro Watershed, Kenya. Egerton Journal: Science and Technology, 7, 56-71.

[2] Booth, D. B. & Bledsoe, B. P. (2011).The Water Environment of Cities. Springer Books.

[3] Coe, M.T, Latrubesse, E. M., Ferreira, M.E. & Amsler, M.L. (2010). Effects of Deforestation and Climatic Variability on Streamflow of the Araguaia River, Brazil. Biogeochemistry (2011), 105: 119-131

[4] Costa, M. H., Botta, A. L. & Cardille, J. A. (2003). Effects of Large-Scale Changes in Land Cover on the Discharge of the Tocantins River, Southeastern Amazonia. Journal of Hydrology 283 Pg 206–217.

[5] FAO Database, CLIMWAT 2.0 for CROPWAT, Water Development and Management Unit.

[6] Foley, J. A., DeFries, R., & Asner, G. P. (2005). Global Consequences of Land Use. Science Magazine, Volume 309 No. 5734, pp. 570-574

[7] FAO, (2011). Forest Resources Assessment, Kenya Forest Information and Data.

[8] Im, S., Kim, H., Kim, C. & Jang, C. (2007). Assessing the Impacts of Land Use Changes on Watershed Hydrology using MIKE SHE. Environ Geol, Volume 57, pp. 231-239.

[9] Kahara, (2002). Nairobi River Basin Project Phase III, UNEP.

[10] Kathumo, V. M. (2011). Application of Remote Sensing and GIS in Assessing Land Use Cover and Land Use Changes and their Impact on Hydrological Regime in River Gucha Catchment, Kenya. Thesis, Unpublished.

[11] Kithiia, S. M. & Wambua, B.N. (2010). Temporal changes of sediment dynamics within the Nairobi River Sub-basins between 1998–2006 time scale, Kenya. Land Reclamation No 42 (1), pp. 17–22.

[12] Konrad, C. P. (2002). Effects of Urban Development on Floods, U.S. Geological Survey.

[13] Krhoda, G. O. & Kwamboka, A. M. (2016). Impact of Urbanization on the Morphology of Motoine/Ngong River Channel, Nairobi River Basin, Kenya. Journal of Geography and Regional Planning, Volume 9(4), pp. 36-46.

[14] Krhoda, G. O. (2002). Nairobi River Basin Project Phase II, Monitoring and Sampling Strategy for Ngong/Motoine River, UNEP.

[15] Mansell, M. G. (2003). Rural and Urban Hydrology. Thomas Telford Ltd, London.

[16] Mati, B. M., Mutie,S., Gadain, H.,Home, P. & Mtalo, F. (2008). Impacts of land Use/ Cover Changes on the Hydrology of the Trans-boundary Mara River; Kenya/Tanzania. Journal of Hydrology. Lakes & Reservoirs: Research & Management, Volume 13, issue 2, pp169-177.

[17] Miller, J. R. & Miller, M. O. (2007). Contaminated Rivers, a Geomorphological-Geochemical Approach to Site Assessment and Remediation, Springer Publishers

[18] Monene, A. K. (2014). Effects of Land Use Change on Streamflow, Channel Erosion and River Geomorphology: A Case Study of Motoine/Ngong River Sub Catchment. Unpublished M.A. thesis, Department of Geography and Environmental Studies, University of Nairobi

[19] Mundia, C. N. & Aniya, M. (2006). Dynamics of Land Use/Cover Changes and Degradation of Nairobi City, Kenya. Land Degradation & Development, Volume 17, Issue 1, pp. 97-108, Wiley Online Library.

[20] Mutie S. M., Home, P., Gadain, H., Mati, B., & Gathenya, J. (2006). Evaluating Land Use Change Effects on River Flow Using USGS Geospatial Streamflow Model in Mara River Basin, Kenya. Center for Remote Sensing of Land Surfaces, Bonn.

[21] Olima, W.H.A. (2001).The Dynamics and Implications of Sustaining Urban Spatial Segregation in Kenya-Experiences from Nairobi Metropolis. Unpublished

[22] Paul, J. B. & Meyer, J. L. (2008). Urban Ecology, Streams in Urban landscape, Springer Publishers.

[23] Payet, R. & Obura, D. (2004). Impacts of Human Activities in the Eastern African Region: An International Waters Perspective. Ambio Volume 33 No. 1/2, pp. 24-33.

[24] Primoz, K. (2010). Mapping Flood Damage in Kibera. http://www.flickr.com.

[25] Tibaijuka, A. (2007). Cities can achieve more sustainable land use if Municipalities combine Urban Planning and Development with Environmental Management. Nairobi and its Environs.

[26] UNEP, (2003). The Nairobi River Basin Project – Phase III. Resource Booklet on Pollution Monitoring Activities.

[27] UNEP, (2001). Nairobi River Project (ROA). Nairobi, Kenya.

[28] UNICEF, (1995). Monitoring Progress towards the Goals of the World Food Summit for Chldren: A Practical Handbook for Multiple Indicator Surveys, New York.