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RESEARCH ARTICLE

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Application of Innovative Approach in Hydrology of Ungauged River Catchments for Sustainable Development (A Case Study of River Meroronyi Catchment, Nakuru, Kenya)

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Abstract

Motivation of the study was the intense degradation of River Meroronyi watershed coupled with continuous changes in land use activities, the environmental importance of the river, where it flows through and a lack of hydrometric gauging network to monitor the river hydrology in response to the catchment environmental conditions. The aim was to set a benchmark for collecting data and information that could be used in planning for sustainable management and development of water resource. Methods used in data collection included visual observation, resource mapping, design of gauging stations along the river, water sampling and measurement of river discharge. Water hydrological data was subjected to laboratory and regression analysis while land use analysis was accomplished by interpretation of landsat images, and photographs of ongoing land use activities. There was a variation in river flow dynamics and suspended sediment concentrations at the selected gauging stations. Results were conclusive as the coefficient of determination between discharge and suspended sediment transport at each gauging site was more than 0.522 which is a statistically significant correlation.

Key Words: River Hydrology, Ungauged River Catchments, Gauging Networks, Sustainable Development

Introduction

Given the importance of the concept of sustainable development and integrated management of water catchments, information on assessment of water quality changes associated with distributed land use activities water resources is required (Paul & Wayne, 1997; WMO, 1994; Kithiia, 2012). From the hydrological point of view, this implies greater requirements for information than have traditionally been used in the decision making process. Thus, important relevant hydrological problems indicators in water resources should be identified for sustainable water resources development to present the scenarios in the field (Biswas & Tortajada, 2001). Improvement on existing traditional methods of hydrological data collection should be a requirement to ensure that the sustainability paradigm is properly reflected in the decision making process (Donald, 1997; DeBarry, 2004).

Despite wide recognition of the need for catchment-scale management to ensure the integrity of river ecosystems, the science and policy basis for joint management of land and water remains poorly understood (Brooks *et al.*, 1997). While that has been acknowledged, few studies have been conducted in developing countries. River Meroronyi, whose water catchment is at

Dundori Forest, Nakuru Kenya, is an example of a degraded watershed faced with hydrological problems attributed to climate changes and intensity in land use activities. It drains the Bahati Plateau in the north, of Nakuru, Kenya, cutting through agricultural farms in its upper part, urbanized area in its middle part and agricultural lands in its lower part. Continued destruction of the forest has affected the catchment hydrology altering the hydrological regime of the river. Hydrological impacts are manifested in marked seasonality in stream flow. The catchment is ungauged and lacks hydrometric gauging networks that can be used to study its hydrology and collect hydrological data that can be used to monitor the problem in an integrated way. This forms an important gap for research whose results can be used to develop a sustainable strategy of its water resources. Such an approach is needed for this ecosystem to make a step towards developing ways to understand effect of its landscape changes on the river hydrology. This is through coordination of the activities on how data is collected and interpreted and to develop a database on hydrological information by establishing long term gauging stations. The goal should then be adoption of integrated hydrological monitoring for the watershed for sustainable development. The objectives were;

1. To assess land use and cover changes at the river watershed from 1986 to 2000.
2. To determine and relate spatial and temporal flow variations and total suspended sediment levels, over a range of flow conditions with accompanying downstream changes in the mix of land uses.

Methodology

Study Area

This study was conducted along River Meroronyi watershed at Nakuru in Kenya. Four water quality monitoring gauging stations were located at distances of 25 km apart. The gauging stations were designated as, A through D from upstream to downstream. Gauging sites were selected to encompass incremental additions and a variety of land uses. Criteria for station selections were largely subjective and partly based on potential influences of near-stream land use activities.

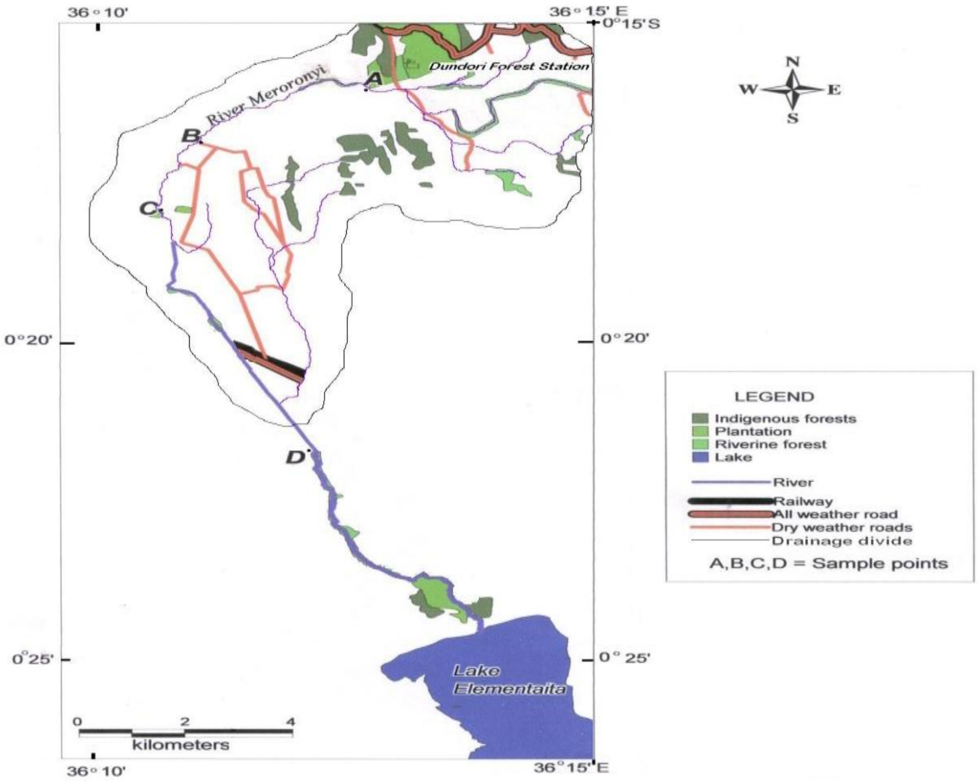


Figure 1. The Study Area and Gauging Stations A, B, C and D
Source: Survey of Kenya (1997)

The location of the gauging sites were selected with section control points where the stream was 100m straight upstream and downstream from the site with no flow bypasses at site. In land use analysis, Topographical map sheet 119/3 of Nakuru at scale 1:50,000, Landsat satellite imagery Path 169, Row 060 of 28th January 1986 and Path 169, Row 060 of 27th January 2000, were used to assess the condition and changes in land use and cover of the physical environment between 1986 and 2000 (Plates 1 and 2).

Measurement of river discharge was determined by measuring water velocity and cross-sectional area at the selected gauging stations. Total Suspended sediment transport was determined by collecting representative water samples in triplicate at each gauging station. Sampling was done at the same time of day (mid morning) for each sampling trip. Samples were taken from the most downstream site first and continued up to the most upstream site. Sampling in this manner ensured that downstream water quality was not altered by cause of disturbances from upstream sites when sampling. The water samples were then subjected for laboratory analysis to determine the average concentration of the suspended sediment load. Data collection was done on daily basis for a period of 8 months, which covered partly the dry season and part of the wet season.

Statistical Data Analysis

Regression analyses were performed on water quality parameters to identify relationships between them at different gauging stations. Their distribution was also determined at spatial and temporal scales. Regression analyses were done using Microsoft Excel data analysis tool pack. The data analysis yields R-square which is the square of the correlation between the response values and the predicted response value. It represents the linear relationship between the data pairs. Correlation coefficient values range from -1.00 to +1.00, where the negative sign indicates an inverse correlation. Zero indicates no correlation and 1 indicates complete correlation (Mark, 2006). The coefficient of determination between discharge and suspended sediment transport gave the R-value at each gauging station. For each gauging station, a sediment rating curve was developed to give the relationship between the two variables at spatial and temporal scales. The curve was presented by the following equation;

$TSS = kQ^m$ where TSS is Total Suspended Solids concentration in (gm/l), Q is water discharge (m^3/sec) and k and m are rating curve parameters (Brooks *et al.*, 1997; Raghunath, 1991; Araujo and knight, 2005). Separate rating curves for different seasons or according to stream flow generation mechanisms, such as rainfall were developed. The mean values of the replicate samples were then calculated. Questionnaires, topographical maps, photographs and Landsat TM images were used as a tool in land use analysis along the river watershed.

Results

Changes in Landuse and Cover

In the year 1986 as in Plate 1, the forest (river catchment) was covered with dense vegetation but by the year 2000, the vegetation had been cleared and only patches of indigenous trees and bushes could be seen (Plate 2). The riparian vegetation of the river had also been depleted over the same period of time. The riverine vegetation (Plate 2) was also declining and the river banks exposed to different agents of erosion. The dark reddish colour represents patches of indigenous trees at the river catchment and riparian zone (Plate 1). At the South East (SE) corner of the image is Lake Elementaita.

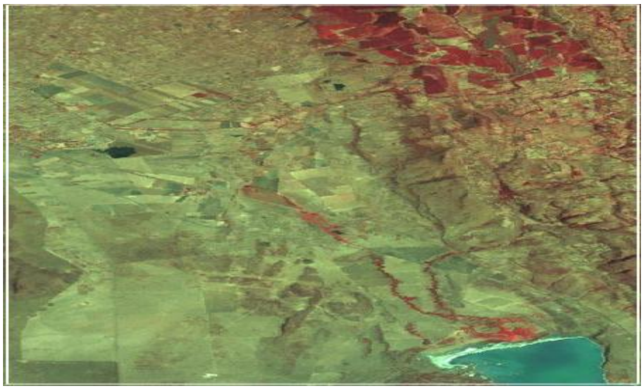


Plate 1. A False Colour Composite Landsat TM Image of the Area of Study as at 1986 (Path 169, Row 060)

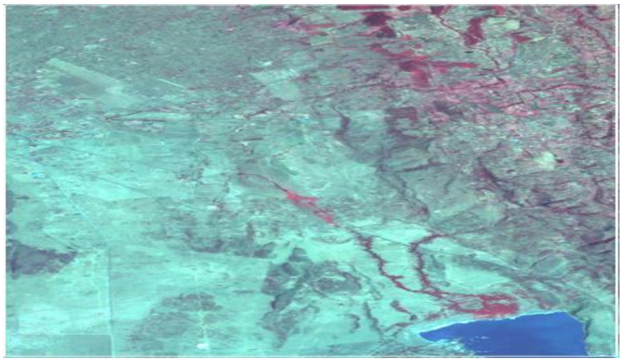


Plate 2. A False Colour Composite Landsat TM Image of the Area of Study as at 2000(Path 169, Row 060)

The dark reddish colour represents patches of remaining vegetation in the catchment area and along the riparian zone. At the SE corner of the image is Lake Elementaita.

NB: The image was pre-processed and colour assignments were done during the processing resulting in the difference of colour observed between Plates 1 and 2.

Catchment Landuse Activities and Characteristics

The river catchment had sparse natural vegetation cover at the time of study. Much of the total land area was dedicated to developed or agricultural land uses. Variation of non forest land use increased downstream. Land use activities identified along the selected gauging sites included agriculture, construction of buildings and roads, settlements, industrial activities, logging and afforestation.

Hydrological Characteristics of River Meroronyi

Results showed temporal and spatial variation of suspended sediment concentration and discharge for River Meroronyi from downstream to upstream gauging stations. Variation of the data sets increased upstream concomitant with changes in land use. Variations were more significant during the peak flows than in periods of low flows. At each gauging station, the total suspended sediment concentration and discharge levels were low during the dry season (week 1 to 16) but increased during the rainy season (Figure 2 below).

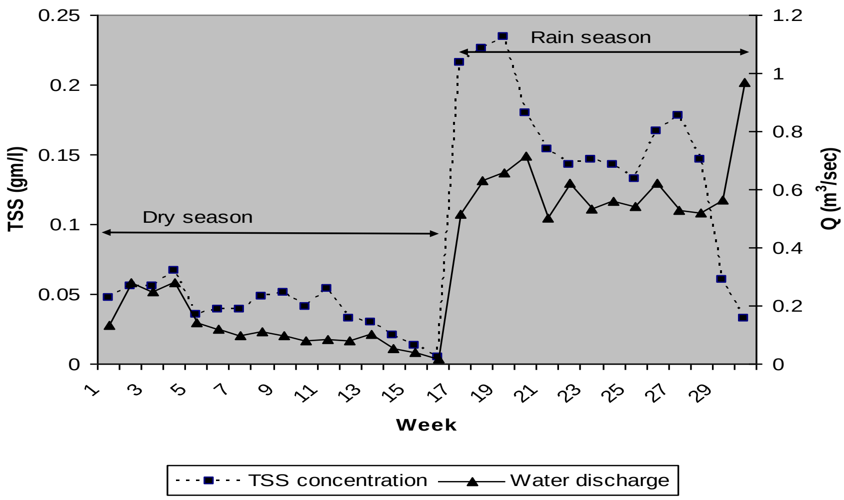
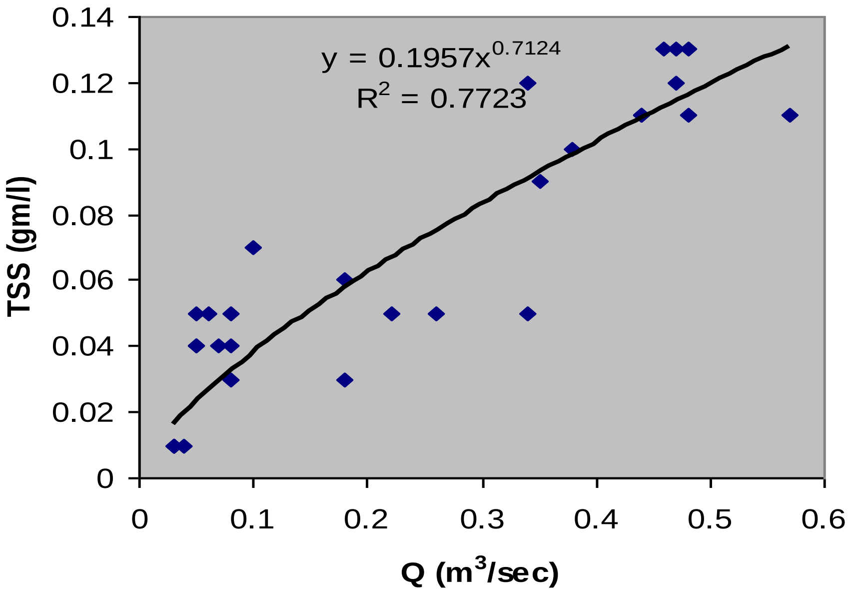


Figure 2. Suspended Sediment Concentration and Water Discharge Relationship for River Meroronyi from 30th November, 2004 to 29th July, 2005

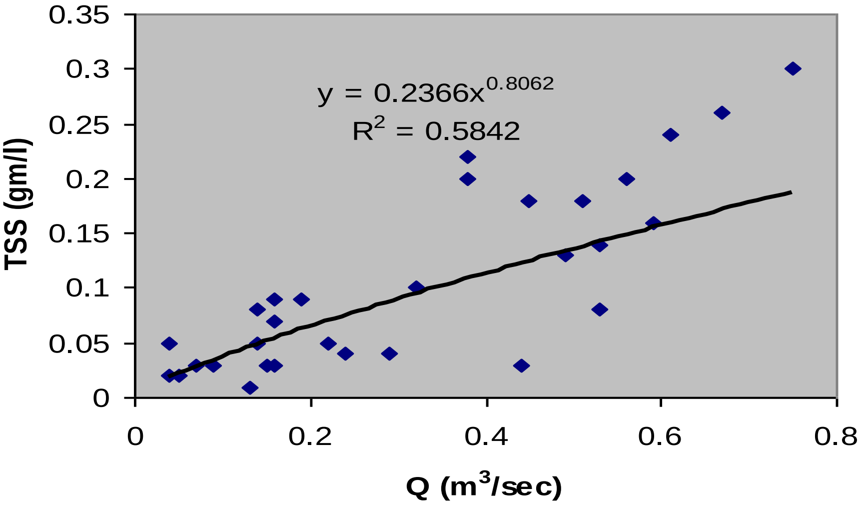
Regression Analysis

There was a statistical significant correlation between suspended sediment concentration and river discharge at each gauging station. R-value ranged from 0.5205 at downstream gauging station D to 0.7723 at upstream gauging station A. The R-values of all gauging stations are presented in figures below.

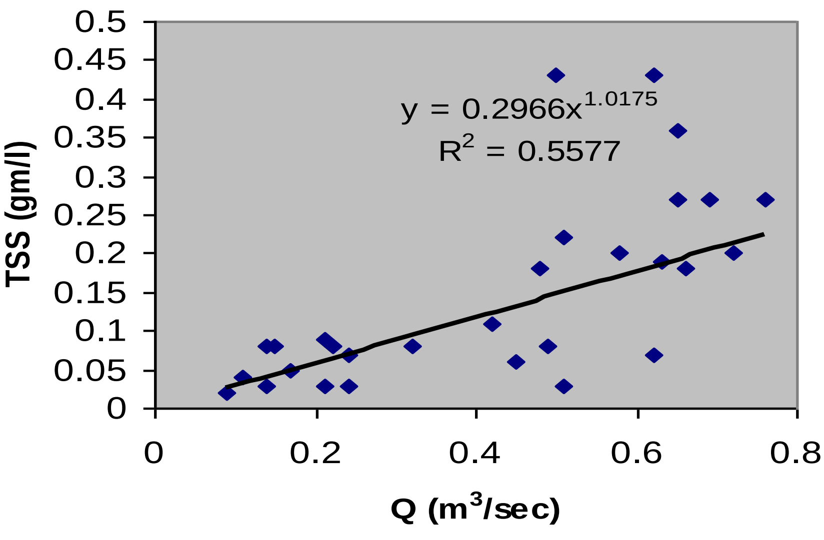
Gauging Station A



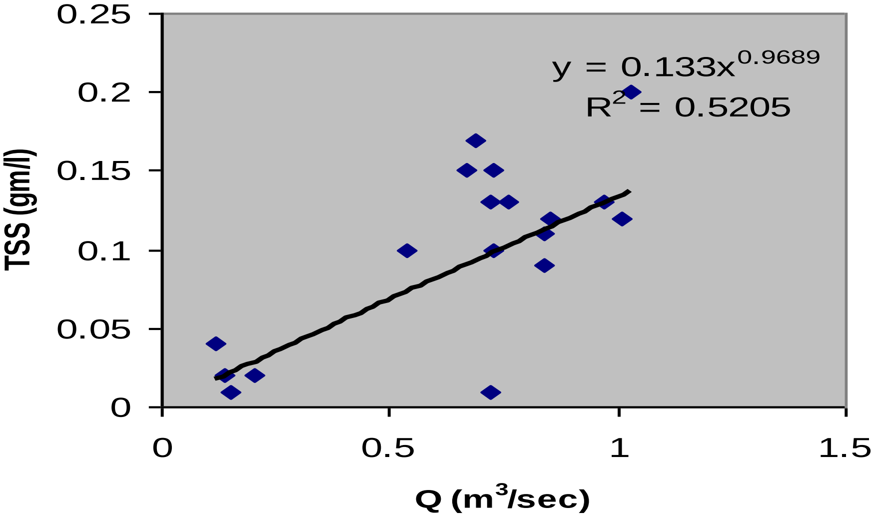
Gauging Station B



Gauging Station C



Gauging Station D



Discussion

The findings from this study indicated that land use changes had profound effects on overall hydrological characteristics of River Meroronyi watershed among other factors like climatic changes. The significant contribution of these land use changes to water quality degradation was quite enormous, especially during the rainy season where overland flow increased and runoff from the upstream areas discharged directly to the river. Karanja *et al*. (1986) and Oketch (2012) carried out similar studies in Lake Nakuru Basin and reported similar trend on their findings that Land use in Nakuru watershed had impacted heavily on its hydrological regimes. The results were degradation of water quality and quantity (Kithiia, 2012; Makwetta, 1999) on land use changes at catchment scale and physical hydrology of rivers conclusively agree with the above based on studies from other regions in the world.

The study also established variations in land use and cover, flow dynamics of the river and suspended sediment concentrations within the period of study. Variations in flow parameters were more significant during the peak flows than in periods of low flows indicating existing river resources degradation that was a threat to sustainable development. Land use analysis from the landsat images, photographs and topographical maps indicated that degradation of the river catchment was attributed to intensive land use changes mainly characterized by persistent expansion of cultivated land and a continuous decrease in vegetation cover. The gauging sites established during the study gave a method to study the hydrological characteristics of the river in reference to the selected control points and land use activities. The results were also conclusive on the relationship between discharge and suspended sediment transport as the coefficient of determination at each gauging site was more than 0.5. The results therefore gave statistically significant correlations. The river discharge was strongly related to suspended sediment transport at each gauging station with high variations observed during storm flows and low during base flows.

Conclusion and Recommendations

The method applied in assessment of River Meroronyi watershed hydrology yielded results that had statistical significant correlations at each gauging station. The hydrometric gauging network framework designed for this study also demonstrated a conclusive means of collecting hydrological data that can be used as a source of information in developing continuous monitoring system and planning strategies for sustainable water resource use and development of data in constrained river catchments. The author recommends the method to be used as a tool for sustainable development and integrated management of water resources in other ungauged river catchments. Important recommendations from the findings are a further research to understand impact of proposed landuse activities on other hydrological parameters at the river catchment. For related studies in our country, there is need to develop frameworks for hydrometric gauging networks for our river systems to promote sustainable development and enhancement scientific research in water resources.

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