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Geospatial Analysis of Flood Occurrences in Selected Sub Wards of Morogoro Municipality - Tanzania

Ernest William Mauya*, Denis Matilya

Department of Forest Engineering and Wood Sciences, Sokoine University of Agriculture, Morogoro, Tanzania

Email address:
mauya@sua.ac.tz (Ernest William Mauya)
*Corresponding author

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Abstract: Flood is characterized by an overflow of water than drainage capacity of what is normally a dry land. Urban flooding has become progressively recurring and deadly natural disaster across different cities in the world. Floods results to a lot of damages which vary from place to place. Therefore, in curbing flood and its effects, it is important to have information on flood occurrences at different geographical scales. In this study, geospatial tools have been used to analyze the flood occurrences of selected sub wards in Morogoro Municipality, between 2016 and 2021. It was found that 41.84% of all houses in the selected 56 sub wards assessed in Morogoro Municipality had experienced flooding within the 5 years. Some sub wards faced high flood occurrence as much as 91.8% of all houses in such sub wards: Gohalema were flooded while others like Mzigila sub ward received a minimal 5.26% flooding occurrence. To further describe the spatial distribution, maps of flooding occurrence, their distribution, intensity and ranges had been generated. Furthermore, flooding simulation of the study area at different elevations was conducted to see what areas would or would not be flooded. To conclude, the study had shown that there was flood occurrences in Morogoro municipality between 2016 and 2021, and further shown that, there was spatial relationship between flood Occurrence and elevation as well as drainage network. However, further studies on the factors that affect flood occurrences in the study area are recommended.

Keywords: Flood Occurrence, Geospatial Analysis, Flooding Simulation

1. Introduction

Worldwide, urban areas are affected by natural disasters at different geographical scales and locations. Such disasters include; wildfire, earthquakes, floods, storms, heat wave and as well anthropogenic disasters. It is of no doubt that these disasters have caused much harm and loss to both people and their environments but there are some disasters that outstands the others in their effects to people. Furthermore, some of these disasters can have long lasting effects to communities. Urban flooding is one of the most dangerous natural disastrous event which takes place every year especially in the cities [6]. Flood disasters had impacted more people than other natural disasters in the world within a period of ten years from 1993 to 2002. Recent studies have shown that flood is the most frequent natural disaster in the world and it had in fact led to 49% of all total disaster events and 44% of deaths in the world in 2019 [20]. Flood occurs when there is an overflow of water than drainage capacity of what is normally a dry land [13]. This can be a result of continuous heavy rainfall, high speed course of water in river, proximity to large water bodies (such as oceans) and poor drainage system of which can be referred as to fluvial, flash, coastal and pluvial floods respectively [11]. It was estimated that in around 90 countries, 190 million people were vulnerable to flood risk and that 170,000 deaths globally were estimated to occur between 1980 to 2000 from such risk [19]. According to Hudson et al since 1980 floods as a natural hazard have accumulated global losses of more than £0.71tn [9]. There are many factors that leads to the increased floods and its effects but climate change and unprecedented increase in urban population have aggravated the frequency and the intensity of urban flooding during the last decade [6-7, 18]. This is especially true in Africa as the trend of population growth of selected cities in Africa shows that Africa has the highest urban population growth in world [17].

Managing the flood risks and making cities safe and resilient have been broadly discussed and discourse in the key global agendas, notably to making cities more inclusive, safe, resilient, and sustainable under the Sendai Framework for Disaster Risk Reduction 2015–2030, the Sustainable Development Goals (SDG) for 2030, the World Humanitarian Summit Commitments to Action, and the New Urban Agenda [1]. However, implementations of these agendas, requires detailed information on flood occurrences as a basis for decision making and development of mitigation plans at different geographical scales. Therefore, this study was conducted to quantify flood occurrences in Morogoro municipality, in Tanzania using geospatial tools. Flooding is fairly a recurring event in Tanzania. It has brought devastating effects such as temporary eviction from residence, heavy traffic, destruction of properties and forth on time and time again. For instance, heavy rainfall in just a day on 11th January 2018 at Morogoro region in Tanzania caused damage to properties and infrastructure such as electricity and water supply lines and sadly also the death of one person [12]. Apart from the direct impacts of floods there are indirect impacts such as eruption of water borne diseases and other related problems such as algal bloom. Increased urbanization adds up as a cause of this problem such as when people settle at flood prone areas, rerouting or blocking water streams and climate change has made it even worse [12]. Specifically, this study intended to 1) determine and map flood occurrence in Morogoro urban district, 2) Study the topology of study area so as to explain flood occurrence spatial distribution, 3) simulate flooding of the study area and relate to the flooding occurrence.

2. Materials and Method

2.1. Study Area

This study was conducted in Morogoro municipality which lies between 6°41’ and 6°50’ South and 37°38’ and 37°43’ East (Figure 1). The municipality has 13 wards the largest being Kihonda with an estimated area of about 5592.7 ha, which is just a bit more than half the size of the municipality. These wards are made up of 153 sub wards. The area receives rainfall twice in a year where by the short rain begins form October to December while the long rains are from March to May. The average rainfall per year lies between 800 to 1000 mm where by the rain fall exceeds 1000 mm per annum in region of high altitudes such as at Uluguru mountain and it then gradually decrease to 600 mm per year in region of low altitudes. The average temperature of the region is 25°C in a year [16].

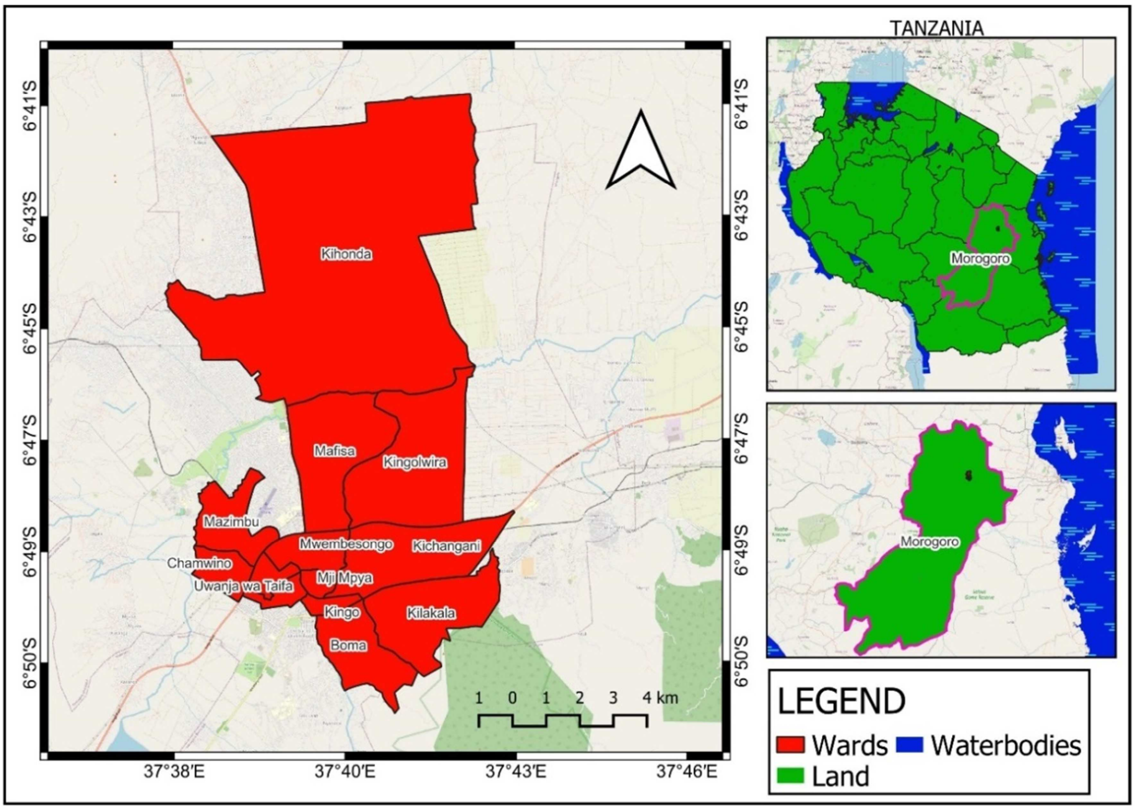

Figure 1. *Location of the study area.*

2.2. Sampling Design

The selection of samples was based on easiness (closeness) on reaching samples and the limits of cost, time and number of data collectors, the willingness and ability of respondents to respond, hence convenience sampling was used [2, 4, 10]. The samples were sub wards of Morogoro Municipality where only 56 out of 153 sub wards were selected. These sub wards fall into 10 out of 13 wards of the municipality namely Kihonda, Mafisa, Mazimbu, Chamwino, Uwanja wa Taifa, Boma, Mji mpya, Mwembesongo, Kichangani and Kiwanja cha Ndege (Figure 2). After the selection of samples census was used where by data were collected from all houses in the selected sub wards such as how it can be seen in Misufini sub ward (Figure 3).

2.3. Data Collection

Data collection was done using Open Data Kit (ODK) across all the houses within the selected sub wards from the actual field. In each of the household, post flooding data between 2016 and 2021, were collected. The spatial distribution of the collected data across the Morogoro municipality is shown in Figure 2. Flooding occurrence data from the post flooding was used in this study.

2.4. Data Analysis

2.4.1. Flood Occurrence and Mapping

Descriptive statistics were used to summarize the flood occurrence across the different sub wards within the Morogoro Municipality. The information was then summarized into tables and Figures. Finally, the information was displayed into maps by using Quantum Geographical Information System (QGIS) software to show the spatial distribution of flood occurrence in the entire area of interest. Houses that had experienced flooding within the five years were denoted 'yes', that did not as 'no' and those with no response were denoted as 'no data' (Figure 3). The following formula was used to determine flooding occurrence of each sub ward.

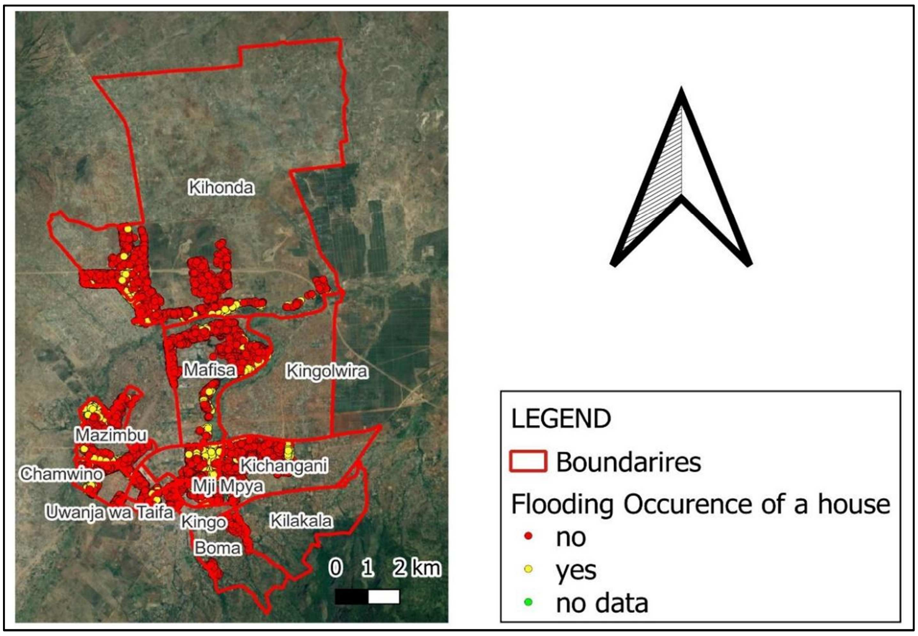

Figure 2. *Flooding occurrence distribution of study area 2016-2021.*

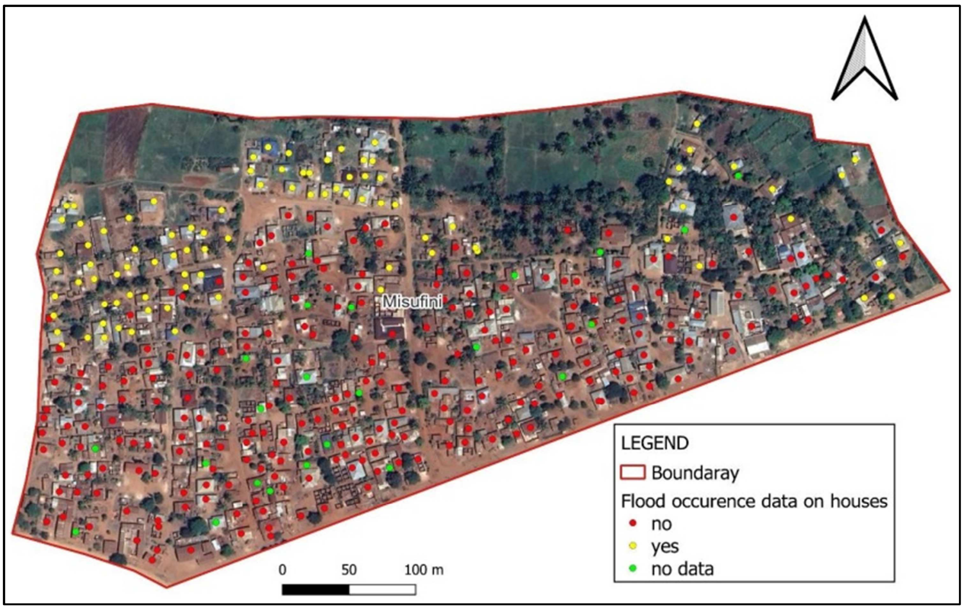

Figure 3. *Distribution of flood occurrence data in Misufini sub ward 2016-2021.*

$$\text{Flooding Occurrence (FO)\%} = \frac{\text{Number of houses experienced flooding}}{\text{Total number of houses in sub ward}} * 100\%$$

2.4.2. Drainage System Mapping and Elevation

Water on the earth surface generally flow from regions of higher to lower elevation due to gravity, governed by the topology of an area. They do so through channels which build up into bigger channels collectively called as tributaries which feeds the rivers with water. An area with a collection of tributaries that all end up to one bigger tributary or a river is a drainage basin (see Figure 8). All of these is what forms natural drainage system of an area and it can be determined through remote sensing and Geographical Information System (GIS). Therefore in this study, Digital Elevation Model (DEM) of 30 m resolution of the year 2021 from Shuttle Radar Topographical Mission (SRTM) was used generate drainage system map, determine and map the elevation of the study area. Drainage density is the length of channels in a basin divided by the length of the area of the basin [3]. But since the unit of observation in this study is a sub ward then drainage density used here would be the total length of channels in a sub ward divided by the area of the sub ward. Drainage All the analysis was performed using QGIS software.

$$\text{Sub ward drainage density} = \frac{\text{Total length of channels in a subward}}{\text{subward area}}$$

2.4.3. Flood Simulation

Flood simulation involves inundating (flooding) the study area in a map at different elevation ranges, so as to see what area would be flooded and which will not. The simulation conducted in this study took the assumption that the earth surface is hard and impermeable. DEM was then used to determine the elevation ranges of different points in the map. Finally, flooding was simulated as the flow of water from region of high elevation to lower in 3- dimensions map. A layer of buildings was added in the map and all the buildings were kept at 6m height. All the analysis was done using QGIS software.

3. Results and Discussion

3.1. Results

3.1.1. Flood Occurrences

Data on 56 sub wards with a total of 18140 houses were recorded for flood occurrences. On average 41.84% (Table 1), of all the houses had experienced flooding between 2016-2021. The summary statistics of the data is presented in Table 1, below. Among the sub wards, Gohalemwa had the highest flooding occurrence of 93% (Figure 4), while Mzigila had the lowest flooding occurrence of 5.3% (Figure 5).

Table 1. *Summary statistics of flooding occurrence in Morogoro urban 2016-2021.*

s/n	Category	Value
1	Number of sub wards	56 sub wards
2	Number of non-flooded houses	9954 houses
3	Number of flooded houses	6835 houses
4	Number of houses-no data	1351 houses
5	Total number of houses examined	18140 houses
6	Percentage number of non-flooded houses	51.83%
7	Percentage number of flooded houses	41.84%
8	Percentage number of houses-no data	6.33%

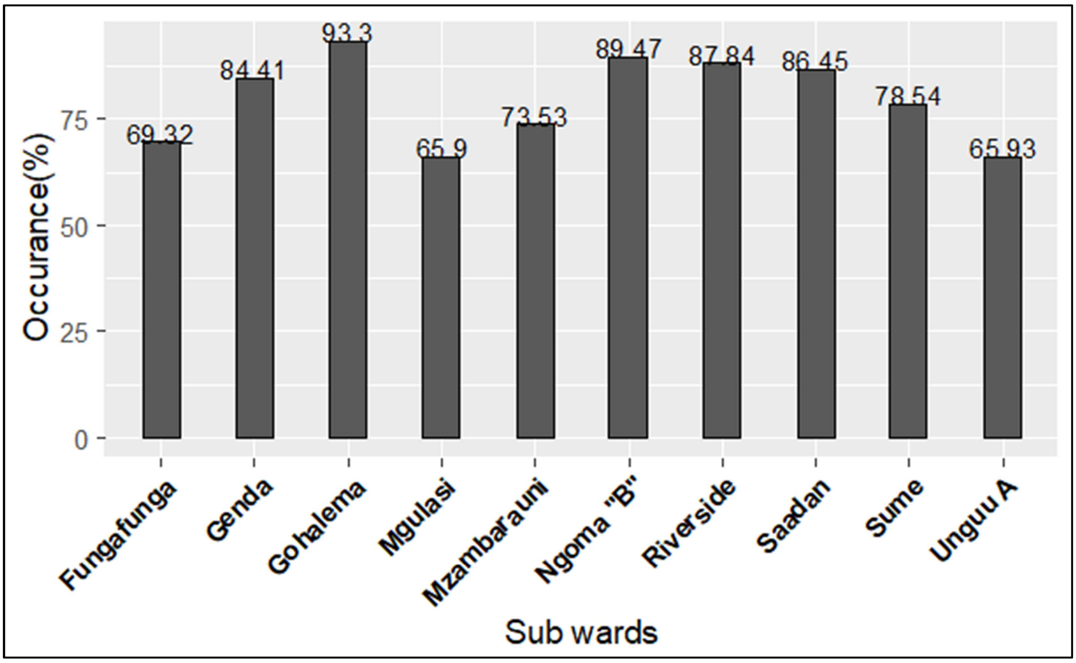

Figure 4. *Top 10 sub wards of highest flooding occurrences.*

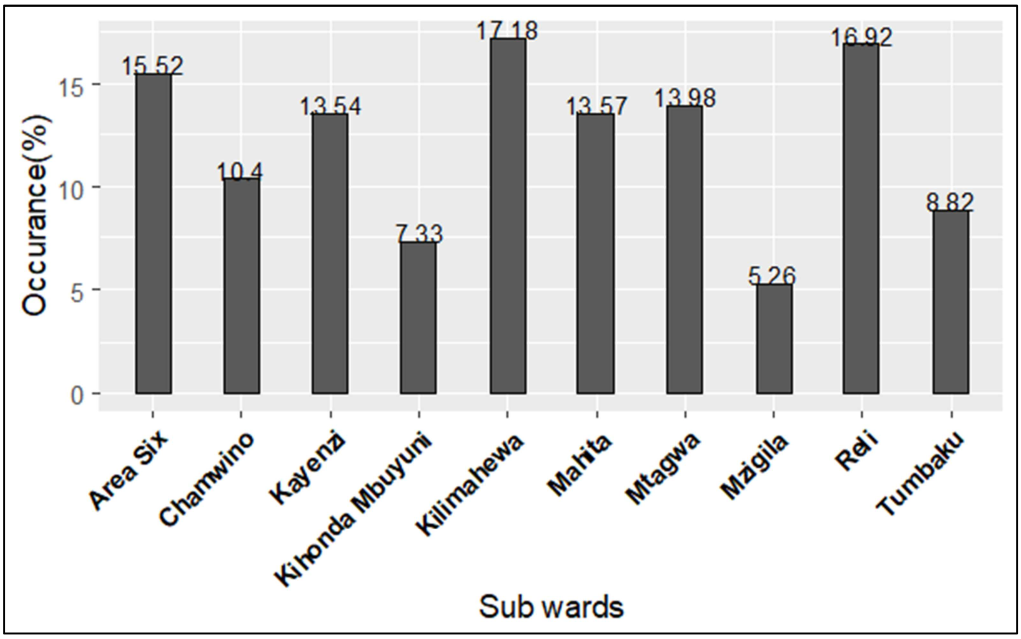

Figure 5. *Top 10 sub wards of the lowest flooding occurrences.*

The flooding occurrence data were put into ranges of 15% intervals except for the first class which had 10% class interval. Most of the sub wards (82%) (Table 2), were found to between 11% and 70% flooding occurrence and almost half (48%) (Table 3), of the sub wards are between 0% and 40%. The spatial distribution of the flood occurrences over different ranges are further shown in Figures 6 & 7.

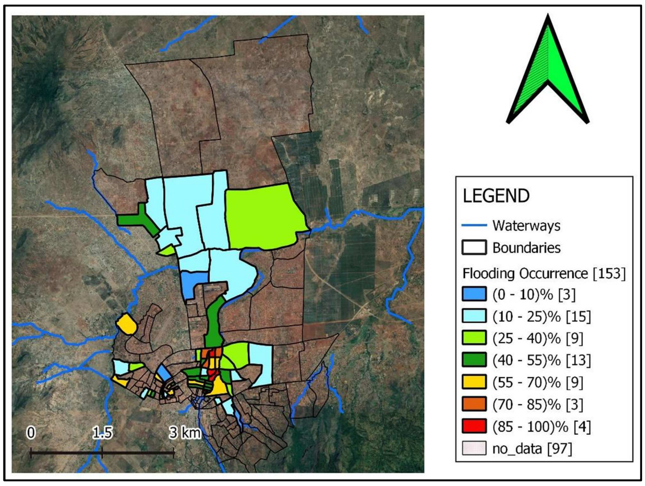

Figure 6. *Flooding occurrence map of the study area.*

Table 2. *Range of flooding occurrence of study area.*

Flooded houses range (%)	# Sub wards	# Sub wards (%)
(0-10)%	3	5%
(11-25)%	15	27%
(26-40)%	9	16%
(41-55)%	13	23%
(56-70)%	9	16%
(71-85)%	3	5%
(86-100)%	4	7%

Table 3. *Cumulative range of flooding occurrence of the study area.*

Flooded houses range (%)	# Sub wards	# Sub wards (%)
(0-10)%	3	5%
(0-25)%	18	32%
(0-40)%	27	48%
(0-55)%	40	71%
(0-70)%	49	88%
(0-85)%	52	93%
(0-100)%	56	100%

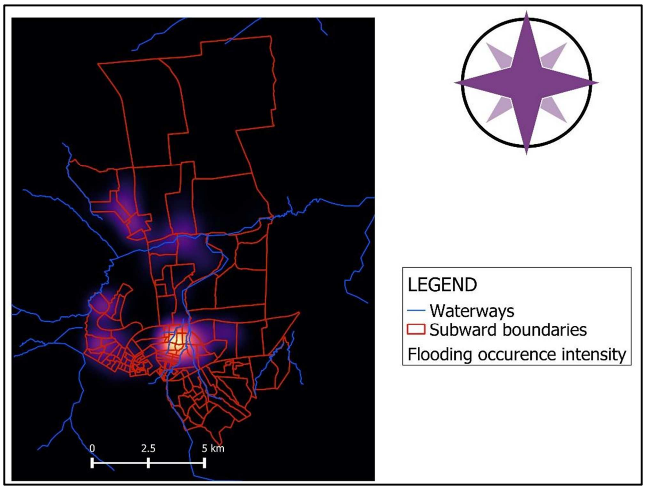

Figure 7. *Flooding occurrence intensity heat map of the study area.*

3.1.2. Drainage System, Density and Elevation

It was found that almost the entire study area was within one drainage basin (Figure 8). The study area was seen to have water ways of 9 strahler levels. Strahler level 9 was river Ngerengere and its tributaries were the water ways of lower strahler levels where by strahler level 1 was the smallest strahler level. Water flows from Uluguru mountains found adjacent to Morogoro Urban and resultantly through the water ways they fill the river (Figure 8). The highest elevation of this mountains adjacent to the study area is at 1816 meters above sea level (m.a.s.l) as it can be seen and denoted by green colors in the map (Figure 8). The lowest elevation of the study area is at river Ngerengere which passes at the center of the study area (see Figure 9) at 461 m.a.s.l. Elevation increases gradually moving north or south of the river as it is denoted by the gradual change in color from blue to pink up to 1000 m.a.s.l (Figure 9).

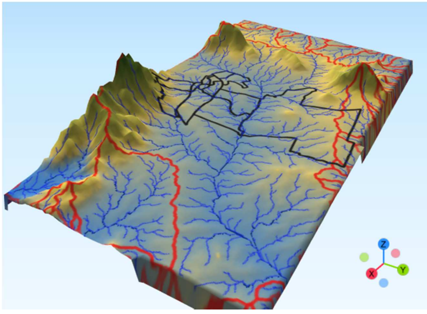

Figure 8. *The 3d map of study area showing its drainage system to the 5th Strahler level.*

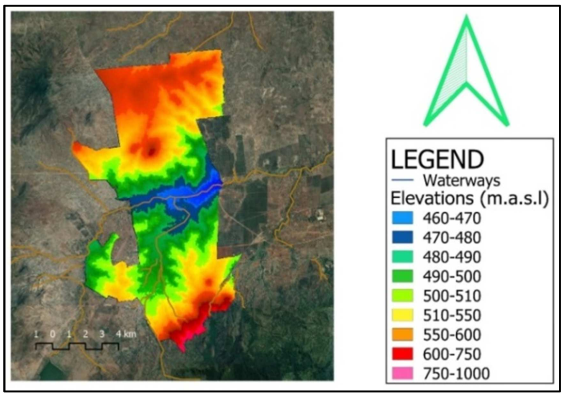

Figure 9. *Study area elevations.*

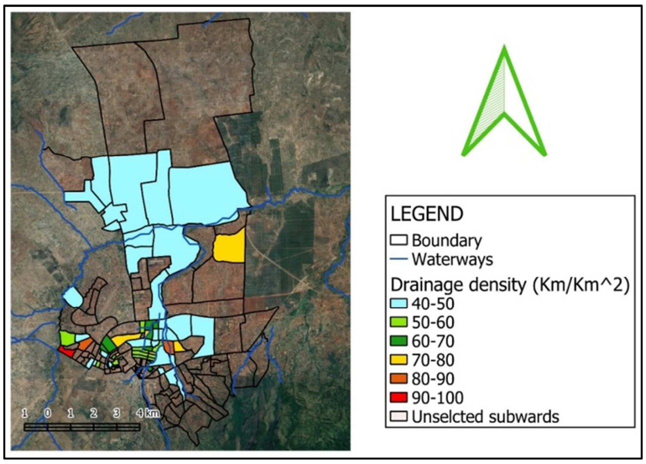

Figure 10. *Drainage density of selected sub wards in the study area.*

3.1.3. Flooding Simulation and Scenarios Analysis

Results on flood simulation at water level heights of 1m, 8m, 15m, 21, 28 and 34 m from the lowest elevation point the study area (461 m.a.s.l), are presented in Figure 11. The results indicated that, water height level, height of the building and proximity to river are the key factors which determine the flooding occurrence and pattern (Figure 11). Based on the results, buildings with heights less or equal to 6m were partially flooded, at lower height water levels of 1m, 8m and 15 m, especially when they were close to the river Ngerengere. At the water height level of 34 m from the lowest elevation point, buildings which were less than 6 m heights, were close to the rivers and were at a lower elevation, they were completely flooded. Spatially, most of these buildings were at Mafisa and Kingolwira wards (Figure 11). However, at the same water level height, building heights and elevations, most of the buildings in the wards of Kichangani, Chamwino, Mazimbu and Kihonda were partially flooded.

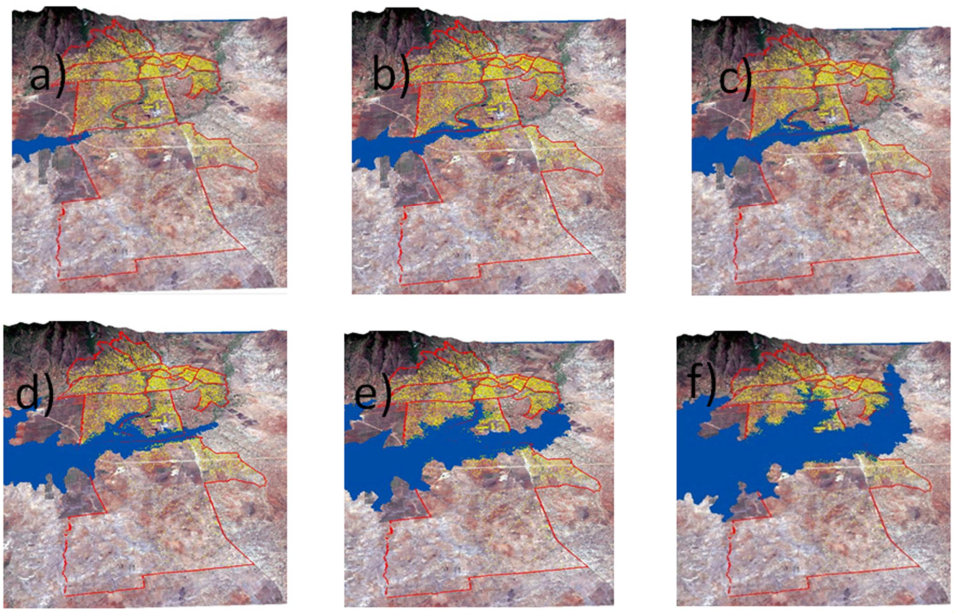

Figure 11. *Maps of Morogoro municipality showing flooding simulation when the study area was inundated by a) 1m, b) 8m, c) 15m, d) 21m, e) 28m and f) 34m heights of water from its lowest elevation point.*

3.2. Discussions

The overreaching goal of this study was to assess the spatial distribution of flood occurrences using geospatial approaches. The study further determined the relationship between flood occurrences and topographical features, simulated the flood occurrences and finally compared it with the real data collected through field survey. To our understanding this is one among the few studies which have been conducted to quantify flood occurrences in urban cities of Tanzania. For the given locality in which it had been conducted i.e. Morogoro urban, this is the first study to determine flood occurrences.

A comprehensive dataset on flood occurrences were collected from 56 flood prone sub wards, which essentially represented the actual situation within the Morogoro municipality. The results indicated that, between 2016 and 2021, 41.84% of all 18140 houses located within the studies sub wards had experienced floods at different scales. However, a question arises to why some sub wards have flood occurrence as high as 91.8% and while other very minimal flooding occurrence for as much as 5.26%. This could be attributed by variety of factors that influence the occurrence and the severity of flood events; these factors can be described by meteorological, geological, geomorphological, hydrological, topology and land use characteristics of flood-prone areas that influence the spatial distribution of flood occurrence [5].

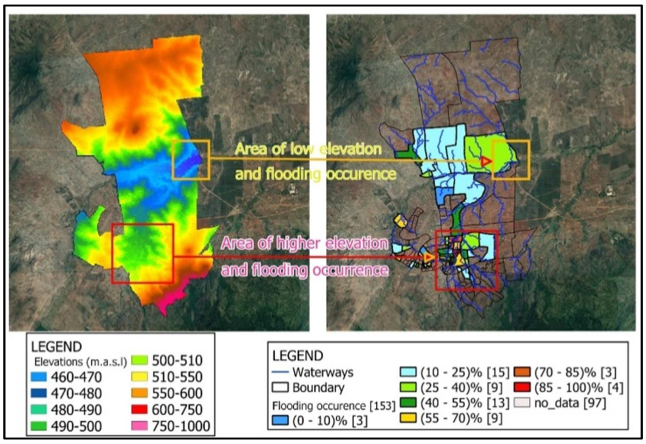

Figure 12. Maps of elevation and flooding occurrence of the study area.

According to Nsangou et al, elevation plays a very important and effective role in flood susceptibility [15]. The lower it is, the more likely the area is to be flooded, as low-lying areas are the points of convergence of the various rivers. In this study we considered the elevation of the study area which spans over 539 meters vertically from 461 to 1000 m.a.s.l. The lowest elevation is situated at central east of the study area and increases gradually to west, north and south of the area (see Figure 9). It was observed that the area with sub wards of the highest flooding occurrence were found at slightly relatively higher elevation than area of lowest elevation which have low flooding occurrence (see Figures 7 & 12). This is not to say that elevation has no impact on flooding occurrences, but is mainly because all the selected sub wards were at relatively lower elevation from the adjacent Uluguru mountains and that the difference in elevation between the areas was small 50 m ([460-470] to [500-510] m.a.s.l) (see Figure 12). Furthermore, even the area with highest flooding occurrence, also contain sub wards with low flooding occurrence (see Figures 12 & 13), indicating that elevation range observed was too small to show significant difference in flooding occurrence between the two areas.

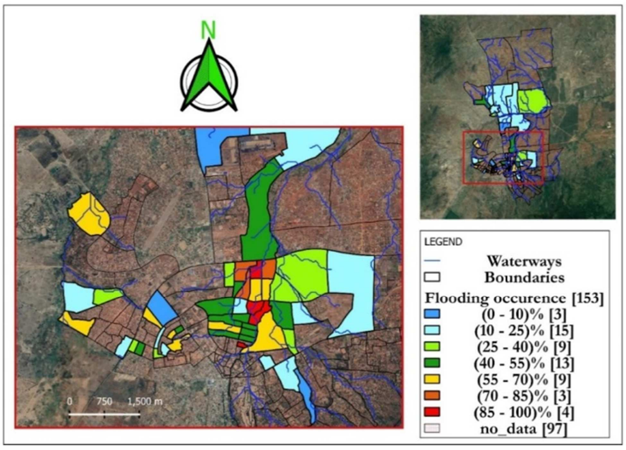

Figure 13. The map of Morogoro Urban showing flooding occurrence and drainage system.

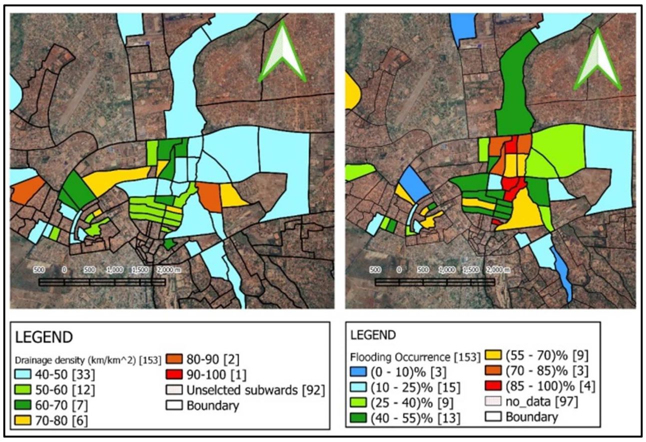

Figure 14. Maps of drainage density and flooding occurrence of the study area.

This is further, evidenced by the results from the flood simulation (Figure 11), which essentially indicated the areas which are at lower elevation and close to the river are more likely to be flooded. Similar study at Ajaokuta also in Nigeria showed that areas of higher proximity to river i.e. 1 km from either side of river Niger had higher risk of flooding than ones that were 1.5 and 2 km from either side of the river [14]. Apart from elevation, drainage system is one among the factors which determine and affect the urban flood occurrences. It can show how the tributaries are spread and their density in an area and this is useful in assessing the risk of an area to be flooded and hence flooding occurrence. See for example, the area with high flood occurrence sub wards also have more dense drainage tributaries (see Figure 13). Drainage density had also been calculated and the areas that had high flood occurrence also had relatively higher drainage density than areas with low flood occurrence (see Figure 14). According to Hewaidy et al high drainage density areas are likely to have weak or impermeable, sparse vegetation and high relief with fine drainage texture and therefore lead to dissected drainage basin with a fast-hydrological reaction to rainfall [8]. This can be simply seen as the higher the drainage density the more likely to have higher flooding occurrence.

4. Conclusion

To conclude, this study had assessed spatial distribution of flooding occurrence in Morogoro municipality using geospatial approaches. Generally, the study indicated that on average 41.84% of all the houses in the study area had experienced flooding between 2016-2021. A step further was taken to study the topology and drainage system of the study area using both field and simulated data. It was observed that, the area with sub wards of the highest flooding occurrence were found at slightly relatively higher elevation than area of lowest elevation which have low flooding occurrence. This mainly because all the selected sub wards were at relatively lower elevation and that the difference in elevation between the areas was small 50 m. However, results from the simulation, indicated that, the areas which were at lower elevation and close to the river were more likely to be flooded. It is then recommended that, in areas with high flood occurrence; they should improve houses to withstand flooding, avoid blocking the natural drainage system, reduce the sedimentation in the drainage system water ways, conserve the urban forest and the catchment zones especially ones in the nearby Uluguru mountains. Lastly, further studies on examining the factors affecting flood occurrence are encouraged.

Authors Contributions

Both of the two authors jointly, designed the study, performed data analysis and developed the manuscript.

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