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Riparian Zones and Their Role in Enhancing Resilience to Flooding in Urban Areas:
A Case Study of Nairobi River Basin

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Abstract

Resilience has been defined as the capacity of a system to absorb disturbance and reorganize while maintaining the same function, structure and identity. In Nairobi river basin, storm water drains have been developed to direct floods away from urban developments. However, when upper areas and riparian areas of rivers are bleached, the ramifications are seen in terms of increased flood resistance that reduces resilience. The main objective of the paper is to investigate the role of functional riparian zones in enhancing resilience to flooding in urban areas. Specifically, the study examined whether there are developments that are at a permanent risk of floods as a result of ignoring potential role of the riparian zone. Secondly, the criteria used during delimitation of riparian zones was assessed in its adequacy to shield development from effects of floods. Data was collected using mapping and archival methods. The study established that the width of the river varies along the river profile and depends on the adjoining topography. The location of the high-water mark therefore is not constant from the river and widens or narrows depending on the adjoining topography. The study revealed that there are structures that are at permanent risk of flooding. It was further established that the criteria used during delineation of the riparian zone is not adequate to protect development from flood hazards. Areas where structures are constructed within defined active flood areas are constricted and they have blocked the flood paths. As a result, floods get elevated due to lower rate of evacuation causing localized flooding in areas not ordinarily affected by floods. The paper concludes that functional riparian zones have potential role of ensuring flood resilience. The study recommends regeneration of the active flood areas through relocation of structures and planting of trees. The study further recommends pegging of inundated flood areas based on the criteria established in the study.

Keywords: Flooding, resilience, riparian zone, urban areas.

INTRODUCTION

The concept of resilience exists in different context-specific meanings fronted by different disciplines. Under ecology, Walker et al. (2004) defines resilience as the capacity of a system to absorb disturbance and reorganize while undergoing change while retaining the same function, structure and identity. Under the socio-ecological context, focus is more on the magnitude of disturbance a system can withstand before transforming into an alternate state controlled by a different set of processes (Carpenter et al., 2001). Adgar (2001) further defines resilience, under the social discipline, as the ability of a society to withstand external shocks to their social infrastructure. It is within this context that human vulnerability to floods can be measured.

Flood adaptation should be through enabling natural flood plain function to build urban resilience to floods (Liao, 2012). However, use of flood control structures to mitigate floods rarely addresses the problem in urban areas. Ecological resilience through proper determination, use and management of functional riparian zones without impairing their ecological and physical existence becomes a fundamental goal of building resilience in urban areas. On the contrary, land administration processes, including allocation, subdivision and construction of structures have ignored this fundamental goal. In some instances, the centre line of the river has been conceptualized and used as the boundary of properties. This alone introduces and encourages developments very close to the river ignoring potential risk of

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flooding.

Legal regimes have also applied very small riparian widths that are not anchored upon the functional boundary that would ordinarily protect properties from floods. The problem has further been exacerbated by increased floods resulting from impervious surfaces in upper reaches of cities. In particular, upper grounds have been developed intensively after policy change to increase ground coverages and plot ratios.

The question that emerges is whether there are developments that are at a permanent risk of floods as a result of ignoring potential risk of floodplains. The second question is whether the criteria used during delimitation of riparian zones is adequate to shield development from effects of floods. Debates have arisen among scholars on the use of fixed or variable width models in the delineation of the zones. Whereas fixed width models would fail to capture areas that ordinarily would be considered as flood plains, the variable width approaches, on the other hand, can best be determined upon mapping of the floodplain. The challenge is that the floodplains have often been developed albeit without due regard to flood paths'. This paper borrows from the ecological resilience theory to show case the riparian zones as a natural system which, if well delineated after mapping, can enhance resilience floods.

THEORY

Many cities are not flood-safe because they are premised on the artificial environmental stability that is forced by flood-control infrastructure and tolerate little socioeconomic fluctuation (Folke, 2003; Anderies et al., 2006). Resilience derives from living with disturbances (Gunderson, 2000; Walker et al., 2004). Studies have shown that communities that are adapted, not resistant, to disturbances are long enduring (Berkes et al., 2003). However, adaptation must be based on establish minimum physical extents that the floods would ordinarily inundate. This is the high-water mark of the wetted floodplain.

Proponents of urban resilience advocate for working with the river rather than against it (White, 1945; Leopold, 1977). For example, the *Room for the River* project in the Netherlands, and the *Making Space for Water* policy in England (Moss and Monstadt, 2008; Opperman et al., 2009). Open spaces can become multifunctional to convey and store floodwater during wet seasons (Douglas et al., 2007).

According to Tobin (1995), floodplains are constantly changing, rearranged not only by inundation but also by channel migration in which land could become the site of a flowing river and vice versa. Tobin (1995) further argues that flood adaptation as the mitigation approach would correct several problems induced by flood control. First, it would not transfer the city's own problem elsewhere, as levees and channelization do by reducing floodplain retention and increasing flow velocity to increase downstream flooding, and as flood-control dams do by submerging upstream areas to displace people. Second, it would not increase long-term flood risk, as there is no threat of flood-control infrastructure failure, through which damages by larger floods would be more catastrophic than if there were no flood-control infrastructure (Tobin, 1995). Third, it would not conflict with, but rather could reconcile with ecological preservation and restoration of urban rivers by allowing ecologically critical periodic floods to reconnect the channel and floodplain (Nienhuis & Leuven, 2001).

According to Liao (2012), resisting floods by means of levees, dams and through channelization neglects inherent uncertainties that arise from human-nature couplings. In any case, flood flow regimes are dynamic and vary depending on changes in urbanization, upstream catchment and climate change factors (Liao, 2012). Home (2004) recommends integration of land and water management issues.

Flood zone mapping is therefore seen in this paper as necessary in determination of the highest water mark that would define a functional riparian zone extent. Such a determination would then guide location of development in relation to the function floodplain. Mapping of flood zones based on the highest water mark has however not been adequately undertaken in most developing nations. As a result, flood plains have been alienated, encroached and developed. This in turn reduces the resilience of urban areas to flooding.

In Nairobi River Basin, river channelization, diversion, erection of boundary walls, solid waste heaps and structures have been used to build urban resistance to floods (Muketha, 2014).

Murimi and Rukwaro's study on *Resilience of City to Flooding* conducted in the city of Nairobi argues that urban resilience principles need to be adhered to in urban planning. This is in order to achieve a city that has ability to cope with flood threats with minimum damage to public safety, health and economy (Murimi and Rukwaro, 2016). The main questions addressed by Murimi and Rukwaro (2016) are, *Why does the city of Nairobi flood every year there is heavy rains and how can Nairobi County Government intervene in future flooding episodes that affects the lives of Nairobians*? The study used observation (photography), interviews and personal experience as the main methods of data collection.

Murimi and Rukwaro (2016) found that obstructions of the flood natural courses have been the main cause of flooding in the city. In particular, the study found out that developments blocking the natural channels of runoffs is the main cause. The study further found that the flood control infrastructure was poorly planned and designed in terms of location and size. The study concluded that the Nairobi city is incapable of, among others, preparing for, responding to and recovering from significant floods that cause physical damage and socio-economic disruptions.

Murimi and Rukwaro (2016) recommend the need to provide right of way for floods through resilient mechanisms. It also recommends the need for appraisal on how to make the city more aware of resilience to floods by adapting ecological and engineering solutions to deal with the food hazards.

However, the study by Murimi and Rukwaro (2016), though acknowledging the effects of flooding within the city of Nairobi, misses out the root cause of the flooding. First, the zoning policy change in zone 3, 4 and 5 (higher elevation areas) of Nairobi city allowed higher plot ratios and ground coverages with the effect of introducing impervious surfaces which have accelerated flow of surface runoff to lower areas. The existing channels, which were not designed with the catchment changes in mind cannot hold elevated flood incidences hence unusual flooding of areas that never used to be affected. Secondly, the methods of data collection appear not to have captured contiguous profile of the floodplain in relation to the location of adjoining developments. This study, therefore goes further from Murimi and Rukwaro (2016) to use spatial mapping approaches to capture the wetted floodplain and documents the developments that are vulnerable to floods.

The determination of the riparian zone has been based on various policies and legislation in Kenya. Although, some of these laws have been repealed and aligned to the constitution, they still apply because the location of existing structures adjoining the rivers ought to have been based on their provision. The Physical Planning Act (Legal notice140 rule 15(c) and (d) of 1998, now repealed, defines riparian reserves as way leaves or reserves along any river, stream or watercourse not less than 10 meters in width on each bank except in areas where there is an established flooding. The question is how would planners and other professionals determine the established flooding without physically mapping the river profile?

The Physical Planning Handbook of 2007 defines the riparian reserve as land on each side of water course with minimum of 2m, or equal to the full width of the river as measured between the banks of the river course up to a maximum of 30m. Again, the full width of the river should be based on mapping of the contiguous profile of the river. At any one point, there are multiple discrete widths of the river since the river profile changes dynamically from its source. For the wetland area the handbook recommends a buffer zone of 30 meters from the high-water mark. In this study, the high-water mark is based on the first 2m contour from the river as indicated in the topographical maps of the city. An additional 10m buffer from the contour is used based on the interpretation of the legal notice.

Liao (2012) applies resilience theory to derive the theory of urban resilience as an alternative theoretical framework for urban flood hazard management. According to Liao (2012) urban resilience to floods is defined as a city's capacity to relate flooding and to reorganize should physical damage and socio-economic disruption occur so as to prevent death and injuries, and maintain current socio-economic identity.

The theoretical framework derives from living with periodic floods as learning opportunities to prepare the city for extreme ones (Liao, 2012). According to Liao (2012), the theory of urban resilience challenges the conventional view that cities cannot survive without flood control, which in effect erodes resilience. Liao (2012) uses the percentage floodable area as a surrogate measure for assessing urban resilience to floods; and advocates for flood adaptation through enabling natural flood plain function to build urban resilience to floods.

Vale (2014) introduces a political perspective highlighting the intricacies of power and inequality in the city. He argues that cities are organized in ways that both produce and reflect underlying socio-economic disparities. As a result, some parts of the city are much more resilient than others and therefore vulnerability is linked to both topography and income.

More specific to urban floods, Liao (2012) presents two major interpretations of resilience; engineering resilience and ecological resilience as the main appropriate theoretical framework for management and developing urban resilience to floods. According to Liao (2012), flood adaptation rather than flood control is the appropriate way to build urban resilience to floods. Holling (1996), on the other hand, argues that engineering resilience and ecological resilience are two distinct interpretations because they lead to divergent problem deformations, focuses and approach to flood hazard management.

Engineering Resilience

Liao (2012) argues engineering resilience depends on four properties; robustness or the physical strength to withstand a disturbance without functional degradation; second, redundancy or the extent to which system components are substitutable; third, resourcefulness, or the capacity to identify problems, mobilize needed resources and lastly; rapidity or the capacity to restore the system in a timely manner.

The main difference between engineering resilience and ecological resilience is that in the former, any change from the optimal is considered deviant, while in the latter, any fluctuation within the regime is normal because ecological systems are inherently dynamic (Holling, 1973). The ability to maintain stability is key to the engineering resilience while the ability to survive regardless of the state embodies ecological resilience (Liao, 2012).

Ecological Resilience

There are two key arguments in the theory of ecological resilience which actually shifts the paradigm of flood hazards management (Liao, 2012). Firstly, ecological resilience results in the event of adaptation to inherently variable uncertainty and surprise (Folke, 2003). Human-nature harmony is lost when variability is artificially surprised to enhance stability via control and command management (Holling and Meffe, 1996). This implies that imposing floodplains to be inundation-free and introducing any other functionality such as residential or social economic activities on unsuitable land results in eroding resilience. This appears to be the case in Nairobi City.

The second aspect of this theory holds that periods of sudden changes complement each other (Folke, 2006). Historically, it has been observed that frequently disturbed ecosystems develop some adaptation mechanisms to enhance their survival-implying resilience (Holling, 1973; Gunderson & Holling, 2002). Flooding itself is an agent for resilience, the experience allows the towns a chance to adjust internal structure to cope with the flood should it reoccur (Folke, 2006; Smit and Wandel, 2006).

According to Liao (2012), urbanized flood plains are such systems where climate, socio-economic trends, built systems and riverine process affect flood hazards and disasters. To operationalize the theory, Liao (2012) argues that since resilience is not observed directly it requires inference from surrogates. One way of finding resilience is to look for internal properties that alter resilience over time (Bennett et al., 2005). Attributes that change gradually are good candidates because they define the systems underlying structure which controls the shape of the basin of attraction, position of the system within the state space and the threshold location (Carpenter et al., 2001). For urban areas, such property that would define floodability would be that which reflects the physical and hydrologic changes that conflict with flood processes to give rise to food disasters (Liao, 2012).

In Nairobi River basin, properties such as buildings on the river channels, or those close to the river bank, and dumping of solid wastes can be indicators of increased floodability (Muketha, 2014). If these surrogates occupy essential flood plain, then the river has no room to store overbank spill. Yet, during major floods the amount of conveyance and storage is greater than that of the channel (Leopold, 1994). This has seen flooding of Nakumatt Ukay and South End Mall on Langata Road before they were demolished. The functions of the floodplain require enhancing channel capacity, improving the efficiency of drainage systems and upstream impoundment. Simultaneously the river now sees higher peak flows with increasing discharge downstream (Criss and Shock, 2001), which eventually increases the flood risk and make the flood plain less tolerant to flooding because of less land for storage and conveyance of water and sediments.

RESEARCH METHODS

The study adopted both secondary and primary methods of data collection. Geographic information system (GIS) and remote sensing were used as tools for assessment of the riparian structure.

Data on determination of riparian reserves, structures within the riparian reserve and the effects of floods on these structures were collected. Data gaps also included the preparedness for, response to and recovering from significant floods that cause physical damage and socio-economic disruptions and flood control infrastructure in the study area.

The nine rivers were selected as they were indicated as rivers of interest by the National Construction Authority (NCA). The study targeted land uses along the nine rivers. Geo-referencing of the updated Nairobi topographical maps was done. They were useful in accurately placing/digitizing the river course where it would not be clear in the satellite and aerial imagery.

Satellite imagery was used to assess the existing ground situation as well as creating the river course profiles across the upstream, mid-stream and downstream as well as to map the wetted area; (total active flood area and the vegetation corridor thereon).

Mapping was done to identify properties (structures and parcels/plots) that are within the delineated riparian zone using two step criteria of 2m above the river bank and the 10m offset from the contour.

A buffer analysis was also run using the created flood plain to determine the number of structures within the riparian zone. A buffer analysis using the 10m minimum offset from the 2m contour boundary was used to identify properties that are completely contained within the 10m buffer and marked in red indicating potential high risk and action needed to be moved away from the buffer zone. However, those which were touching the 10m were marked in pale brown to indicate minimum risk, however appropriate action needs to be taken.

A visual overlay analysis was conducted to assess whether cadastral survey plans had provided or not provided any or desired riparian buffer/corridors. The outputs were presented in plans and the affected properties were tabulated.

RESULTS AND DISCUSSION

Determination of the High-Water Mark

The width of the river varies along the river profile and depends on the adjoining topography. The location of the high-water mark therefore is not constant from the river and widens or narrows depending on the adjoining topography. In Ngong River for example (**Figure 1**), at the former South End Mall (demolished) which was at the confluence point of Motoine River and Ngong River, the high-water mark on the upper side of the river is fairly constant while on the lower side the high-water mark changes regularly.

The high-water mark determined using GIS tools

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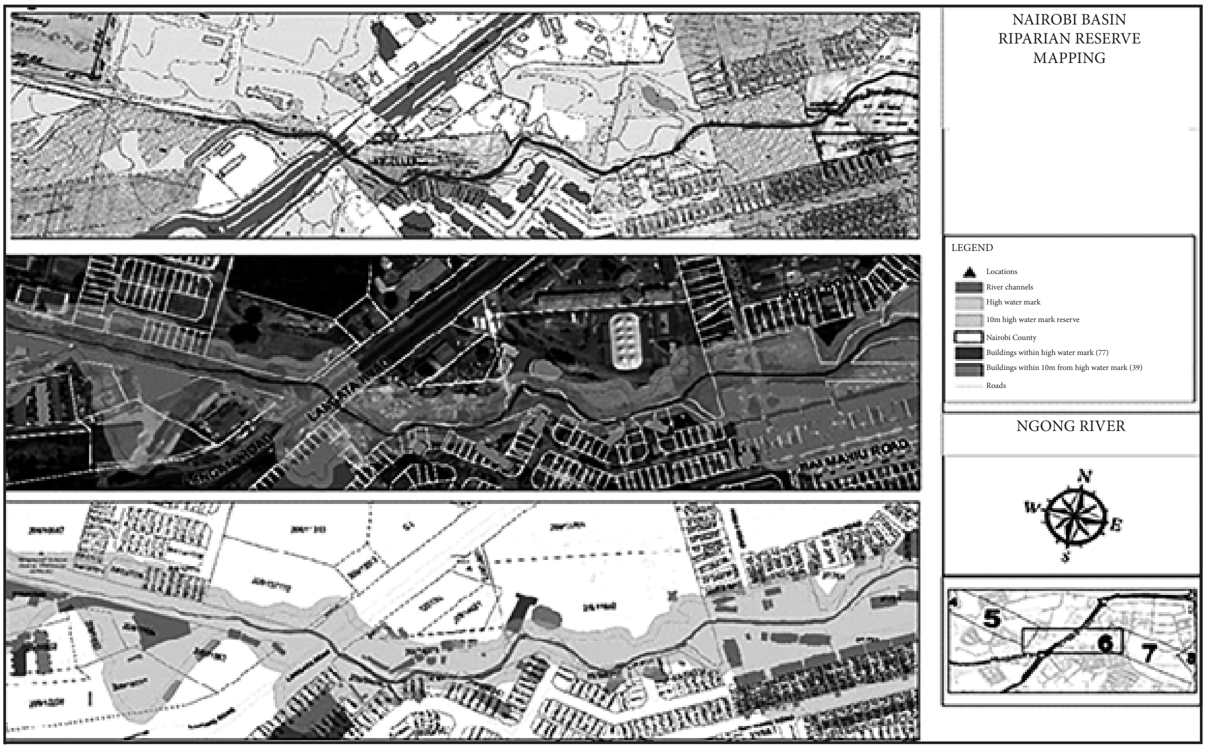


FIGURE 1
High-water mark (Ngong River at former South End Mall)
Source: Survey of Kenya (SoK) 2018; Google Earth 2018

re-established the swamps indicated in the survey plans. In Gatharaini River for example (**Figure 2**), the swamp indictated on the cadastral plan, perfectly overlayed with the first 2m contour from the river. This shows that the swamps on the river as indicated on the plan is a floodable area and should not be developed. The 10m buffer form the high water mark in this section has structures within it however farther downstream along the river there are open sections where the high water mark can be delienated and conserved.

Structures within the Riparian Reserve

Based on mapping analysis the total number of structures on the river channel, 6m and 10m riparian reserves are enumerated in **Table 1**.

Figure 3 shows the comparison in the enumeration of number of structures within the flood plain along the nine rivers in Nairobi City County. Ngong River which passes through major informal settlements and industrial zones has the highest number of structures within the riparian reserve followed by Mathare River and Nairobi River while Karura and Kamiti Rivers have the least since they are bordered by public institutions and a gazetted forest.

The study found out that in areas where the structures are constructed within the flood plains, the riparian zone is constricted and the structures have potential of blocking the floods. This reduces resilience to floods because the floods have to rise to higher levels where they cause flooding. For instance, the study established that the canalized Kibagare stream is 1.9m wide at the now demolished Nakumatt Ukay Mall. In addition, it was found that the adjoining ground is gently sloping. As a result of a constricted narrow river, high walls of the mall and adjoining stone fence, the water rose at various occasions (2007, 2010) flooding the mall and adjoining areas. **Figure 4** illustrates flooding in the former Ukay Mall. South End Mall (demolished) at the confluence of Motoine and Ngong Rivers, was often flooded during heavy rains (**Figure 5**).

The study revealed through analysis of satellite imagery that the upper areas presently (2019) have much higher intensity of development compared to the 1990s and early 2000s. This translates to more paved surfaces and therefore less surface

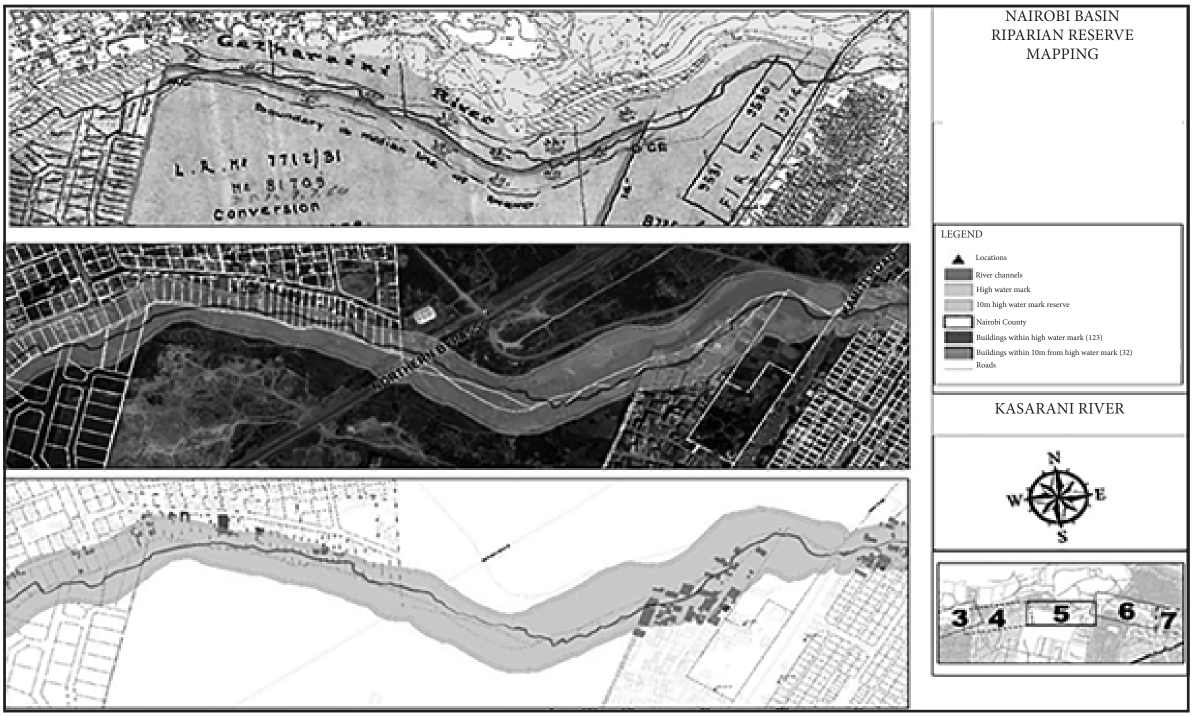
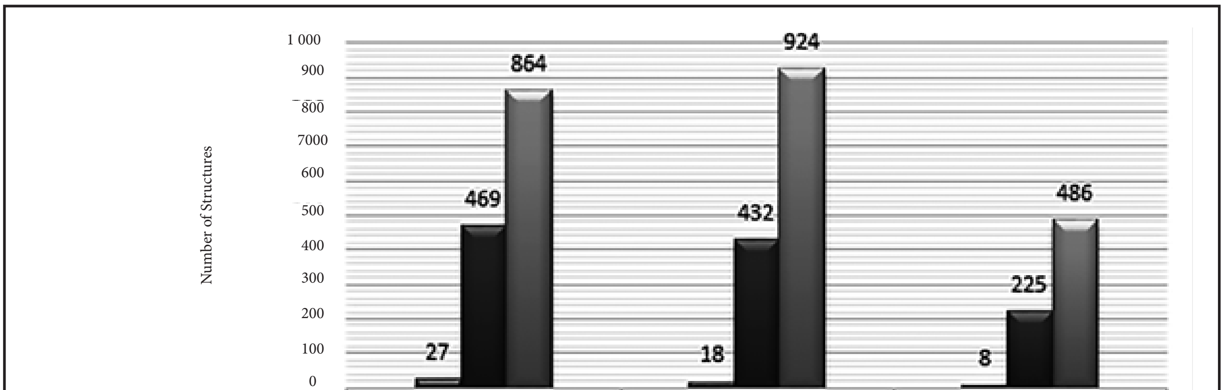


FIGURE 2
High-water mark on Gatharaini River
Source: SoK 2018; Google Earth 2018



	Ngong River	Mathare River	Nairobi River
Structures on the River Channel	27	18	8
Structures on 6m	469	432	225
Structures on 10m	864	924	486

FIGURE 3
Enumeration of number of structures on 10m riparian reserves of various rivers
Source: Field survey 2018

runoff infiltration. Hence, increased rate of flow of surface run off in areas of lower elevation. The increased development in zones 3, 4 and 5 of Nairobi city can be attributed to policy change in 2006 that allowed higher plot ratios and ground coverages.

Field observations enabled enumeration of structures based on permanent or semi-permanent structures criteria. The study established that there are more semi-permanent structures within two meters of the river channel than the permanent ones (**Table 2**). Ngong River was found to have the most semi-permanent structures within the two meters followed by Nairobi and Mathare rivers. Kamiti and Karura rivers had no semi-permanent

TABLE 1: Enumeration of structures within the riparian reserve

	River	Number of structures on the riparian reserve	Number of structures within the high-water mark
1	Ngong	2904	6315
2	Mathare	1384	2424
3	Nairobi	1295	3458
4	Gatharaini	178	699
5	Ruiruaka	355	1008
6	Gitathuru	228	153
7	Karura	6	41
8	Kamiti	0	4
9	Kirichwa	677	1330

Source: Field survey 2018

FIGURE 4
Instances of flooding in the former Ukay Mall
Source: Google 2019

FIGURE 5
Former South End Mall
Source: Goggle 2019

structures on the 2m zone. The three major rivers of Ngong, Nairobi and Mathare are the most dangerous in terms of flood hazards, yet they are the most inhabited by informal settlements in the city of Nairobi. Semi-permanent structures are the most vulnerable since they are easily destroyed during flood incidences. This scenario therefore complicates flood resilience in the city. The structures act as flood control infrastructure that resist floods.

The study has established that there are structures on the defined active flood area that constrict the flood paths (**Figure 6**). As a result, it leads to greater flood incidences in the immediate neighbourhood and in lower areas of the city. As more structures are built on the functional riparian areas, the free flow of floods will get more affected and will further reduce resilience to floods. More structures in this active flood area, will continue to replace natural riverine vegetation (trees, shrubs and grass) and will as a result increase the rate of flow of the surface runoff to an already dire situation of structures within the floodplain.

The mere fact that structures are haphazardly located on the river channel and very close to it in the basin, is a clear indication that policy makers, developers and professionals have not considered the potential function of the riparian zone as a natural belt that buffers residents and developments from flood hazards. Construction of structures on the footpaths appears more an effort towards engineering resilience than ecological resilience. Adaptation to floods has become a major challenge in the basin as long as development continue to disregard natural flood paths that have existed from time immemorial. Mapping of structures in relation to the lowest 22m contour and based on existing wetted flood plains becomes inevitable.

CONCLUSION

The study concludes that there is improper determination of riparian zones in Nairobi River Basin. Following this, the areas that ought to be

TABLE 2: Enumeration of structures within the highest water mark

	River	Structures within 2m elevation from defined River Bank			Structures within 10m from defined flood plain		
		Permanent	Semi-permanent	TOTAL	Permanent	Semi-permanent	TOTAL
1	Ngong	2205	4110	**6315**	960	1081	**2041**
2	Nairobi	1002	2456	**3458**	739	653	**1392**
3	Mathare	877	1547	**2424**	364	412	**776**
4	Gatharani	664	35	**699**	210	17	**227**
5	Ruiruaka	799	209	**1008**	286	19	**305**
6	Gitathuru	18	135	**153**	28	65	**93**
7	Karura	41	0	**41**	41	4	**45**
8	Kamiti	4	0	**4**	2	0	**2**
9	Kirichwa	1226	104	**1330**	372	18	**390**
Total		**6836**	**8596**	**15432**	**3002**	**2269**	**5271**

Source: GIS mapping 2019; Google Earth 2018; Survey of Kenya 2018

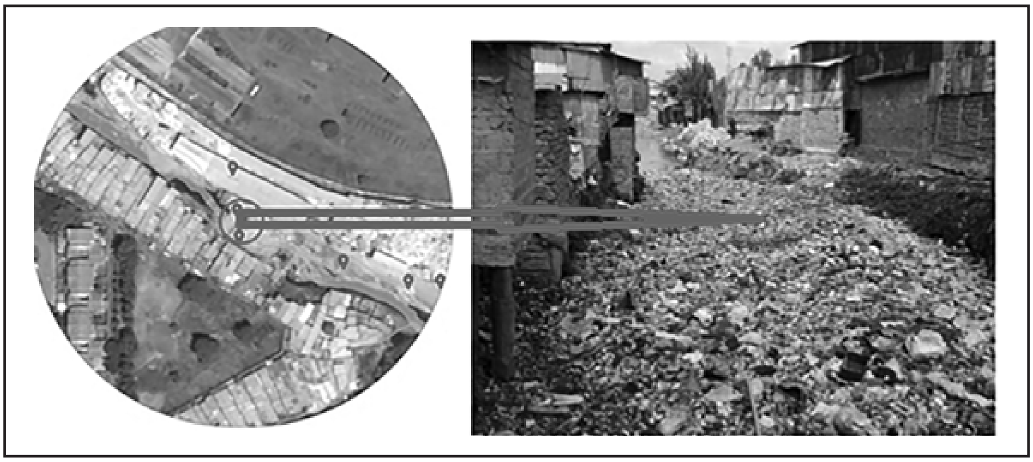


FIGURE 6
Proximity of structures to the Ngong River and solid waste disposal into the river channel
Source: GIS mapping; Field survey 2018

physically and ecologically riparian zones, are encroached and degraded by urban land uses. The land uses within the flood plains block the flow of the river and reduce permeability of the surface thus reducing flood resilience.

RECOMMENDATIONS

To enhance resilience to floods in Nairobi River Basin, the study recommends adoption of the concept of ecological resilience. Regenerating the active flood areas through an appropriate functional riparian zone is a sure way of ensuring flood adaptation. This is because engineering solutions that have been used before to address flooding in the city have not comprehensively resolved the problem.

The study further recommends pegging of the highest water marks as defined by the 2m contour and the functional areas beyond it that remain active flood areas and are often inundated by floods. Such markers would act as warning to developers that erecting structures beyond, would not only be detrimental to the riverine ecosystem, but also risky to lives and property.

The paper additionally recommends relocation of structures in high risk flood areas and planting of trees that are associated with riparian areas such as reeds to reduce surface runoff velocity and increase ground percolation. The paper recommends activities that are compatible with conservation of the riparian zones, and nature should be allowed within this zone. Additionally, city planners and policy implementers should promote establishment of more green open spaces in place of the paved. Green open spaces can become multi-functional to convey and store floodwater during wet seasons.

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