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Geospatial Assessment of the Occurrence of Flooding In Informal Settlements in Ilala Municipality, Tanzania

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Abstract

This article assesses the occurrence of flooding in informal settlements of Ilala Municipality using quantitative and qualitative approaches. Non-probability sampling technique was used to select participants for participatory mapping. Data collection was done through participatory mapping, remote sensing, document review, and field observation. The weighted sum tool in ArcGIS was used to combine flood factors layers and create flood-prone area maps. Participatory mapping was used to map flood depth before data was converted for map visualization. Results indicated that areas with high to very high risk of flooding are generally decreasing over time. From 1990–2000 areas with high risk of flooding covered 31.1% of the study area, decreasing to 21.1% from 2001–2010, while from 2011–2020 it covered 21.6%. However, flood depths increased over time. From 1990–2000 the highest flood depth was 5ft, that decreased to 4ft between 2011–2020. Hence, people living in informal settlements are more vulnerable and mostly affected by floods because of disposing of solid wastes into the river valley, which blocks drainage systems, thereby causing overflow of water. Therefore, regulations guiding human development near the river valleys should be improved and unlawful activities in the river valley be discouraged. Again, storm water drainage systems should be protected and well managed as the levels of storm water have become very high over time. Waste collection contracts should be given to private companies which are flexible and able to use alternative means of accessing unplanned streets to easily collect wastes.

Keywords: *floods, informal settlements, flood depth, GIS, participatory mapping*

1. Introduction

Globally, more than 50% of the world's population is living in urban areas (UN-Habitat, 2020). Out of these, nearly 23.5% live in informal settlements (UNSD, 2019), and the ratio is expected to rise to 68% in 2050. People who live in these informal settlements cannot afford suitable housing, thus they illegally occupy fragile lands which have poor services and infrastructure, and poor surface drainage services (Satterthwaite et al., 2018).

Life conditions in informal settlements elevate risk, especially from climate related impacts such as increased temperature and heat wave, abnormal precipitation events of high intensity, flooding, and rise in the sea level

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(Satterthwaite et al., 2018). Flooding in many parts of the world, especially in informal settlements has led to the loss of human life, destruction of property, environmental degradation, environmental pollution, and disease outbreaks (Lerise & Malele, 2005). It is said that climate change has led to more frequent and destructive floods, and more severe impacts have been seen in developing countries (Melore & Nel, 2020). In developed countries, a population of 54m out of 1.2bn lives in informal settlements (UN-Habitat, 2003). Some of the informal settlements in these countries are the result of outdated master plans causing more people to concentrate in poorly developed and unplanned settlements (Tsenkova, 2012). As a result, planning for hazard management such as floods cannot be easily done (Krueger et al., 2019).

In developing countries—and in Africa in particular—many cities are unable to accommodate the pressure of concentrated economic and social activities spatially, administratively, and socially. The more these cities grow and the number of people increases, the more informal settlements multiply compared to formal settlements (Attia et al., 2016). Records show that in 1990 more than 689m people in developing countries were living in informal settlements. However, the number grew to 880m in 2014, a 28% increase in 24 years (John, 2020). Due to high population density, coupled with residents' limited resources, it has been difficult for most of the cities to maintain adequate infrastructure and services in informal settlements (Satterthwaite et al., 2018). This has been a problem whenever these areas get hit by hazards such as flooding. For example, when flooding occurred in the Graveyard Pond in 2010 and 2011, a small and fairly young informal settlement in Philippi, Cape Town, many people faced health problems related to a cold and wet environment. The floods also caused damage to belongings such as furniture and clothes. Again, data on floods from NOAA VIIRS in September 2020 estimated that floods covered 20,957km^2 in Chad, 3,483km^2 in Burkina Faso, and 213km^2 in Niger (Ajayi, 2022).

Informal settlements in Tanzania are especially susceptible to natural disasters like floods (Sakijege et al., 2012). Most of the time these floods happen when heavy rainfall renders natural watercourses incapable of accommodating the additional water; and occasionally, this rainfall cannot instantly sink into the earth as runoff (De Risi, 2013). Heavy rainfall, poor land use, and inadequate drainage are the main contributors to floods (Kwayu, 2019). Floods in informal settlements have significantly contributed to the destruction of housing stocks and other valuable properties. For example, in Dar es Salaam, people living in the Msimbazi River Valley usually lose their houses and other properties during floods that are induced by heavy rainfall (Williams et al., 2018).

Unplanned areas of Ilala District have been experiencing frequent flooding events that are affecting people's livelihood options as damage to properties puts the affected population at risk. Furthermore, flooding has been causing health risks, displacement of people, destruction of public infrastructure—such as schools, churches, mosques roads and bridges—and significant damage to houses; and sweeping away personal household items such as furniture, clothes, and appliances. Over time, one of the most affected areas of the district has been the informal settlements of Tabata Ward (Erman & Malgioglio, 2019). Despite frequent flooding in Tabata Ward, the extent of flooding in terms of depth is unknown. To clearly inform decision makers about flood management and response in the ward, there should be precise information about the spatial location of areas that are most likely to be affected. This can be achieved by availing information such as the availability of well-prepared and informed thematic maps showing the areas in Tabata that are likely to be affected by floods, and the extent of such flooding.

2. Methodology

2.1 Study Area

The study was conducted in three sub-wards of Tabata Ward in Ilala District in Dar es Salaam Region, Tanzania. The sub-wards are Msimbazi, Matumbi, and Mandela, located at latitude 6° 49'S and longitude 39° 13'E; with elevation between 0 and 900m above sea level (Figure 1). The area has humid temperatures varying from 26°C in August to 35°C in December and January, and average monthly rainfall ranging between 75mm–300mm. The soil type in the area consists of sand, clay, and loam properties. The study area had a total population of 1,220,611 people, and a population density of 5,810 people per square kilometre in 2022.

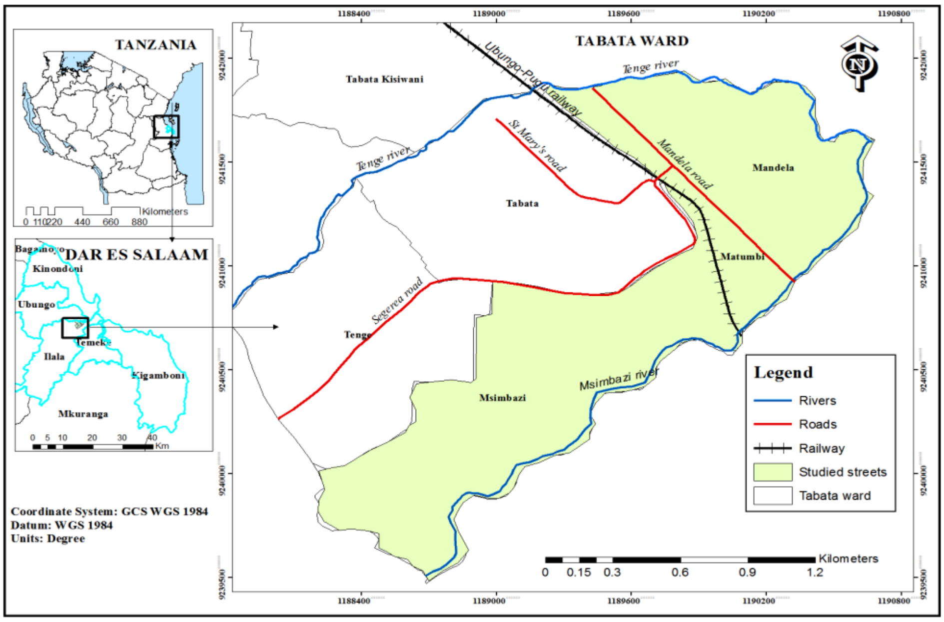


Figure 1: Location of the Study Area

Source: Authors (2021)

The main economic activities in the study are include retail companies, bars, construction businesses, restaurants, craft businesses, transportation facilities, agribusinesses, agriculture and livestock husbandry. The three sub-wards purposively chosen are found in the low-lying land; and are repeatedly affected by flooding. Moreover, Tabata occupies a large part of the Msimbazi Valley, which is home to many informal settlements.

2.2 Data Collection

This study used both primary and secondary data sources. Primary data sources included participatory mapping and direct observation. The secondary data sources were remote sensing and scanning of raster data and digitization. In addition secondary data—such as population, rainfall, and administrative boundaries—were collected from the National Bureau of Statistics (NBS); Tanzania Meteorological Authority (TMA), specifically at the Julius Nyerere International Airport station; and the Ministry of Lands, Housing and Human Settlements. The use of mixed data sources and collection methods was meant to get a variety of information that covered all aspects of this study, which would have been a difficult task if one method was to be used.

With participatory mapping, members contributed their own experiences, information, and ideas about location and extent of flooding in the study area; a process that enabled the creation of community flood maps. In executing participatory mapping, a base map in the form of high resolution satellite imagery was used to map locations of different levels of floods using a systematic procedure. First, fifteen (15) residents who were later engaged in participatory mapping were identified. These residents were those who had stayed in the study area for at least thirty years. Secondly, the selected residents took part in the mapping process (Photos 1a & b), by examining historical and current depth of floods. This was done by showing locations on the map and estimating flood depth using normal body parts such as the ankle, shin, knee, thigh, waist, stomach, and chest heights; and marked them off with pebbles of different colours using a pre-established guide with structured questions. Thirdly, the obtained measurements were calibrated to actual measurements to determine actual flood depth. For instance, a place where floods reached thigh-height of an average person, the flood depth was estimated to be 2ft; and residents marked it on the map with blue coloured pebbles.

The 10m × 10m high resolution coloured images representing the area covered by a single cell on the ground were used for participatory mapping. These images had three bands (red, green, and blue), with a scale of 1:3600. Common features such as the Msimbazi River, Tenge River, Mandela Road, Tabata Primary School, and a railway were used to orient participants during the participatory mapping process. Data obtained were transferred into a vector format ready for visualization using the ArcGIS 10.7 software.

(a) Msimbazi sub-ward (b) Mandela sub-ward

Photo 1: Participatory Mapping with Residents in Tabata Ward
Source: Fieldwork (2021)

Field observation was used to complement participatory mapping. Items observed were location of flooding zones, land uses, soil types, buildings (homes) which were close to the river, and topography and drainage systems in the area. Ground Control Points (GCPs) of the features were collected using Global Positioning System (GPS) to allow ground truthing.

Satellite images of ten years interval such as the Enhanced Thematic Mapper Plus (ETM+) for 2000 and 2010, and Landsat 8 Operational Land Imager (L8-OLI) for 2020, with cloud cover less than ten percent (<10%), were downloaded from the United States Geological Survey (USGS) earth explorer (earthexplorer. usgs.gov) to acquire land use/land cover data. The 90m × 90m resolution Digital Elevation Model (DEM) was acquired from the National Aeronautics and Space Administration-Shuttle Radar Topography Mission (NASA–SRTM) to get topographic characteristics such as slope, flow direction and accumulation, which were used in the delineation of flood-prone zones.

3.3 Data Analysis

The Multicriteria Decision Analysis (MCDA), alongside with the Analytic Hierarchy Process (AHP), were used to map the flood-prone zones using selected possibilities based on a set of criteria. The MCDA approach was adopted in this study to allow consideration and combination of many factors used in the assessment of flood-prone zones, and factors contributing to flooding. To generate maps of flood-prone zones using the MCDA approach, criteria maps were prepared, weighted, and overlaid. Then, the DEM of the study area was clipped, from which a map of distance categories from the rivers and a slope map of the area were generated. To create a rainfall map, rainfall data of 30 years collected from the TMA was used. Rainfall data in a daily time scale for the period 2000–2020 was obtained from the TMA in Excel file format. It was then converted into raster format using the ArcGIS conversion tool ready for analysis. To create isohyet maps, Inverse Distance Weighting (IDW) was undertaken under a spatial analyst who interpolated the sample data using equation 1 to create an output raster data.

$$X^{*} = \frac{w_1 x_1 + w_2 x_2 + w_3 x_3 \ldots + w_n\, x_n}{w_1 + w_2 + w_3 \ldots + w_n} \qquad [1]$$

Where;

x^{*} is unknown value of rainfall to be determined at the location;
w is the weight; and
x is known values of rainfall at the location.

Weight (*w*) is given by equation 2.

$$w_1 = \frac{1}{d^{p}_{ix^{*}}} \qquad [2]$$

Where;

p is power; and
d is the distance to known value of rainfall at location.

To create land use/land cover maps, raw satellite data was georeferenced to a known coordinate and map projection. This was done by associating the centre pixel and four corner pixels of the raw image to the actual points on the surface in the data of the same place with coordinate UTM Zone 37S. This was done to correct the distortion of the image that is a result of the image acquisition process. To reduce atmospheric noises from downloaded images, radiometric correction (also known as atmospheric correction) was done in ArcGIS using an image analysis toolbar. A masking function was applied to remove clouds in the image, followed by a mosaicking function to integrate the cleaned image. The atmospheric correction process was followed by image classification using the maximum likelihood classification tool (equation 3) of the supervised classification. To execute image classification, training samples were created with the aid of Google Earth images of the years 2000, 2010, and 2020.

$$P(i\backslash w) = \frac{P(\omega|i)P(i)}{P(\omega)} \qquad [3]$$

Where;

$P(\omega|i)$ is the likelihood function;
$P(i)$ is the priori information, i.e., the probability that class (*i*) occurs; and
$P(\omega)$ is the probability that ω is observed.

After creating the criteria maps (land use/cover, rainfall, distance, and slope maps), this was followed by weighting of the criteria by ranking them from 1–5 according to their importance as per the number of selected factors, and comparison of criteria in pairs according to Saaty's scale. With comparison, assigned grades were entered into the Decision Expert software, where Index of Consistency (IC) was computed. The relative weight of all criteria was obtained by combining individual assessment of evaluators presented using a pairwise comparison matrix (equation 4).

$$A = [a_{ij}], i = 1,2,..,n \qquad [4]$$

Where;

A is the pairwise comparison matrix;
A_{ij} is each element of the matrix, which represents the importance of the i-th criterion in the relation to the j-th criterion; and
n is the number of considered evaluation criteria.

After weighting the factors, the process of combining all the criteria maps was done to create a flood-prone areas map using the 'weighted sum' method. In performing this, each criterion map was given a weight according to its importance/contribution to flood hazard; and then the 'weighted sum' tool, an operation in ArcGIS, was used to multiply each map (raster) by their given weight and summing them together (equation 5).

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i \, w_i}{\sum_{i=1}^{n} w_i} \qquad [5]$$

Where;

$\sum$ is summation;
w is the weights given to each criteria; and
x is the value or the criteria.

To map the inundation level (flood depth), the hardcopy maps obtained through participatory mapping from each sub-ward were georeferenced and projected with coordinate UTM Arc 1960 Zone 37S to extract the flood points using GIS. The hardcopy maps were georeferenced by associating the known features on the picture such as rivers, schools, corners of playgrounds, and corners of clearly-seen tall buildings, with the same features on the same image with a correct projection. After the projection of the pictures of the hardcopy maps, the responses on the image were digitized and overlaid with other features such as rivers for visualization (Figure 3). Shapefiles containing flood depths were created based on the colour of the pebbles used in the field to represent areas with certain depths.

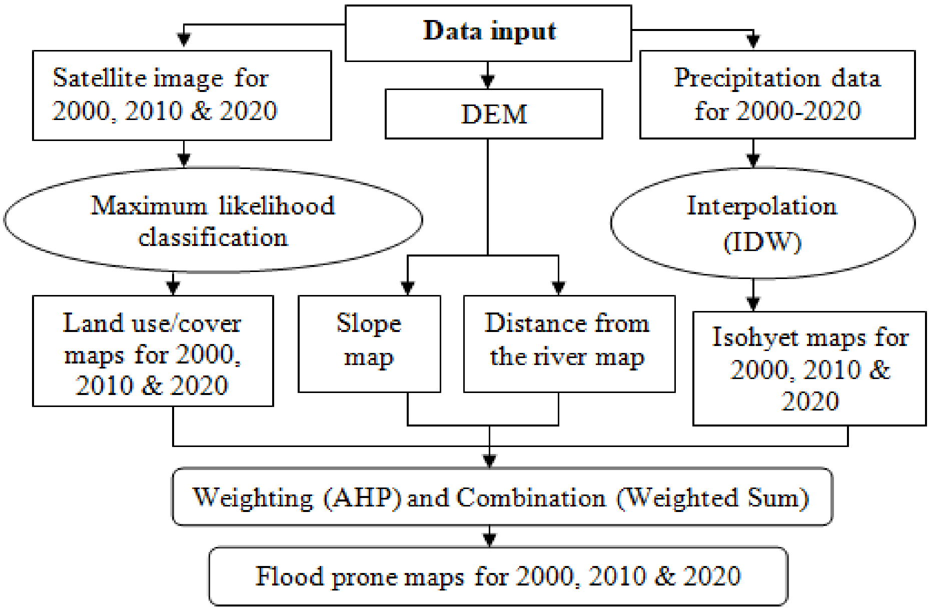


Figure 2: The Analytical Model of Flood-prone Areas
Source: Author (2021)

The digitized flood data was overlaid with the sub-ward shapefiles and river shapefiles to depict flood depths in the study area over time. GCPs were entered into an Excel file and saved in a comma-delimited text file (CSV) format, uploaded into ArcGIS and overlaid with the sub-ward shapefiles to verify the responses obtained from participatory mapping.

3. Results and Discussion

3.1 Characterizing Flood Prone Areas

Factors used in the characterization of flood-prone areas were hydrology (rainfall and river buffer), topography (slope), geology (soil), and land cover. The slope map extracted from the digital elevation model indicates that the study area is dominated by very low slope classes covering 30.65% (0.61km^2) of the entire study area. The area with very high slope class is relatively small (0.09km^2 (4.63%)) compared to other sloping characteristics, implying high probability of extreme flooding during intense storm events (Figure 3). A large part of the east, southeast, and northeast sides have gentle slopes to almost a flat surface, which attract runoff accumulation than on the western side, which is steep allowing fast runoff. The observed slope characteristics were similar to the slopes reported by Ramesh et al. (2020) in Greater Mumbai in India, and Abduh et al. (2018) in Gorontalo Province in Indonesia, which are also characterized by frequent flooding.

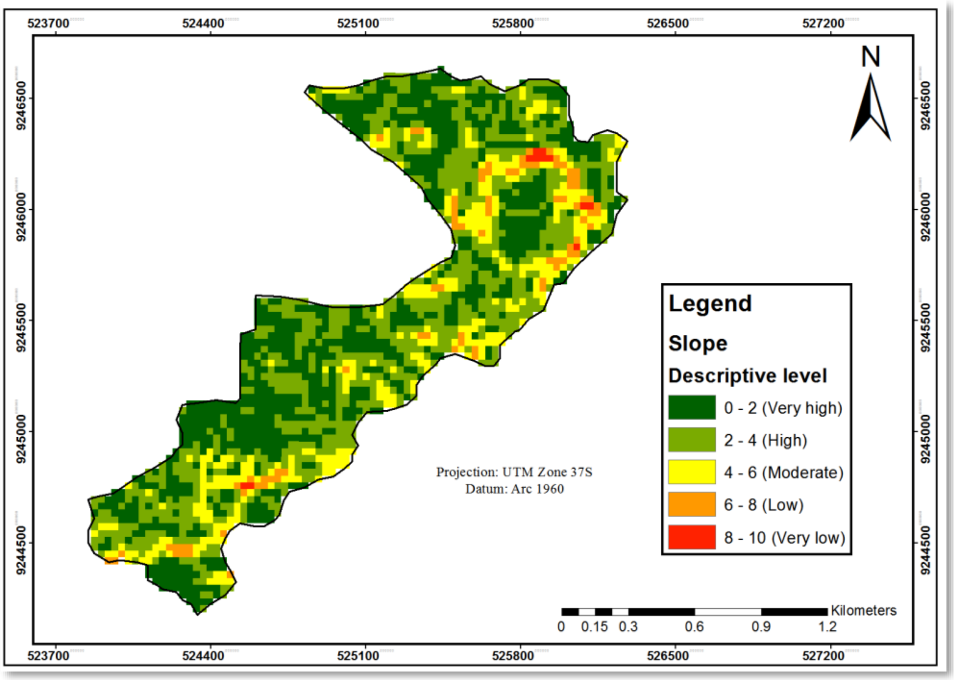


Figure 3: Classified Topographic (slope) Map of the Study Area
Source: Fieldwork (2021)

Results of the soil types indicate that the entire study area is covered by Cambic Arenosols soils. These soils are sandy-textured, and lack any significant soil profile development, and have excessive permeability. These soils are very sensitive to erosion, which can as well influence high gravels and sand deposition that can block natural and artificial drainage channels, ultimately causing overflow of water, which results in flooding of the area. Similar observations were reported by Ajibade et al. (2021) in flood-prone areas of Ibadan City in Nigeria; and by Danumah's (2016) study in Abidjan, Ivory Coast.

Proximity (distance) of settlements from the river was another factor considered in this study. Results show that a large part of the residential houses (50.15%) in the study area lies near the river valleys as the majority of the settlements are within 200m (Figure 4) from the active river channel, thus making it highly susceptible to flooding. It was reported that in most cases, especially during heavy rains, the river overflows onto its buffer and adjacent areas. Although some parts of the river are deep, the amount of storm water exceeds the river depth, and causes floods in sub-wards such as Mandela. Elsewhere, a study by Kombaitan et al. (2018) about prediction on flood-prone areas in Bandung, Indonesia, found areas near the river to be highly susceptible to flooding during the heavy rain season.

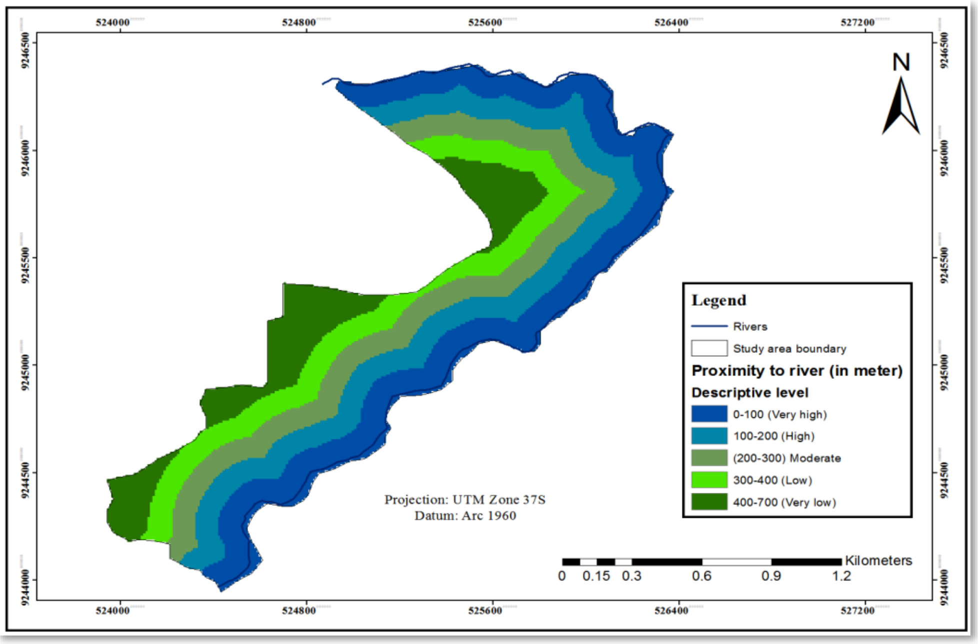


Figure 4: Areas near the River Valleys
Source: Fieldwork (2021)

Land use/land cover plays an important role in the movement of water. Land use/land cover can delay the infiltration process and accelerate runoff since some human activities may block natural water flow. In Tabata Ward there are three dominant land use/land cover types, which include grassland, built-up areas, and bare lands (Figure 5). Over time, the expansion of the Dar es Salaam City has led to an increase in impervious surface, while the grassland and bare land are decreasing. For instance, the size of the land occupied by bare land and grassland in the year 2000 was 40% (0.8km^2), and 15% (0.3km^2), respectively; while the built-up areas covered 45% (0.9km^2). However, in the year 2010, the size of bare land and grassland decreased to 10% (0.2km^2), and 20% (0.4km^2), respectively; while the built-up land use increased to 65% (1.3km^2). By the year 2020, he built-up areas had increased to 75% (1.5km^2). With the increase in built-up land, it is very likely that extreme flooding events will occur because built-up areas reduce infiltration, thereby exacerbating runoff in the study area. The study findings concur with the findings by Danumah (2016) who found that the Abidjan District, Ivory Coast, which was covered by built-up areas, was being frequently flooded. Also, a study by Hagos et al. (2022) in the upper Awash River Basin, Ethiopia, reported that the expansion of built-up areas at the expense of forest cover, contributed to increase in overland flow in the area.

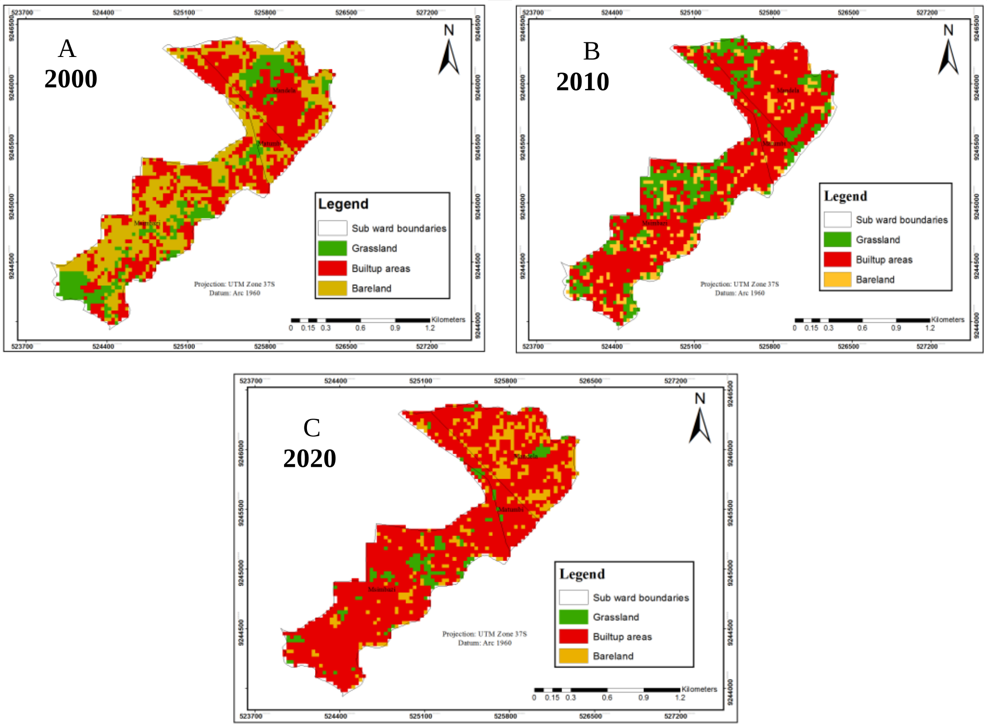


Figure 5: Land Use/ Land Cover Change in the Study Area from 2000–2020
Source: Fieldwork (2021)

Rainwater is one the prominent factors that contribute to flooding; therefore, in assessing flooding, rainfall was integrated as a factor in drawing the maps of the flood-prone areas. Results show that annual mean rainfall in the year 2000 ranged from 46–650 inches, from 52.8–55.7 inches in 2010, and 104–125 inches in 2020 (Figure 6). The observed pattern suggests that rainfall has been increasing in the study area over time, indicating that susceptibility of the area to extreme flooding events is probably increasing over time since higher rainfalls lead to increased run-off. In turn, this causes overflow of drainage channels and rivers, which are already suffering from blockage.

3.2 Flood-prone Areas

Flood-prone area maps (Figure 6) show that all years yielded five (5) levels of risk, ranging from very high-risk areas to very low-risk areas. However, area coverage of flood risks has been changing over time (Table 1). As per Table 1, areas with very low risk of flooding in the year 2000 covered 7.9% of the entire study area, while the areas with very high risk of flooding covered 14.7% of the entire study area. In the year 2010, areas with very low risk of flooding covered 11.1%; while areas with very high risk covered 13.7%. In the year 2020, areas with very low risk of flooding covered 10.5%, while areas with very high risk covered 12.1% of study area.

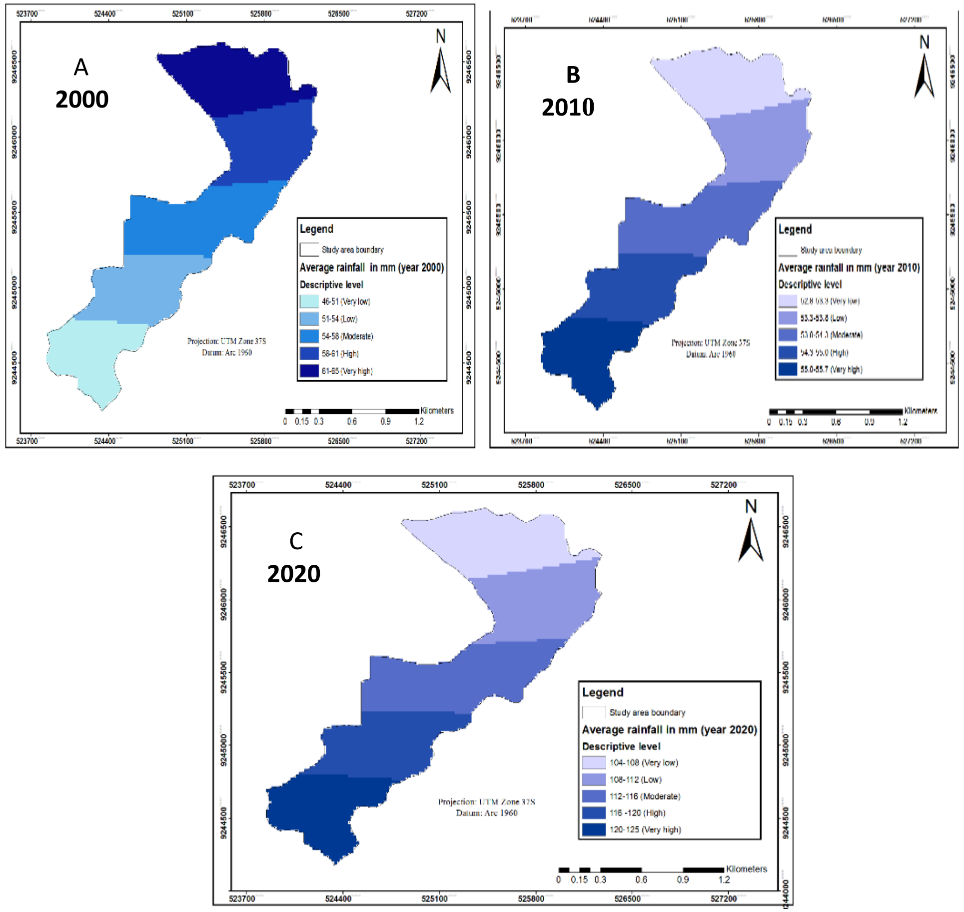


Figure 6: Temporal Variations in Rainfall Amount in the Study Area
Source: Fieldwork (2021)

Table 1: Floods Susceptibility in Tabata Ward from 2000–2020

Flood Susceptibility Class	Years					
	1990–2000		2001–2010		2011–2020	
	Area (km²)	*% Area*	*Area (km²)*	*% Area*	*Area (km²)*	*% Area*
Very low	0.16	7.9	0.22	11.1	0.21	10.5
Low	0.4	20	0.48	24.2	0.47	23.7
Moderate	0.54	27.4	0.6	30	0.59	29.5
High	0.62	31.1	0.42	21.1	0.43	21.6
Very high	0.29	14.7	0.27	13.7	0.24	12.1

Source: Fieldwork (2021)

From Table 1, areas under high and very high risk of flooding are generally decreasing over time. As indicated in Figure 6, areas with high to very high flooding risk are unevenly distributed. They are characterized by gentle slopping land, very proximal to the river valleys, receive more rainfall per year, and are unplanned built-up lands that mostly have impervious surface. Areas with very low, low, and moderate cover are also unevenly distributed. They are characterized by high slopes, low-to-medium annual rainfall, located very far from the river valley, and they are planned areas with bare land and grassland. These findings comply with those of Danumah (2016), who found similar characteristics of flood-prone areas in the city of Abidjan in Ivory Coast. Again, a study by Kebede (2012) established similar observation in Dugeda Bora Wereda in East Shewa Zone, Ethiopia.

3.3 Extent of Flooding

3.3.1 Flood Depths in 1990–2000

The results show that four levels of flooding occurred in the study area from 1990–2000. Some areas flooded to a depth of 1–5ft (Figure 7). Areas with low flooding depth (1ft) occurred mostly in places near the Msimbazi and Tenge rivers, especially at Matumbi Street. A flooding level of 1ft could not cause harm and destruction because during this epoch (1990–2000) there were no buildings and other infrastructure around the flooded areas, except that there were only activities such as paddy cultivation, which were not affected by floods.

Storm water in the paddy farms was advantageous as it supported paddy farming. However, flood depths of 1.5ft caused damage to infrastructure and properties in the upper Msimbazi due to poor design of the storm water drainage system, which could not cope with heavy rainfall. However, these floods disappeared shortly after the stoppage of rains. High flood depths were mainly caused by the narrow width of the Tenge and Msimbazi valleys during this time because the valley was not wide enough to accommodate all the water from heavy rains. However, the valleys have been expanding over time.

The results further indicate that flooding depths of 2–5ft occurred in some areas near the Tenge and Msimbazi river valleys, especially at Mandela and Msimbazi sub-wards, respectively (Figure 7).

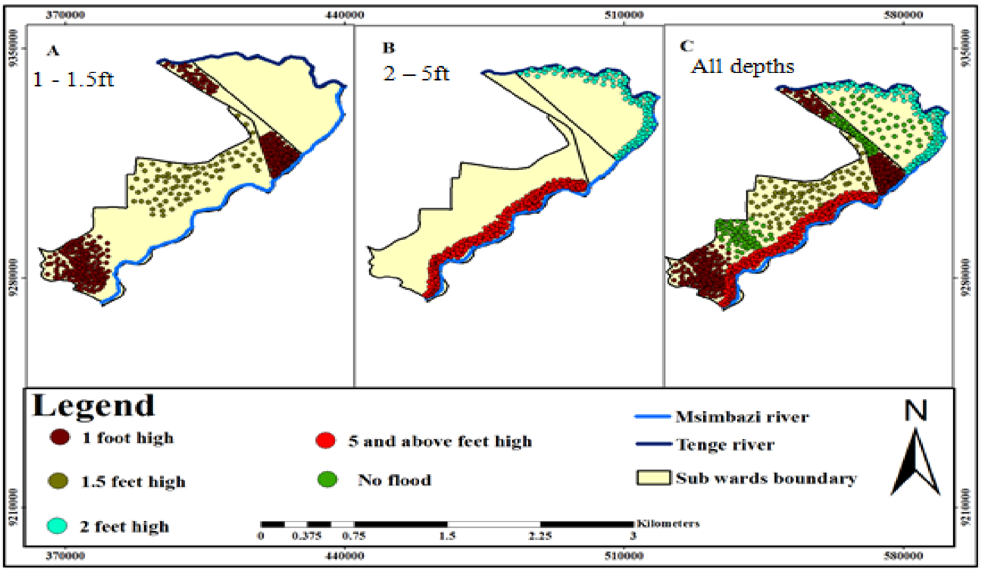
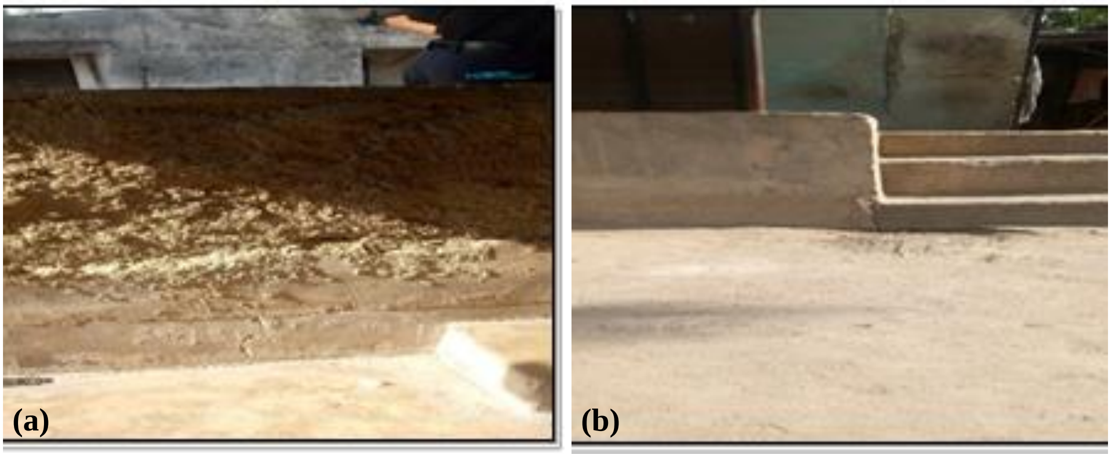


Figure 7: Flood Depths Observed in 1990–2000
Source: Fieldwork (2021)

The observed high flood depths were triggered by the El Niño rains that fell in 1998. Places far from the Tenge and Msimbazi river valleys experienced flood levels of 1ft high. This forced residents in the areas to elevate walls bordering doors to a height of 1ft or higher, which acted as indoor flood barriers (Photos 2(a) & (b)). This implies that a sudden rise in flood depth in 1998 was to a large extent caused by El Niño rather than an increase in rainfall intensity.



Photos 2(a) & (b): Walls Built as Flood Barriers at Matumbi Sub-ward
Source: Fieldwork (2021)

Flooding due to El Niño was also reported by Twumasi et al. (2017) in his study in Lamu, Kenya. The study found that the El Niño incidence from the beginning of 1998 had caused widespread downpours over Southern Africa, which triggering floods and caused damage to infrastructure and crops. These floods forced the Limpopo River to overflow its bank. Also, a study by Yvonne et al. (2020) reported similar El Niño disasters in Lamu County in 1999, which caused flooding of some parts in the county.

3.3.2 Flood Depths in 2001–2010

From 2001–2010 flood depths seemed to have relatively decreased compared to those that had occurred between 1990–2000. Areas that had experienced a depth of 1.5ft in the year 1990–2000 recorded a flooding level of 0.5ft during 2001–2010. The decrease in flood depth was partly contributed by improvement of infrastructure, including the extension and widening of storm water drainage paths. At the Msimbazi Sub-ward, areas which previously had a flood depth of 1ft maintained the same depth during the 2001–2010 period, while areas that previously had no flood records, reported flood depths of 0.5–1.5ft in the year 2001–2010 (Figure 8).

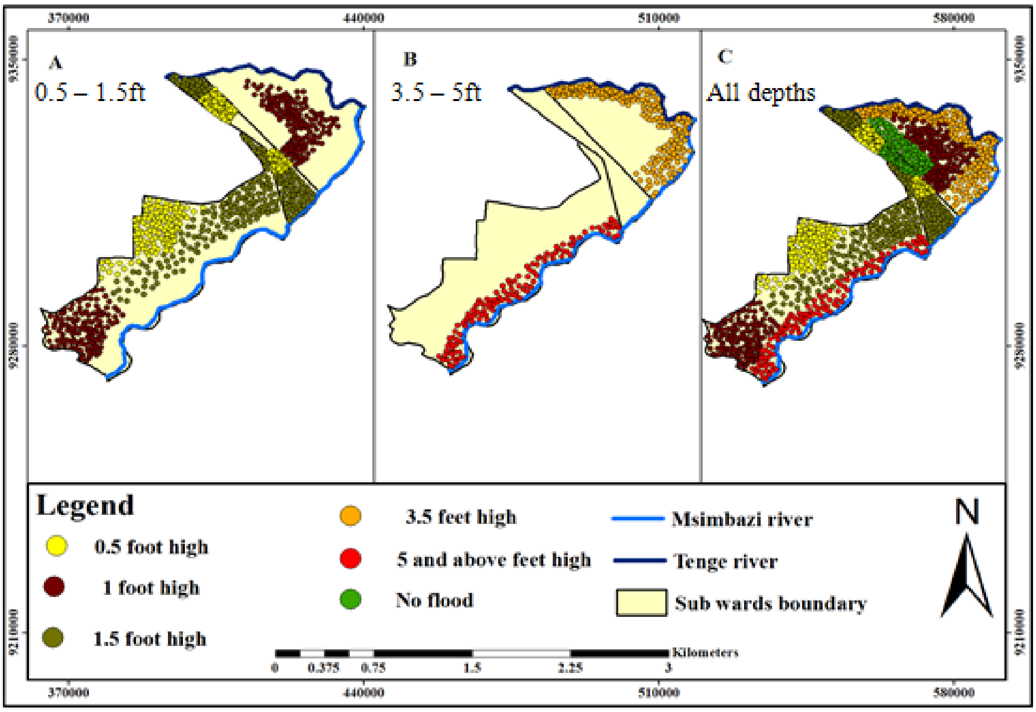


Figure 8: Flood Depths Observed in 2001–2010
Source: Fieldwork (2021)

The reason for this situation was because buildings at the Msimbazi sub-ward are located 60m away from the river valley, as spelt out in the National Environmental Management Act and the National Water Policy of Tanzania. However, despite the provision stated in the Act about the recommended distance between river valleys and settlements, increased channel flow resulting from intense rainfall has been causing flooding in the Msimbazi Valley.

The same case is seen in the Mandela sub-ward. Areas of the sub-ward that had not been affected by flooding in 1990–2000 were experiencing a flooding depth of up to 1ft in the period 2001–2010. The increasing flooding depth was partly due to the expansion of the Tenge River, which previously had a narrow river valley. This expansion has influenced floods of 0.5ft in some sub-wards, such as Matumbi, which were previously unaffected by floods; while places that previously experienced flood depth of 1ft started experiencing a flood depth of 1.5ft. As pointed out earlier, incidences of flooding have been increasing over time partly due to a poor drainage system, as culverts are too narrow to handle increased storm water, thereby causing it to overflow and spread in settlements, thereby destroying properties and causing loss of life. Also, poor disposal of plastic bottles—which later accumulate and lead to the blockage of culverts and the entire drainage system—is one of the factors causing flooding in the study area (Photos 3(a) & (b)). These findings are in line with those of a study by John (2020), who also found that the lack of maintenance of infrastructure and river channels was a weakness of local authorities.

(a) Condition of storm water drainage facilities at Mandela sub-ward

(b) A land previously owned by a resident at Mandela sub-ward

Photos 3(a) & (b): Condition of Storm Water Drainage Facilities and Expanded Tenge River

Source: Fieldwork (2021)

A flood depth of 5ft high was observed in the Msimbazi sub-ward, especially in areas that are near the Msimbazi River. Most of the time, this depth was observed during the major rainfall seasons, which are between the end of March and beginning of May. This high level of storm water occurred mostly because of storm water that did not originate from the impact of rainfall in Dar es Salaam, but came from other places such as Kisarawe in the Coast, and Morogoro regions. This is because geographically these regions are at a higher elevation than Dar es Salaam, hence most of their storm water flows into rivers such as Msimbazi.

Again, an increase in construction activities, especially in lowland areas, leads to increased sand mining in the river. Sand mining causes the divergence of the river to settlements during high rainfall, which ultimately causes flooding of the settlements. Also, with time, the number of houses built near the river valley increases, thus blocking the river from expanding its width during heavy rainfall.

3.3.3 Flood Depths in 2011–2020

The results show that during the period 2011–2020, flooding levels of 0.5ft–4ft were recorded, indicating great variation in flood depth from previous years, especially in the Msimbazi sub-ward (Figure 9). In the Msimbazi River Valley, a flood depth of 1ft was observed in the months of May to June compared to the 5ft flood depth observed in the period 2001–2010 during the same months. The period 2011–2020 recorded highest rainfall. If there was any decrease in flood depth, it was partly due to the efforts made by the Municipal Council, in collaboration with the National Environmental Management Council (NEMC) and the Wami-Ruvu Basin Authority. These authorities contracted engineers to construct the riverbank and remove sand and solid wastes accumulated in the Msimbazi River (Photo 4b). The task also included building of an artificial wall along the riverbanks (Photo 4a) and planting weeds to prevent riverbank erosion and storm water from reaching the riverside settlements. The construction has increased river depth and width to 3 metres and 30 metres, respectively, thus making the flow of storm water easier and faster during the rainy season.

Areas that had flood depth of 0.5ft in 2000–2010 experienced an increased flood depth to 1ft in 2011–2020 as a result of the expansion of the Tenge and Msimbazi rivers in some parts of the Matumbi sub-ward (Figure 9). Also, the continued construction of industrial infrastructure within 60 meters from the river course has led to increased flooding that affects the nearby settlements. The expansion of the Tenge River in terms of width has increased flooding in the informal settlements built within 60 metres from the river. As a result, Mandela and Matumbi sub-wards experience a flood depth of about 1ft and 0.5ft, respectively, during the rainy season. There has been a rapid increase in the number of houses informally built in the area, leading to blockage of the drainage system, hence increasing flooding.

(a) A wall built along the banks of Msimbazi river

(b) Excavator removing wastes and sand from Msimbazi river

Photos 4(a) & (b): Recent Endeavours in Msimbazi Sub-ward to Reduce Flood Depth

Source: Fieldwork (2021)

The results show that in the study area, river depth decreased as settlements were built closer to the Msimbazi River; and depth increased as distance of settlements from the river increased. In areas where settlements are closer to the Msimbazi River, flood depth doubled compared to the depth recorded ten years earlier, increasing from 1.5ft in 2010 to 3ft in 2020. At the Matumbi sub-ward, flood depth of up to 4ft increased in some areas where settlements were closer to the Tenge River. This was not the case in the Msimbazi sub-ward where flood depth increased with increase in the distance from the Msimbazi River (Figure 9). This was due to efforts made by the government that involved cleaning, deepening, and widening the Msimbazi River Valley caused by improper disposal of solid wastes, especially in the storm water drainage systems. This was common in unplanned settlements where contracted trucks were unable to pick wastes for disposal due to inaccessibility as a result of unplanned streets in the Msimbazi sub-ward.

Also, the results show that most of the settlements in Mandela and Matumbi sub-wards, which were near Tenge River, experienced a flood depth of 4ft high. Increased inflow in the Tenge River is partly the reason why there was an increase in flood depth in the settlements located near the river valley. Again, the construction of industries near the Tenge River has increased its volume since most industrial affluent is discharged into the Tenge River Valley. For instance, in the Matumbi sub-ward, some of the people who own industries have diverted one of the tributaries of the Tenge River (Mabibo River), making the Tenge River incapable of accommodating storm water after heavy rainfall.

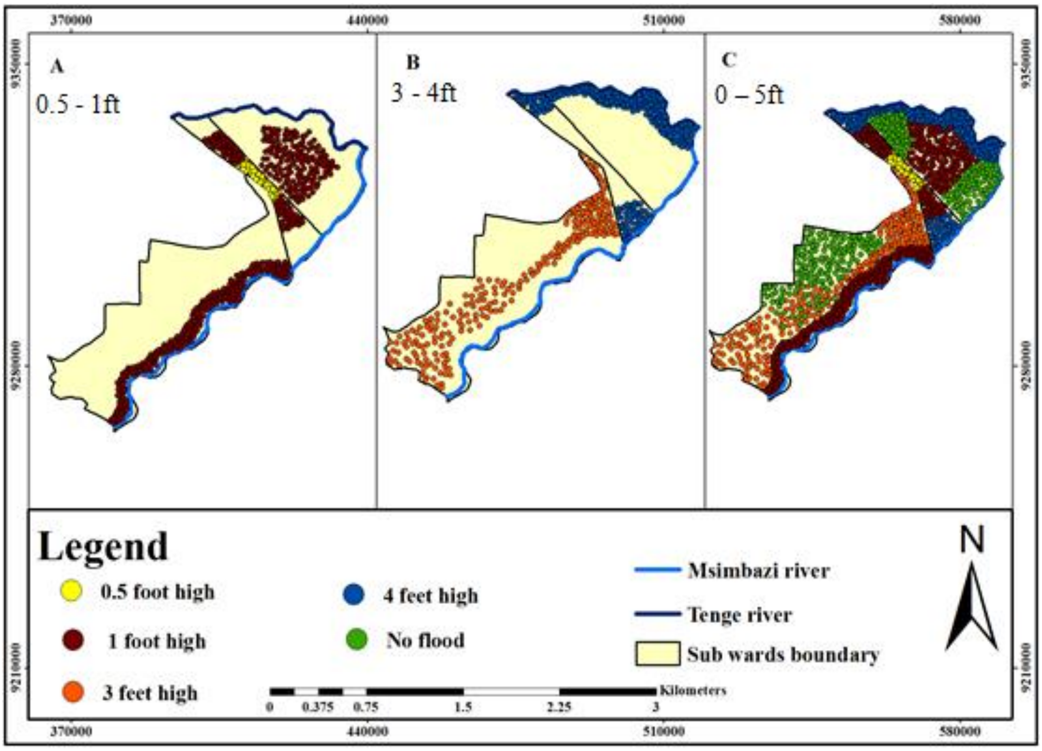


Figure 9: Flood Depths Observed in 2011–2020
Source: Fieldwork (2021)

Most of the industries near the Tenge River have increased the risk of flooding to the settlements near the valley because industrial walls are built in such a way that they extend within the river valley, hence decreasing the width of the valley. For example, in Mandela sub-ward, settlements that are closer to industries are safe from floods despite being very close to the river valley. This is because strong walls constructed by industrial owners not only protect industries but also neighbouring settlements as rivers cannot overflow.

Overall, the results show that in 1990–2000 floods were more pronounced in sub-wards located near the Tenge River, and decreased towards the Msimbazi River. In the period 2001–2010 floods were common in few areas neighbouring the Tenge River, but dominated large parts near the Msimbazi River (Figure 10). In the mentioned decade, areas that were relatively far from the Msimbazi River had very-low-to-moderate floods. In the period 2011–2020, floods of high-to-very-high intensity decreased in many parts of the study area. In this decade floods of very-high intensity were more pronounced in areas near the Msimbazi River, while the remaining part of the study area reported very-low-to-moderate floods.

1-1.5ft

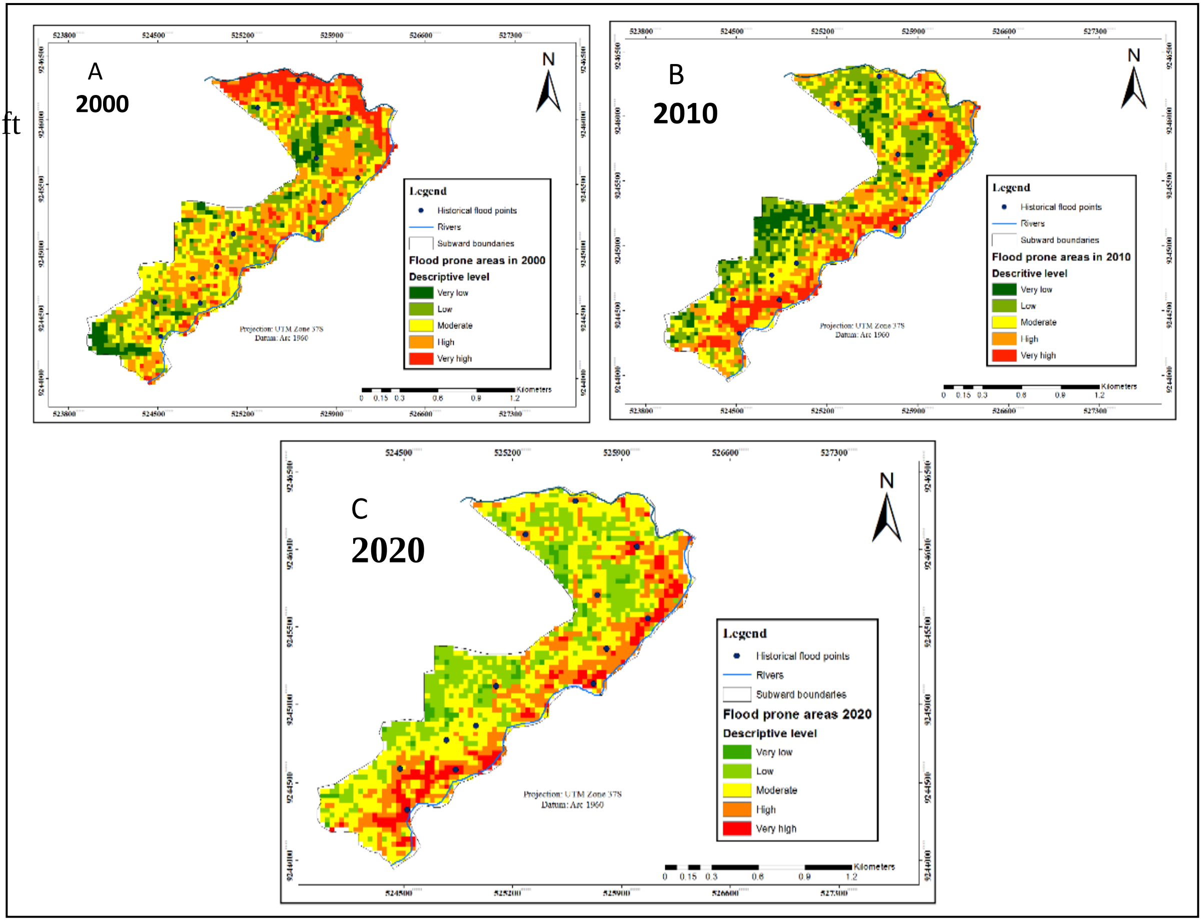


Figure 10: Flood-Prone Areas Variation Overtime in the Study Area
Source: Fieldwork (2021)

4. Conclusion and Recommendations

This study has established that people living in informal settlements are more vulnerable and mostly affected by floods, especially during heavy rainfall seasons compared to their counterparts living in planned settlements. This happens because unplanned settlements have been extended to very close to the river valley, thus narrowing the river width, which in turn causes the squeezed Msimbazi and Tenge rivers to overflow towards people's settlements. This study has also found out that, in the study area, river depth decreased as settlements moved closer to the Msimbazi River; and the depth increased as the distance of settlements from the river increased. This means that households close to the river valley dispose of solid wastes into the river valley, thus blocking drainage and reducing river depth. Flooding has frequently brought about costs related to the destruction of houses and infrastructure, as well as the loss of life to many residents in Tabata ward. These costs and effects have been increasing over time due to the rapid establishment of unplanned settlements neighbouring the river margins.

Generally, this study has shown the relevance and strength of geospatial techniques in assessing natural hazards, such as floods in informal settlements. Therefore, it is recommended that regulations guiding human development near the river valleys should be enforced to limit unlawful activities within 60m from the active river flow. Again, storm water drainage systems should be protected and managed properly as the levels of storm water have become very high over time in the study area. This should involve regular cleaning, deepening and removing solid wastes in the river valleys to allow smooth flow of water in the rivers. Since a large part of the study area is unplanned, and the accessibility to solid waste service providers is limited, contracts should be given to private contractors who are flexible and able to use alternative means—like using carts or wheelbarrows—to access unplanned streets to collect wastes, which are considered to be main sources of the blockage of storm water drainage systems, which in turn aggravates floods in the study area.

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