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Full Length Research Paper

Assessing Morphological Changes of the Msimbazi River Using Satellite Images

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ABSTRACT

This study assessed historical morphology changes of the Msimbazi River in Dar es Salaam City, Tanzania, following heavy rainfall events using historical Google earth images. The erosion and sedimentation processes that cause morphological changes of a river are also associated with flooding within the river catchments. In this study, the bank-line movement, erosion and sedimentation areas and changes in river section width were analyzed under three-time periods: 2005- 2012, 2012- 2018, and 2018- 2020. Data shows that, the timing for floods coincides with the historical records for heavy rains. It was found that, area in the upper reaches of the river such as Kinyerezi suffer from river bank erosion most, as indicated by the large increase in river width. This has resulted into washing away of infrastructure including houses and loss of land. The river channel width at Kinyerezi has widened a lot since 2005, with some sections having widths of more than 90 m. On the lower reaches for example around Kigogo and Jangwani areas, deposition of the soil materials prevails, resulting into raised river bed and reduced river widths. As the river section an hence carrying capacity is reduced, inundation of river banks occurs. This is among the causes of river bank flooding reported at these areas whenever there is a heavy storm event. It is therefore recommended that interventions to solve the flooding events in Dar es Salaam city should also include preventing catchment and river bank erosion on the upstream areas.

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INTRODUCTION

Floods following heavy rainfal events are becoming incresingly common, especially in fast growing cities of low income countries with unplanned settlements (Akay et al., 2020; Amoako, 2012; Douglas et al., 2008; Izdori & Katambara, 2021; Nchito, 2007). These floods are attributed to climate change impacts and urban expansion, with subsequent increase in generated run-off and decreased infiltration capacity (Douglas, 2017; Goodwell et al., 2014; Izdori & Katambara, 2021; Monte et al., 2016). Absence and/ or inadequate provision of drainage infrastrucrture results into flooding in such scenarions. Modification of landforms such as through clearing of forests for urban expansion and agriculture leads to increased erosion in upstream catchments. This in turn leads to deposition of the eroded materials in the downstream, hence reduce channel capacity and results into river bank flooding (Das & Samanta, 2022; Douglas, 2017). Communities living in lowlaying areas in the downstream are more prone to flooding with associated impacts including loss of propery and life (Das & Samanta, 2022; Kironde, 2016; Monte et al., 2016; Nchito, 2007). Although floods impact both the rich and the poor, literature shows that the impacts are more felt by the urban poor as they normally do not have any alternative dwellings and have limited capacity to get back on their feet after the disasters (Amoako, 2012; Kironde, 2016; Nchito, 2007).

River Msimbazi catchment in Dar es Salaam is among the highly populated and rapidly urbanizing areas of Tanzania (Sauka, 2019). However, the catchment has been a subject of increased floods in recent years (Sauka, 2019). Severe floods were reported in 2009, 2010, 2011, 2014, 2015, 2017, 2018, 2019 and 2020 (John et al., 2019; Kironde, 2016; Sauka, 2019; Valimba & Mahe, 2020), exposing the city’s vulnerability to climatic events. The floods are associated with heavy rains (Valimba & Mahe, 2020), whereby within a few hours of the rain event the water rises to a height of two meters or more above the banks of the river. These flood events have led to a number of social and economical impacts including deaths, loss of properties, destruction of infrastructures, displacement and the closure of main roads (Morogoro and Ali Hassan Mwinyi) that traverses the river (John et al., 2019; Valimba & Mahe, 2020). Following the recent increase in flood events and the associated impacts, a number of local and international organizations have come up with proposals to mitigate the Msimbazi River flooding (Sauka, 2019). Among the proposed mitigation measures is the control of erosion and sedimentation along Msimbazi River and its catchment. This research seeks to study the erosion and deposition hotspots along the river interms of changing in morphology for prioritizing interventions.

Floods in the Msimbazi River are a result of both natural phenomenon and anthropogenic activities. Recent climate change and variability trends are attributed to the change in rainfall patterns, increased intensities and frequency hence increased river discharge (John et al., 2019; Sauka, 2019; Valimba & Mahe, 2020). These climatic impacts coupled with other site specific factors such as land degradation and poor solid waste management (Akay et al., 2020; Petersson et al., 2020; Smiley & Hambati, 2020), have exacerbate the erosion and sedimentation in the Msimbazi River channel, and hence modifications of the channel morphology, including decrease river width and depth in some areas (Das & Samanta, 2022). Literature show influence of morphological changes of a river to the coveyance and carrying capacity of the river, and a direct contribution to flooding (Das & Samanta, 2022; Reisenbüchler et al., 2019). Therefore, a better understanding of morphological changes of river channel, particularly channel changes through erosion and sedimention processes, as well as techniques to detect such changes would be useful for effective planning and management of erosion and hence bank flooding along the Msimbazi River.

Among the existing methodologies, remote sensing offers a convenient and effective potential of determining erosion and sedimention areas even for large rivers (Zhang et al., 2019). Several studies have shown the potential of using satellite imagery for studying the changes in shorelines (Akay et al., 2020; Boothroyd et al., 2021; Buyana et al., 2020; Chu et al., 2006; Li et al., 2021; Uddin et al., 2011).

Satellite images are availablie for historical times since 1970s when the first satellites were launched, and are mostly free. The only disadvantage is the cost associated with purchase of latest high resolution images (Malarvizhi et al., 2016).

Therefore this study established the morphological changes of Msimbazi river for the period between 2005 and 2020, concentrating in three sites of Kinyerezi, Kigogo and Jangwani. These study sites were purposively selected as the areas reported to suffer from the impacts of erosion and deposition. Establishing the morphological changes of the river will aid in identifying the river sections that are more prone to shifting and those with more erosion hence increase in width. It is anticipated that identification of these problematic areas will facilitate prioritization of intervention measures for river bank stabilization, using hard engineering approaches such as river training for critical areas to soft approaches forexample by planting trees and natural vegetation in least critical erosion areas.

METHODS AND MATERIALS

Description of Study Area

Msimbazi River (Figure 1) is the second longest river within Dar es Salaam originating in Pugu Hills and discharging into the Indian Ocean. It has a length of around 35 km and a catchment area of 289 km^2. Its important tributaries include rivers Sinza (Ng'ombe), Luhanga, Ubungo, and Kinyerezi. The Msimbazi River flows through Dar es Salaam city, the commercial capital of Tanzania. In 2018, Dar es Salaam's population was estimated at 6 million people, with the highest population growth rate in the world. It is also East Africa's largest and fastest-growing capital city, expanding at around 8–12% per year with the city's growth largely centred along the Msimbazi Basin. It is estimated that around 27% of its population lives in the catchment and along its tributaries.

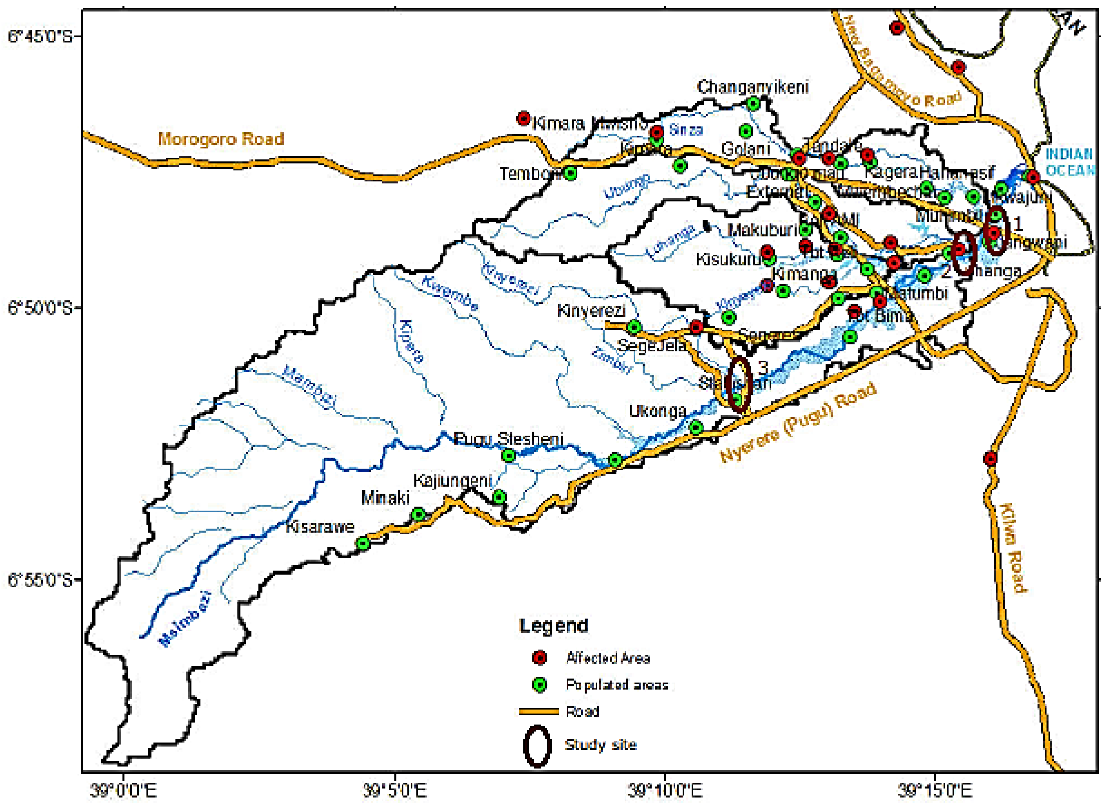

Figure 1: Map of the Msimbazi river and its catchment, showing the study sites (Modified from (Valimba & Mahe, 2020)).

Landsat images were downloaded for analysis, but it was impossible to detect Msimbazi River especially in the earlier years (prior to 2005) mostly due to its size as compared to that of Landsat image tiles (30 m × 30 m). Therefore Google earth images were used have been shown for use in land cover land use studies (Duhl et al., 2012; Malarvizhi et al., 2016), especially in urban areas as they provide a clear view of features such as buildings and roads (Malarvizhi et al., 2016). In establishing periodic morphological changes of Msimbazi River, historical Google earth images were obtained from the Google earth engine and then analysed to establish changes in river morphology over the years. Emphasis was on years following significant or extreme rainfall events as well as good quality images with no cloud cover. Images for the dry period were used so as to avoid areas that are only temporarily inundated (flood plains). The images used were for 2005 (baseline year), 2012, 2015 2018 and 2020, and they were checked for shifts by setting a reference location on one structure and matching all the other images to it.

The banklines were delianeated manually from the images of different years. Lines were drawn at 10 m intervals at the sections of interest as shown in **Figure 2**. Zooming and visual inspection were used to identify the river banks, then marker and lines were used to demarcate the river extend. To quantify changes in river bank that have occurred, distance between river banks were measured for consecutive years, as well as the direction of change. For left hand bank, if the bank edge shifts to the left of the previous year's bank, it means there was bank erosion on that side and the change is assigned a positive sign. Moving to the right means there was deposition on this section hence it is a negative change. Similarly, for the right-hand bank, if the bank edge shifts to the right of the previous year' bank, it means there was bank erosion on that side (positive change) while shifting to the left means there was some deposition on this section (negative change).

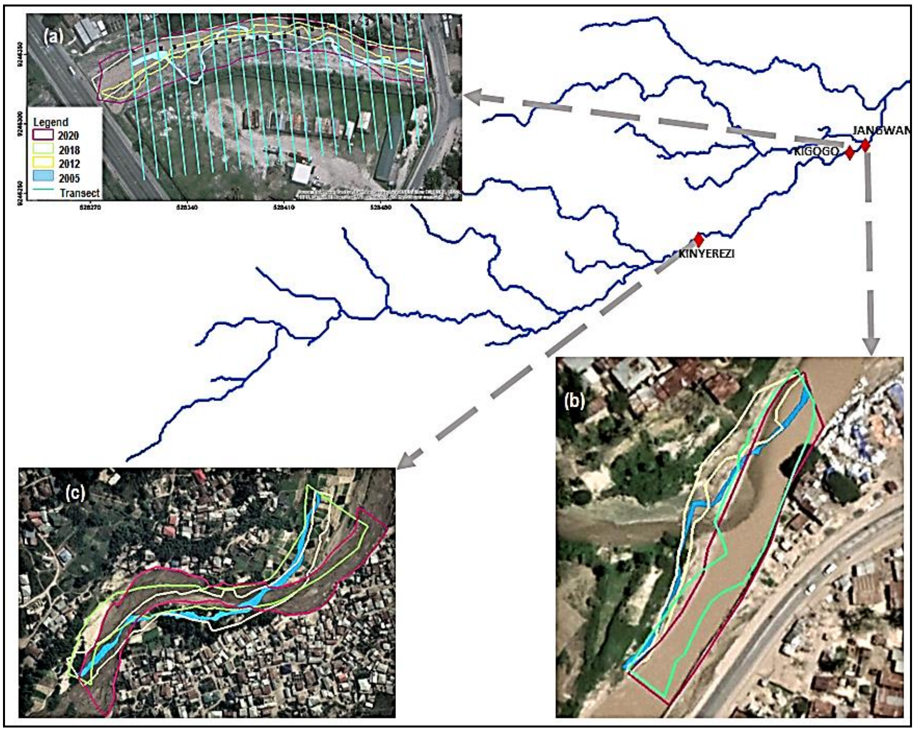

Figure 2: Changes in river widths for different years at selected locations along the Msimbazi river. Figure 2a shows the transects used in obtaining the river widths.

RESULTS AND DISCUSSION

Rainfall and Floods

Monthly rainfall data for Dar es Salaam Internation Airport (JNIA) for the period between 1987 and 2017 was obtained from the department of Water Resources Engineering at the University of Dar es Slaam. Long term monthly average rainfall was calculated using this data and the results are presented in Figure 3. Dates for annual maximum daily rainfall events at JNIA from 1983 to 2011, as well as dates of historical flood events for Dar es Salaam between 1953 and 2011 were obtained from (Muruke, 2012) and overlayed on the monthly rainfall data graph in Figure 3. From this figure it can be seen that the highest rainfall events for Dar es Salaam are recorded in the months of April, followed by May and December. Consequently, most flood events occur in April, followed by May and December.

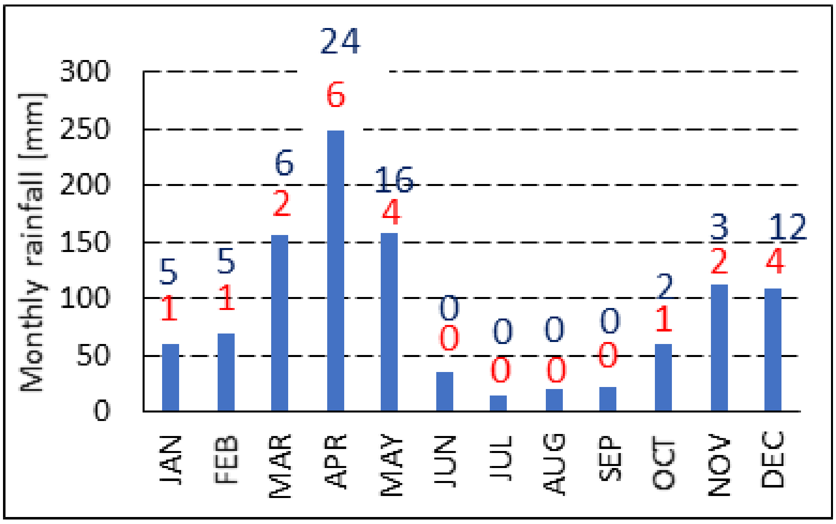

Figure 3: Long-term monthly average rainfalls (blue) for Dar es Salaam International Airport. The blue and red numbers are the frequencies of occurrence of maximum annual rainfall (since 1953) and flood events (since 1983) respectively.

Bankline shift, erosion and sedimentation of the Msimbazi River

Adopting the methodology outlined in section 3, whereby negative change indicates deposition while positive change is bank erosion, the results of bank line shift for the three sections of the Msimbazi River are presented below.

The LHS bank at Jangwani section has both negative and positive change, indicating deposition and sedimentation respectively while the RHS bank has mostly bank erosion (Figure 4 a& b). The highest positive change indicating bank erosion for LHS occurs at section 110 m while for negative change indicating deposition highest change occurs at section 60 m (Figure 4a). The changes in the LHS bank are smaller, ranging between -16.8 m and 10.8 m, compared to RHS bank where the changes range between -6.9 m and 30 m. This indicates a somehow stable left side bank as compared to the right-hand side bank.

At Kigogo, the LHS bank has consistently a positive change indicating erosion on this side while the RHS has both bank erosion and sedimentation (Figure 4 a&b). The largest shift for the LHS is recorded at the 40 m intersect, where the LHS bank shifted for about 40 m. At the same location, a shift of negative 20 m is recorded on the RHS, which represents deposition. Therefore, these two shifts resulted into an overall shift in the location of the river, and disappearance of the meander which was initially there (Figure 2b).

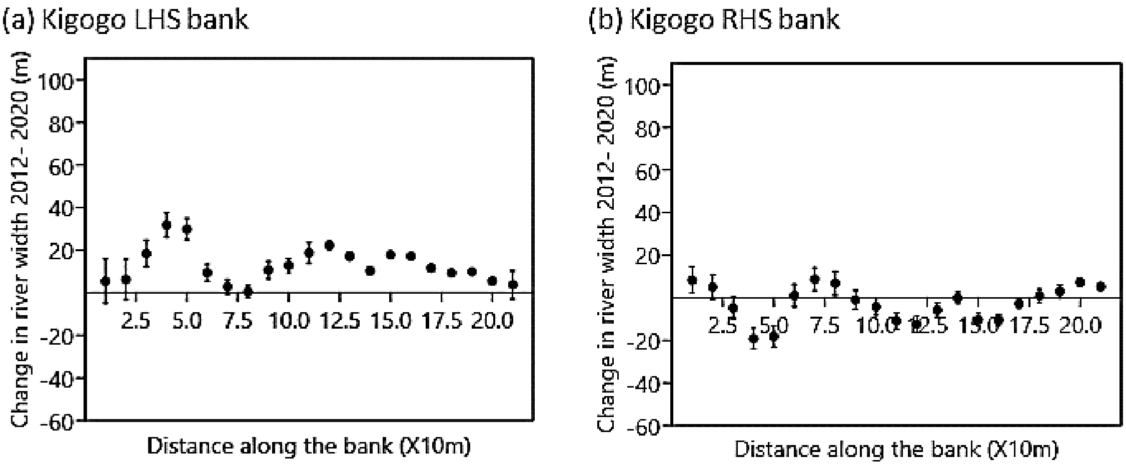

Figure 4: Bankline shift at Kigogo.

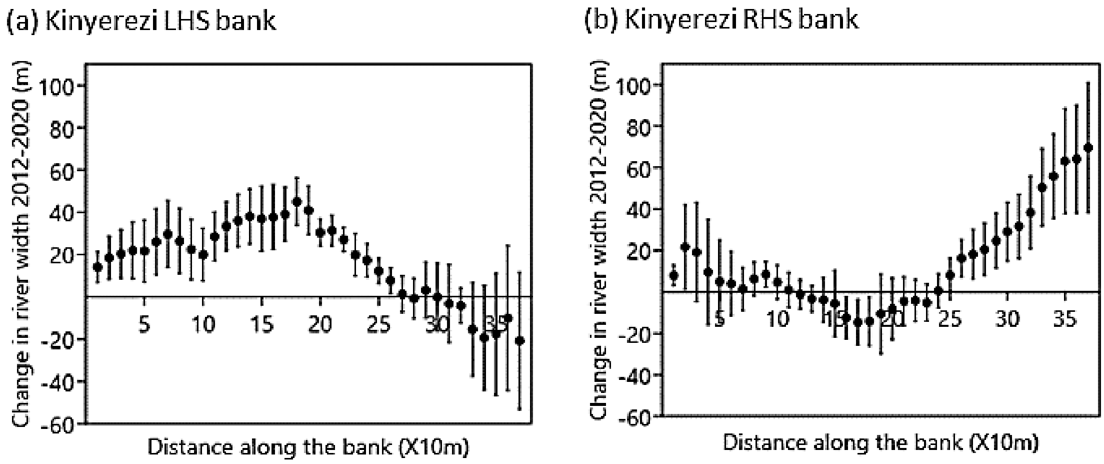

Figure 5: Bankline shift at Kinyerezi.

Changes in river channel width between 2005 and 2020

The Msimbazi River exhibits variable width for different years and at different sections along its length as shown in Figure 6a-c. The river width is widest at Kinyerezi, which is upstream, and decreases downstream closer to the outlet to the Indian ocean at Kigogo and Jangwani. Between 2005 and 2020, the river width increased from 0.7 to 21.4 m, 1.3 to 34.4 m and 1.8 to 96.5 m at Jangwani, Kigogo and Kinyerezi respectively. In Kinyerezi, the extent of river bank erosion extends beyond the 60 m buffer zone proposed by (Kironde, 2016), implying its impracticability.

This variation in river width is in opposite to expectations as normally river sections tend to be smaller at the upper reaches where the catchment is smaller but widen in the lower reaches as the catchment area increases. This is mostly a result of erosion as Kinyerezi is at a higher elevation and experiences more erosion while the downstream areas around Jangwani have more deposition. Apart from the changes in channel width discussed in this paper, literature indicates morphological changes from sedimentation to also include modifications of the bedform, such as increased bed elevation and formation of mid-channel bars (Luchi et al., 2010; Reisenbüchler et al., 2019).

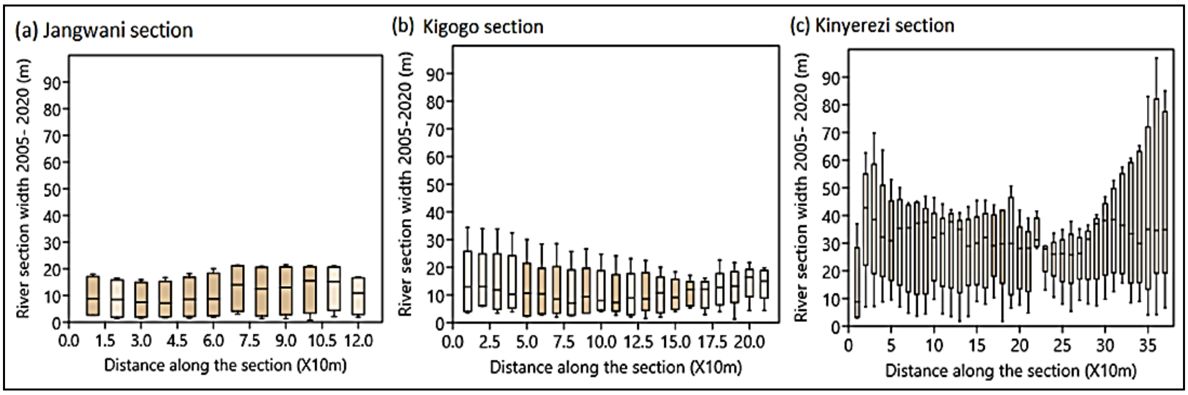

Figure 6: Changes in river width at the study sites.

CONCLUSION AND RECOMMENDATION

This study explored the morphological changes of Msimbazi River, focusing on channel width changes through erosion and sedimentation processes using historical google earth images. Highest changes in channel width through bank erosion were found at Kinyerezi. This was confirmed through site survey and informal interviews with residents. The residents reported a number of houses which had been washed away by the widening river, with parts of some damaged houses remaining as evidence of this. All this eroded soil is carried and deposited downstream at Kigogo and Jangwani areas, they also increase elevation of the river bed. The increased elevation of riverbed decreases the channel carrying capacity, hence result into bank flooding. Every year after floods the city authority go through a lot of expenses scooping the soil from the river and damping it to prevent more flooding. However, the findings of this research emphasize the management of the whole basin as a solution to river bank flooding along the Msimbazi River This research emphasizes on the recommendations by (Kironde, 2016) that Jangwani area should not be considered in isolation when developing mitigations for flooding in the catchment. Also, the recommendations by (Kironde, 2016) that identification of hazardous land with regard to flooding should be prioritized are emphasized. Based on this research, these should also include identification of areas susceptible to erosion by establishing the spatial variability of erodibility of the riverbank materials and the Msimbazi catchment in general.

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