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PLANNING AND CONSERVATION OF URBAN RIPARIAN RESERVES: SPATIOTEMPORAL EVIDENCE FROM EARTH OBSERVATION

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ABSTRACT

Context and background:
Although a growing body of literature maintains that riparian reserves are infrequently conserved, a knowledge gap exists on how their status may be assessed through a triangulation of spatial and temporal approaches.

Goal and Objective:
This article sought to investigate through geospatial analysis the extent to which riparian reserves in Kenya were conserved as provided for under the legislation. The scope covered sections of Rivers Nyakomisaro and Nyanchwa which flows through Kisii town.

Methodology:
A case study research design was adopted to query the extent to which the standard that regulates riparian reserves was complied with along the two rivers. Geospatial data were collected using Google Earth images for the years 2005, 2011 and 2021 and analyzed using GIS.

Results:
Results showed that in 2005, 26% of the riparian reserves had been intruded by eucalyptus trees which are known to deplete water resources. This correspondingly increased to 28% and 29% in 2011 and 2021. Conversely, land under cultivation and short vegetation in 2005 covered 53%, 51% in 2011 and further declined to 41% in 2021. While built-up land covered 21% in 2005, it increased to 22% in 2011 and 29% in 2021. It generally recorded the highest intrusion into the riparian reserves as evidenced by an increase of 8% between 2005 and 2021. The study concludes that intrusion into the riparian reserves in the study area continues unabated due to insufficient development control, the absence of a common legislative framework, and a lack of monitoring to determine the magnitude of land use change that is continuously degrading the riparian landscape.

Keywords

Compliance, GIS, Kenya, Kisii town, riparian reserves

1. INTRODUCTION

The world's urban population reached 4.5 billion in 2021, surpassing the 1975 world's total population of 4.1 billion. Relatively, the number of people residing in urban areas in the last 60 years has grown more than four times. With this trend, the proportion of the people currently living in urban areas has reached 56% compared to 15% in 1900 and 34% in 1960 (Ritchie & Roser, 2018). This is projected to be 68% by 2050 with approximately 90% of the growth happening in Africa and Asia (United Nations, 2021). Surprisingly, the world's urban population had by 2009 surpassed the number of people residing in rural areas (United Nations, 2018). While the rural population is expected to peak in the next few decades and then decline, that of urban areas will exponentially grow to 6.7 billion by 2050 (World Economic Forum, 2018). On a positive front, urban areas are expected to produce more than 70% of the worldwide gross domestic product which will promote economic productivity and innovation (World Economic Forum, 2020; Zipperer, et al., 2020). However, due to insufficient development control, the progressive rapid growth especially in developing countries has and will continue to attract a multiplicity of environmental challenges with a particular orientation to the conservation of riparian reserves (Arif et al., 2020). This is bound to negate the sustainable development goal that targets to lessen the per capita environmental impacts of urban areas by 2030 (Hedden & Hedden, 2020). The riparian reserves also referred to as "buffer zones" are, therefore, one of the planning standards adopted by countries for promoting environmental conservation.

The word "riparian" is traced from the Latin word *riparius*, meaning "shore" or "riverbank" (Man, 2019). Several efforts in literature have therefore attempted to qualify this definition. For example, some say that it is an interface between a river/stream and land, and usually experiences flooding (the Republic of Kenya, 2019). The green ribbons of trees, shrubs, and herbs grown along watercourses (Headwaters Science Institute, 2019). Part of land adjoining any natural channel or depression in which water regularly or erratically flow such as the banks of rivers and streams (Wanjama, 2018; KIPPRA, 2017). Green natural vegetation zones along the lakes or rivers that are enclosed by vegetation (Holly et. al., 2017). Also encompass areas which are semiaquatic or semiterrestrial and predisposed to freshwater, ranging from the limits of water bodies to the limits of communities located on the uplands (Décamps et al., 2009), or lands occurring along watercourses and water bodies such as flood plains and streambanks (National Research Council, 2002). Riparian reserves have many documented benefits. Some of these include protecting river banks from soil erosion by stabilizing them to prevent collapsing, denitrifying groundwater, providing in-stream food supplies, and maintaining microclimate (Das et al., 2020; Boakye et al., 2017; Zanetti, et al., 2016; Goble, et al., 2015). They also provide habitats for migratory animals (Hamilton, et al., 2019; Lind et al., 2019; Zúñiga-Vega et al., 2019), and sieving water (Holly et. al., 2017) to eliminate residues before they could be discharged into the natural water channels. Despite the ascribed benefits, there is still a growing concern about their conservation status, particularly regarding incompatible uses that continually encroach on their lawfully recognized extents. This article, therefore, sought to investigate the extent to which urban riparian reserves in Kenya are conserved using geospatial analysis. It attained this through a case study of Rivers Nyakomisaro and Nyanchwa which traverse Kisii town. The study was motivated by the realization that the County Government of Kisii (CGOK) as a planning institution in the study area lacks an effective way of monitoring the unlawful use of riparian reserves. The study additionally provides empirical insight to policymakers on how the nexus between land use change and the conservation of urban riparian reserves may be spatially and temporally analysed. It further apprises the broader academic community to how the conservation of urban riparian reserves may be investigated through a systematic triangulation of both spatial and temporal approaches, thus addressing a limitation that existed in the literature. The study was undertaken between October 2021 and January 2022 in Kisii town, Kenya.

2. LITERATURE REVIEW AND THEORETICAL CONTEXT

This section reviews the literature on the conservation of riparian reserves. It seeks to align the present research with the existing body of knowledge consequently identifying gaps in land use planning literature. It also presents the theoretical background upon which the research problem is anchored.

2.1 Intrusion in the Riparian Reserves : An International Outlook

A study by Noviandi et al., (2017) along the midstream of River Ciliwung, Jarkata, Indonesia, sought to determine the extent of compliance with the 50 m and 100 m riparian reserves guidelines, a strategy for flood control and protection of water catchment. Analysis was undertaken by classifying riparian landscapes as developed and undeveloped. Research findings disclosed that developments occupied 37% of the riparian reserves resulting in ecological damage and annual flooding. In Narmada Basin, India, Sajjad et al., (2014) using a rapid on-foot survey on the banks of River Chandni Nall, also demonstrated that 80% of the riparian buffer zone was dominated by illegal agricultural practices which degraded the stream ecosystem. These findings support that of Oluwayemisi et al., (2020) who through observation and in-depth interviews confirmed the existence of incompatible activities such as fuel pumps, disposal of solid wastes, washing of cars, and sand harvesting, on the riparian reserves of rivers Omidu and Okomayan in Okun-Ijebu, Nigeria. Gazettement of 240 feet riparian buffer zone was hence recommended as a strategy for protecting the affected areas. A growing body of literature further demonstrates that compliance with recommended riparian reserves may be assessed through spatial analysis. For example, using remote sensing, Pu et al., (2021) quantified a 17% loss of riparian vegetation along Genesee River in New York between 2006 to 2015. A comparable study using Landsat 7 by Olokeogun et al., (2020) between 1999 and 2019 also showed that despite the ecological importance of riparian reserves in mitigating against floods, 19% of built-up areas were located within them in the Eleyele area of Ibadan, Nigeria. Similar findings have been recently reported by Olatidoye et al., (2021) who confirmed the destruction of 31% of the original forest land cover along the 150 m Omo Biosphere Reserve, between 1986 and 2016, and Nsor et al., (2021) who established that grazing, bush fires, farming and logging were responsible for the loss of 54% of plant species in the riparian zones of Kamawu district in Ghana. Comparable results have also been reported by Xu et al., (2020) whose analysis around Lake Tanganyika between 2001 to 2011 confirmed a high rate in the conversion of riparian forestland to arable land that fluctuated as the distance to the settlement increased.

2.2 Status of Riparian Reserves in Kenya

Various studies in Kenya have also been undertaken on the conservation of riparian reserves. For example, between 1987 and 2019, Ndalilo et al., (2021) established that cultivated lands, built environment and water bodies along River Lumi riparian reserve, Taita Taveta county, increased by 21%, 112% and 2% respectively compared to areas under forests, land used for grazing and vegetation along the rivers that respectively declined by 53%, 3% and 37%. This contributed to a loss of biodiversity hence affecting household livelihoods. In a different setting, Muketha (2020) found out that industrial and informal settlements, low, medium and high-density dwelling units heavily intruded the riparian zones along Nairobi, Mathare and Ngong' rivers in Nairobi city, resulting in adverse implications on public health. Similar findings were also reported by Meso (2013) who showed that residential developments, commercial developments, informal garages, automobile mechanical enterprises and urban agriculture encroached on the Nairobi river riparian in Ngara, Nairobi city. The space near the river remained the most highly contested with businesses making them extend into the riparian reserves that were perceived as idle. Karisa (2010) as well confirmed that 30% of the informal settlements that were located in Mathare Valley, Nairobi city, were within the thirty-metre riparian land. The problem was deepened by informal economic activities that were also sited along the reserve. As such, recovery and restoration attempts of the affected riparian reserve may not be realized as the plan is likely to displace more than 7000 households. This condition according to Omondi (2014) was further made worse by the fact that over 70% of the households directly disposed of their solid and liquid waste into the river. From the literature review, it is emerging that the legislative requirements used in regulating riparian reserves are infrequently observed. However, while most studies examine compliance concerning land use adjacent to the riparian reserves within a specific year, the current study, through spatial and temporal analysis focused on land use change within the confines of the riparian reserves thus addressing a limitation that existed in the literature.

Conservation of riparian land in Kenya is covered under various legislation. For instance, the Agriculture Act Cap 318 (Basic Land Usage Rules) prohibits farming or cutting of any vegetation on land that is situated within 2 m of a watercourse, on the other hand, if the width of a watercourse is more than 2 m, to a maximum of 30 m (the Republic of Kenya, 1965). The Survey Act conversely recommends a 30-metre minimum riparian reserve above the high-water mark for rivers whose flow and level are influenced by tides. This only applies to rivers that are on public land (the Republic of Kenya, 2012). The Environmental Management and Coordination (Water Quality) Regulations, 2006 (the Republic of Kenya, 2006) has also retained 6 m as a minimum and 30 m as maximum riparian on both sides of the river guided by the highest flood level to be ever recorded. A challenge with this requirement is that records on flood levels are rarely retained in Kenya. Lastly, the Water Resources Management Rules, 2007 (the Republic of Kenya, 2007) also bans the development of permanent structures within a minimum and maximum riparian reserve of 6 m and 30 m respectively (see Fig. 1).

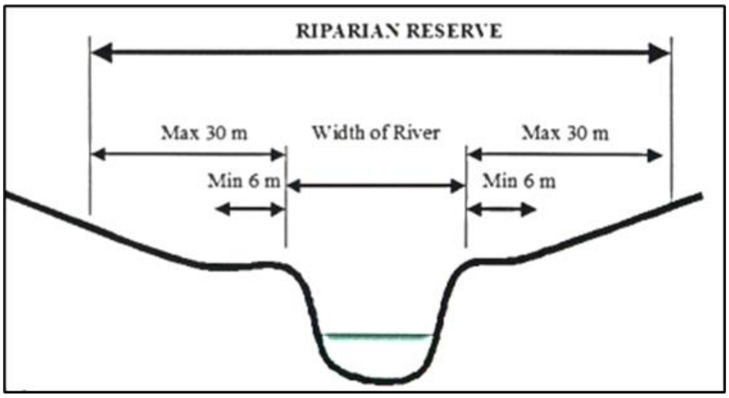

Fig. 1: Illustrated riparian reserve as per the selected laws of Kenya

However, one may argue that this is subject to manipulation by developers because it is silent on the implication of having temporary developments. Several initiatives have therefore been undertaken to reclaim riparian reserves in Kenya. For example, in 2018, the National Environment Management Authority (NEMA) for two weeks demolished buildings located on the riparian reserves in Kileleshwa, Nairobi (Omulo, 2018). This was part of a directive to demolish over 4000 buildings that were on riparian reserves. Past efforts have, however, been thwarted by influential businessmen or through court injunctions. For instance, in 2018 the Government of Kenya unsuccessfully stopped the construction of palatial residences in Spring Valley, Nairobi city, which were on riparian reserves. Although the projects stopped in 2009 following protests by activists, they were still completed in the subsequent years (Mbaka, 2018). In the same year, though the buildings hosting big shopping malls were found to be occupying riparian reserves, they could not be demolished because NEMA lost an appeal case that had been lodged by the developers (Makokha, 2018). In a similar setup, the court stopped the demolition of Greenpark Estate which had 500 houses as the Water Resources Management Authority had sought on the strength that the development sat on a riparian reserve. The houses were unfortunately completed and sold to third parties as the case dragged into court (Ochieng, 2018). Further, although NEMA in 2020 found out that 140 companies in Nairobi occupied riparian reserves, up to now, no action has been taken. The proprietors hastened to seek legal redress in the courts, therefore, delaying enforcement (Wabala, 2020). In Kisii town, several houses along the River Nyakomisaro riparian reserve were demolished after the 90-day enforcement notice given to the owners by NEMA elapsed (Nyagesiba, 2020). The move was however selective as houses on other riparian reserves were spared. It is so far apparent that legislation that regulates riparian reserves in Kenya is not only in conflict with each other but similarly not uniform. This is because they recommend varying riparian reserves in addition to being enforced by different government agencies with no coordination framework. The stalemate may suggest why encroachment on riparian reserves remains uncontrolled in the country, Kisii town being no exception.

2.3 Theoretical Context

The current research problem was guided by the Theory of Regulatory Compliance. This theory (Fiene, 2016) emphasizes the relevance of complying with guidelines, rules, legislation and regulations that have been stipulated by some authority. Applied to the study area, the theory directly underpins why riparian reserves as provided for in legislation and policy framework in Kenya should be conserved through enforcement to ensure compliance and conservation.

3. MATERIALS AND METHODS

3.1 Description of the case study area

Kisii town was formerly named by the Gusii community as “Bosongo”, a term which was associated with the practices of "white people" who once resided in the town during the colonial period. It is located in the southwestern part of Kenya, about 1,700 m above sea level, 313 km from Nairobi, the capital city of Kenya (Fig. 2) and currently serves as the Kisii County headquarters. The major economic activity in the town's hinterland and some of its neighbourhoods are agriculture (Ondieki et al., 2021). Its population in 2019 was 112,417 and is projected to be 250,000 by 2030 with an annual growth rate of 2.4%. With a population density of 2,862 per km^2, Kisii town is the third most densely populated urban area in Kenya (Kenya had 307 urban centres by 2022). Concerning spatial extent, although the town covers 34 km^2, just 4.35 km^2 is planned, meaning that much development is taking place without any spatial planning intervention (Omollo, 2018). This may suggest why most riparian reserves have been intruded on by developers. The town is traversed by permanent rivers which flow westwards into Lake Victoria. These include Getare, Nyakomisaro and Riana. The current study covered 4 km of rivers Nyanchwa and Nyakomisaro (Fig. 2) . The sections were selected because they existed within the most densely built-up areas. They are also placed within the 4.35 km^2 covered by the town’s physical development plan. It was therefore necessary to find out if the plan was effective in development control.

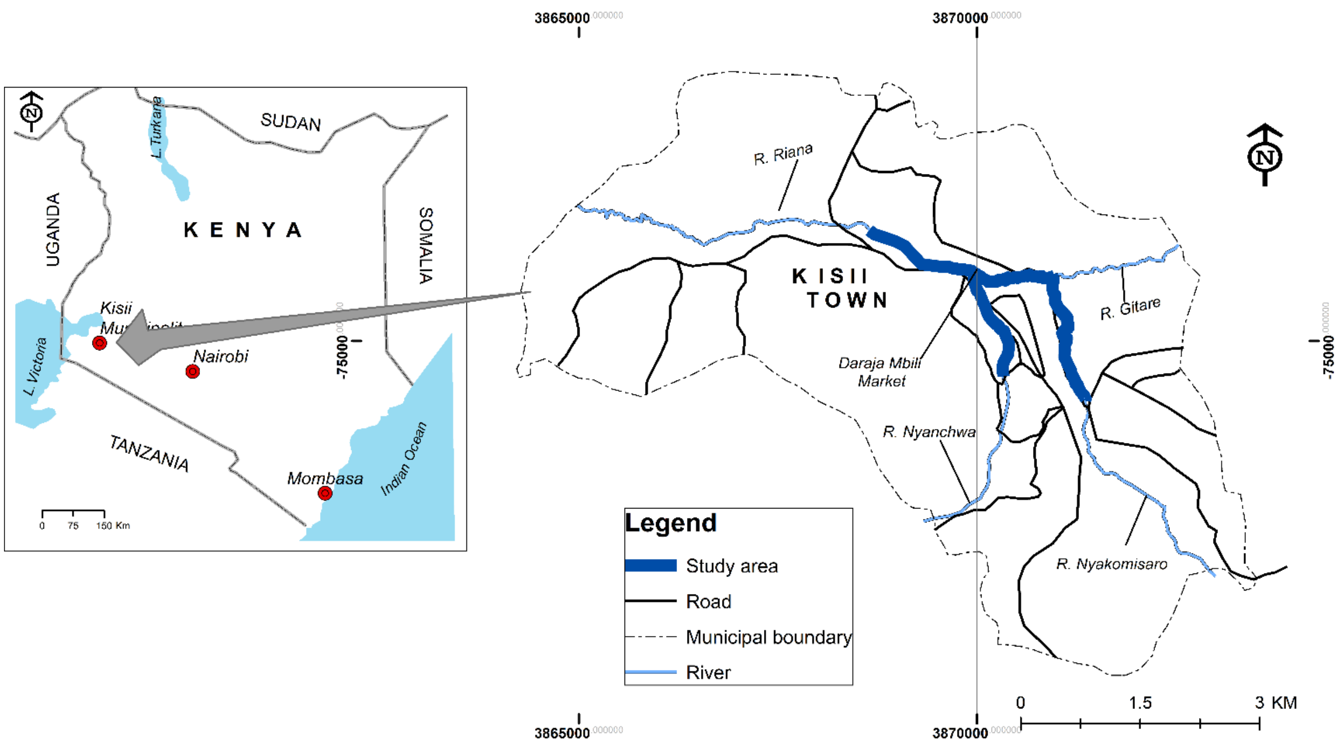

Fig. 2: Location of the study area

Both River Nyanchwa and River Nyakomisaro are tributaries of River Riana. River Nyakomisaro is highly depended on by residents of Kisii town because it is their major source of water. The two rivers intersect at Daraja Mbili to form River Riana. River Getare on the other hand is a tributary of River Nyakomisaro.

3.2 Research Design

This research espoused a case study design, a technique that is suitable when there is a necessity to undertake an in-depth understanding of an intricate issue within its natural and real-time setting (Rashid et al., 2019; Crowe et al., 2011). Applied to the current study, the approach was used to intensely query the extent to which the standard that regulates riparian reserves is complied with in Kenya with detailed attention to the sections along with the riparian reserves of Rivers Nyakomisaro and Nyanchwa in Kisii town, Kenya. Because of the in-depth nature of the geospatial analysis that was adopted, the design may also be applied in other urban centres that are also facing a challenges in the conservation of their riparian reserves.

3.3 Choice of appropriate riparian reserve

Given an absence of unanimity on the widths of riparian reserves by legislation in Kenya, the current study adopted the upper limit of 30 m on either side of Rivers Nyakomisaro and Nyanchwa. This fact was corroborated by the realization that there is a lot of rainfall (average of 1895 mm) throughout the year in Kisii town (Weather Atlas, 2021), the driest months not being an exception. The average rainfall day per month is 24, signifying that the rivers in the town are susceptible to flooding. For instance, in 2015 (Abuga, 2015), heavy rains made River Nyakomisaro burst its banks subsequently affecting traders who lost large quantities of their horticultural produce sold at the busy Daraja Mbili market. Further, in May 2021, 150 people in Mokubo village were rendered homeless after a landslide destroyed their houses and crops due to heavy rains (Nyagesiba, 2020). In consequence of the foregoing evidence, a minimum riparian reserve of 6 m is not sustainable in the study area.

3.4 Data collection and analysis

The existing online resources with satellite imagery present a useful point of reference for obtaining free and current geospatial data that is easy to use. Google Earth (GE) images as one of such readily available tools for gathering spatial data can be used for spatial analysis in a rapidly changing urban environment (Pu et al., 2021; Zhao et al., 2021; Jacobson et al., 2015). Due to this, GE is commonly used in undertaking land use studies toward solving problems related to spatial planning (Hossein et al., 2021). Based on these suggestions, spatial data was collected using three GE images covering the epochs 2005, 2011 and 2021 to determine the implications of land use change in the study area. The following steps were followed in collecting and analysing the collected spatial data:

a. Copying and saving in jpeg file format the three images.
b. Georeferencing the images using 150 ground control points and afterwards transformation using 1st order polynomial (affine). The step also involved defining the appropriate coordinate reference system, in this case, WGS 1984 UTM zone 36S, false easting 500,000 m, false northing of 10,000,000 m and a central meridian of 33,000 m.
c. Digitizing the rivers and generating 30-metre buffers on either side of the three images to depict the riparian reserves.
d. Clipping the areas covered by the 30-metre buffers from each image.
e. Running iso cluster unsupervised classification to automatically divide the spatial data into groups of similar items from each of the images.

f. Accuracy assessment through stratified random sampling (using 150 points on each image) of 2005, 2011 and 2021 classifications to a certain validity.
g. Preparing land use classification maps for 2005, 2011 and 2021.
h. Computing and spatially analysing land use change between 2005, 2011 and 2021based on the data contained from the respective attribute tables.

4. RESULTS AND DISCUSSION

This study sought to gain insight into whether the planned urban riparian reserves in Kenya are conserved by planning authorities. It accomplished this through a case study of Rivers Nyakomisaro and Nyanchwa which traverses Kisii town. This section therefore presents and discusses the results that have emanated from the research findings. To attain this, it is organized into four different but related subsections. While the first subsection discusses the land use classification scheme that was adopted, the second, third and fourth subsections respectively focuses on land use change within the riparian reserves of Rivers Nyakomisaro and Nyanchwa for the years 2005, 2011 and 2021.

4.1 Land Use Classification Scheme

Land use entails a description of the grouping and extent of human activities that occur in a certain location. Land use classification, therefore, provides the basis for monitoring and forecasting the patterns of urban development, management of natural resources and spatial planning. This contributes to a better understanding of the environment and its dynamics (Liping et al.,2018). Even though several land use classifications have been developed, there is still no universally accepted scheme for classifying land use (Jansen & Di Gregorio, 2015). Due to this gap in the land use and earth observation literature, classifications are always designed to address what the users aim to achieve. Based on the knowledge gained from the study area along with surveys that were undertaken, a land use classification scheme, guided by a proposal from Anderson et al., (1976) was developed in Table 1 to determine the extent to which riparian reserves in the study area were conserved.

Table 1: Land use classification scheme for the study area

Type of land use	Description
Trees	Densely planted trees that form closed canopies.
Cultivated land/short vegetation	Land used for cultivating crops, for example, bananas, napier grass, maize, vegetables or tea bushes. Also include short riparian vegetation that occurs or grows in situ or without human intervention.
Built-up land	Areas having residential, commercial, industrial, business/residential, roads and transportation terminus developments. Also included areas that were intermittently converting or changing from one land use to another. Similarly ensues when any category of land use stops occurring as its area become temporarily bare or barren.

4.2 Land Use in 2005

The year 2005 was taken as the base for determining the interplay among various categories of land use on the riparian reserves in the study area. Initial spatial analysis showed that during this period, cultivated land and short vegetation covered 53% compared to trees and built-up land that respectively covered 21% and 26%. This is spatially depicted in Fig. 3

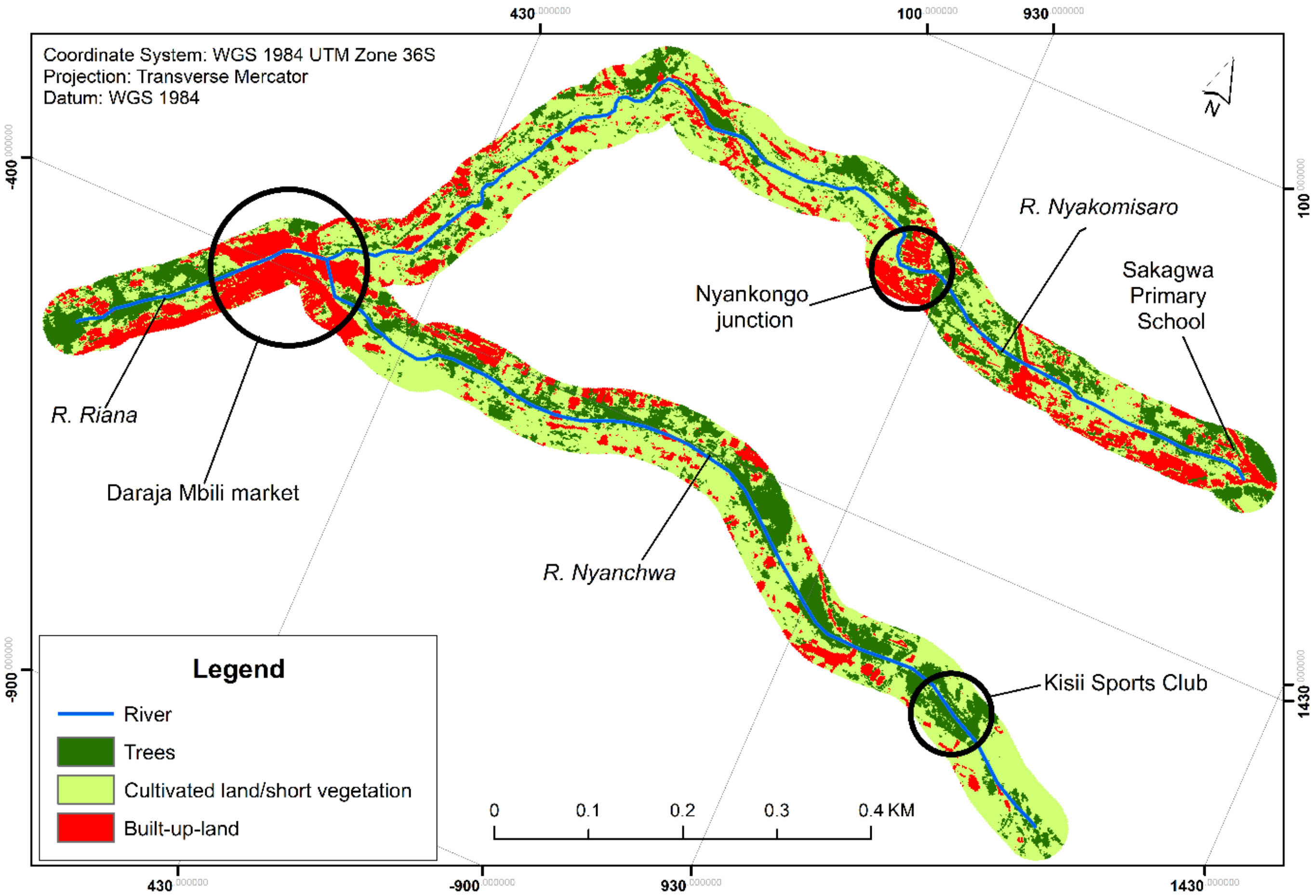

Fig. 3: Intrusion in the riparian reserves, 2005

Much of the built-up land was located around the Daraja Mbili market at the confluence of rivers Nyanchwa and Nyakomisaro (Fig. 3). The market accommodates approximately 7,000 large and small-scale traders every Monday and Thursday. A majority of those who sell goods on a large scale in the market travel from as far as Uganda and Tanzania. The spatial analysis further confirms that most of the area covered by the market is located within the 30-metre riparian reserve. Intrusion in the riparian reserve in 2005 was, therefore, more pronounced around Daraja Mbili than in any other place. Regarding River Nyakomisaro, the most affected sections by built-up land were the strip of land behind Sakagwa Primary School, a public school, which was dominated by comprehensive commercial developments. It is also worth noting that part of this public school also fell within the riparian reserve of River Nyakomisaro. Other built-up land brought about by commercial developments also occupied the junctions of major roads adjoining riparian reserves hence contributing to non-conformity. Cultivated land and short vegetation were also observed to occupy the riparian reserves as shown in Fig. 3.

Another visible land use with the riparian reserves was the planting of eucalyptus trees. Much of these trees were dominant around the Kisii Sports Club and Gusii Stadium. Eucalyptus trees suck up lots of water and are known to deplete water resources, therefore, having them along rivers and waterbodies is not sustainable. Accuracy assessment is one of the obligatory steps in the analysis of data that has been acquired through remote sensing (Radoux & Bogaert, 2017). It refers to the degree to which the results of calculations, observations or approximations correspond to the known true values (Lyons et al., 2018). To assess the validity of the 2005 classification, the overall, producer and user accuracies, along with the Kappa coefficient were computed. Results are presented in Table 2 in form of a confusion (error) matrix that compares the classified image against the corresponding satellite image for 2005 which also provided the ground truth data.

Table 2: Confusion matrix for 2005 land use classification

	Trees	Cultivated land/short vegetation	Built-up-land	Total	User Accuracy	Kappa
Trees	26	0	0	26	1	
Cultivated land/short vegetation	0	45	8	55	0.85	
Built-up-land	0	0	21	21	1	
Total	26	45	29	100	-	
Producer accuracy	1	1	0.72	0	0.92	
		Kappa				0.87

User accuracy is the likelihood that a value predicted to belong to a specific class truly belongs to that class. It is determined by the proportion of the values that have been correctly predicted to the sum of values that have been predicted to exist in a class. It shows accuracy from the viewpoint of a map user by displaying how the class shown on the map will be existing on the ground. The user accuracy for the 2005 classification was correspondingly 100%, 85% and 100% for trees, cultivated land/short vegetation, and built-up land. The commission error for cultivated land/short vegetation land was 15% due to spectral similarity with built-up land. The producer's accuracy, in contrast, displays accuracy from the viewpoint of the person making the map, that is, the producer. It determines how the real features on the ground have been correctly displayed on the map or the likelihood that a particular land cover on the ground is accurately classified, and is associated with the omission error. The producer accuracies for 2005 were respectively 100%, 100% and 72% for trees, cultivated land/short vegetation, and built-up land. The omission error of 28% for built-up land suggests that some of its cells had spectral similarities with cultivated land/short vegetation. The overall accuracy of 92% exceeded the 80% threshold that Anderson et al., (1976) recommend. Kappa Coefficient (87%) also showed an almost perfect agreement for the classification.

4.3 Land Use in 2011

While land use under trees in 2011 accounted for 28% of the total riparian land use (2% increase from 2005), that of cultivated land/short vegetation was 50% (a decline of 3% from 2005). Built-up land constituted 22%, (1% increase from 2005). Similar to 2005, most of the change concerning built-up land continued to occur around Daraja Mbili market at the confluence of Rivers Nyanchwa and Nyakomisaro, eventually forming River Riana (see Fig. 4).

Cultivated land/short vegetation declined due to their probable change of use to residential developments in response to an increase in demand by the town's growing number of households. The escalation of built-up land in Daraja Mbili was driven by the urge to expand it to a modern economic hub in the Western Kenya region (the County Government of Kisii, 2016). To attain this vision, the CGOK partnered with the national government in ensuring that the market would accommodate over 700 traders. Through this initiative, it was envisaged that the market will favourably compete with other popular regional open-air markets in Kenya such as Kibuye and Kongowea in Kisumu and Mombasa cities respectively. The expansion entailed the construction of parking spaces, modern stalls, retail and wholesale shops, washrooms and high mast floodlights among others. Modernizing the market was further intended to increase employment opportunities and revenue for the CGOK while also improving the livelihoods of traders. The proposal was nevertheless not preceded by risk-based land use planning as the project further resulted in the expansion of the built-up land on the neighbouring riparian reserve. An increase in the built-up land was also fast-tracked by the unplanned commercial developments at the strip of land behind Sakagwa Primary School (see Fig. 4), further attracting intrusion into the riparian reserves at the expense of attaining sustainable urban development.

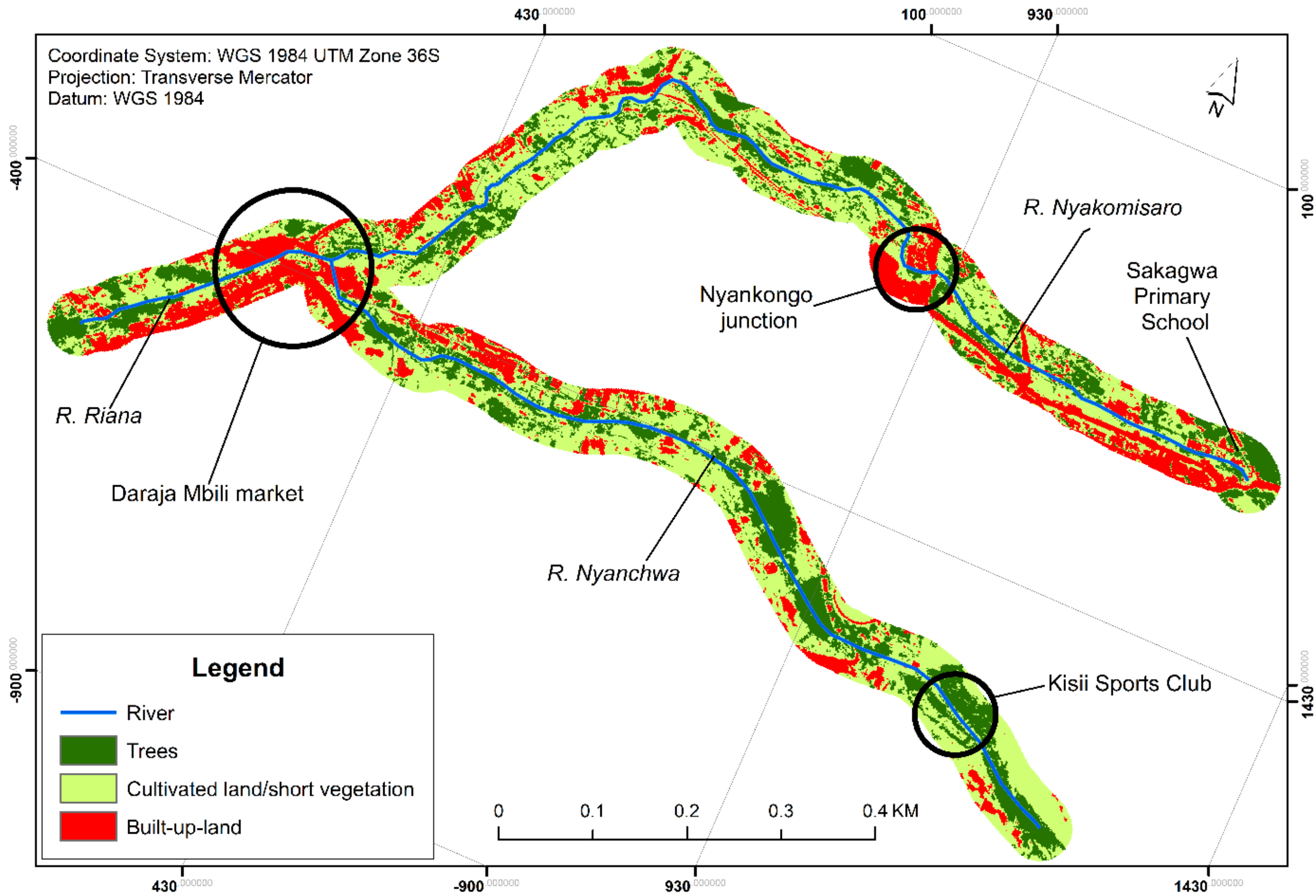

Fig. 4: Intrusion in the riparian reserves, 2011

Relating to trees, their coverage also increased, therefore, endangering the fragile riparian ecosystem. As alluded to before, the dominant species are the eucalyptus owing to their rapid growth rate which makes them readily available to satisfy the demand created by the local and regional building construction industry. In an attempt to curb the problem, the Assistant County Commissioner during the celebrations to mark world environment day recommended their urgent removal from riparian reserves (Miruka, 2011). These sentiments were also echoed by the Governor of Kisii county (Obebo, 2019) when he gave an executive order requiring all residents to within three months, remove eucalyptus trees from the riparian reserves in Kisii town. In its place, he recommended that the trees be planted at least 50 m from the water catchment areas. The directive is, however, yet to be complied with as evidenced by Fig. 4 because the orders were not followed by monitoring and enforcement. It is also worth noting that currently, there is no policy or legislative framework in Kenya that has set a minimum distance of 50 m. from rivers when planting trees as stated by the Governor.

A similar edict was issued by the Cabinet Secretary, Environment, in 2019 when he stated that the Government will not allow the planting of eucalyptus trees on riparian reserves and water catchment areas because they contribute to the depletion of water. In concurrence with the Governor, he opined that the residents should be planting trees that are water-friendly. These directives, though well-intended, confirm the argument by Karisa (2010) who stated that fragmented regulations and policies are among the topical challenges facing the conservation of riparian areas in Kenya. Akin to 2005, cultivation of the riparian reserves continued to prominently feature in 2011 with no attempts at monitoring and development control. This problem may have arisen on the presumption that because the reserves appeared vacant with no prior ownership claim, they may be freely used for cultivation, hence threatening the fragile ecosystem. As the case of the 2005 classification, an accuracy assessment for the 2011 classification was also undertaken in Table 3.

Table 3: Confusion matrix for 2011 land use classification

	Trees	Cultivated land/short vegetation	Built-up-land	Total	User Accuracy	Kappa
Trees	28	0	0	28	1	
Cultivated land/short vegetation	2	44	4	50	0.88	
Built-up-land	0	0	22	22	1	
Total	30	44	26	100	-	
Producer accuracy	0.93	1	0.85	0	0.94	
Kappa						0.91

The overall accuracy for the 2011 classification was 94%, exceeding the 80% threshold that Anderson et al., (1976) have recommended. The corresponding Kappa Coefficient of 91% also confirmed an almost perfect agreement, giving credence that the classification was reliable. The user's commission error of 12% was a result of cultivated land/short vegetation whose spectral characteristics correlated to that of built-up land. A similar explanation arose for built-up land whose producer accuracy was 15%.

4.4 Land Use in 2021

The interplay between land use change and riparian reserves continued being witnessed in 2021. By this time as compared to 2005, built-up land covered 29% representing a marginal increment of 8% (see Fig. 5 and Table 4). While trees covered 29% with an increase of 3% from 2005, cultivated land/short vegetation accounted for 41%, a decline from 53% that existed in 2005.

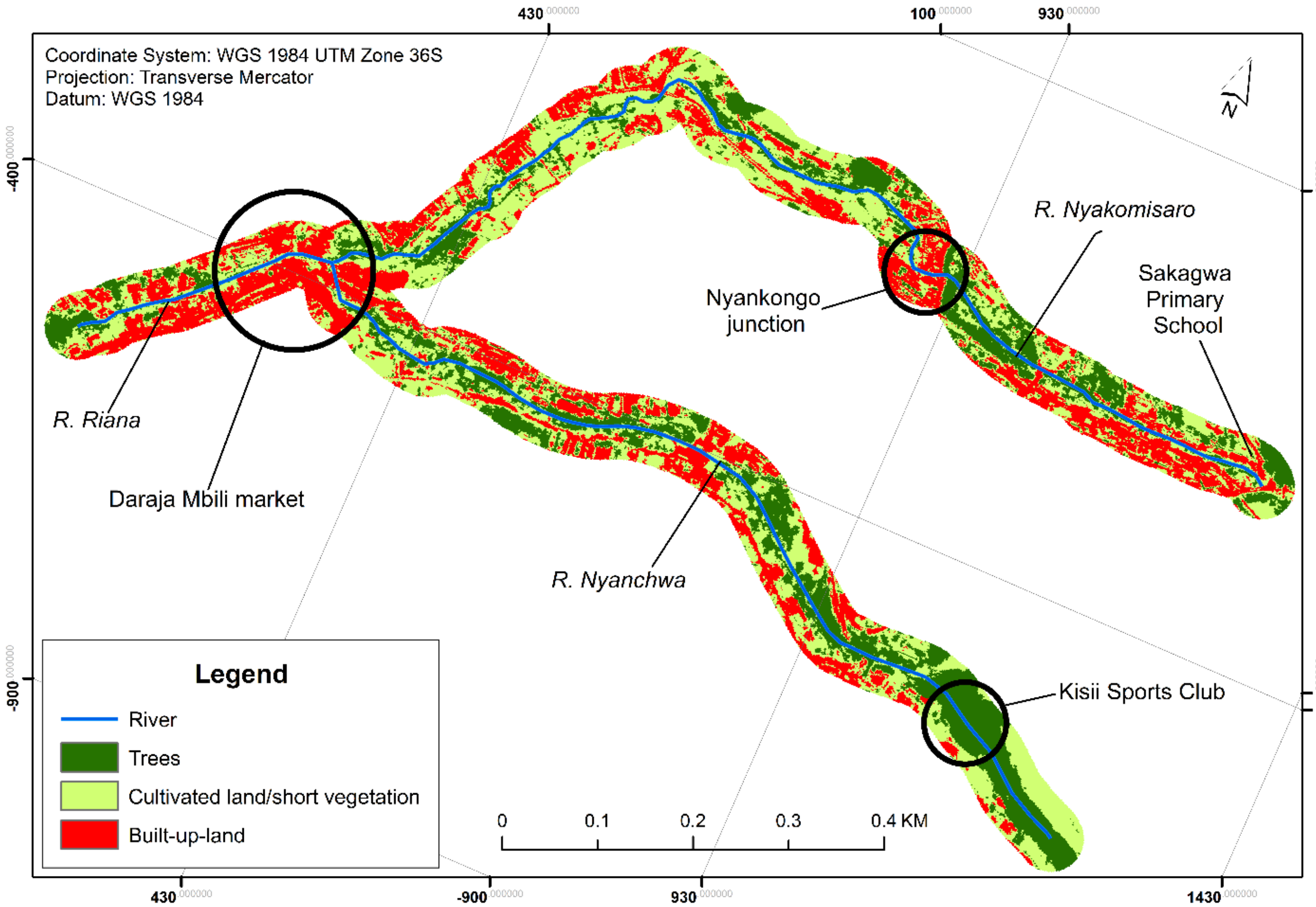

Fig. 5: Intrusion in the riparian reserves, 2021

Further comparison was undertaken between 2021 and 2011 (Table 4). Results showed that during this period, tree covers slightly increased by 1%, cultivated land/short vegetation reduced by 9% and built-up land increased by 7%. It is therefore evident that built-up land emerged as the most dominant land use in the riparian reserves of the study area.

Table 4: Comparative land use change, 2005, 2011 and 2021

	2005	%	2011	%	2021	%	% Change, 2011-2021
Trees	5	26	5	28	5	29	1
Cultivated land/short vegetation	10	53	9	50	7	41	-9
Built-up land	4	21	4	22	5	29	7

Table 4 corroborates Fig. 5 which shows that by 2021, most of the built-up land formed a linear pattern on the riparian reserves further confirming the magnitude by which the planning standard had been overlooked. Unlike in 2005 and 2011 when Daraja Mbili appeared to have the highest density of built-up land, in 2021, the built-up land is now evenly distributed and appears to be dominating the riparian reserves. It confirms the magnitude that the built-up land is now having on the riparian reserves. Due to this, it is predicted that in absence of adequate development control, much of the riparian reserves in the study area will quickly change to built-up land at the expense of sustainable environmental conservation and urban development. It is worth noting that the recently launched Kisii Municipality Economic Development Plan is likely to accelerate the town's economic growth through increased demand for built-up land. In absence of spatial planning interventions, the invasion of riparian reserves is bound to escalate as investors will strive to earmark more land for development. The problem is also likely to hasten because of the projected increase in the town's population. Another notable change that is also evident in 2021 is an increase in land under trees. An example is a part of River Nyanchwa (Fig. 5) that falls within the Kisii Sports Club where most trees planted on the riparian reserve are eucalyptus. Cultivated land/short vegetation witnessed the highest loss (9%) in 2011. It is likely that this transition was triggered by their change of use to built-up land and partly to trees. The accuracy assessment for the 2021 land use classification is presented in Table 5.

Table 5: Confusion matrix for 2011 land use classification

	Trees	Cultivated land/short vegetation	Built-up-land	Total	User Accuracy	Kappa
Trees	29	0	0	29	1	
Cultivated land/short vegetation	1	29	19	41	0.51	
Built-up-land	0	0	30	1	1	
Total	30	21	39	100	-	
Producer accuracy	0.97	1	0.61	0	0.80	
Kappa						0.71

User accuracies for trees and built-land were respectively 100%. The commission error for cultivated land/short vegetation was 49% since most of this category was incorrectly classified as built-up land. Regarding producer accuracies, areas covered by trees and built-up land had omission errors of 3% and 39% respectively, showing that a pixel belonging to trees was excluded in favour of cultivated land/short vegetation. Also, pixels belonging to built-up land were omitted in favour of cultivated land/short vegetation. The errors do not, however, affect the validity of the classification since the overall accuracy is 80% with a Kappa Coefficient of 71%. Conformity is also demonstrated within a section of Daraja Mbili using satellite images of 2005 and 2021 (see Fig. 6 and Fig.7 for a comparison).

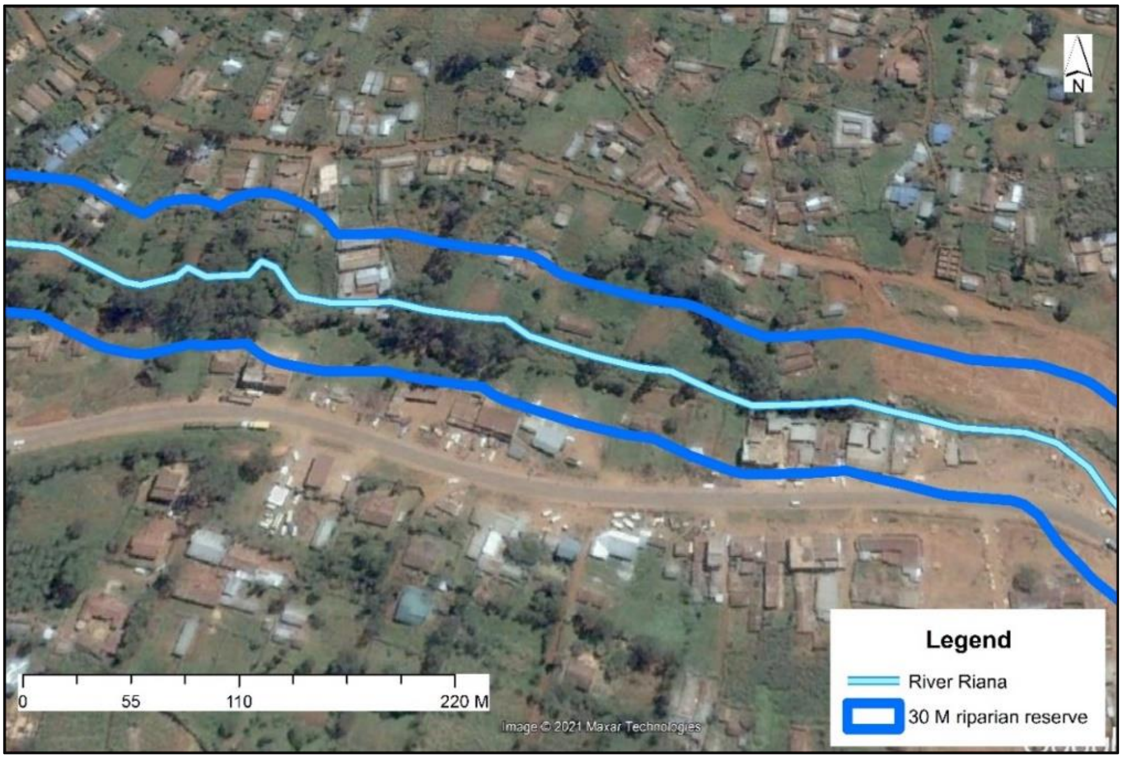

Fig 6: Land use on riparian reserve in 2005

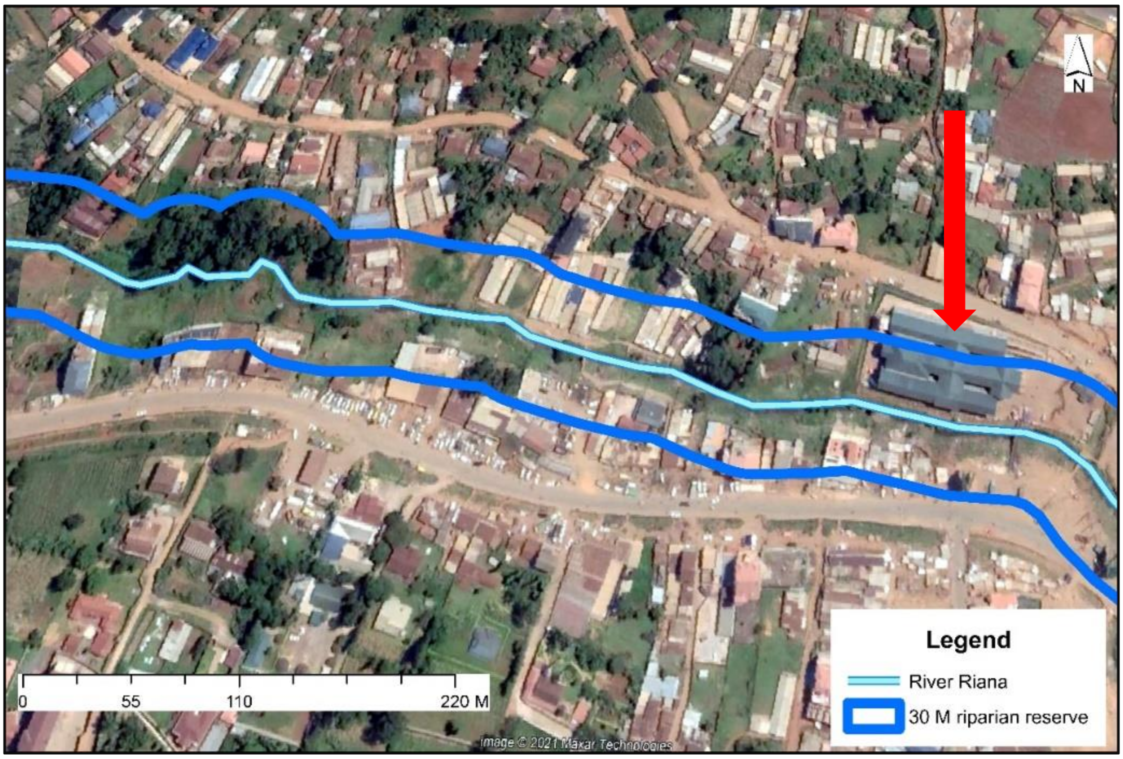

Fig. 7: Land use on riparian reserve in 2021

Fig. 6 shows that in 2005, the 30-metre riparian reserve was largely dominated by cultivation agriculture. The density of built-up land was also limited as demonstrated by building developments that were sparsely distributed. The riparian reserve is also mainly characterized by cultivation agriculture. The situation is however different in Fig. 7 where built-up land now dominates the riparian reserve. Also evident are trees that have now been cleared to provide room for building developments. Much of the cultivated land/short vegetation that existed along the riparian reserve in 2005 has now been converted to built-up land. A more conspicuous change in 2021 was the building constructed by the CGOK as an initiative toward modernizing Daraja Mbili Market (see red pointed arrow). Unfortunately, this is also located within the riparian reserve. A similar project is the recently constructed fire station by the CGOK which is also located within the riparian reserve of River Nyakomisaro. It can therefore be argued that the CGOK as a planning authority also contravenes the guidelines that regulate the use of riparian reserves. Fig. 6 and Fig. 7 have, therefore, validated that the spatiotemporal interplay between various land use has been contributing to the degradation of the riparian reserves in the study area. Fig. 8 also shows a section of the River Nyakomisaro riparian reserve that has been invaded by informal settlements, consequently polluting the water.

Fig. 8: Developments along sections of River Nyakomisaro riparian reserve

The findings of this study concur with that of Noviandi et al., (2017) who established that 37% of developments had intruded the recommended 50 m and 100 m riparian reserves along River Ciliwung, Jarkata, Indonesia. The findings further corroborate well with that of Sajjad et al., (2014) who established that 80% of the River Chandni Nall riparian reserve had been dominated by uncontrolled agricultural activities, as well as Yunus et al., (2004) who established that rapid development along the 50 m Pinang River reserve in Malaysia had significantly deteriorated the riparian ecosystem between 1992 and 2000. The findings from this study further compare to that of

Karisa (2010) who found out that most informal housing units in Mathare Valley, Nairobi ignored the 30 m riparian reserve. However, these studies are limited by either examining compliance from the perspective of general land use that is adjoining the riparian reserves, or by examining noncompliance within a single year. On the contrary, the current study, through a spatial triangulation of temporal analysis focused on land use change within the exclusive confines of the recommended riparian reserves consequently addressing a limitation that existed in the land use and town planning literature. Through this approach, the current study has provided a basis for a comparative analysis of land use change, thus forming a trajectory for spatially modelling the likely future scenarios on the conservation of urban riparian reserves.

5. CONCLUSION

This study sought to determine whether the planned urban riparian reserves in Kenya are conserved as per the standards provided in the legislation through a case study of Rivers Nyakomisaro and Nyanchwa in Kisii town. To this end, it is manifest that although the existing legislation recommends appropriate widths for riparian reserves in the study area, the standard is disregarded as evidenced by space contestation on the riparian reserves that are driven by the cultivation agriculture, planted eucalyptus trees and built-up land. Expansion of built-up land on the reserves however remains the most dominant among the three competing land use categories. The existing setup contributes to the dilapidation of the riparian reserves consequently undermining the development control principles of conservation, conformity and compatibility. The problems continue even though the CGOK retains the statutory powers of controlling unauthorized developments on riparian reserves. As a way forward, three recommendations are made. First, because the existing legislation in Kenya provides conflicting widths of riparian reserves, it is suggested that to operate within a common standard, the determination of riparian reserves should be based on the classified widths of the river channel. However, for this to be realistic, a comprehensive audit of rivers in the country that will result in their classification through legislation should be undertaken. Second, the CGOK should establish a GIS and earth observation laboratory to provide a spatial framework for monitoring land use change within riparian reserves. Third, the CGOK should fully utilize the existing legislative instruments for development control to deter unauthorized developments in the riparian reserves in Kisii town. The findings of the current study have therefore provided compelling evidence to policymakers on how to spatially determine the nexus between land use change and conservation of urban riparian reserves. It has further apprised the broader academic international community on how the conservation of riparian reserves may be investigated through a triangulation of spatial and temporal approaches, thus addressing a gap that previously existed in the literature. This study was, however, limited to spatially determining conformity to recommended riparian reserves. To further enrich the debate, future research agenda in urban land use planning and earth observation may be conducted to explore the nexus between an intrusion on riparian reserves and the loss of biodiversity.

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8. AUTHORS' CONTRIBUTIONS

Dr. W.O. Omollo initiated the research concept and developed the methodology. He further interpreted and analyzed the spatiotemporal data. Dr. G. M. Ogendi sourced for the satellite images, undertook a literature review, and provided the introductory background as well as the theoretical context. Both authors edited the paper to ensure completeness and consistency with the journal's formatting guidelines. They also jointly provided the conclusion and recommendations.

9. REFERENCES

Abuga, E., (2015, 10 November). Floods daze Kisii town following heavy down pour. *The Standard Newspaper.* https://www.standardmedia.co.ke /nyanza/article/2000182165/floods-daze-kisii-town-following-heavy-down-pour

Anderson, J.R., Hardy, E.E., Roach, J.T., & Witmer, R.E.(1976). A land use and land cover classification system for use with remote sensor data. *Geological Survey Professional Paper 964.* https://pubs.usgs.gov/pp/0964/report.pdf

Arif, M., Zhang, S., Jie, Z., Wokadala, C., P.S, & Changxiao , L. (2020). Evaluating the effects of pressure indicators on riparian zone health conditions in the Three Gorges Dam Reservoir, China. *Forests,* 11(214),1-20. https://www.mdpi.com/1999-4907/11/2/214

Boakye, E.A., Hyppolite, D.N., Barnes, V.R., & Porembski, S. (2017). Importance of forest buffers for preserving soil carbon and nutrient stocks in farmed landscapes along two river sites in the savannas of the Volta basin, Ghana. *Arid Land Research and Management*, 31(2), 219–233. https://www.tandfonline.com/doi/abs/10.1080/15324982.2016.1276984

County Government of Kisii. (2016). State embarks on construction of daraja mbili market. https://kisii.go.ke/index.php/item/2033-state-embarks-on-construction-of-daraja-mbili-market

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, 11(100), 2-10.____https:// bmcmedresmethodol.biomedcentral.com /articles/10.1186/1471-2288-11-100

Das, M., Das, A., Momin, S., & Pandey, R. (2020). Mapping the effect of climate change on community livelihood vulnerability in the riparian region of Gangatic Plain, India. *Ecological Indicators*, 119(2020), 1-13. https://www.sciencedirect.com/science/article/abs/pii/S1470160X20307536

Décamps, H., Naiman, R.J., & McClain, M.E. (2009). Riparian zones. Editor(s): Gene E. Likens, Encyclopedia of Inland Waters, *Academic Press*, 396-403. https://www.worldcat.org /title/encyclopedia-of-inland-waters /oclc/319211428

Fiene, R. (2016). Theory of regulatory compliance SSRN. https://papers.ssrn.com/sol3/ papers.cfm?abstract_id=3239691

Goble, D. D., Cosens, B., Davis, F.W.J., & Scott, M. (2015). A riparian conservation network for ecological resilience. *Biological Conservation*. 191, 29–37. https://escholarship.org/content/ qt37c5j22w/ qt37c5j22w.pdf

Hamilton, M., Nelson, S.V., Fernandez, D.P., & Hunt, K, D. (2019). Detecting riparian habitat preferences in "savanna" chimpanzees and associated Fauna with strontium isotope ratios: Implications for reconstructing habitat use by the chimpanzee-human last common ancestor. *American Journal of Physical Anthropology,* 170(4), 551-564. https://pubmed.ncbi.nlm.nih.gov/31633810/

Headwaters Science Institute. (2019). Spotlight: Riparian areas. https:// headwatersscienceinstitute.org /spotlight-riparian-areas/

Hedden, M.J.D., & Hedden, S. (2020). Are we on the right path to achieve the sustainable development goals? *World Development*, 127(2020), 1-3. https://www.sciencedirect.com/science/article/pii /S0305750X19303985?via%3Dihub

Holly, B., Gray, C.L., Luke, S,H., Nainar, A., Jake L. S., &Turner, E.C. (2017). RSPO Manual on Best Management Practices (BMPs) for the management and rehabilitation of riparian reserves. https://rspo.org/publications/download/291282332c4e5b5

Hossein S.M., Morteza, K., Seyed, K.A., & Qihao, W. (2021). Google Earth Engine for large-scale land use and land cover mapping: an object-based classification approach using spectral, textural and topographical factors. *GIScience & Remote Sensing*, 58 (6), 914-928. https://www .tandfonline.com /doi/full/10.1080/15481603.2021.1947623

Jacobson, A., Jasjeet, D., Godfrey, J., Jacobson, H., Rossman, Z., Stanish, A., Walker, H., & Riggio, J. (2015). A novel approach to mapping land conversion using Google Earth with an application to East Africa, *Environmental Modelling & Software*, 72:1-9. https://www.sciencedirect.com /science/article/ pii/S1364815215001747

Jansen, L, J.M., & Di Gregorio, A. (2015). The problems of current land cover classifications: Development of a new approach**.** https://www.researchgate.net/publication/257314048_The_problems_of_ current_land-cover_classifications_development_of_a_new_approach

Karisa, C.D. (2010). A negotiated framework for rehabilitation of riparian zones in Nairobi city: the case of Mathare River Valley. A paper presented at the 46th ISOCARP Congress. http://erepository.uonbi.ac.ke/handle/11295/45770

KIPPRA. (2017). Destruction of riparian zones in the Nairobi metropolitan region, KIPPRA Discussion Paper No. 197. https://repository.kippra.or.ke/handle/123456789/2499

Liping, C., Yujun S., & Saeed, S. (2018). Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques—A case study of a hilly area, Jiangle, China. *PLoS ONE,* 13(7), e0200493. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0200493

Lind, L., Hasselquist, E.M., & Laudon, H. (2019). Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. *Journal of Environmental Management*. 249(2019). https://www.sciencedirect.com /science/article/pii/S0301479719311090

Lyons, B., Keith, D A., Phinn, S. R., Mason, T. J., Elith, J. (2018). A comparison of resampling methods for remote sensing classification and accuracy assessment. *Remote Sensing of Environment.*, 208(2018), 145–153. https://www.sciencedirect.com/science/article/abs/pii/S0034425718300324

Makokha, T. (2018, 14 June). The year of demolitions, the Sunday Standard. https:// www.standardmedia.co.ke/nairobi/article/2001307652/the-year-of-demolitions

Man, K.H. (2019). Flora and species diversity of riparian zones at Yongheung Stream, Hapcheon-Gun Province, Korea, *European Journal of Engineering and Technology Research*, 4 (7), 21-27. https://www.ejers.org/index.php/ejers/article/view/1410/585

Mbaka, J. (2018, 07 August). Impunity thwarts efforts to reclaim riparian land, *Star News.* https://www.the-star.co.ke/news/2018-08-07-impunity-thwarts-efforts-to-reclaim-riparian-land/

Meso, J. (2013). Space contestation in the riparian zone of Nairobi CBD, Ngara section. Unpublished master's thesis, University of Nairobi. https://www.academia.edu/4219098/Space _Contestation_in_the_Riparian_Zone_of_Nairobi_CBD_Ngara_Section

Miruka, K. (2011, 7 June). Eucalyptus threatens water sources in Kisii, The standard newspaper (1 page). https://www.standardmedia.co.ke/busia/article/2000036659/eucalyptus-threaten-water-sources-in-kisii

Muketha, M. (2020). Riparian land control, contestation and its implication to conservation in Nairobi City :A case study of Nairobi, Mathare and Ngong' Rivers, *Africa Habitat Review Journal*, 14(3):1941-1962. http://uonjournals.uonbi.ac.ke/ojs/index.php/ahr/article/view/667/667

National Research Council. (2002). Riparian Areas: Functions and strategies for management. Washington, DC: The National Academies Press. https://doi.org/10.17226/10327

Ndalilo, L. A., Maranga, E. K., & Kirui, B. K. (2021). Land use and land cover change along River Lumi riparian ecosystem in Kenya: Implications on local livelihoods. *Open Journal of Forestry*, 11, 206-221. https://doi.org/10.4236/ojf.2021.113014

Noviandi, T. U. Z., Kaswanto, R. L., & Arifin, H. S. (2017). Riparian landscape management in the midstream of Ciliwung River as supporting water sensitive cities program with priority of productive landscape. OP Conference Series: *Environmental Earth Sciences*. https://ui.adsabs.harvard.edu/ abs/2017E&ES...91a2033N/abstract

Nsor, C,A., Mensah,J.N., Barnes, V.R., & Akomatey, P.K. (2021). Anthropogenic drivers of plant species coexistence in selected riparian systems, Kumawu district, Ashanti region (Ghana), *Journal of Freshwater Ecology*, 36 (1), 323-344. https://www.tandfonline.com/doi/pdf/10.1080/ 02705060. 2021.1985642

Nyagesiba, B., (2020, 04 May). Floods, landslides displace over 400 households in Kisii. *Star Newspaper.* https://www.the-star.co.ke/news/2020-05-04-floods-landslides-displace-over-400-households-in-kisii/

Obebo, M., (2019, 09 July). Ongwae orders removal of eucalyptus from river banks. *Star newspaper*. https://www.the-star.co.ke/news/2019-07-09-ongwae-orders-removal-of-eucalyptus-from-river-banks/

Ochieng, A., (2018, 21 June). High Court stops demolition of posh Greenpark Estate in Athi River. *Nairobi news*. https://nairobinews.nation.africa/high-court-stops-demolition-of-posh-greenpark-estate-in-athi-river/

Olatidoye, O.R., Orimoogunje, O.O., Oyelowo, O.J., lubode, O.S., & Oloketuyi, A.J. (2021). Mapping riparian vegetation change in the Omo Biosphere reserve, Ogun State, Nigeria, *Makerere University Journal of Agricultural and Environmental Sciences*, 10 (1), 47 – 59. https://mujaes.mak.ac.ug/wp-content/uploads/2021/07/3Olatidoye.pdf

Olokeogun, O.S., Ayanlade, A., & Popoola, O.O. (2020). Assessment of riparian zone dynamics and its flood-related implications in Eleyele area of Ibadan, Nigeria. *Environmental Systems Research* 9, 6 (2020). https://environmentalsystemsresearch.springeropen.com/articles/10.1186/s40068-020-00167-4#citeas

Oluwayemisi, S., Olokeogun , A. A., & Olusola, O. P. (2020). Assessment of riparian zone dynamics and its food-related implications in Eleyele area of Ibadan, Nigeria. *Environmental Systems Research.* 9 (6). https://environmentalsystemsresearch.springeropen.com/articles/10.1186/s40068-020-00167-4 2-11.

Omondi, B.O. (2014). The challenge of cleaning and maintaining Mathare River in the face of growth of the Mathare slum settlements in Nairobi**.** Unpublished master thesis, Kenyatta University. https://www.semanticscholar.org/paper/The-Challenge-of-Cleaning-and-Maintaining-Mathare-Osore/e779af1278d8bd7a7220ee6e689c042ed1ccee20.

Omollo, W.O. (2018). Development control a tool for plan implementation. Unpublished PhD thesis, Jaramogi Oginga Odinga University of Science and Technology. http://62.24.102.114/cgi-bin/koha/opac-detail.pl?biblionumber=20779.

Omulo, C., (2018, 13 August). Posh Kileleshwa homes on riparian land to be demolished this week Nairobi News. https://nairobinews.nation.co.ke/posh-kileleshwa-homes-on-riparian-land-to-be-demolished-this-week/

Ondieki, J.K., Akunga, D.N.P.N., & Kenyanya, O. (2021). Bacteriological and physico-chemical quality of household drinking water in Kisii Town, Kisii county, Kenya. *Heliyon*, 7(5), 1-7. https://www.sciencedirect.com/science/article/pii/S2405844021010409.

Pu, G., Quackenbush, L. J., & Stehman, S. V. (2021). Using Google Earth Engine to assess temporal and spatial changes in River geomorphology and riparian vegetation. *JAWRA Journal of the American Water Resources Association*. 47(5): 789-806. https://onlinelibrary.wiley.com/doi/epdf/ 10.1111/ 1752-1688.12950

Radoux, J., & Bogaert, P. (2017). Good practices for object-based accuracy assessment. *Remote Sensing*. 9(7), 646 https://www.mdpi.com/2072-4292/9/7/646

Rashid, Y., Rashid, R., Muhammad, A.K., Sana, S.S., & Waseem, A., (2019). Case study method: A step-by-step guide for business researchers. *International Journal of Qualitative Methods*. 18, 1–13. https://journals.sagepub.com/doi/pdf/10.1177/1609406919862424

Ritchie, H., Roser, M. (2018). Urbanization. https://ourworldindata.org/urbanization? source= content_type%3Areact%7Cfirst_level_url%3Aarticle%7Csection%3Amain_content%7Cbutton%3Abody_link#citation

Sajjad, A.W., Ankit, K., & Vipin, V. (2014). Assessment of riparian buffer zone of Chandni Nalla-A stream in Narmada Basin, India. *Advances in Applied Science Research.*, 5(2),102-110**.** https://www.imedpub.com/articles/assessment-of-riparian-buffer-zone-of-chandni-nallaa-stream-innarmada-basin-india.pdf

The Republic of Kenya. (1965). Agriculture (basic land usage) rules, 1965. http://www.kenyalaw.org:8181/exist/ kenyalex/sublegview.xql?subleg=CAP.%20318

The Republic of Kenya. (2006). Environmental management and co-ordination (water quality) regulations, https://www.nema.go.ke/images/Docs/water/water_quality_regulations.pdf

The Republic of Kenya. (2007). The water resources management rules. https://wra.go.ke/wp-content/uploads/2019/05/Water-Resources-Management-Rules-2007.pdf

The Republic of Kenya. (2012). Survey Act. http://kenyalaw.org/kl/fileadmin/pdfdownloads /acts/surveyact_cap299.pdf

The Republic of Kenya (2019). Report on inquiry into the encroachment into the riparian areas of Kenya.http://www.parliament.go.ke/sites/default/files/2019-09/report%20on%20the% 20inquiry% 20into% 20the% 20encroachment %20into%20the %20riparian %20areas%20in%20kenya _compressed_0.pdf

United Nations. (2018). World urbanization prospects. The 2018 revision. https:// population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf

United Nations. (2021). 68% of the world population projected to live in urban areas by 2050, says UN.https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

Wabala, P. (2020, 7 September). NEMA to shut 140 firms for polluting city river**.** *Nation Newspaper.* https://nation.africa/kenya/business/nema-to-shut-140-firms-for-polluting-city-river-1932448

Wanjama, P. (2018). What is riparian land and why NEMA is demolishing buildings in Nairobi**.** https://www.kenyans.co.ke/news/32175-what-riparian-land-and-why-nema-demolishing-buildings-nairobi?amp=1

Weather Atlas. (2021). Monthly weather forecast and climate Kisii, Kenya. https://www.weather-atlas.com/en/kenya/kisii-climate

World Economic Forum (2018). 70 years of urban growth in 1 infographic. https://www.weforum.org/agenda/2019/09/mapped-the-dramatic-global-rise-of-urbanization-1950-2020/

Economic Forum. (2020). 70 years of urban growth in one infographic. https://www.themandarin.com.au/123752-70-years-of-urban-growth-in-one-infographic/

Xu, L., Zhao, S., Chen, S.S., Yu, C., & Lei, B. (2020). Analysis of arable land distribution around human settlements in the riparian area of Lake Tanganyika in Africa. *Applied. Geography*, 125 (2020). https://www.sciencedirect.com/science/article/pii/S0143622818312062

Yunus, A.J.M., Nakagoshi, N., & Ibrahim, L. (2004). Riparian land-use and land cover change analysis using GIS in Pinang River watershed, Malaysia. *Tropics,* 13 (4), 235-248. https://www.jstage.jst.go.jp/article/tropics/13/4/13_4_235/_pdf

Zanetti, C., Macia, J., Liency, N., Vennetier, V., Mériaux, M., & Provensal, M. (2016). Roles of the riparian vegetation: the antagonism between flooding risk and the protection of environment. 3rd European conference on flood risk management, October 2016, Lyon, France. https://hal.archives-ouvertes.fr/hal-01427431/document

Zhao, Q., Yu, L., Li, X., Peng, D., Zhang, Y., & Gong, P. (2021). Progress and trends in the application of Google Earth and Google Earth Engine. *Remote Sensing*. 13, 3778. https://www.mdpi.com/2072-4292/13/18/3778

Zipperer, W. C., Northrop, R., & Andreu, M. (2020). Urban development and environmental degradation. *Oxford Research Encyclopedia of Environmental Science*, https://www.fs.usda.gov/treesearch/pubs /60941

Zúñiga-Vega, J. J., Israel; S.Z., M. Fernanda., & Sáenz-Escobar, M.F. (2019). Habitat traits that increase the probability of occupancy of migratory birds in an urban ecological reserve. *Acta Oecologica,* 101(2019). https://www.researchgate.net/publication/336964735Habitat_traits_that_increase _the _probability_of_occupancy_of_migratory_birds_in_an_urban_ecological_reserve

10. KEY TERMS AND DEFINITIONS

Earth observation: Gathering information from the Earth's physical environment using remote sensing. The aim is to monitor and assess the extent of land use change overtime.

Land use: The anthropological use of land such as built-up land (for instance residential, commercial, transportation, roads and industrial), cultivated land as well as naturally occurring or human induced short vegetation.

Planning standard: Guidelines or rules showing the amount of space needed in accommodating particular infrastructure or facility. In the current study, the planning standard was the 30-metre riparian reserve.

Riparian reserve: Land that is adjacent to rivers.

Spatiotemporal analysis: Data that is collected and analysed across both space and time.