EVALUATION OF THE IMPACT OF LAND USE CHANGE ON CATCHMENT HYDROLOGY: THE CASE OF WUNDANYI RIVER CATCHMENT IN TAITA HILLS, KENYA

Dishon M. Mkaya[a, b,*], Benedict M. Mutua[b], Peter M. Kundu[b]

[a]Smallholder Horticulture Empowerment & Promotion Unit Project, P. O. Box 19024-00100, Nairobi, Kenya.

[b]Egerton University, Faculty of Engineering and Technology, Department of Agricultural Engineering, P.O. Box 563, Njoro, Kenya

Running title: Case study of Wundanyi River Catchment

*Corresponding Author: Smallholder Horticulture Empowerment & Promotion Unit Project, P .O. Box 19024-00100, Nairobi, Kenya. Tel.: +254-722-773-356.

E-mail address: mkdishon@gmail.com (D. Mkaya)

Abstract

The purpose of this study is to evaluate the impact of land use change on catchment hydrology. To do this evaluation, changes in the state of land use were mapped by classifying selected landsat satellite images based on eleven land use classes which were found in the catchment. The classifications were assessed using GEOVIS and processed in ArcView GIS with the help of ground information. The hydrologic impacts of the detected land use changes were analyzed within catchment. Results obtained shows that forests land declined by 57% while agricultural land and built-up area expanded by 10% and 156% respectively over the study period. Evaluation of the impact of land use changes revealed that there was an increase of surface runoff from 4.12 to 110.96mm and sediment yield from 0.43 to 20.10t/ha within the catchment due to impact of the land use change. Simulated model results showed an increase of surface runoff in the catchment with the highest being of the post change period 2001 which had severe land use changes. The results were found that they can be used by catchment stakeholders and policy makers to address challenges brought by the catchment degradation. The results will further help in making informed decisions in selecting and developing viable catchment management options that will promote sustainable utilization of land and water resources within Wundanyi River Catchment

Keywords: Land use change; Remote sensing; GIS; SWAT Model; Surface Runoff; Catchment Hydrology

1. Introduction

The conversion of rural land to agricultural land and urban settlement usually increases soil erosion, and volume of storm runoff in a catchment. As part of programmes established to alleviate these problems, engineers are increasingly assessing the probable effects of urban development, as well as designing and implementing measures that will minimize these adverse effects. The need for settlement and agricultural development has increased with increase in population (Chemelil, 1995). As a result of increased population and the need for more land, the natural vegetated areas have been cleared and cultivated (Séguis *et al*., 2004). This has been observed not only in the high potential areas but also in marginal areas which were earlier on predominantly under grazing livestock because of low rainfall (Onyando, 2000). In Kenya, the rural communities are encroaching into the humid areas to open up new lands for agricultural production and settlement (Onyando, 2000; Olang, 2004; Hartemink *et al*., 2006).

Increased agricultural and urban development has led to subdivision of land and as a result brought about changes in land use patterns. These changes have led to environmental degradation, which has negatively altered the hydrologic regimes of many catchments in Kenya. For instance, deforestation, subdivision of land to small units and urbanisation have significantly altered the seasonality and magnitude of discharge, and annual distribution of stream flows (Karanja *et al*., 1986; Donner, 2004; Mustafa *et al*., 2005). Degradation resulting from intensive agriculture and other activities include: loss of top fertile soil due to erosion, siltation of rivers, high incidence of floods, and eutrophication of surface water bodies. Another result of catchment degradation is the hypoxia condition resulting in loss of aquatic biodiversity, effluent of agrochemicals and low stream flows during dry periods (Donner, 2004; Araujo and Knight, 2005; Lim *et al*., 2005; Onyando *et al.*, 2005). In addition, the effect of land degradation in most catchments has reduced the infiltration rates and therefore caused increased runoff generation from the catchment.

The Wundanyi River catchment is one of the catchments that have undergone rapid land use changes over the last 50 years. The population of the whole of Taita/Taveta County has grown from 90,146 in 1968 (Republic of Kenya, 1970) to over 285,000 people in 2009 (Republic of Kenya, 2010). The catchment has a population density of about 60 people per km^2 that depends on the scarce natural resources such as land and water (Pellikka *et al.,* 2004). As a result of high population growth over the years, the forest cover has rapidly been replaced by crop cover and built- up areas, which has led to changes causing the soils to be impervious (Mustafa *et al*., 2005). The Wundanyi catchment comprises eleven sub-catchments. The sub-catchments have been subjected to continuous changes of land use. They are in the semi urban stage with approximately 20% impervious area and intensive agriculture as well as a rapid increase in construction activities.

The understanding of the effects through catchment modelling allows for monitoring and correlating environmental changes with factors such as socio-economic and health (Troyer, 2002). In addition, it enables planners to formulate policies to minimize the undesirable effects of future land use changes on catchment hydrology (Mustafa *et al*., 2005). The catchment modeling needs hydrologic data such as precipitation, temperature, evaporation, and streamflow. However, the Wundanyi River catchment lacks continuous hydrologic data records. Therefore, there was need to develop alternative approaches for getting hydrological data for this catchment. One such approach is runoff simulation using SWAT model. By using such models, this study provided a technique to produce hydrographs which were used directly or in a GIS environment to provide information for future studies on water availability, urban drainage, flow forecasting, and the impact of future urbanization and floodplain regulation.

2. Study Area

The Wundanyi River catchment is part of the larger Taita Hills catchment and covers approximately 356 km^2, lying to the west of Voi town. It is located within Latitude $03^0$20´ S and Longitude $38^0$20´E. The elevation ranges from 700 to 2208m above mean sea level (a.m.s.l) and is drained by Wundanyi/Voi River that join Galana/Sabaki River in Tsavo East National Park. The climatic conditions are quite diverse due to considerable differences in altitude and relief. The annual temperatures range from 14 to 30^0C. The rainfall regime within the catchment is influenced by local relief, with two rainy seasons being experienced in the catchment. Long and short rains occur in the months of March to May and between October and November respectively. The plains experience an average annual rainfall of 500 mm, and the wettest slopes of Taita hills receive as much as 1400 mm per annum. The major soils are of volcanic origin. Soils found on the hills and major rocks of the catchment are developed on undifferentiated basement system rocks, predominantly gneisses (Jaetzold and Schmidt, 1983). They are generally well drained, moderately deep, reddish brown to brown, friable, stony sandy clay loam; with humic topsoil (1.2-1.8 m). They are generally classified as humic cambisols.

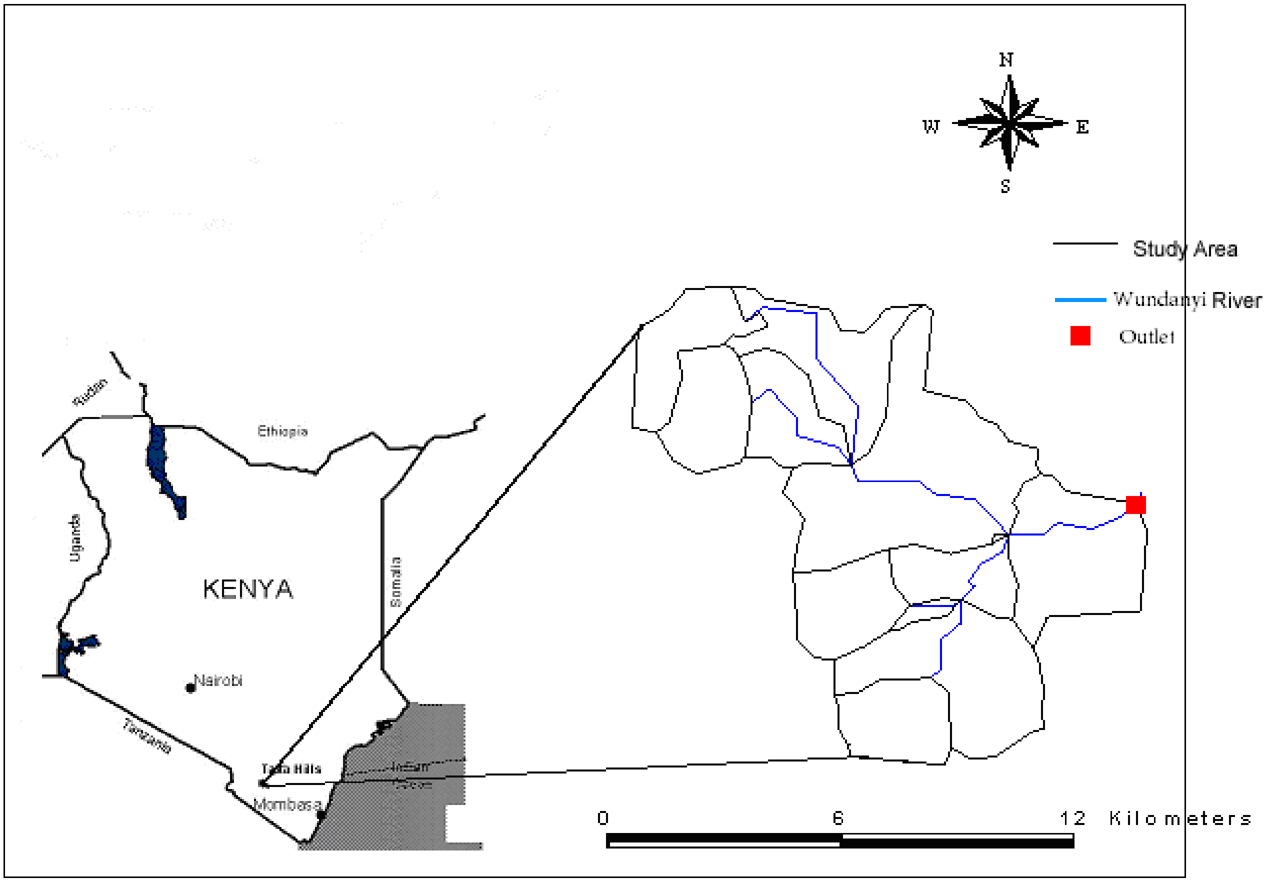

Figure 1: The study area

3. Data and Methods

The general approach used in this study was to acquire geospatial information relating to land use, topography, and soils for the study area; assess the overall land use/cover trends of the past thirty year; and analyze the consequent impacts on simulated surface runoff and sediment yield.

Input parameters required by SWAT were estimated by AGWA as a function of the topographic, soil, and cover characteristics of the individual catchment response units. Look-up tables relating soil and land use/cover associations to relevant hydrologic parameters (e.g., curve number, saturated hydraulic conductivity, and surface roughness) were defined through literature review and calibration exercises.

In this study, the variability in rainfall through time serves as a confounding variable in the interpretation of the impacts of land use change on hydrologic response, so it was necessary to apply the same rainfall data to each parameter set associated with different land use/cover scenes. Since rainfall is held constant for each model run, changes in model results are due solely to changes in input parameters affected by land use/cover change.

The SWAT model uses daily rainfall input data for multi-year simulation. Multi-year rainfall was extracted from long-term Metrological department records and input to the SWAT model. These rainfall records represent periods in which a minimum of data were missing from the long-term records. For this effort, two gauges that record rainfall in the Wundanyi River catchment contain long-term historical data for input to SWAT. A 10-yr period of record was extracted for each scene in this area.

4. Results and Discussion

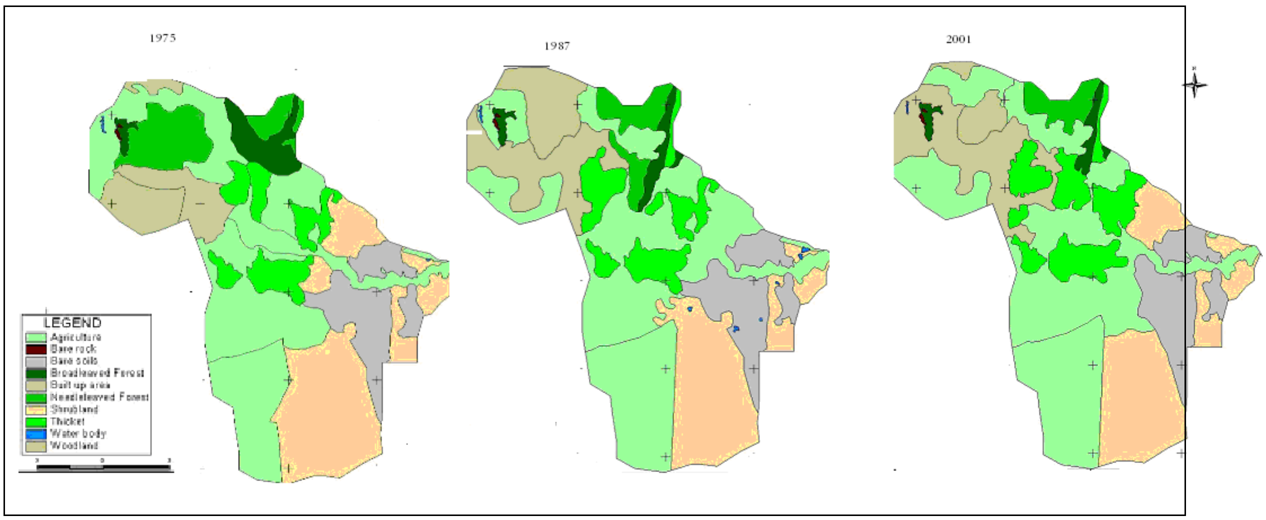

Figure 2: Classified land use/cover for the study periods in the Wundanyi River Catchment

Significant land use/cover change occurred within the Wundanyi River catchment between 1975 and 2001. A matrix showing the relative change within each land use/cover class for the different scenes (1975, 1987 and 2001) is presented as shown Table1

Table 1 : Relative change of land use/cover types in the Wundanyi River Catchment

Land use	**Classified maps**						Relative change **(%)**		
	1975		1987		2001				
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	75-87	87-01	75-01
Agriculture	13445.66	38.0	14918.770	41.9	14821.133	41.6	11.0	0.08	10.0
Bare rock	21.128	0.06	21.128	0.06	21.128	0.06	0.0	0.0	0.0
Bare soils	3493.229	9.8	3491.661	9.8	3294.874	9.2	-0.05	-5.6	-5.7
Broadleaved Forest	1430.709	4.0	736.071	2.1	576.709	1.6	-48.6	-21.7	-59.7
Built-up area	1640.858	4.6	3332.589	9.3	4202.057	11.8	103.0	26.0	156.0
Needleleaved Forest	2727.133	7.7	1427.896	4.0	949.240	2.7	-47.6	-33.5	-65.0
Shrublands	8327.151	24.4	6419.769	18.0	6751.256	18.9	-22.9	5.2	-18.9
Thicket	2699.979	7.6	3120.808	8.8	4009.889	11.2	15.6	28.5	48.5
Water body	19.954	0.06	61.264	0.17	8.676	0.02	207.0	-85.8	-56.5
Woodland	1840.417	5.2	2116.259	5.9	1011.326	2.8	15.0	-52.2	-45.0

The most significant changes were large increases in Built-up areas, Thicket, and agriculture and commensurate decreases in bare soils, broadleaved forest, Needleleaved forest, shrublands, water body and woodland. This overall shift indicates an increasing potential for localized large–scale runoff and erosion events (due to the decreased infiltration capacities and roughness associated with the land use/cover changes). The

Wundanyi River catchment experienced significant land use/cover change between 1975 and 2001, with the dominant changes within this catchment being the declines in broadleaved forest, Needleleaved forest and woodland and increases in built up areas and agriculture (Figure 3).

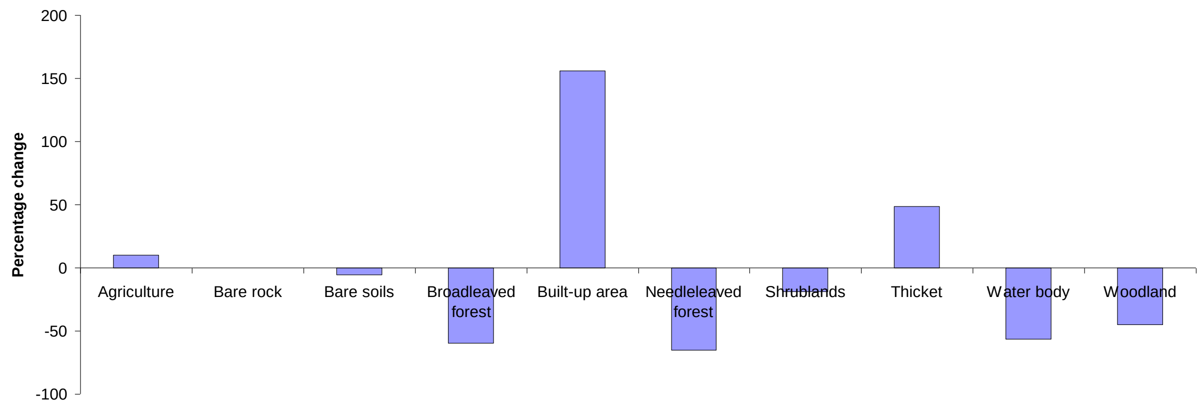

Figure 3: Percentage changes in Land use/cover between 1975 and 2004

Simulated surface runoff results show an increase in annual surface runoff over time commensurate with increasing built-up areas and agriculture invasion. Considerable spatial variability in the observed land use/cover change has implications for hydrologic modeling and assessment (Fig. 5 and Table 1).

To evaluate how the surface runoff depths changed, the increases in the simulated values for the three time intervals of pre-changed period 1975, post- changed period1987 and 2001 were observed as shown in Figure 4. The per-change period 1975 was taken as the base. From results given for simulation periods 1975 and 2001 showed a 106.84mm increase in depth of surface runoff. This indicated a significant difference in the amounts generated**.** Also this was demonstrated by the results for simulation periods of 1975 and 1987 showed 8.88mm increase in depth of surface runoff. Results obtained indicated that the highest change effect occurred in post-change period 2001 where about 106.84mm increase in the simulated surface runoff were noted. This implies that the land use change noted produced more impact on the catchment hydrology.

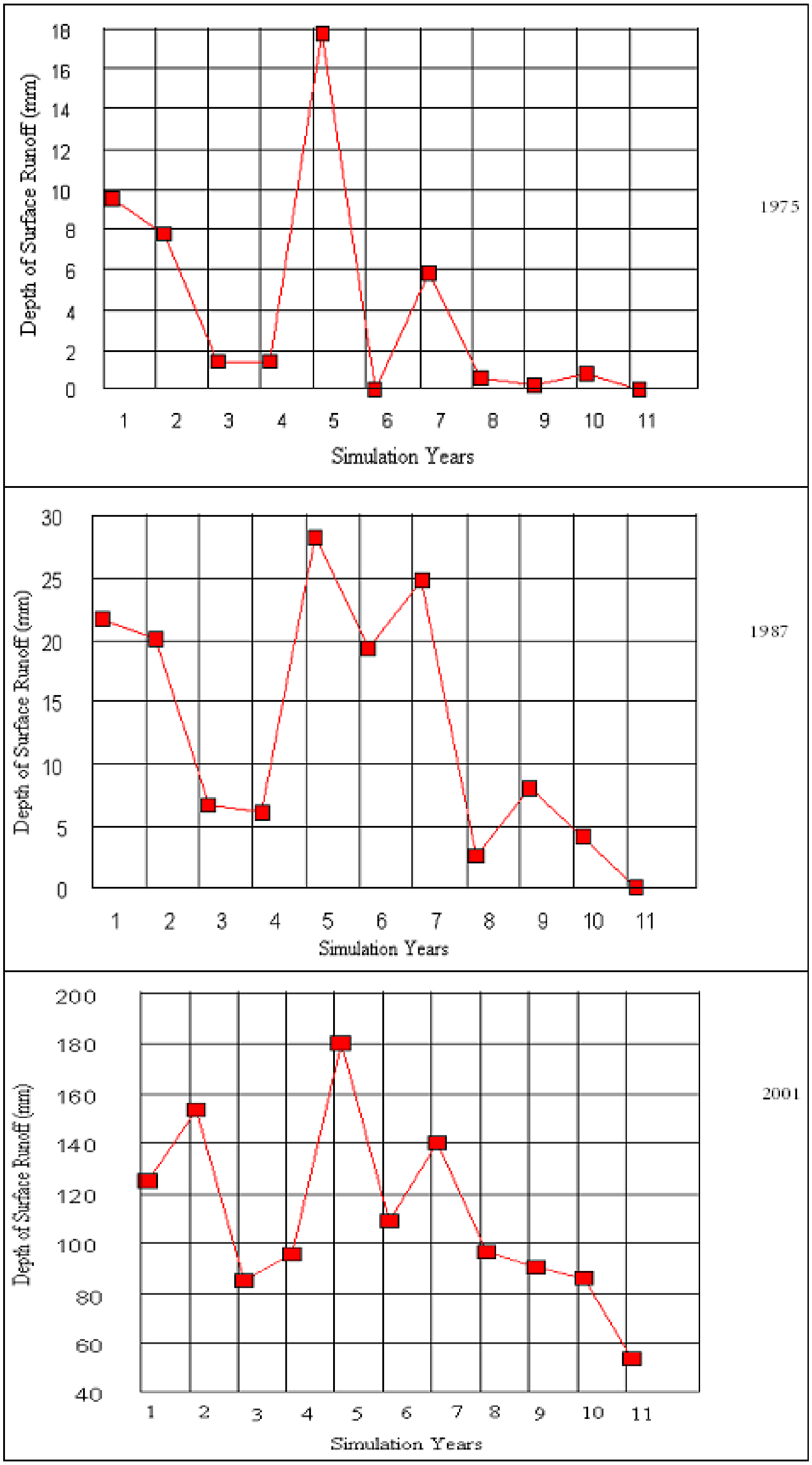

Figure 4: Annual surface runoff, Q for period (1975, 1987, and 2001) for Wundanyi River Catchment

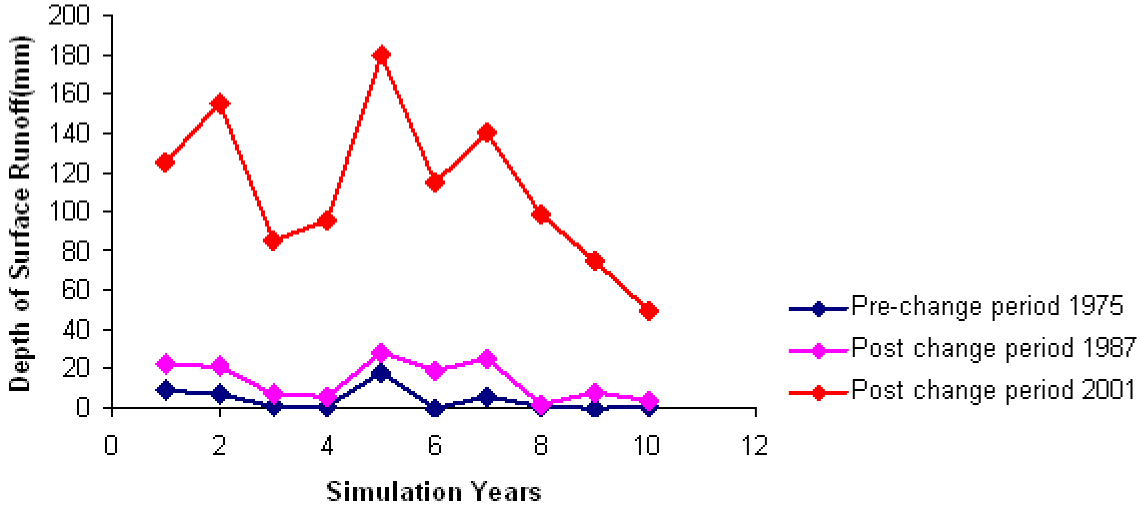

Figure 5: SWAT simulation results for the Wundanyi River Catchment

To evaluate how the sediment yield changed, the increases in the simulated values for the three time intervals of pre-changed period 1975, post- changed period1987 and 2001 were observed as shown in Figure 6. The average amounts per hectare were 0.43, 9.17 and 20.10t/ha for pre-change period 1975 and for post-change period 1987and 2001 respectively. Results obtained also indicated that the highest change effect occurred in post-change period 2001 where about 20.10t/ha increases in the simulated sediment yield were noted. Thus land use changes indicating more impact on the catchment hydrology.

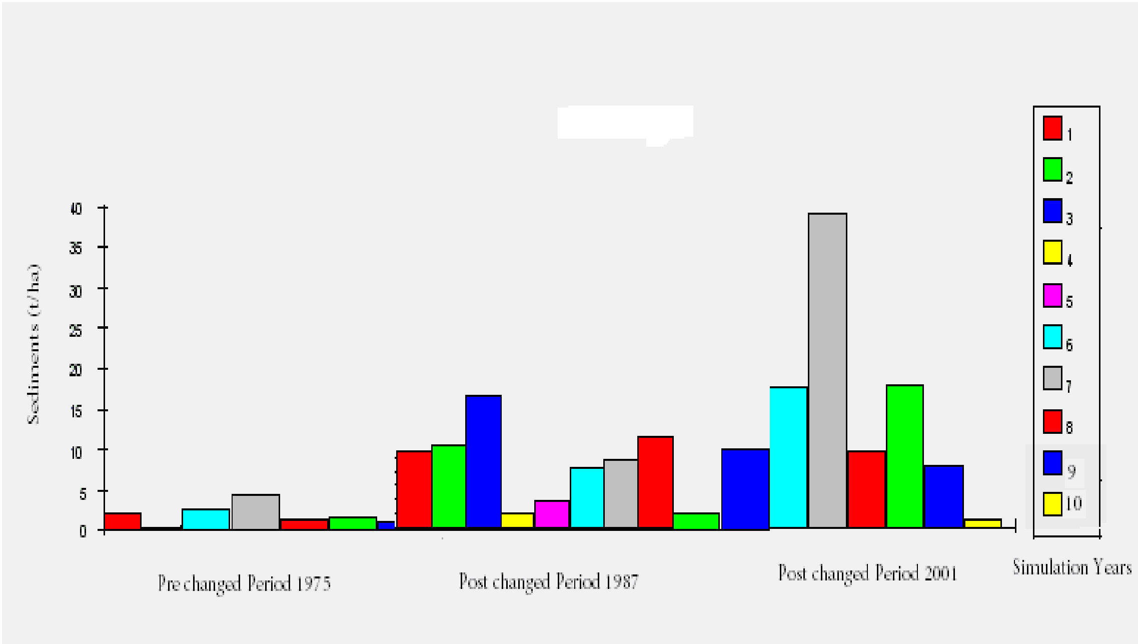

Figure 6: Annual Sediment Yield for Wundanyi River Catchment

5. Conclusion and Recommendation

The study evaluated spatial and temporal changes in land use changes in the Wundanyi River catchment and their impact on the catchment hydrology, using a hydrological model for simulating of surface runoff and sediment yield. Land use classes which have hard impact on catchment hydrology were selected. Results obtained indicated that over the last 30 years, the catchment had undergone vast land use changes. There was decline in forest cover and expansion of agricultural land and built-up area.

From the pre-change period 1975 simulation of the surface runoff was compared to the post-change period simulation surface runoff of 1987 and 2001 respectively. The pre-change period simulation of surface runoff of 1975 were however, noted to have low surface runoff value than the post-change values for 1987 and 2001 respectively. In summary, this study demonstrated the possibility of using multi-temporal landsat satellite images as a cost effective way of mapping and quantifying land use changes in data constrained catchment. The study found out that land use changes witnessed in the Wundanyi River catchment, have impacted the hydrological response of the catchment in terms of increased surface runoff and sediment yield. However, further studies to include other hydrological models and high resolution satellite images after ETM and of recent time is recommended. SWAT model results from this study should be used for extrapolating in filling the existing data gaps in the study area and other catchments within the region.

Acknowledgements

We would like to acknowledge the support of Government of Kenya through the Ministry of Agriculture for sponsoring this study.

Our special thanks go to colleagues, Maina G., Joan W., and Omondi V., for their generous assistance in GIS and Remote sensing techniques. Also thanks go to Water Resource Management Authority (WRMA), Mombasa office for availing the streamflow data that was used in this study.

REFERENCES

Araujo, J. C., and Knight, D. W. (2005). Review of the measurement of Sediment Yield in different scales. *Engenharia Civil*, 58(*3*), 257 – 265.

.**Chemelil, M. C.** (1995). *The effects of human-induced watershed changes on stream flows*, PhD Thesis. Loughborough University of Technology, Texas.

Donner, D. S. (Ed). (2004). Land Use, Land Cover, and Climate Change across the Mississippi Basin: Impacts on Selected Land and Water Resources. *Merican Geophysical Union*, 249-262.

Hartemink, E. A., Veldkamp, A., and Bai, G. Z. (2006). *Land cover change and fertility in tropical regions*. IFA Agricultural Conference. Kunming, China.

Jaetzold, R., and Schmidt, H. (1983)**.** Farm Management Handbook of Kenya. Vol. II/C, Kenya.

Karanja, A. K., China, S. S., and Kundu, P. M. (1986). *The influence of land use on Njoro River Catchment between 1975 and 1985.* Department of Agricultural Engineering, Egerton University College, Njoro.

Lim, J. K., Sagong, M., Engel, A. B., Tang, Z., Choi, J., and Kim, K. (2005). GIS-Based Sediment Assessment Tool. *Elsevier, Catena,* 64, 61 - 80.

Mustafa, Y. M., Amin, M. S. M., Lee, T. S., and Shariff, A. R. M. (2005). Evaluation of Land Development Impact on a Tropical Watershed Hydrology Using Remote Sensing and GIS. *Journal of Spatial Hydrology*, 5(2), 16 - 30.

Olang, L. O. (2004). *Adaptation of rainfall-runoff models for runoff simulation in humid zones of Kenya: A case study of the Ewaso Ngiro drainage basin,* Master's Thesis. Egerton University, Njoro.

Onyando, J. O., Kisoyan, P. K., and Chemelil, M. C. (2005). Estimation of potential Soil rosion for River Perkerra catchment in Kenya. *Water Resources Management*, 19, 133 - 43.

Onyando, J. O. (2000). *Rainfall-runoff models for ungauged catchments in Kenya.* PhD thesis, Bochum University, Germany.

Pellikka. B., Clark, P., Hurskainen, A., Keskinen, M., Lanne, K., Masalin, Nyman, P. H., and Sirviö, T. (2004). *Land use change Monitoring Applying Geographic*

Information Systems in Taita Hills, SE-Kenya. Master Thesis. Department of Geography, Heslinki, Finland.

Republic of Kenya. (1970). *Kenya Population Census 1969. Vol.1. 1235. Statistics Division*, Ministry of finance and Economic planning, Kenya.

Republic of Kenya. (2010). *Kenya Population Census 2009. Bureau of Statistics*, Ministry of Planning and National Development, Kenya.

Seguis, L., Cappelaere, B., Milsi, G., Peugeot, C., Massuel, S., and Favreau, G. (2004). Simulated impacts of climate change and land-clearing on runoff from a small sahelian catchment. *Hydrological Processes*, 18, 3401 - 3413.

Troyer, M. E. (2002). *A spatial approach for integrating and analysing indicators of ecological and human condition.* Ecological Indicators. USDA-NRCS, (1986). Urban Hydrology for small watersheds. USDA-NRCS Technical Release 55.