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Spatio-temporal dynamics of land use practices on rivers in tropical regions: A case study of Ruiru and Ndarugu Basins, Kiambu County, Kenya

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Land use dynamics are known to cause considerable modifications to the environment with broad and sometimes severe impacts on water quality and aquatic natural resources. In this study, the impacts of land use practices on water quality were estimated during the dry and wet seasons in Ruiru and Ndarugu Rivers, Kenya using remote sensing, geographic information systems and statistical techniques. A total of 12 sampling sites associated with three different land use types (forest, agriculture and urban) were selected. All water quality parameters were measured *in situ* in two dry seasons and two wet seasons and subjected to Kruskal Wallis statistical analyses. Significant variations were seen in water quality parameters between land use types. Higher temperatures were associated with urban dominated sub-basins, while dissolved oxygen was highest in forest sites. Turbidity was highest in agricultural sites and lowest in forested sites, but pH did not differ significantly across all sites. Seasonal impacts were recorded for most water quality parameters tested in all land use types, with agriculture and urban land use showing stronger impacts on water quality in the wet season than in the dry season. This study indicates that both agricultural and urban land use are key factors that affect water quality change. Land-use specific water conservation measures should be enhanced to limit both point and non-point sources of pollution in the study area.

Key words: Land use, water quality, seasons, Ruiru and Ndarugu Rivers, water conservation measures.

INTRODUCTION

Rivers are susceptible to land use change and continuous exploitation (Withers and Jarvie, 2008; Vörösmarty et al., 2010). Deterioration of rivers in terms of water quality as a result of unsustainable human activities has become a major environmental concern (Chen and Lu, 2014), which are directly reflected in land use and land cover characteristics (Kang et al., 2010). To make meaningful decisions for effective water quality management, there

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is need to understand the relationship between land use and water quality as this relationship can be used to target critical land use areas and to institute appropriate measures to minimize pollutant loading in water resources (Abler et al., 2002). Population expansion in Kenya is closely associated with a massive increase in demand for land, which is highly related to urban growth and increased agricultural activities. Kenya is classified as one of the water-scarce countries in the world (UNESCO, 2006), and land use implications on water systems have been shown to cause far-reaching consequences, both ecologically and economically. Agriculture accounts for the highest demand for freshwater resources in Kenya, with demand predicted to rise from 3,965 million m^3/day in 1990 to 8,138 million m^3/day in 2010 (UNESCO, 2010). It is expected that the large and growing proportion of the population living in urban areas will put considerable pressure for continued transfers of water out of agriculture to supply growing urban centers (World Bank, 2010). Other competing uses of water in Kenya include hydroelectricity, protection of aquatic ecosystems, and recreation. The high population expansion and intense land utilization in the catchment are attributed to increased land degradation, leading to degradation of water resources, one of the critical ecosystem services. Additionally, increased demand for food leads to intensive farming practice and increased destruction of forest cover to open up areas for cultivation.

The rapid land use degradation, especially in developing countries will continue to be one of the crucial factors that must be considered in the human dimension of the 21st century (Torrey, 1998). The lack of basic knowledge of the landscape attributes to hydrology and its ecological impacts has made us unable to asses, much less to manage and restore limited water resources in the country. Therefore, timely and accurate estimation of implications of population systems to land use attributes is of considerable significance for decision makers in watershed planning and for a better understanding of the relationships between population growth, economic and environmental conditions (Yu and Changshan, 2004). Despite these dire needs to monitor ecosystems, the ecological and health values of the Ndarugu and Ruiru Rivers catchment, particularly within the settlement and agricultural areas are not yet fully addressed.

Since ecosystems have been degraded worldwide leading to loss of valuable environmental services that they provide, there has been a growing search for practical solutions. The rapid land use degradation, especially in developing countries will continue to be one of the crucial factors that must be considered in the human dimension of the 21st century (Torrey, 1998). The lack of basic knowledge of the landscape attributes to health problems and its ecological impacts has made us unable to asses, much less to manage and restore limited water resources in the country. Therefore, timely and accurate estimation of implications of population systems to land use attributes is of considerable significance for decision makers in watershed planning and for a better understanding of the relationships between population growth, economic and environmental conditions (Yu and Changshan, 2004). Despite these dire needs to monitor ecosystems, the ecologic and health values of the catchment of Ndarugu and Ruiru Rivers, particularly within the settlement and agricultural areas are not yet entirely addressed.

MATERIALS AND METHODS

Study area

The Ruiru River (1° 4'43.90"S, 36°50'54.24"E) and Ndarugu River (1° 0'49.80"S, 36°55'8.86"E) are major tributaries of Athi-Galana River, the second longest river in Kenya. Both rivers are located in Kiambu County in the central part of Kenya. The rivers originate from Gatamaiyo Forest, the southern-most tip of the Aberdare Ranges (Figure 1). The drainage area of the Ruiru and Ndarugu Rivers are, approximately, 367 and 230 km^2; length of the main river channels 40 and 48km; and average gradients of about 0.057 and 0.054, respectively. Rainfall is predominantly influenced by altitude, with the mean annual rainfall ranging from 500 mm in the lower parts and increasing gradually to 2000 mm in the upper region. The rainfall regime is bimodal, where long rains fall in April and May. This is followed by a cool dry season in July and August, before short rains which fall from October to December. The mean maximum temperatures range from 26 to 28°C in the eastern and southern parts, and 18 to 20°C in the Northwest; while the mean minimum temperatures vary between 14 and 16°C in the eastern parts and 6 to 8°C in the north western parts. The study area is mainly composed of volcanic rocks of varying ages (Saggerson, 1967). To the northeast, geology varies from Miocene to Pleistocene volcanics while intermediate and basic lavas are found in the south. Land use consists of smallholder mixed farming, large holder farming (mainly tea and coffee), grazing, nature conservation and human settlements. The main economic activity is agriculture in tea, coffee, dairy, poultry, and horticulture farming.

Landsat multispectral scanner (MSS), thematic mapper (TM) and enhanced thematic mapper plus (ETM+) imagery for the years 2005, 2010 and 2015 were collected from Global Land cover Facility (University of Maryland, 2016), and US Geological Survey (USGS, 2015) and employed for analyzing the spatial and temporal changes in land use-land cover in the study area. Other available reference data such as aerial photography and topographic maps, and ancillary data were also acquired from Survey of Kenya. Historical land use classifications from Food and Agricultural Organization (FAO), Africover data (International Livestock Research Institute- ILRI data base) on land use and land cover classification for Kenya were also used as reference. Additionally, review of different documents on land management; conservation legislations in forest, watershed services, wetland management and urban development plan were used to support a better understanding and get reference data on land use and land cover in the region.

Several image processing procedures were employed for this study including image pre-processing, classification, accuracy assessment and time-series analyses. Landsat 7 bands 4, 5, 3-Red, Green, and Blue (RGB) were composited, as well as

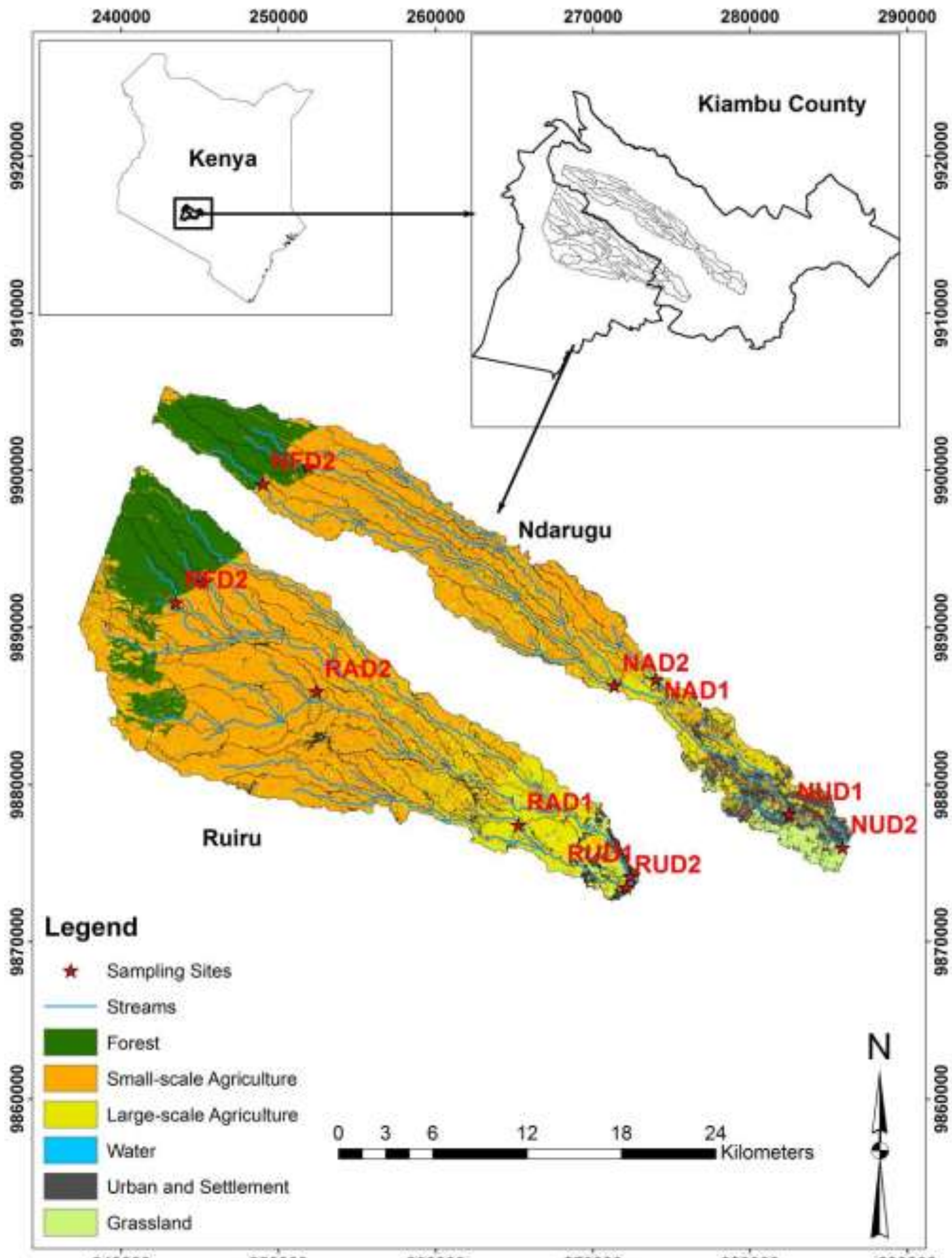

Figure 1. Map of the study area.

corresponding Landsat 8 bands (5, 6 and 4 RGB). Geometric rectification and radiometric normalization were performed for image pre-processing. The Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm was adopted to identify clusters from image data. In ISODATA analysis, unsupervised classification was first conducted to identify spatial clustering of different classes. The image was segmented into unknown classes depending on its statistical similarities by using a suitable clustering algorithm. Supervised classification was done, by taking sample points in stratified random sampling scheme for ground truth data and with the support of field knowledge and ancillary data for land use. Those classes were labeled to the relevant land use/land cover patterns by a posteriori analysis. This technique implies a grouping of pixels in multi-spectral space. Pixels belonging to a particular cluster are therefore spectrally similar. In order to quantify this relationship, Euclidean distance was used as a similarity measure.

Table 1. Land use classification scheme.

Indicator	Class name	Description
Vegetation	Forest	Areas under forest mainly on the higher altitudes to the north-west of both Ruiru and Ndarugu watersheds
	Grassland	Areas vegetated with grass and herbaceous species, with relatively low occurrence of shrubs
Agriculture	Small-scale agriculture	Areas under subsistence farming, typically less than 5 hectares in size
	Large-scale agriculture	Areas under commercial large-scale farming
Built up areas	Urban and settlement	Areas characteristic of highly developed town/ urban areas, residential areas at the urban fringes, roads, and other built-up areas
Hydrology	Water	Dam reservoir, lakes, rivers and streams.

Table 2. Description of sampling sites for water quality assessment.

Sampling site	Altitude (metres)	Location	Dominant Land use
RFD1	2231	0° 58.582'S, 36° 42.026'E	Natural Forest
RFD2	2226	0° 58.793'S, 36° 41.690'E	Natural Forest
RAD1	1655	1° 6.474'S, 36° 53.438'E	Small scale Agriculture dominated by tea and coffee bushes
RAD2	1971	1° 1.866'S, 36° 46.514'E	Large-scale Agriculture (flowers)
RUD1	1551	1° 8.257'S, 36° 57.270'E	Urban areas and settlement
RUD2	1482	1° 8.495'S, 36° 57.325'E	Urban areas and settlement
NFD1	2140	0° 54.858'S, 36° 44.628'E	Natural Forest
NFD2	2135	0° 54.705'S, 36° 44.696'E	Natural Forest
NAD1	1608	1° 1.464'S, 36° 58.139'E	Small scale Agriculture dominated by tea and coffee bushes
NAD2	1630	1° 1.666'S, 36° 56.724'E	Large-scale Agriculture (flowers)
NUD1	1500	1° 6.113'S, 37° 2.712'E	Urban areas and settlement
NUD2	1487	1° 7.257'S, 37° 4.546'E	Urban areas and settlement

Finally based on reference data which was gathered during field work, accuracy assessment was employed to measure the reliability or the overall accuracy of the classification. The reference classes were compared with the result of classification and the ratios of correctly versus incorrectly classified pixels was calculated for each class. The accuracy assessment was conducted through a standard method described by Congalton (1991) Table 1.

Water quality was assessed from a total of 12 sites (6 in each watershed Sites were selected based on land use characteristics to encompass a variety of land uses based on near-stream land use activities. Sites were chosen across the entire basin to ensure results would not be tied to local characteristics. Sites were selected based on land use classes derived from image classification as indicated in Table 2. Fieldwork was carried out four times: Twice during the dry season (mid-January 2014 and 2015) and twice during the wet season (mid-April 2014 and 2015) under stable flow conditions. The following physical-chemical parameters were measured *in situ* using an ecolab multi-parameter water quality meter: pH, temperature, electrical conductivity (EC), turbidity and biological oxygen demand (BOD).

Statistical analysis

For class-specific and overall accuracy estimates, cross tabulation of classified image with ground truth data was used, where a total of 60 ground truth samples were used. An error matrix was used to assess the accuracy of image classification. For water quality measurements, not all of the water quality parameter data met the parametric assumptions, and therefore the Kruskal-Wallis test was used to determine whether the values of the water quality parameters differed significantly between the dry and wet seasons as well as land use types (Bu et al., 2014; Hively et al., 2014). Five variables for the water quality datasets were analyzed: (1) Dissolved oxygen (DO), (2) Temperature, (3) pH, (4) Turbidity, and (5) Electrical conductivity. All dry season and wet season data collected in 2014 and 2015 was pooled. The design therefore included two main fixed factors: (1) "Land use" (with 3 levels; i. forest, ii. agriculture, iii. urban), and (2) "Season" (with two levels; wet vs. dry). The water quality datasets were also subjected to principal component analysis (PCA) multivariate analysis to explore and separate various water quality variations with land use systems. Additionally, discriminant function analysis was used to allow simultaneous examination of the influences of land use variables on all water quality parameters investigated. Discriminant function analysis enabled the computation of two important outputs: (1) The correlations of land use variables with canonical axes, which indicate what land use variables have the largest influence on the ordination; (2) The variance proportions (%) of the water quality parameters that are explained by canonical axes and

Table 3. Land cover classification accuracies computed from ground truth reference points over the 2015 maximum likelihood-classified image.

Reference data	Forest	SSA	LSA	Water	Urban/settlement	Grassland	Row total	Commission accuracy
Forest	8	1	0	0	0	0	9	0.89
SSA	0	13	0	0	1	0	14	0.93
LSA	0	0	10	0	1	0	11	0.91
Water	0	0	0	7	0	0	7	1.00
Urban/settlement	0	0	0	0	6	0	6	1.00
Grassland	0	1	0	0	0	8	9	0.89
Column total	8	15	10	7	8	8	52	
Omission accuracy	1.00	0.87	1.00	1.00	0.75	1.00		
Overall accuracy		0.87						
Kappa coefficient		0.84						

individual land use variables (Sliva and Williams, 2001).

RESULTS AND DISCUSSION

The image error matrix shown in Table 3 gave a Kappa coefficient value of 84% while the overall classification accuracy for the classification was 87%. The classes with the highest user accuracy (commission) were urban and grassland, while those with the highest producer accuracy (omission) were forests, large scale agriculture and water. Using ground truth data and high resolution imagery from google earth, the output of maximum likelihood was further refined to achieve a better representation of land cover types in the study area.

In all the time steps, small-scale agriculture dominated the landscapes of both Ruiru and Ndarugu Watersheds, with a range of 56.455 to 60.93% for Ruiru Watershed, and 54.02 to 55.96% for Ndarugu Watershed.

An expansion of urban areas is attributed to a reduction in areas under grasslands, and along major infrastructural facilities (roads) to the east of the landscape as shown in Figure 3. In these areas, grasslands decreased significantly, and this is attributed to the urbanization process whereby areas previously occupied by grasslands are gradually being taken up by built-up areas. These grasslands have been observed to be ranging ground for wildlife, and have also been used by pastoralist communities as dry-season grazing grounds. The grasslands are located in the drier parts and have not provided the much needed land for cultivation. The fact that urban and settlement areas mainly increase in the eastern part of the catchment may be due to better accessibility (e.g. highway). In addition, being a relatively drier area, the alternative to use the area for settlement than agriculture is reasonable. An increase in built-up areas can lead to an increase of the water yield and decrease in evapotranspiration as has been found in several studies (Im et al., 2009; Wijesekara et al., 2012; Wagner et al., 2013). Numerous valleys in the area classified as large-scale farms are covered with reservoirs. These reservoirs account for a large proportion of areas under water.

From the analysis of classified imagery, a general shift from other land use types to urban and settlement is being observed in both watersheds as indicated in Figure 3. This pattern is strongly consistent with results of Thuo (2013) as well as Kiio and Achola (2015). Parts of the study area, and particularly the lower reaches of Ruiru and Ndarugu basins form part of the Nairobi-Thika urban-rural fringe. The rural-urban fringe, or hinterland, is sometimes described as the landscape interface between town and country, and is often characterized by a mix of urban and rural landscape characteristics. Rapid urbanization of the rural-urban fringe has led to new income opportunities for the people who originally worked in farms as farmers or labourers (Thuo, 2013). A visual analysis of high resolution NASA and Digital Globe Imagery from Google Earth show that urban land use replaced areas previously occupied by grasslands. An increase in stone quarrying activities is also an indicator of high demand for building materials. Immigrating population from other areas presents the local residents with new opportunities, such as establishing of businesses and construction of rental houses to accommodate the immigrant population. In addition to new opportunities, residents have interacted with new comers who have brought in new technology and skills. Thuo (2013) observes that as a result of land use change, small-holder farming systems have been negatively affected as there is less availability of labour to work in the farms. There is also a general shift from growing of traditional food crops to crops such as kales, spinach and tomatoes which have a ready market among the residents.

Traditionally, the area has undergone land sub division

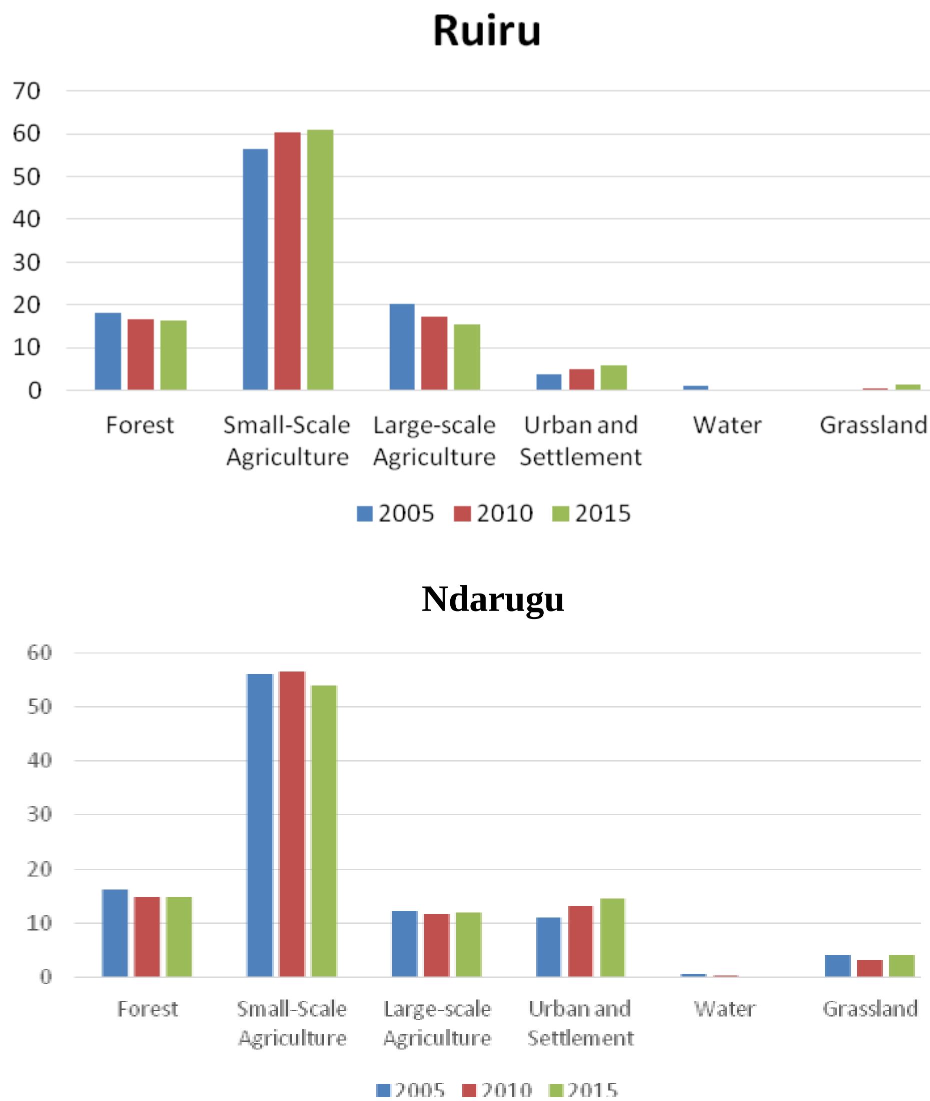

Figure 2. Land use change in Ruiru and Ndarugu Watersheds (2005 to 2015).

to smaller pieces of land. Consequently, this new mode of farming is suitable for the smaller land parcels. The image analysis evidence of surface water scarcity in the area is already visible (Figure 2), with numerous boreholes that have been sunk. The Ruiru-Juja Water and Sanitation Company rations water as part of the management strategy to curb the problem of surface water availability.

The increasing population is leading to pressure for conversion of more farmland to residential areas (Figure 3). In future, opportunity for farmers to increase production by buying additional parcels of land in their locality will be unavailable. Demand for high value horticultural produce by urban consumers can stimulate production by small farmers (Tacoli, 2002), but expansion of urban centres leads to competition over the use of essential natural resources, particularly land and water.

The concentrations of measured water quality parameters in the dry and wet seasons across sampling sites are shown in Table 4. The Kruskal-Wallis tests revealed significantly higher values of DO ($H = 24.71$, $p < 0.01$) and EC ($H = 7.98$, $p < 0.01$) in the dry season than in the wet season. Temperature ($H = 6.92$, $p < 0.01$) was significantly lower in the wet season than in the dry season. The concentrations of pH and turbidity showed no significant differences in the two seasons. Multiple comparisons of water quality parameters revealed wide variations between Urban, Agriculture and Forest groups as shown in Figure 4.

Results of the PCA analysis revealed that three

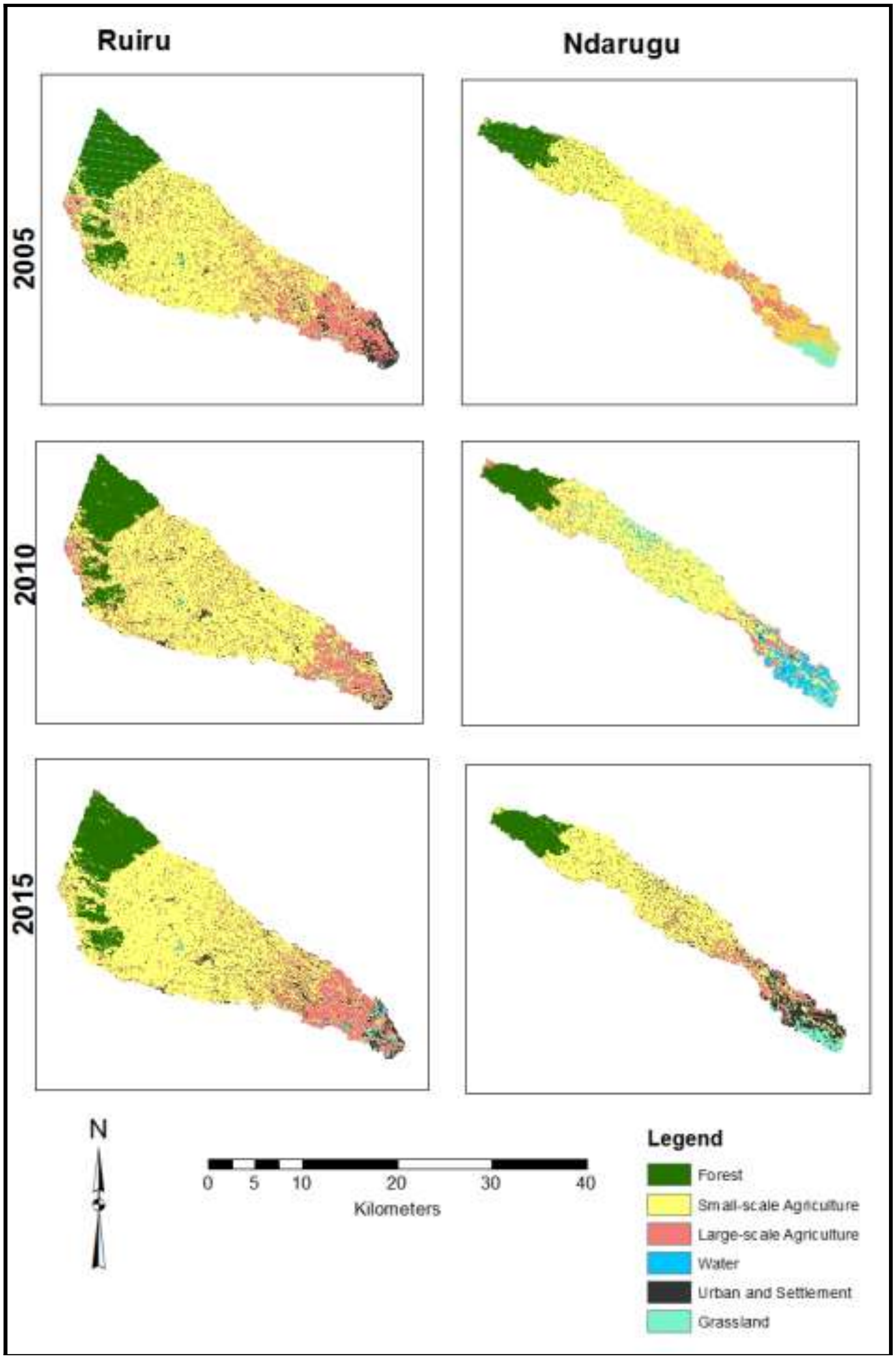

Figure 3. Land use and land cover characteristics of Ruiru and Ndarugu watersheds in 2005, 2010 and 2015.

components explained 77.7% of the variance: Component 1 (32.5%), component 2 (26%) and component 3 (18.8%). Component 1 distinguished temperature, component 2 distinguished pH, turbidity and electrical conductivity while component 3 distinguished dissolved oxygen (Figure 5).

Table 4. Surface water quality between the dry and wet seasons in the Ruiru and Ndarugu Rivers, Kiambu County.

Parameter	N	Dry season (Mean± SD)	Wet season (Mean± SD)	Kruskal Wallis H	p Value
TEMP	48	17.9±2.35	16.27±1.87	6.92	0.009
DO	48	11.30±1.28	15.77±3.07	24.71	0.000
EC	48	75.40±42.82	102.26±42.36	7.98	0.005
TURB	48	23.94±18.40	36.99±28.52	2.65	0.103
pH	48	6.81±0.55	6.75±0.60	2.08	0.1488

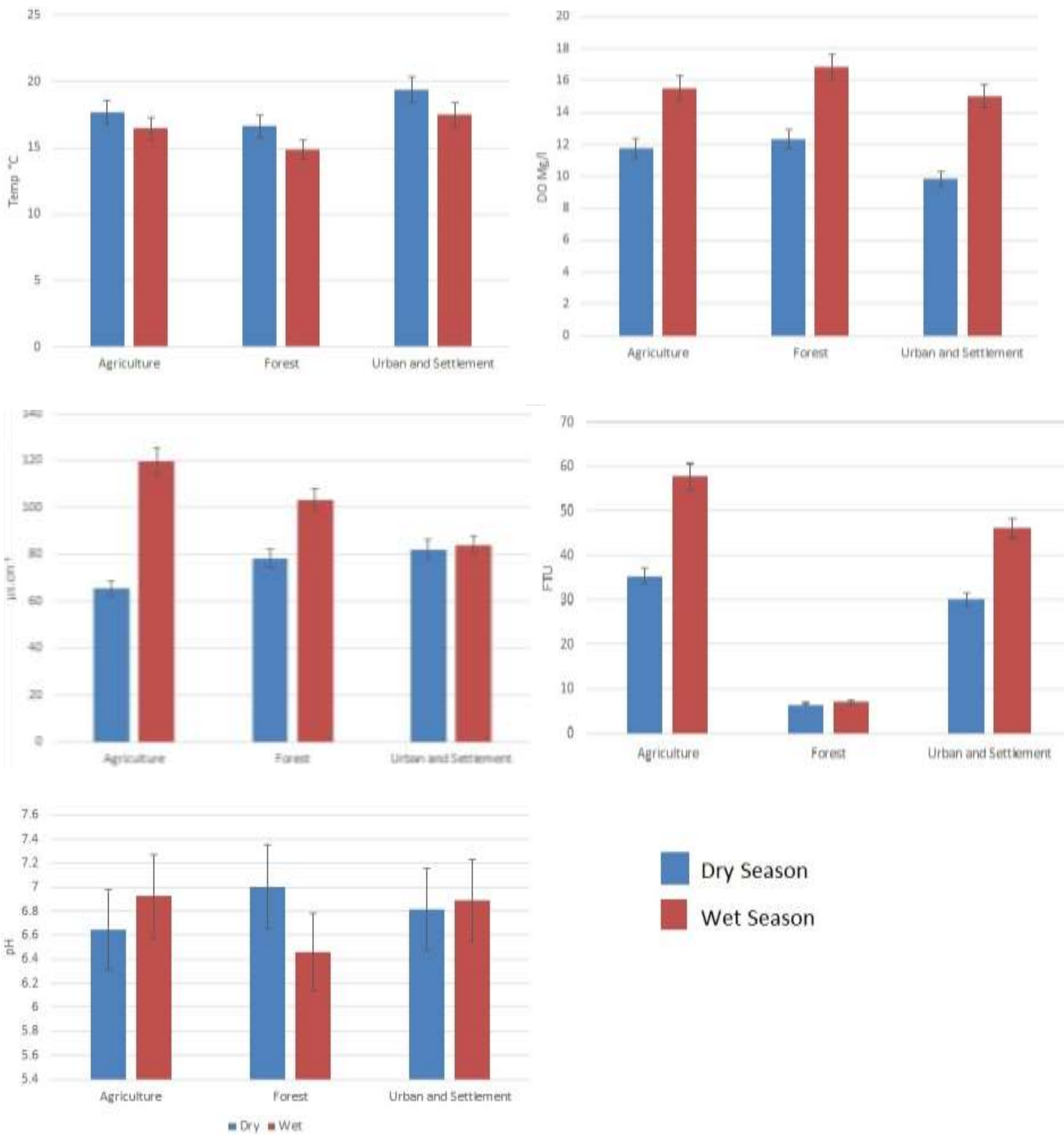

Figure 4. Mean ± standard error values for the water quality parameters among three land use-based site groups in Ruiru and Ndarugu Watersheds.

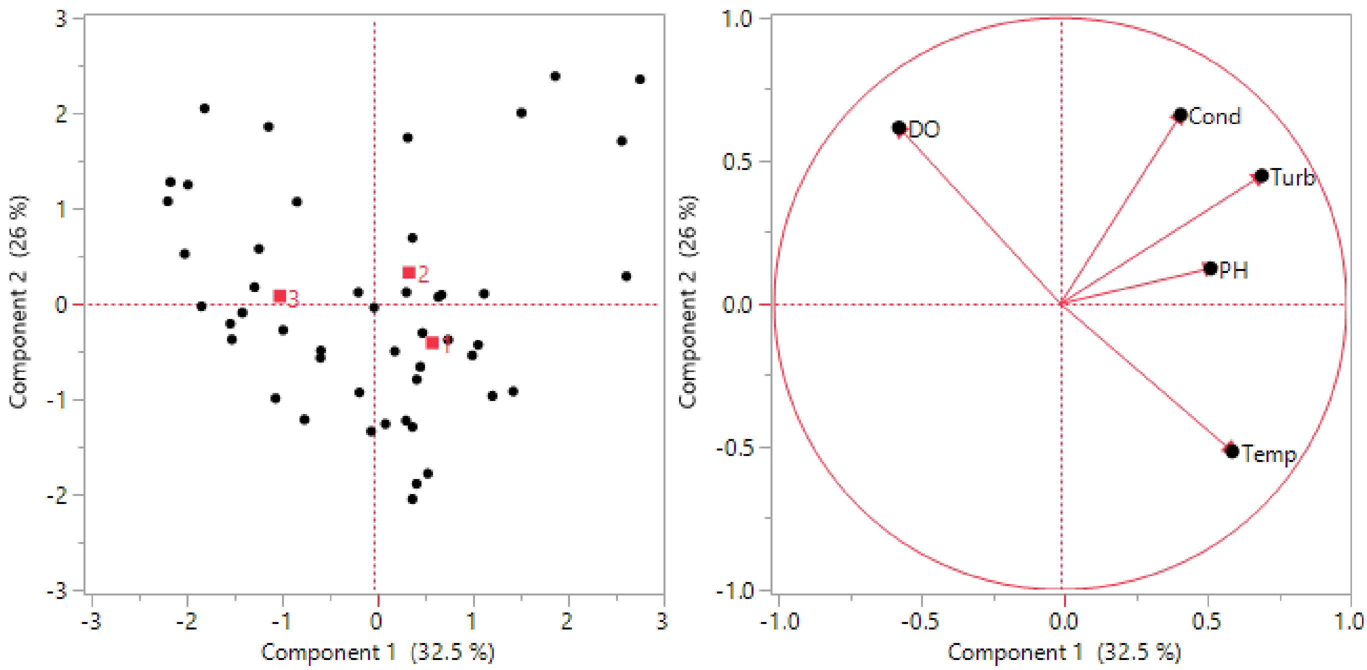

Figure 5. PCA analysis of water quality parameters across land use systems in Ruiru and Ndarugu basins, Central Kenya. The first two axis components 58.5% of the variation: Component 1 (32.5%) and Component 2 (26%).

Results indicate land use and land cover have significant impacts on water quality in the two basins. Forested areas have better water quality than either agricultural dominated and urban dominated landscapes in both wet and dry seasons as shown in Figure 6. This may be attributed to low anthropogenic inputs in forested lands. The variation in physico-chemico characteristics in Ruiru and Ndarugu basins are shown were found to vary across different land use and land cover types, depending on season. The relatively high variation between water quality parameters associated with different land use types are characteristics that can be used to inform or predict water quality aspects in rivers that lack data. In the dry season, farmers in the study area have been practicing irrigation using water abstracted from the rivers and streams. As areas under agriculture are gradually being taken up by urbanization, agricultural intensification is observed. This includes increased farming activities in the dry season, which abstracts water from the rivers. Urbanization on the other hand, is known to result in more runoff during rainy season due to the increase of paved surface area.

In the study area, and most other regions in the country, agricultural activities are strongly tied to seasons. The onset of the long rains triggers a flurry of farm-based activities. The application of farm-based inputs, including fertilizers and chemicals, are also expected to follow this seasonal pattern. Thus, this may aggravate the imbalance between water quality parameters and lead to seasonal water quality variations. In this study, urbanization has been identified as the main driver of change in the study area. There is a general increase of urban/settlement areas more to the east than to the west in both watersheds. The eastern parts are generally drier, and settlement areas are cropping up there. In this study, measured levels of dissolved oxygen are higher in the wet season than in the dry season in all the land use types as shown in Figure 4. Although this trend is consistent with observations from other studies (Schneider et al., 2000), some studies have recorded lower DO levels in the dry season than in the wet season. For example, in a study conducted in lowveld sand river system in South East Zimbabwe, dissolved oxygen concentration levels were higher in the dry season compared to the wet season (Tafangenyasha and Dzinomwa, 2005), and this was attributed to the loss of photosynthetic aquatic plants by faster current. However, the study was conducted in a semi-arid region, where ecological patterns could be different from areas that are wet, such as in the present study area. Other factors that could result in variation in DO levels may include oxygen depletion resulting from the eutrophication of natural water that receives excessive amounts of nutrients normally limiting to plant growth (Dodds, 2006; Breitburg, 2002; Brosnan and O'Shea, 1996). Such nutrients are sometimes associated with urban land use. In this study,

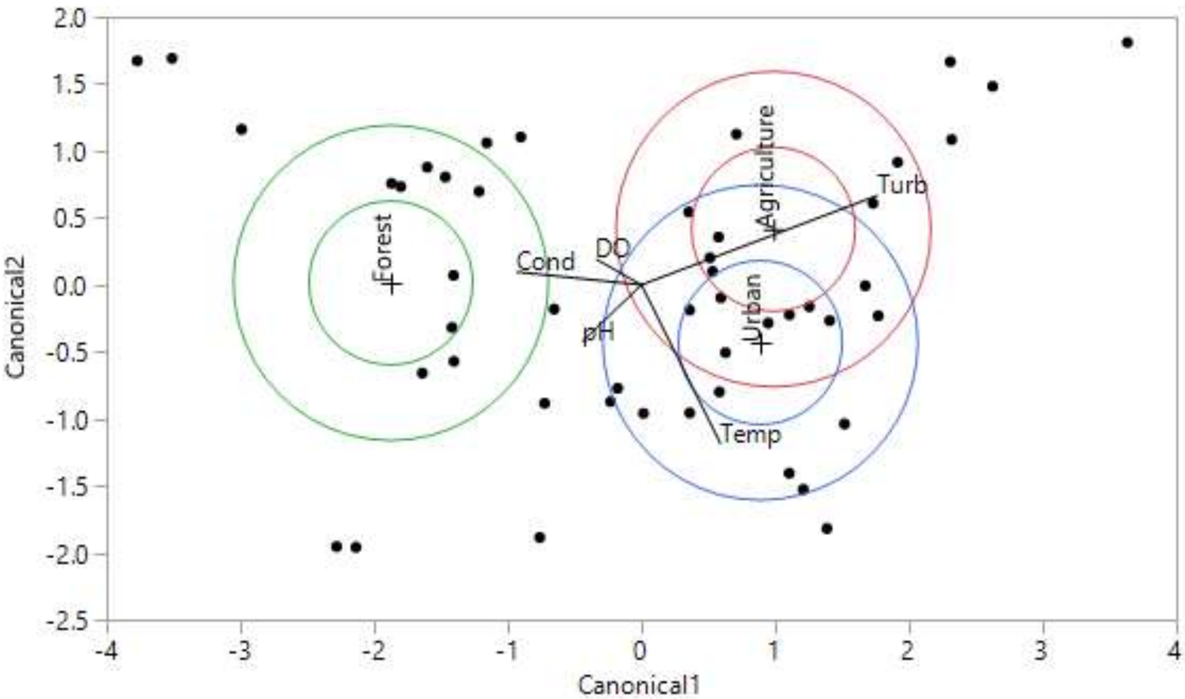

Figure 6. Discriminant analysis on measured water quality parameters across land use types on two canonical axes showing water quality parameters and their associated land use types.

urban/settlement land use recorded lower levels of DO as indicated in Figure 4 compared to both agriculture and forested land in both the dry and wet seasons. This is associated with sewage effluent from urban and settled areas, which increases nutrient inflows in rivers and streams (Carpenter et al., 1998). As the human population increases due to immigrating population from other areas, pressure is exerted on the current sewer infrastructure, which is already overstretched. In all sampling stations, pH did not deviate from the 6.1 to 8.2 range expected for most surface freshwater systems, but vary seasonally in different land use types. In the dry season, pH was higher in forests compared to urban/settlement land uses and agriculture. The wet season recorded higher pH levels in urban/settlement areas and agriculture, and lower values in forest. This suggests that although land use and seasonal changes may be a factor that influences pH, other external factors may also be major determinants of pH measurements in rivers. A number of factors may affect the proportion of major ions (hence pH) in a landscape, including geological, atmospheric, biological and anthropogenic activities (Fawzi et al., 2002). For example, consumption of carbon dioxide by aquatic plants results in an increase in pH during photosynthesis, while during respiration and decomposition, released carbon dioxide results in decreased pH (Schneider et al., 2000).

Theoretically, biological activity and human activity would be the primary determinants of pH, whereby the human activities trigger nutrient loading while biological activity plays a secondary role (Tafangenyasha and Dzinomwa, 2005). The Ruiru and Ndarugu basins are enriched with nitrate while passing through agricultural dominated areas, then and then they receive sewage effluent rich in phosphate from an urban/settlement areas as shown in which could support algal blooms.

Turbidity was highest in agricultural dominated sites and lowest in forest sites (Figure 4). Forested landscapes generally have less erosion and runoff. In forested sites, turbidity levels were minimal between the wet and dry seasons, but strongly variant in agricultural and urban/settled sites. Surface runoff, and its erosive action, is attributed to an increase in turbidity in the dry season in both agricultural areas and urban/settled areas. This periodic input of sediment into the rivers leads to decreased water clarity, thereby inhibiting light penetration and leading to reduced biological activity. Highly turbid waters have more suspended solids and are prone to oxygen depletion (Vesilind et al., 1994).

As shown by this study, the wet season increases erosive conditions in agricultural and urban/settled areas as rains and flood waters increase. This may lead to an overshoot on the recommended threshold of turbidity levels in surface water, set at less than 5 nephelometric turbidity units (NTU) for drinking water, according to World Health Organization Water Quality Standards (WHO, 2016). The influence of seasons and land use may be compounded by other factors, such as the composition and solubility of materials in the rock, soil, primary production and inflows that the water flows through (Tafangenyasha and Dzinomwa, 2005). Although this study reported that land use and seasonal aspects have a great influence on turbidity and other physico-chemical patterns of rivers, the impacts from natural river processes may also have an influence.

Conclusion

This study has demonstrated that land use systems are rapidly changing in the Ruiru and Ndarugu watersheds, and are having a direct impact on water quality parameters in rivers as a result of anthropogenic activities associated with land use types. The study highlights the important effects of agriculture and urbanization areas on surface water quality, and the potential risks that they may cause on dwindling water resources. Identification of sustainable land management systems that help maintain acceptable levels of surface water quality to optimize sustainability in water resources management are needed in this region. As demonstrated by this study, forested areas present a land use system associated with better water quality, and efforts should therefore be made to promote agriculture/urban land uses that mimic or incorporate forested areas (e.g. agroforestry and development of green areas in urban areas respectively). Such land use systems would have a favorable effect on the surface water quality in streams and rivers, which in turn may assist in reducing the risks associated with poor water quality including human health. Research on how such systems can be developed is urgently needed. In addition, this study supports Intergrated Water Resources Management (IWRM) and the potential of agricultural/urban areas to be better managed for sustainable development.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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