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Analysis of Nonpoint Source Pollution Loading on Water Quality in an Urban-Rural River Catchment Using GIS-PLOAD Model: Case Study of Sosiani River Watershed

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Abstract

Nonpoint sources of pollution (NPS) are inherently difficult to identify and estimate since they originate from diverse sources. This study presents a case study on the estimation of NPS loading using the GIS-based Pollutant Load (PLOAD) model in River Sosiani, Eldoret Town in Kenya, through the analysis of the transport and decay of pollutants in a catchment, in comparison with in situ measurements in order to validate the model results. Within a catchment area of 574.30 km^2, with four main land use classes, the developed areas contributed to the highest event mean concentrations. From the PLOAD simulation results, fecal coliforms (FCOL) was the most dominant NPS with a maximum concentration of up to 5g/m^2 and the least was phosphates (PO4) with a maximum concentration of 1.9 g/m^2. Cross-plot validation of the PLOAD results with the in situ event mean concentrations of PO4, NO3, BOD, TDS, TSS, and FCOL showed a good fit for all the four sampling sites along the River Sosiani. Some Best management practices (BMP) were introduced in the model in order to mitigate against the pollutants. Constructed wetlands showed significant reductions in the PO4, BOD and TDS loadings. The approach and results in this study can be used for the monitoring and mitigation against the impacts of urban effluent on a river.

Keywords: nonpoint source pollution (NPS); urban-rural river watershed; water quality; event mean concentrations (EMC); GIS-PLOAD model; best management practices (BMP)

1. Introduction

In most developing countries with rapid and haphazard developments, surface water quality in general continues to deteriorate due to pollution. In these regions and areas, there also tend to be lack of consistent analytical studies on the quantifications of spatial-temporal water quality variations, which are largely due to human settlement and the associated socio-economic activities. Rapid urbanization and high population influx is a characteristic of an urban river catchment (Rana 2011). Factors and sources of water pollution have been studied for many years and this should continue so as to reinforce the understanding of the characteristics and mechanisms of water quality dynamics within an urban-rural river catchment. Most research mainly concentrate on the issues of surface water quality within urbanized areas instead of the entire river catchment so as to get the true picture of the health of the river system.

Water pollutants are classified as point and nonpoint sources (U.S. Environmental Protection Agency 1997), whereby point sources can be identified as all dry weather pollutants that enter the river or stream through specific flow channels and therefore easily identified. In situ and ex situ methods can be used to measure pollutant concentrations in point sources (Malakahmad et al. 2008). 'Nonpoint source pollutants (NPS) are defined as contaminants of surface and subsurface soil and water resources that are diffused in nature and cannot be traced to a point location' (Notovny & Chesters 1981). 'Nonpoint sources are derived from activities on extensive units of land, originating from urban runoff, construction, hydrologic modification, silviculture, mining, agriculture, irrigation return flows, solid waste disposal, atmospheric deposition, stream bank erosion, and individual sewage disposal' (Robinson & Ragan 1993).

In recent years, nonpoint source pollutants have greatly degraded the water quality in most urban-rural river watersheds in Kenya. Eldoret Town is one of the five main towns in Kenya and is drained by River Sosiani. Due to poor urban drainage and waste disposal systems, the river collects waste generated in the town, thus heavily polluting River Sosiani with solid, liquid and organic wastes. The polluted water has a negative impact on the town's inhabitants and other living organisms as well as on the environment in general.

In order to carry out a complete pollution load assessment on the river profile, information on the extent of the watershed basin, type of population (urban, rural), industries (type of wastes), land uses, climate (rainfall), vegetation, soil types, sewage (percentage of population sewered, water supply, infiltration of sewage, treatment and type of treatment) is normally necessary. By integrating these factors, different approaches can be used to study nonpoint pollution. Surface runoff, sediment, nutrient leaching and pollutant transport have been investigated and studied for better understanding using different methods in the past. To name a few; Risk assessment of pollutants for aquatic ecosystems have been studied using GIS-based procedures (Sala & Vighi 2007); artificial neural network-based water quality models for prediction of concentrations of fecal indicator bacteria for beach advisories (He & He 2008); statistical models for identifying highest nutrient loading areas

(Bouraoui & Grizzetti 2007). 'Nonpoint pollution models are basically a description of the hydrologic rainfall-runoff transformation processes with attached quality components' (Notovny & Chesters 1981).

Numerous studies have similarly been conducted on the relationship between land use and water quality (Tsihrintzis & Hamid 1997; Stewart et. al 2001; Grobicki 2001). Stewart et. al. (2001) for instance determined the spatial relationship between land use and water quality in a watershed in Ohio, USA. The study found that there was significantly lower water quality downstream of urban land areas compared to non-urban areas. In South Africa, Grobicki (2001) and Mtetwa et al. (2003) found out that the land uses surrounding rivers had a direct effect on the water quality in the rivers. While Mtetwa et al. (2003) conducted a study in a semi-arid rural watershed where the main land use was agricultural, Grobicki's (2003) study was based in Cape Town in an urban watershed, and assessed how informal settlements impacted on water quality. Tsihrintzis & Hamid (1997) concluded that nonpoint source pollutant load in runoff is directly affected by land use. Davies & Day (1997) in conclusion added that the state of a river often mirrors the landscape in the watershed. The estimations of ecosystem-scale mass loads emanating from sources is one of the first data requirements needed to develop a plan of action (Balcom et al., 2007).

For a developing urban-rural catchment such as River Sosiani, similar studies can be carried out with the broad objective of the determination of the influence of land use on the water quality parameters for effective plan of action towards best management practices and sustainability.

A spatially distributed and physically based watershed-scale water quality model and estimating the movement of materials through both nonpoint and point sources in both surface and subsurface waters is required for a comprehensive NPS modeling. In order to model and estimate pollutant loads within an urban river system, this study proposes the use of the GIS-based PLOAD model and in situ event mean concentration (EMC) observations. Further, from the determined pollutant distributions and loadings, appropriate best management practices (BMP) are introduced in order to derive the mitigation measures. Section 2 of this paper presents the study area, followed by Section 3 on data and methods. Section 4 presents the study results and discussions and Section 5 is on the study conclusions and recommendations.

2. Materials and Methods

2.1 Study Area

The River Sosiani catchment is situated between latitude 00º 03´S and 00º 55´N and longitude 34º 50´E and 35º 37´E and traverse through Eldoret Town (Figure 1).

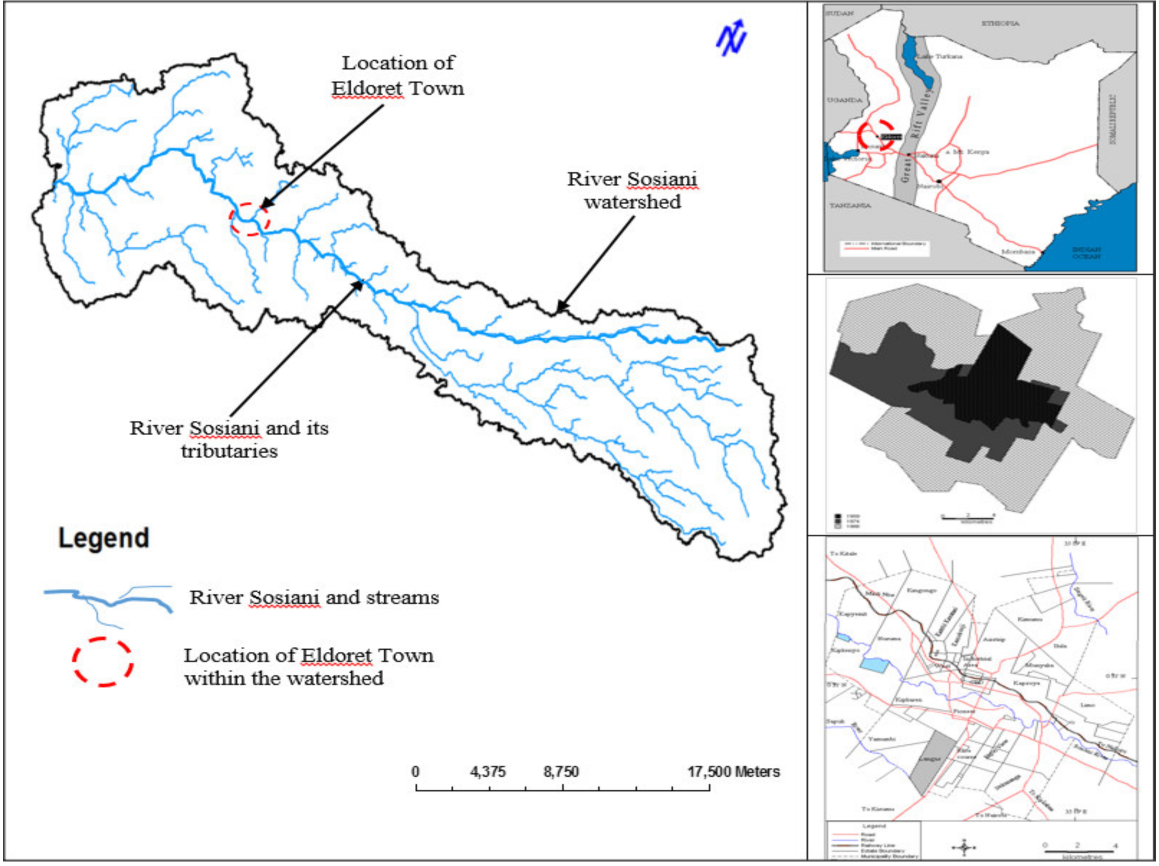

Figure 1: Location and extent of Eldoret Town and the River Sosiani drainage network.

The river is a sub-catchment of the larger Nzoia River Basin, and is a major source of water for most of the population living upstream and downstream. Located in the River Sosiani watershed, Eldoret town has grown to become the fifth largest town in Kenya, with a total area of 147.9 km^2 and an estimated population of 500,000. The population growth within the catchment has been rapid and this has been attributed to developments in agricultural and industrial activities.

2.2 *Methodological approach*

Figure 2 shows the GIS-based PLOAD model for modelling the nonpoint source pollutants. GIS enables the simulation and interpretation of results in a spatial context, such that the joint applications of GIS with physically based models like PLOAD allows for the development of spatial decision support systems.

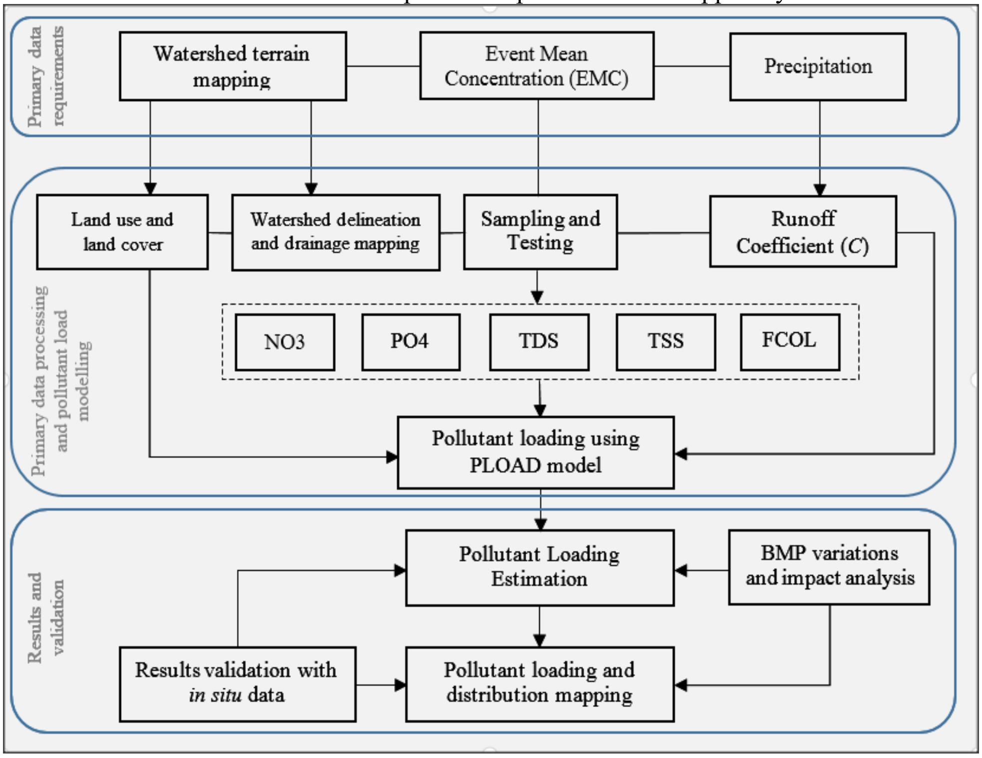

Figure 2: Schematic flowchart for nonpoint source pollution modelling and mapping.

2.3 *PLOAD model*

The model is a versatile environmental analysis system for which can be used by regional, state and local agencies in performing watershed and water quality studies and for examining management alternatives (U.S. ENVIRONMENTAL PROTECTION AGENCY, 2001b). The GIS-based PLOAD model estimates nonpoint sources of pollution on an annual average basis, and for any user-specified pollutant, and it can integrate best management practices in computing total watershed loads. PLOAD is part of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). Through the use of GIS, BASINS has the flexibility to display and integrate a wide range of information (e.g., land use, point source discharges, and water supply withdrawals) at a scale chosen by the user.

Pollutant loads for specific watershed can be calculated using PLOAD (U.S. Environmental Protection Agency, 2001a), moreover PLOAD can estimate nonpoint source pollution for urban, suburban and rural watersheds on an annual basis. It has the ability to estimate total suspended solids, nutrients, metals, and fecal coliform. As depicted in Figure 2, PLOAD model requires the following inputs: land use, watershed, event mean concentration (EMC) data, runoff coefficients and allows BMP specifications. Pollutant export coefficient or simple methods can be used to calculate annual pollutant loads for each watershed (U.S. Environmental Protection Agency 2001a). Selecting the model type or method depends on the land use composition and size of the watershed being studied and on the data availability for the area. For this study, the PLOAD Simple Calculation Method was used since it is suitable for sub-drainage areas of less than 2.59 km^2, and the “simple” method requires event mean concentration data.

2.4 *Land use and watershed delineation*

Nonpoint source pollution is directly affected by Land use and land cover. Dynamics of water quality through individual watersheds are strongly affected by Land use. It is one indicator of the relationship between environmental and human influences affecting waterways and water quality. Therefore every point in the sub-basin must be assigned a land use category. Dominant land use and land cover were categorized and derived according to the homogeneity and extent within the watershed. For this study the land use and land cover data were derived by classifying Landsat 8 data of 2014, and the results compared with ground truth data and the existing land use zoning map. In order to define the areas for which the pollutant loads are calculated, the extent of the watershed is required. The watershed is delineated from the ASTERDEM downloaded from USGS, and the drainage network and density within the area can also be determined. ArcGIS 9.3 was used in delineation with the help of spatial analyst extension to fill the DEM. Flow directions and accumulation were obtained and ran so as to create pour points which include the outlet of the watershed and later all these points were snapped and the resulting raster was converted to polygons to enable delineation. In addition four sampling points were identified along the river, each point was located approximately at the outlets of each of the four categories of land use.

2.5 *Mean watershed precipitation*

Higher levels of precipitation are observed to yield higher levels of stormwater pollution and areas of higher rainfall are observed to pollute streams more than areas of low rainfall (U.S. Environmental Protection Agency, 2006a). Thus the average annual precipitation is needed over a specific study time to be properly utilized in the PLOAD model. For the case study area the rainfall regime is bimodal. The 11-year annual average from 2004-2014 is of 1086.73 mm as summarized in Table 1.

Table 1: Average annual rainfall data of River Sosiani watershed from 2004-2014

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Dekadal average
Annual mean rainfall (mm)	892.2	976.3	1074.6	945.4	1329.2	1142.1	1031.5	871	1350.3	1106.4	1235	1086.7

2.6 *Discharge and flow rate determination*

The area-velocity technique was used to determine the flow rates employing a mechanical-current meter (The USGS Water Science School 2015). Discharges in a small and wadeable sections of the river were determined where total stream discharge is the sum of all segment discharges and obtain the average as in Eq. 1.

$$Q = \frac{1}{n}\sum_{i=1}^{n} Q_i \qquad (1)$$

Where: Q = flow rate (m^3/s); A = average cross-sectional area (m^2); V = surface velocity (m/s), and k = the correction factor.

2.7 *Identification of nonpoint source pollutants*

To site and identify the types of nonpoint sources of pollution geographical locations and coordinates along the sampling points of the river were required guided by the dominant land use type. The following water quality parameters were selected for the quantification of nonpoint pollution sources. Total phosphorus (TP), Total nitrogen (TN), Biochemical oxygen demand (BOD), Total dissolved and suspended solids (TDS & TSS) and Fecal Coliforms (FCOL). The experimentation aimed at determining the concentrations of the named parameters was done by collecting and procedurally testing samples and analyzing the same according to the Kenya Standards of measuring and testing surface water.

2.8 *Event mean concentrations (EMCs)*

'EMCs represent the concentration of a specific pollutant contained in stormwater runoff coming from a particular land use type within a watershed' (U.S. Environmental Protection Agency 2001a). Thus the EMCs define the pollutant rates associated with a particular land use type in a watershed. For this study, the EMCs were derived from laboratory experiments carried out on samples from four different sampling points and were calculated according to Eq. 2.

$$EMC = \left[\frac{\text{Total annual loads for a given pollutant}}{\text{Total annual runoff volume}}\right] = \left[\frac{C*Q}{Q}\right] \qquad (2)$$

The EMC values depend on the nutrients under consideration and land use type and the units are in mg/L. The runoff coefficients were calculated according to Eq. 3.

$$C = 0.005 + (0.009 * I_u) \qquad (3)$$

Where: C = runoff coefficient for land use type u, in inches (runoff)/ inches (rainfall) and
I_u = percent imperviousness.

The impervious factor was used to calculate the EMC runoff coefficient.

2.9 Pollutant loadings

To calculate the pollutant loadings $\left(L_P\right)$, Eq. 4 summarizes the mathematical model of simple approach in the PLOAD model as given in PLOAD user's manual.

$$L_P = \sum u\left(P * P_J * C * C_U * A_U * \frac{2.72 * 4046.873}{12}\right) \tag{4}$$

where: L_p = pollutant load (lbs/yr); P = precipitation (in/yr); P_J = ratio of storms producing runoff (0.5875); C = runoff coefficient for land use type u (inches (runoff)/ inches (rainfall)); C_u = EMC for land use type u (mg/1), and A_u = area of land use type u (in acres).

The PLOAD model results produce both graphical and tabular outputs. The graphical output includes maps with watersheds for the study area, symbolized in graduated colour per watershed boundary, depicting total pollutant in lbs/yr. Tabular output comprise of tables for total pollutants in lbs/yr. or in lbs/ac/yr. by watershed and a table of total pollutants by watershed by land use in lbs/yr. and lbs/ac/yr.

2.10 Incorporating Best Management Practices

Best management practices (BMPs) are practices, systems, and measures that keep or diminish water contamination from nonpoint sources by utilizing the best and practicable methods so as to accomplish water quality objectives (U.S. Environmental Protection Agency 2001a). In this study, BMPs were introduced in the PLOAD model to reduce stormwater volume, peak flows, and nonpoint source pollution through evapotranspiration, infiltration, detention and filtration or biological and chemical actions in comparison to inflow duration, which dilutes the stormwater discharged into a larger volume of upstream flow. For these reductions in stormwater and pollution to be achieved Dry retention ponds, Wet detention ponds, Grassed swales and Constructed wetlands were selected.

The BMPs effectiveness distinguishes the contaminant removal proficiency for each BMP type for the pollutant under assessment. For the purpose of this study, the BMP efficiency used for different scenarios were designed to specify pollutant removal efficiencies for individual BMPs in the system. Further in the study, the following factors were considered for BMP establishment: temperature, aesthetics, physical suitability, maintenance requirements and effects on other resources and cost-effectiveness.

3. Results and discussions

3.1 River Sosiani watershed delineation and sub-basin mapping

From the ASTER DEM (Figure 3(a)), the watershed and the drainage channels were delineated, with the results presented in Figures 3(b).

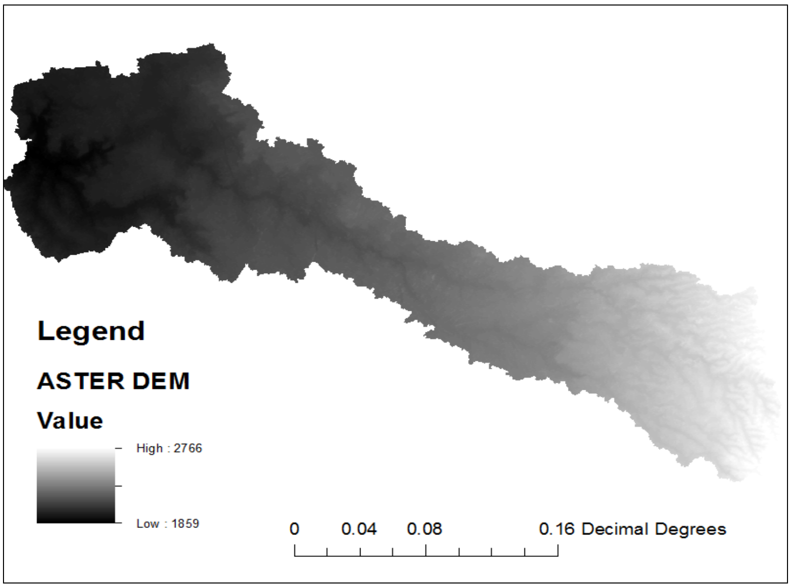

Figure 3: (a) Watershed ASTER DEM

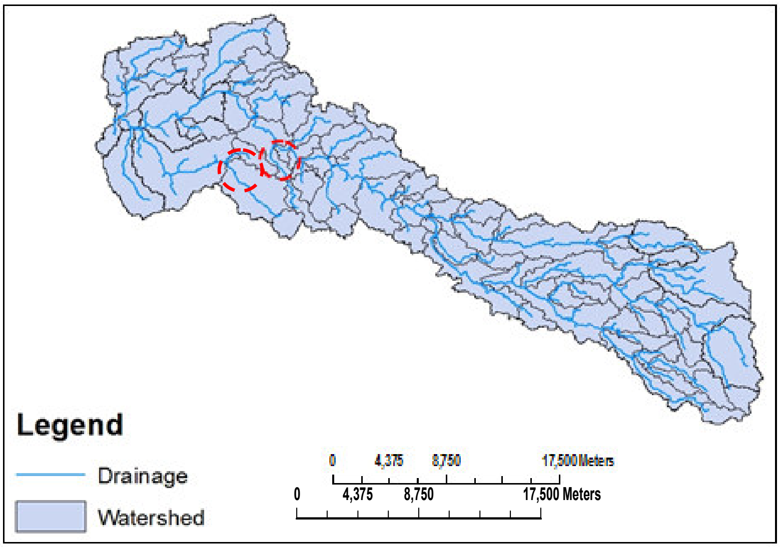

Figure 3: (b) the River Sosiani watershed with the drainage channels and sub-catchments.

3.2 *River Sosiani watershed land use mapping*

The classification results shown in figure 4 comprises a spatial distribution of four dominant land use and land cover types as agriculture (310.47 km^2), forest (140.53 km^2), developed area (15.85 km^2) and grassland (107.45 km^2). The geographical locations of the four main EMC sampling stations (1-4) are shown along the river line and located at a particular land use/cover type.

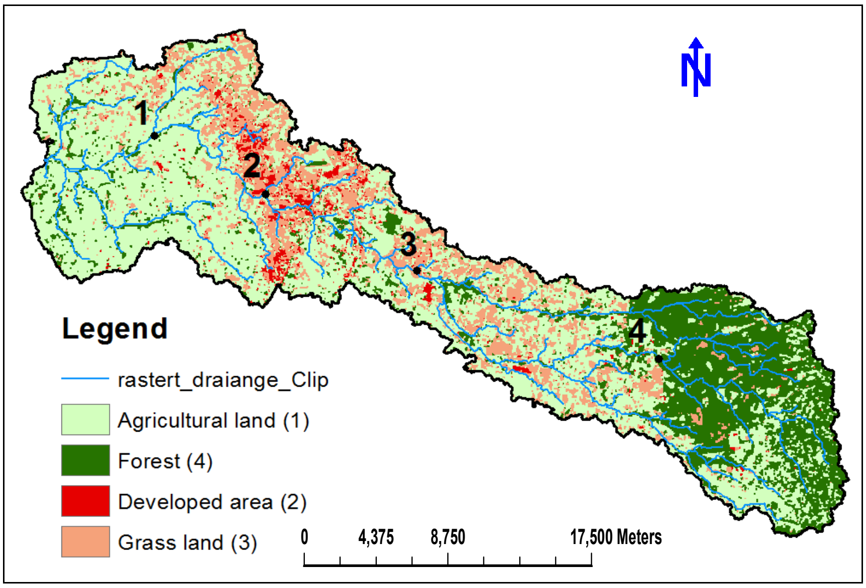

Figure 4: Land use and land cover map of the Sosiani River watershed showing the location of the main sampling points.

3.3 Discharge and flow rate determination

For this study, two discharges were selected, one during the dry season (January (Q_1)) and the other during the wet season (May (Q_2)). Sampling for EMC data and discharge measurement were carried out in the four sampling points located within the predetermined four main land use classes.

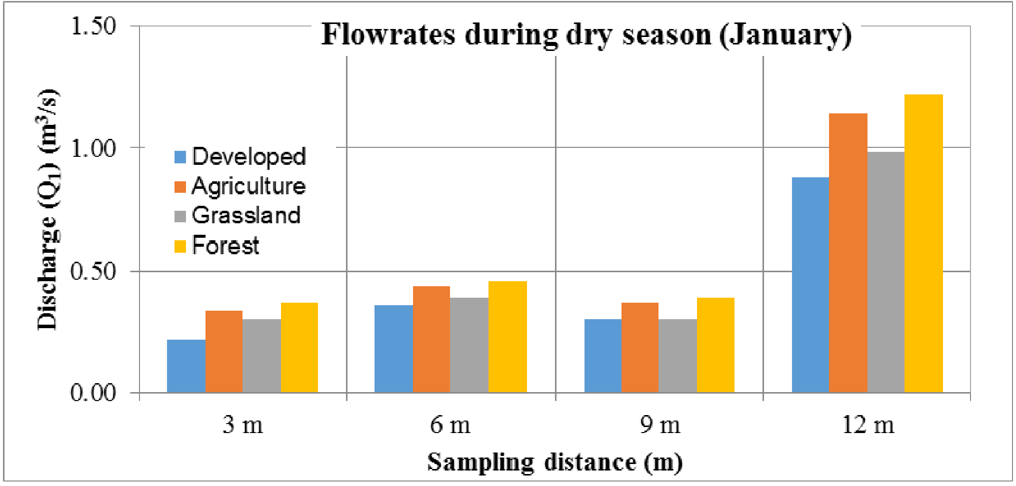

Figure 5(a): Flow rates during dry season.

The intervals of measurements were from 3m to 12m. The results in Figure 5(a) and 5(b) correspond to the expected results, thus during the wet season, the flow rates are higher than during the dry seasons.

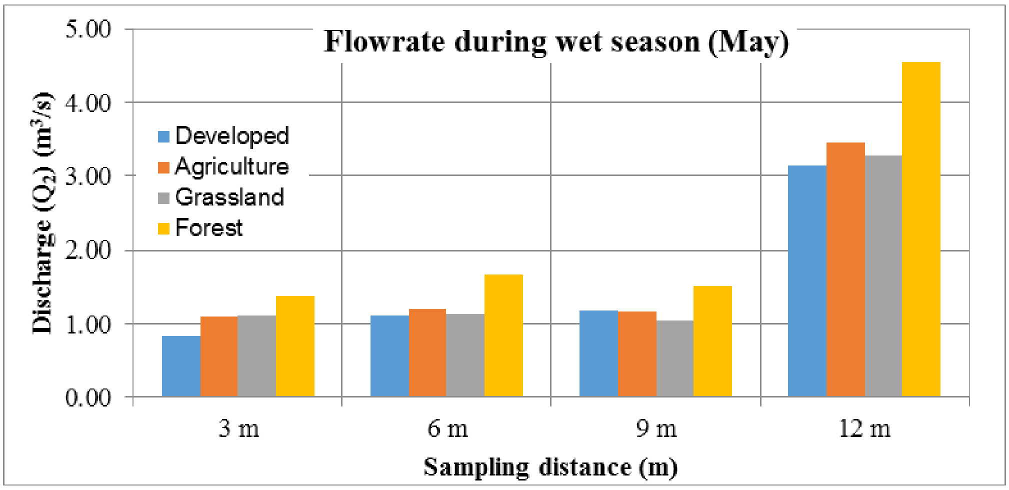

Figure 5(b): Flow rates during wet season.

3.4 *Land use runoff coefficients and degree of imperviousness*

The results in Table 2 show that the developed area has 90% of its rainfall draining as runoff due to the paved surfaces. This provides an indication of expected high pollutant materials to be carried into the stream. Grasslands are observed to have least coefficient since the plants offer a great detention to rainfall allowing more time for infiltration. This is also related to imperviousness factors, where the developed areas also show high imperviousness due to paved surfaces. The mean runoff coefficient in the watershed from the table is equivalent to 0.59.

Table 2: Land use runoff coefficients and percent imperviousness

Land use (*u*)	**Runoff Coefficient (*C*)**	**Degree of imperviousness (%)**
Agriculture	0.50	2
Forest	0.60	2
Developed	0.90	90
Grassland	0.35	2

3.5 *Event mean concentration data*

Results from the two sampling periods, during the dry season and wet season are presented in Tables 3(a) and 3(b). Table 3(a) shows the laboratory test results carried out in January, which is the period of low flows due to low rainfall recorded. Table 3(b) shows results collected in late May after a series of rainfall events, when there is expected higher infiltration rates, and it is further noted that the resulting flows did not substantially increase. The slight increase in pollutant concentrations from the second sample is attributed to flows from precipitation carrying pollutants to the stream. The final EMC is obtained by incorporating discharges as calculated from the river cross-section data and velocities with the results in Table 4.

From the results, the second sampling was given a 70% weighting to the final EMC, because of the onset of rainfall events that contribute to more runoff and hence dispose more pollutants into the River Sosiani, while the first sampling assigned 30% due to ability of the soil or land to absorb 70% of pollutants in rainfall that infiltrates through it and leaves as base flow to join the river.

Table 3(a): EMC (mg/L) for the five pollutant indicators in January

Land use	**BOD**	**TSS**	**TDS**	**FCOL**	**NO3**	**PO4**
Agriculture	4.00	4.00	98.10	18	0.90	0.06
Forest	3.00	6.00	55.60	16	0.68	0.04
Developed	8.00	17.00	97.20	115	16.72	4.39
Grassland	3.80	4.20	98.20	18	0.88	0.05

Table 3(b): EMC (mg/L) for the five pollutant indicators in May

Land use	BOD	TSS	TDS	FCOL	NO3	PO4
Agriculture	4.40	4.50	98.40	19	1.10	0.09
Forest	3.30	6.30	56.00	17	0.82	0.08
Developed	8.60	17.80	97.80	116	17.00	4.74
Grassland	4.00	4.40	99.10	19	0.92	0.09

Table 4: Derived EMC (mg/L) values after incorporating discharge

Land use	BOD	TSS	TDS	FCOL	NO3	PO4
Agriculture	4.30	4.38	98.33	19	1.05	0.08
Forest	3.24	6.23	55.70	17	0.79	0.08
Developed	8.47	17.62	97.70	116	16.94	4.53
Grassland	3.95	4.35	98.89	19	0.91	0.08

The graphical representation in Figure 6 shows that there is a high pollutant level in developed area. This is attributed to the high levels of waste generation, resulting from increased populations and human activities. This is followed closely by agricultural land use and grassland, with least levels of pollutants being observed in forested land cover. The low levels observed in forest land cover are attributed to the self-sustainability of the life of the river. Self-sustainable rivers are able to recover from disturbances and respond to changes on the landscape while maintaining ecosystem services (Gene 2010).

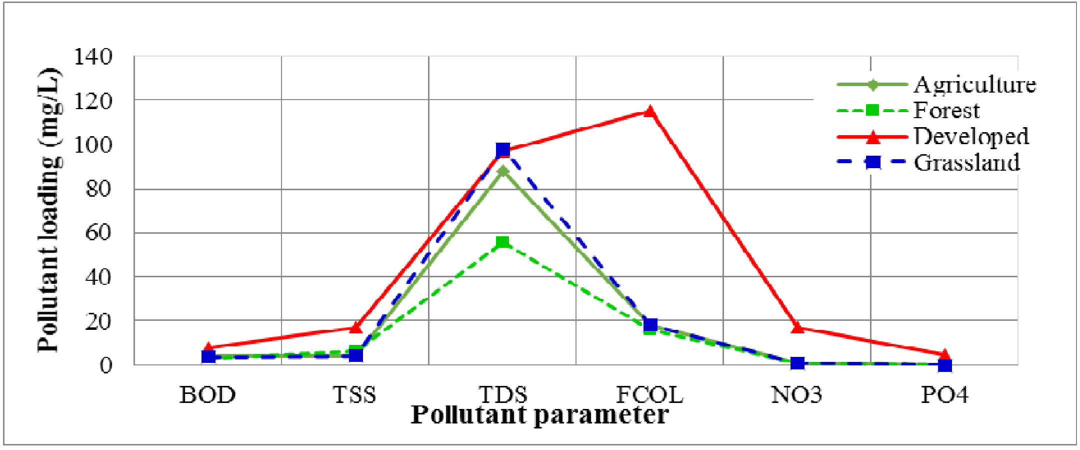

Figure 6: Variations of pollutant parameters with land use type.

3.6 Pollutant mapping

The pollutant mapping scenarios for the study area comprises of analyzing the data input for each pollutant. The results for each pollutant are presented in the following sections.

3.6.1 Phosphates and nitrates

The adverse effects of high concentrations of phosphates and nitrates results into eutrophication, which is the reduced dissolved oxygen in water bodies. In this study there is a high concentration of phosphates and nitrates elements in the developed area due to large concentrations of population that results into gaseous automobile emissions, domestic detergents discharge, sewage and waste water discharge from treatment works, raw and septic leaks from poorly kept slums, amongst other causes.

The results from the study show that the concentrations of nitrates are higher than those of phosphates as shown in Figure 7(a) and 7(b). This is because a larger percentage of the land use in the watershed is agricultural and the farms mainly employ fertilizer use which is rich in nitrates and phosphates. Wastes resulting from production and handling of fertilizers in the developed area is consequently higher.

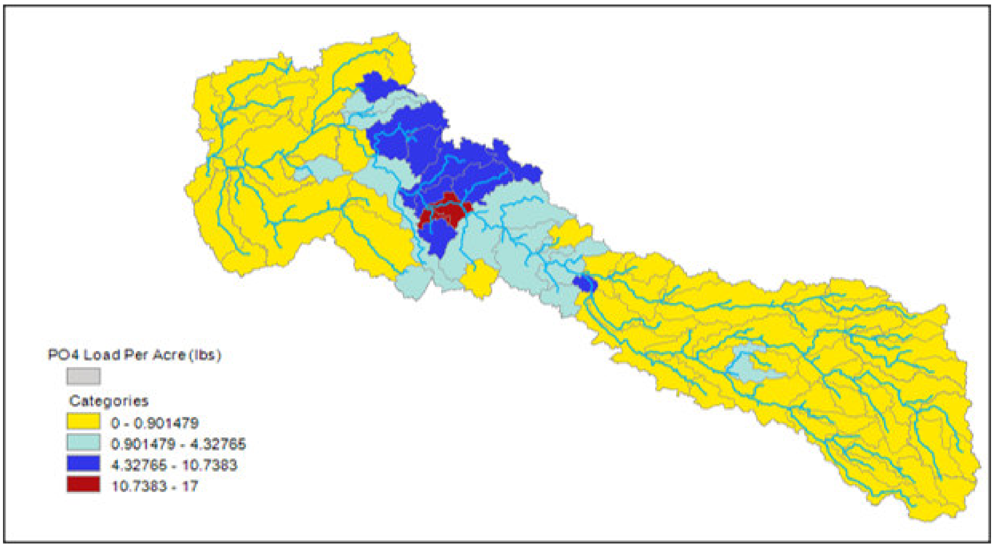

Figure 7(a): Distribution of phosphates load per acre.

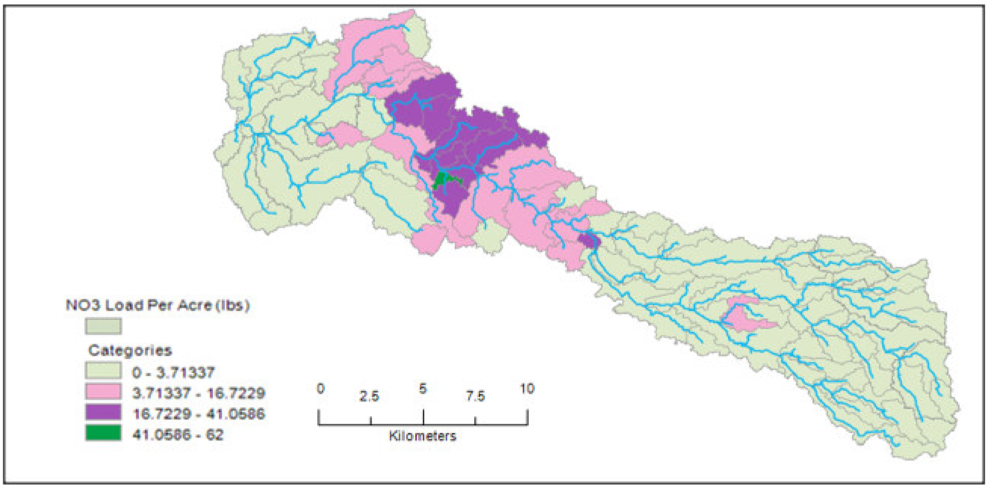

Figure 7(b): Distribution of nitrates load per acre.

3.6.2 Biochemical Oxygen Demand

Figure 8 shows the variability in the level of organics in the study area and by comparison the BOD pollutant is highest in the developed area, with an average of 25 pounds per acre (lbs/acre). The town center has the highest BOD concentration ranging from 20.5–31 lbs/acre. This result is attributed to the diverse and high levels of wastes materials in the developed or urban area. Such wastes include domestic wastes, septic tanks, industrial effluent, urban solid waste, lawn fertilizers.

It is observed that in the forested and partially agricultural areas, the BOD loading is generally very low. This is because these areas have plant wastes that demand less of oxygen. The fertilizers used in the agricultural areas are mostly dissolved into the soil and absorbed by the plants, thus the partial contribution to the BOD concentration. The production of waste within the urban area becomes enormous with higher population growth. Grasslands come second due to organic wastes from animals and decaying natural plant leaves.

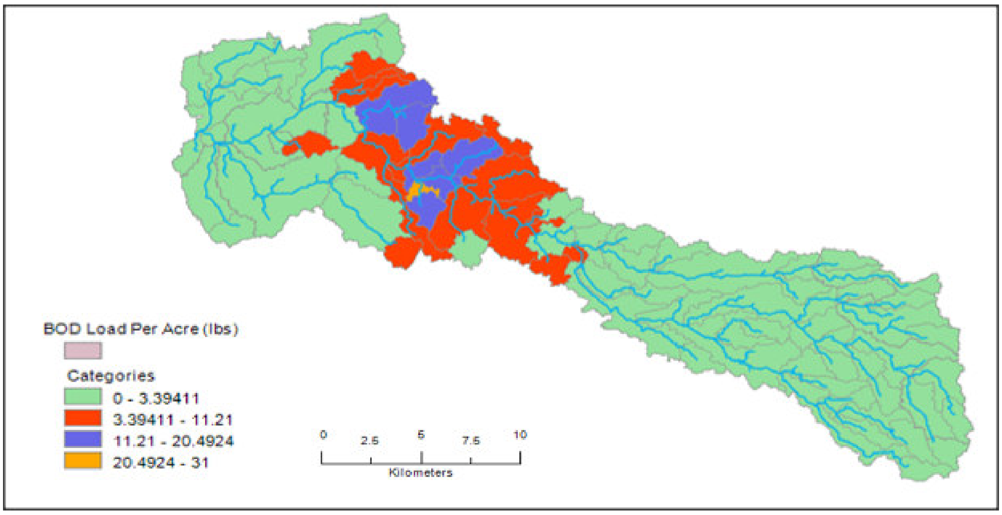

Figure 8: Distribution of the BOD load per acre obtained for the watershed.

3.6.3 TDS and TSS

From the modelled pollutant mapping results, it was observed that there is generally a high level of dissolved solids than suspended solids throughout the watershed (Figure 9(a) and 9(b)). These observations are attributed to the higher levels of soluble fertilizers used in the agricultural sections and soluble dissolvable effluents from the developed urban areas.

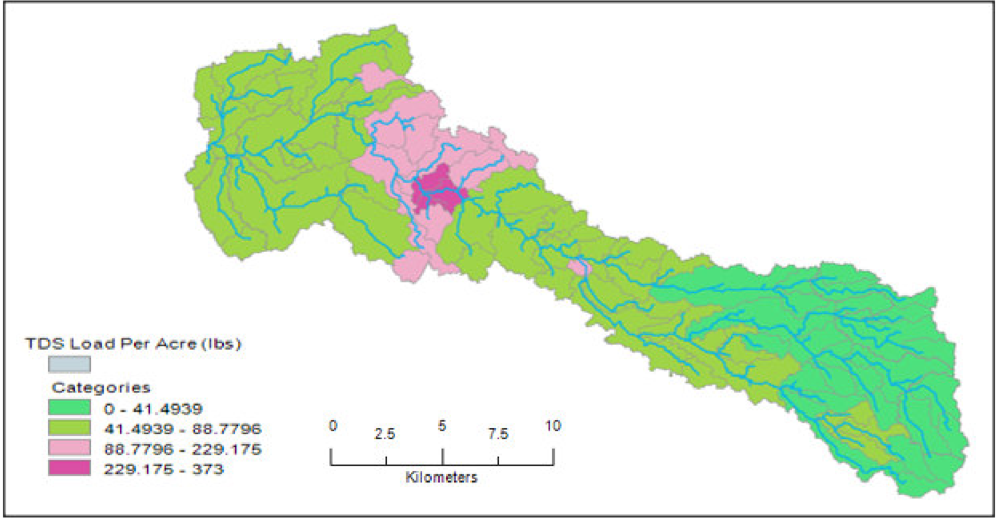

Figure 9(a): Loadings and distributions of TDS within the River Sosiani watershed.

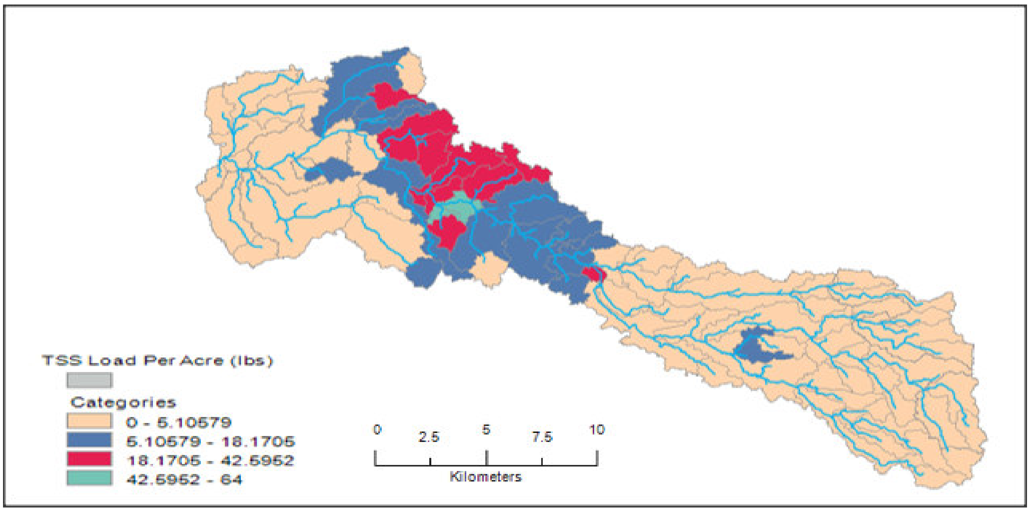

Figure 9(b): Loadings and distributions of TSS within the River Sosiani watershed.

The results show that TDS occurs at high concentrations in the developed area (300 lbs/acre) and its surrounding. This is mainly because after storm events, salts are washed into the stream. Similarly tilled agricultural land during storm events experience soil erosion that carries soluble components of soil particles to the river. The forest region is seen to have the least effect on the TDS due to its compact and stable ground covers. TSS is similarly higher on the river section that passes through the developed area as a result of reduced infiltration and increased velocities since most areas are paved and built. As such, most if not all sediments on the surfaces are carried directly to the river. However, TDS is much uniformly distributed across the agricultural and grassland because of the effects of decaying plants and animals within the watershed which also contribute to suspended organic particles.

3.6.4 Fecal Coliforms

FCOL are microscopic bacteria, which when found in water indicates presence of fecal matter and disease carrying microorganisms. In the developed area the concentrations of FCOL is seen to be highest (356 lbs/acre on average) as shown in Figure 10.

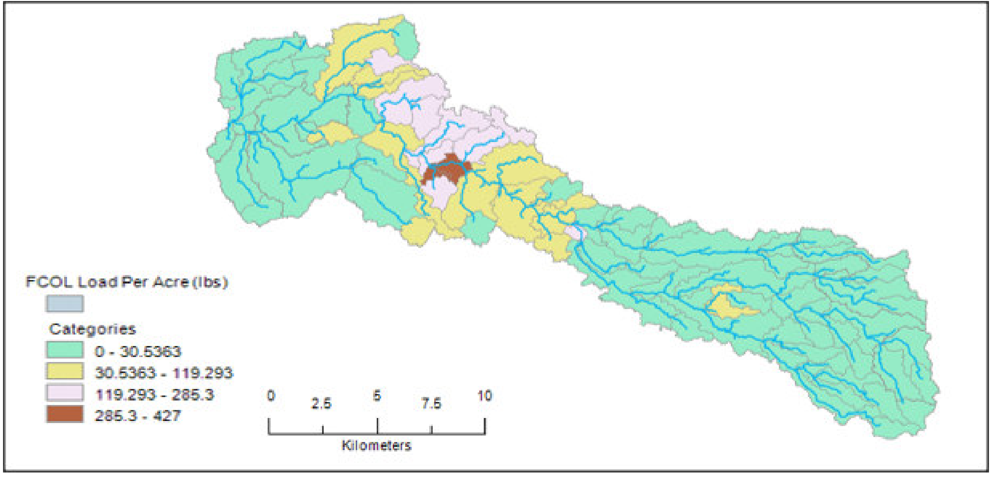

Figure 10: Concentration of FCOL load per acre within the watershed.

Apart from seepage from septic tanks, this high concentration is attributed to the Huruma wastewater treatment plant discharge and leaking sanitary sewers. The presence of decaying solid waste from informal settlement areas also result in high levels of bacteria through leachate that drains during and after storm events.

Further, the results of FCOL concentrations in most sections of mixed grassland and agricultural are attributed to livestock grazing near the river, and the spreading of manure and fertilizer during the wet periods. The forest region is seen to contribute far less bacteria concentrations due to their self-sustaining environment and recycling of excreta by plants before they reach the main streams.

3.7 Results validation with in situ measurements

The pollutant outputs from the model were cross-correlated and verified by comparing with the results from in-situ data sampling and testing in the same time period. The predicted data was also subjected to Nash-Sutcliffe efficiency test to see how well the model performed compared to observed data. The comparative results are presented in Figures 11-13 for three sampling stations namely, Downstream, Huruma and Kisumu Bridge. From the validation results, it is observed that the Huruma area presents the perfect match of the pollutant modelling indication with a Nash-Sutcliffe efficiency of 0.879. This can be attributed to the visible green colour caused by algae in the treatment discharge and also it is an open area with no vegetation cover therefor efficiently captured by satellite imaging. The greatest deviation from the observed data by the model was the results from Kisumu bridge sampling point with an efficiency of 0.245, whose aerial observation is blurred by surrounding huge trees and the settlement around, though its error can also be attributed to instant variations in point pollutions since its right in the middle of the developed area prone to runoffs from paved surfaces and industrial waste that vary with time and season.

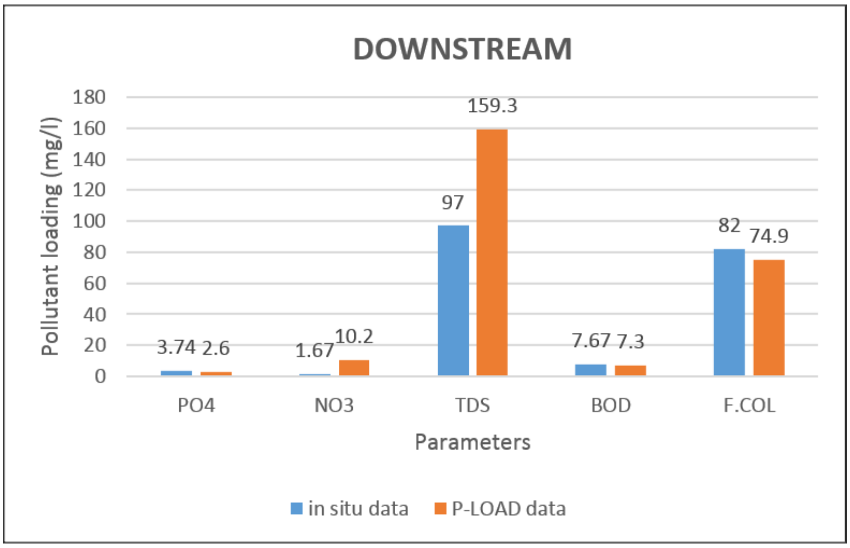

Figure 11: Pollutant cross-correlation variation at the downstream river sampling point.

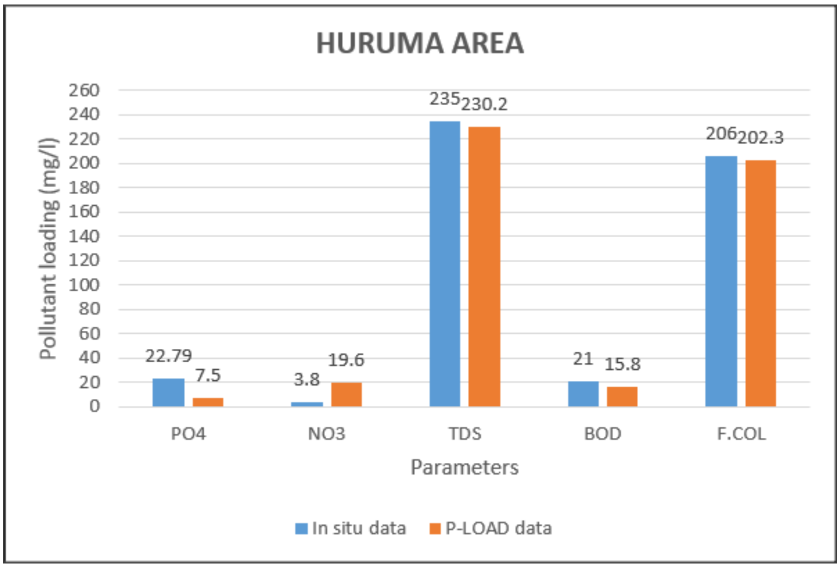

Figure 12: Pollutant cross-correlation variation at the Huruma sampling area.

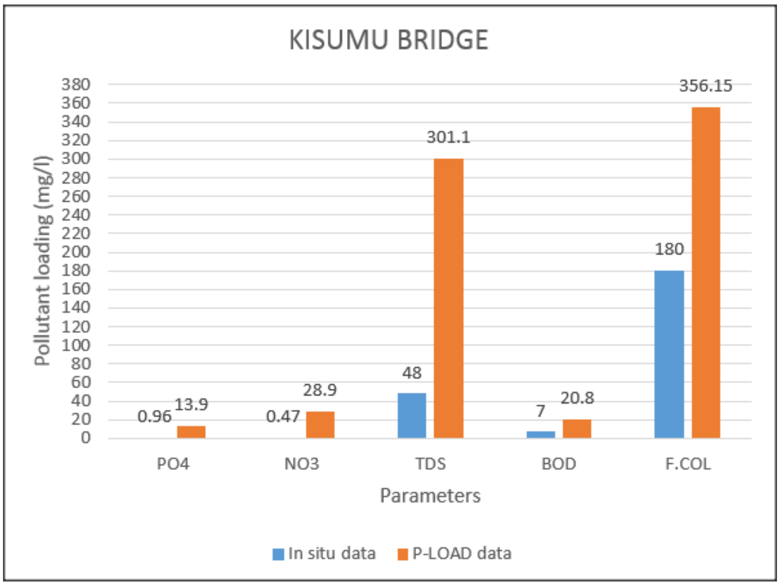

Figure 13: Pollutant cross-correlation variation at the Kisumu bridge sampling point.

3.8 Effect of multiple BMP on water pollutants

It is generally observed that from the generated pollutant maps there is a scenario of high concentrations in the developed region and this reduces outwardly with least concentrations observed in the self-sustaining forest environments. On the other hand increased population and related human activities results into higher generation of wastes in the developed area and resulting into high concentrations of pollutants. It is therefore necessary to use the model as a way of improving the practices in land use planning for water quality control.

BMPs are soft engineering approaches that utilize the resources around so as to reduce the effect of pollution on the wider ecosystem. Some of them are composed of resistant plants to absorb pollutants, while others are designed to have physical obstructions so as to detain sediment, silt or pollutant particles from reaching the water body of interest.

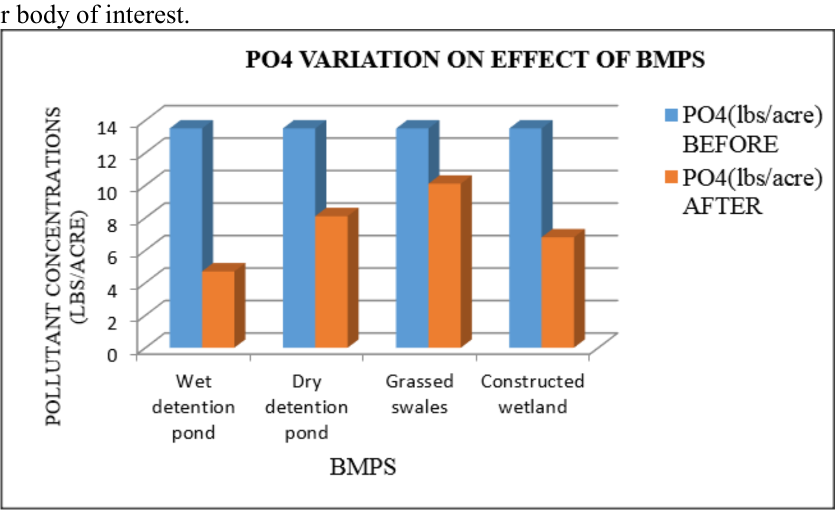

Figure14: Effect of inclusion of BMPs on phosphates variations.

In this study BMPs were introduced in the model so as to assess pollutant reduction efficiencies. This will provide the water resource engineers and environmentalists with indications of what management strategies to put in place so as to mitigate the pollution in the River Sosiani. Dry retention ponds, Wet detention ponds, Grassed swales and Constructed wetlands were considered and pollutant reductions are indicated as shown in Figures 14–16, with the efficiencies tabulated in Table 5. In this study area, the results show that BMPs substantially reduce TDS as compared to the other pollutants.

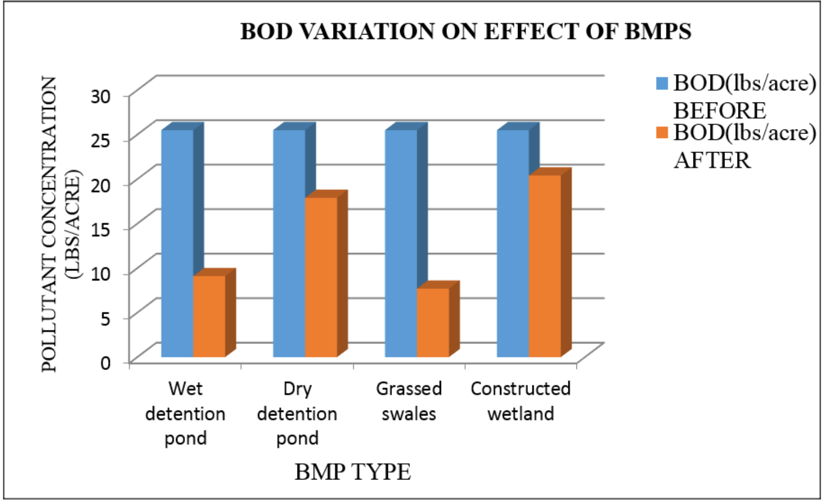

Figure 15: Effects of BMPs inclusion on BOD variations.

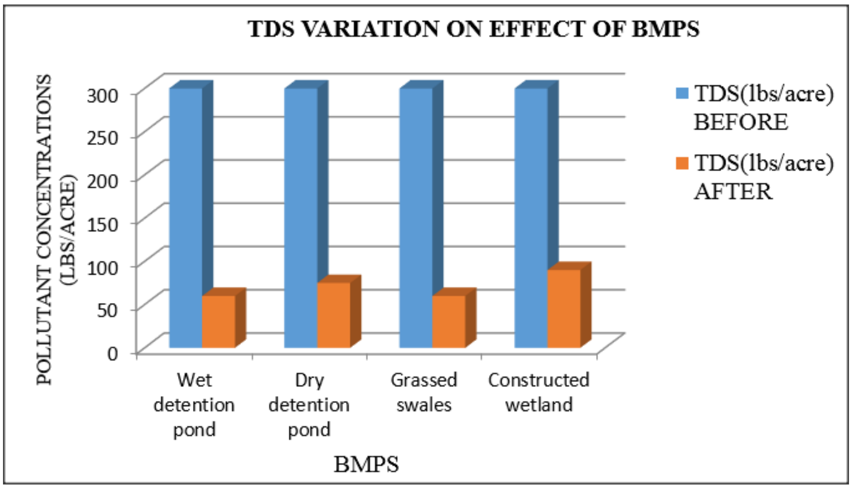

Figure 16: Effects of BMPs inclusion on TDS variations.

The collective impact of BMPs on water quality and runoff is summarized in Table 5. The results show that the implementation of the four BMPs reduced nutrient export to the stream over the entire watershed. As seen in Table 5, the four BMPs collectively reduced the average annual total, dissolved and particulate phosphates export by an average of 45%. The average annual total, dissolved and particulate nitrates export was reduced by an average of 41.25%. The BOD was reduced by 46.25% on average while the TDS/TSS realized the highest reduction in by up to 76.25%. From the PLOAD model, of the four BMPs implemented, the water detention pond and the grassed swales appear to provide the largest proportion of nutrient reduction.

Table 5: Efficiency of application BMP on pollutants

	Pollutant control and removal (%)			
BMP	**PO4**	**NO3**	**TDS/TSS**	**BOD**
Wet detention pond	65	25	80	65
Dry detention pond	40	60	75	30
Grassed swales	25	55	80	70
Constructed wetland	50	25	70	20
Average reduction	45	41.25	46.25	76.25

4. Summary and conclusions

Water pollution is an environmental threat and of concern to the sustainability of the ecosystem. Coupled with the increased population and more settlement areas, and the increased industrial growth activities, a lot of waste is generated in the Eldoret and its environs. Most of this waste normally ends up being discharged into the River Sosiani, which is also a major source of water for both domestic and industrial uses within the catchment. Because of lack of fast and effective ways of monitoring pollution levels in River Sosiani, this study aims to use the GIS-based PLOAD model to aid in generating pollutant indicator loads by correlating the impacts of land use change on water quality.

The model generated a spatially distributed pollutant loading of PO4, NO3, BOD, TDS/TSS and FCOL pollutants for the watershed. The results showed that the highest contributor to the River Sosiani pollution was FCOL with an average 356 lbs/acre, and mostly concentrated in the urban areas. The least pollutant contributor was from PO4 with a maximum loading of 17 lbs/acre. In overall, the urban and the developed areas strongly showed the highest impacts in contributing to the pollution of the river, with the least contribution from the natural forested as compared to the forested area.

By modelling the impacts of BMP, in order to simulate the strategies for the reduction of pollutants within watershed, it was determined that the introduction of wet and dry ponds, grassed swales and constructed wetlands would significantly reduce the pollution of the river with an efficiency of above 40%.

From the results, water resources and environmental departments can easily evaluate basins that show worse pollution scenarios and this can aid them in prioritizing the few resources held aside for mitigation purposes. The mitigation options are also further enhanced by the model through assessing and evaluating pollutant removal efficiencies by the BMPs. Findings of the study show that land-use management can also play a crucial role in water quality improvement.

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