

## Examining the Nature of a Floodplain Using GIS Open Data: A Case Study of Jangwani Floodplain Terrain in Dar Es Salaam, Tanzania

Daniel Morgan Kwayu<sup>1</sup>

### Abstract

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Flooding is one of the rampant and persistent problems in many of the developing countries. Sustainable and innovative actions are needed to address the continuously increasing flood risk in developing countries. The aim of this study was to demonstrate how open-source GIS data source and its functionalities can be used to analyze the nature of a flood plain, particularly in developing countries. The selected case study area is a flood-prone area called Jangwani, found in Dar Es Salaam city in Tanzania. Different GIS open-source data were processed to generate flow direction, flow accumulation, slope, hillshade and contour raster in the floodplain area. Insightful findings were obtained. About 16.4 percent of the surrounding population by area is likely to be affected by the floodplain during the rainy season. The floodplain slopes were found to be flat which impedes the discharge of water to the Indian Ocean. The elevation in the floodplain was found to be lower than in surrounding areas. Thus, the watersheds intersecting Jangwani floodplain which are four times greater than the area of Jangwani floodplain are most likely to discharge in the plain due to the plain's lower slope. Further, two major transport infrastructures namely the BRT bus terminal and Jangwani bus station, are likely to be inside the floodplain in the occasion of heavy rainfall. This may result in serious transportation hurdles for the populations that surround the floodplain area during the rainy seasons. The results of this analysis can assist in the appraising of effective flood mitigation measures in developing countries where there are limited resources for data acquisition.

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**Keywords:** floodplain, open-source GIS data, Jangwani, Tanzania

### 1 Introduction

Flooding is one of the rampant and persistent problems in many of the developing countries. Different studies have been conducted to address this issue. Opere(2013) studied floods in Kenya and suggested the reasons for frequent flooding in Budalang'i area is high rates of sedimentation and accumulation of sediments in river bed causing the elevation of the river course above the general level of the flood plain. This results in overbank flow across the protection dykes causing massive flooding. It is stated that the protection dykes have exceeded their life span of 20 years which results in frequent breaching of the dykes by water. The study further suggests climate, geology, and topography, settlement patterns, poor land-use and degradation of catchment areas as factors contributing to frequent flooding in Kenya. Nwigwe, et al., (2014) assessed the causes and effects of flood in Nigeria and stated that urban flooding occurs in towns situated on flat or low lying terrain characterized by little or no provision for surface drainage, or where existing drainage is clogged with municipal waste. Urban dwellers were used in the study survey, and majority of the dwellers selected inadequate drainage channels, poor waste management, nature of terrain, illegal structure on and across the drainage channels, among other causes as the substantive causes of flood in Nigeria's urban areas. Edongo, et al., (2019) evaluated flood management policies in City of Yagoua, Cameroon and stated that the area is exposed to frequent flooding due to the presence of a flat topography which has almost no slopes combined with the increase in annual rainfall.

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<sup>1</sup> P.O.Box 17 Himo, Tanzania, Tel: +255745290690. Email: [danielkwayu1@gmail.com](mailto:danielkwayu1@gmail.com)

In Tanzania, various studies have been conducted to address the issue of floods and floodplains at various locations. Mbura(2014) analyzed floods pattern in Dar Es Salaam and stated that the low elevation of the region (low land), closeness of the region to Indian Ocean, poor infrastructures in the region which blocks water channels, and poor city planning i.e. bad settlement policies and construction of homes in valleys which blocks drainage system of the region, are the reasons for persistent floods in Dar Es Salaam region. In another study, Dinesen(2016) studied the Kilombero valley floodplain in Tanzania and found that the cause of flooding in the plain is the extremely low plain gradient. The floodplain is surrounded by high land areas (flanked by the Udzungwa Mountains that rise to 2600m to the west and Mahenge Highlands to the east). In addition, the hydrology of the floodplain contributes to its flooding, as several rivers both large and smaller streams, transverse the floodplain, and some mergers within the floodplain forming larger rivers. Furthermore, both permanent and seasonal streams draining the Udzungwa Mountains (borders the floodplain in the west) flow into the floodplain.

There are various sources of GIS open data that have been utilized in different applications. Each GIS open data has its own strengths and limitations. Donnelly(2010) studied six Free and Open Source Software (FOSS) and provided their overview in comparison to ArcGIS. The six FOSS that were reviewed in the study were GRASS, QGIS, uDig, gvSIG, OpenJUMP, and MapWindow. The study suggested that while each FOSS had a unique strength, in comparison to ArcGIS, free and open-source GIS software were weaker in terms of support for various geoprocessing operations. Basiri, et al., (2016) assessed the quality of OpenStreetMap (OSM) and stated that since many contributors of OSM are not geospatial data experts, the reliability of OSM is doubtful despite its wide use. Their contributions to OSM such as geometry and attribute data inserts, deletions, and updates, can be imprecise, inadequate, varying, or vague. A similar argument is provided by Cezarino, et al., (2017) study that assessed geospatial open data sources and on the availability of the data. The study found the lack of a single major organization that compiled and organize all type of spatial data of an area.

Rosen, et al., (2002)stated that due to noise in the metrology and radar data, processing the accuracy of SRTM data is difficult. As an alternative, the study suggested that the wide processing of substantial quantities of SRTM data around the world reflects high accuracy of the data. Further, Liu(2008) evaluated the data quality of Shuttle Radar Topography Mission (SRTM) DEM and suggested that the quality of its DEM is dependent on the map scale used, and in comparison to actual DEM obtained from ground surveys, the absolute elevation error in SRTM DEM is lower in low lands than in high lands.

There has been a wide application of open source GIS data despite its current limitations. One of the useful applications of GIS is in the field of hydrology. Rusko, et al., (2010) explained the use of GIS for storm water systems. The study states that GIS is efficient in the management of watershed storm water, management of flood hazard and floodplain mapping. Further, open-source GIS platforms can be used in modeling of hydraulic and hydrologic storm sewer systems which involves using digital elevation model data to estimate surface elevation, slope, and using the physical characteristics of the watershed to reckon the runoff of storm water. Abdeyazdan, et al., (2015) stated that mixing geographic information system with mathematics, hydrologic and hydraulic models expedites flood zone drawing processes, increases the accuracy and speed of establishing floodplain or flood zoning, determines the water logging extent of floodway and river margins. The study suggests that mixing and integrating various layers of GIS can be used to show possible damages of residential regions, infrastructures and route networks that are around rivers and/or floodway. In addition, Mohamed(2019) found that satellite images with GIS increase the effectiveness of flash floods mapping.

The aim of this study was to demonstrate how open-source GIS data sources and its functionalities can be used to analyze the nature of a floodplain, particularly in places or countries where the resources for area-wide data collection are limited. The study had four main objectives. First, to determine whether the floodplain is a sink or there is a blockage ahead of the area which traps the water. Secondly, to determine the flow direction of water in the area and which streams or channels of water discharge in the area that contribute to the flooding of the area. Thirdly, to explore the efficiency of the created drainage systems of the area by establishing their slopes with respect to the area. The slopes will be examined to determine whether they are steeper than the area to allow the desired drainage. Lastly, to estimate part of the population and infrastructures that are likely to be affected by the floodplain during the rainy season.

## 2 Study Area

This study focuses on a flood-prone area called Jangwani, found in Dar Es Salaam city in Tanzania as shown in Figure 1. The floodplain extends to 12 divisions of the Dar Es Salaam region. Jangwani is a low land area with floods occurring each year and has caused the destruction of properties, infrastructures, and deaths of people. My interest is particularly on the nature of the area; even under a small amount of rainfall, water gets trapped in the area and remains stagnant for days as shown in Figure 2. Furthermore, on occasion of flooding, it appears as the direction of water flow is contrary to the expected one i.e. there is a river mouth within the area which supposedly, drains its water in the Indian Ocean which interestingly lies in the opposite direction to the visually observed flow of water in the area during flooding.

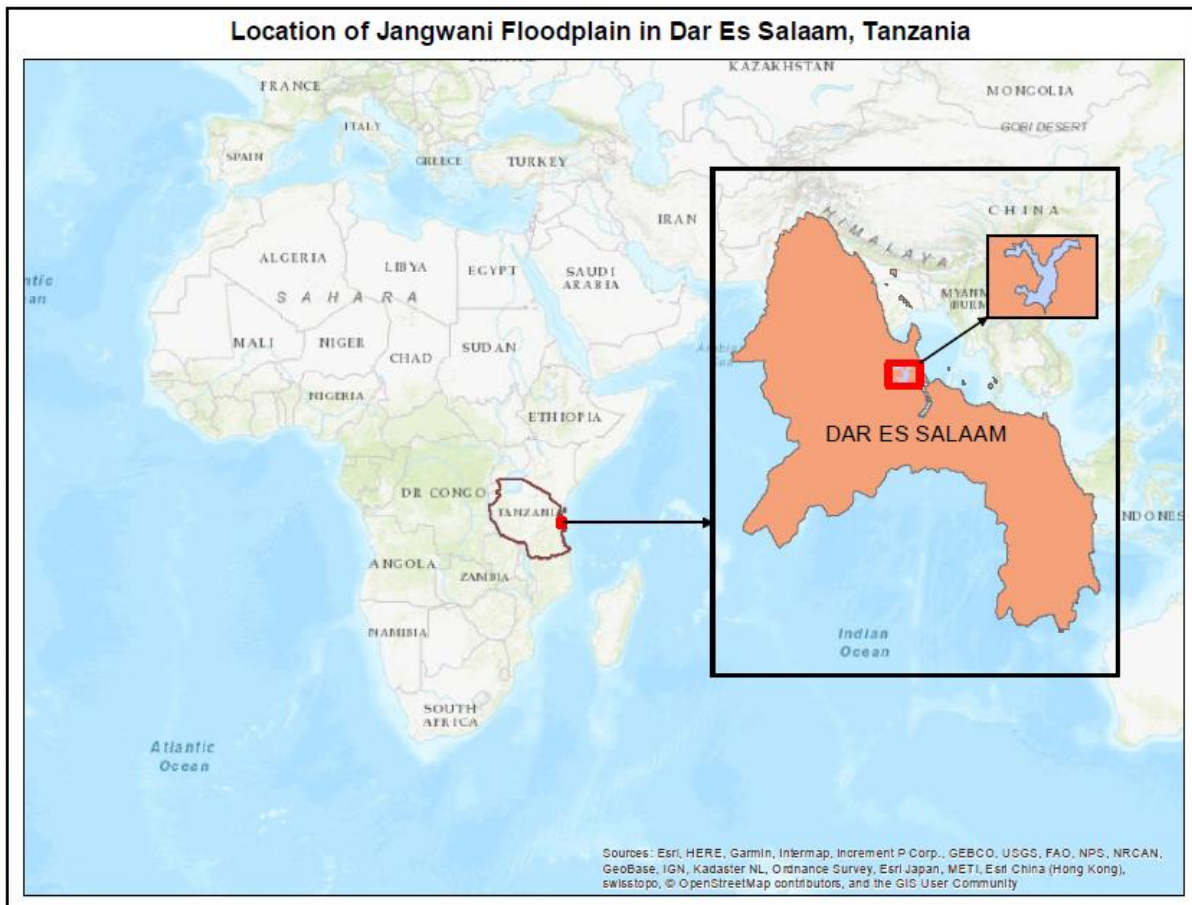


Figure 1. Location of Jangwani floodplain in Dar Es Salaam, Tanzania



Figure 2. Image from Google Earth showing the outline of the floodplain (left), and an image from the department of disaster management in Tanzania showing flooding in the floodplain (right)

### 3 Data Source

All the data required for analysis were obtained from GIS open-source portals as shown in Table 1. The dataset include data on bodies of water comprised of floodplains found in the country, data on the waterways comprised of rivers, streams and drains, data on roads comprised of both local, regional and national roads, data on buildings comprised of the layout and position of private and public buildings in the country, transport infrastructures data comprised of the location and position of bus terminals and bus stops all over the country, elevation data comprised of the DEM of a portion of the country, administrative boundary data comprised of borders of the country, regional and divisional boundaries of Tanzania, and data on the population of the country comprised on population of each division, in each region of the country.

**Table 1. Data and sources used in the study**

<b>Data</b>	<b>Source</b>
Bodies of water	
Water ways	Geofabrik (OpenStreetMap partner)
Roads	<a href="https://download.geofabrik.de/africa/tanzania.html">https://download.geofabrik.de/africa/tanzania.html</a>
Buildings	ia.html
Transport infrastructures	
Elevation	Earthexplorer <a href="https://earthexplorer.usgs.gov">https://earthexplorer.usgs.gov</a>
Administrative boundary	DIVA-GIS <a href="http://www.diva-gis.org/gdata">http://www.diva-gis.org/gdata</a>
Population	National Bureau of Statistics, Tanzania <a href="http://statistics.go.tz/group/national-statistics">http://statistics.go.tz/group/national-statistics</a>

### 4 Methods

#### 4.1 Data Preprocessing

The area of interest was first generated from the regional boundaries layer found in the administrative boundary dataset through selection by attribute. The selected region of interest i.e. Dar Es Salaam was then exported into a file and personal geodatabase format. As all the dataset were in a geographical coordinate system WGS 1984, they were first projected to the coordinate system of the area WGS 1984 UTM Zone 37S. They were then all clipped to the generated area of interest to limit the extent of analysis to the desired area only.

For the DEM, two raster datasets were merged through mosaicking into a single DEM raster covering a portion of the country, inclusive of the area of interest. The mosaicked raster was then projected from WGS 1984 geographic coordinate system to WGS 1984 UTM Zone 37S projected coordinate system. The DEM covering the area of interest only was then extracted from the projected mosaicked raster through extraction by mask, using Dar Es Salaam region polygon as the mask. The generated DEM covering the area of interest was first filled to cover the sinks present which were due to small imperfections in the data which could have limited the flow analysis of the area. The filled DEM was then processed to generate flow direction, flow accumulation, stream links which were then used to generate watersheds of the Dar Es Salaam region. Furthermore, the filled DEM was used to generate slope, aspect, hillshade and contour rasters of the area of interest as demonstrated in Figure 3 and Figure 4.

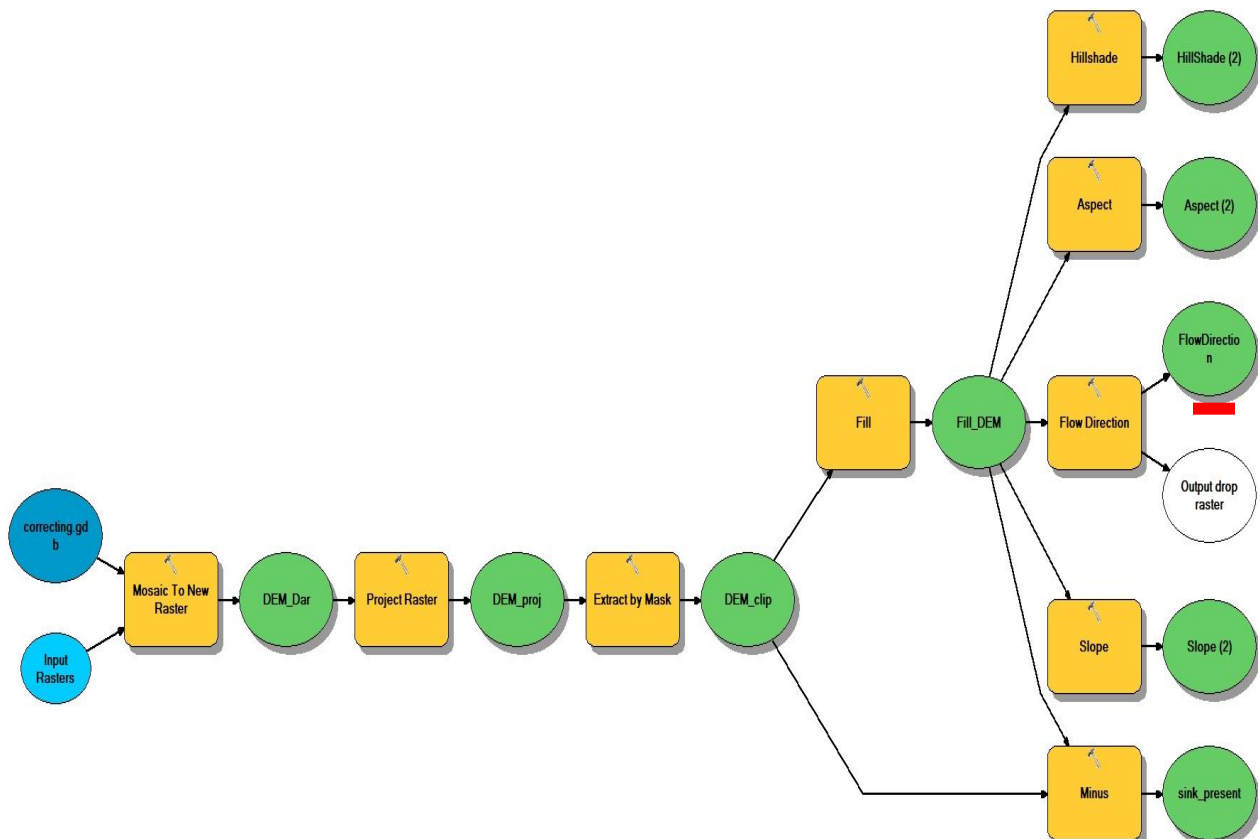


Figure 3. A model used to generate flow direction and slope rasters from SRTM DEM

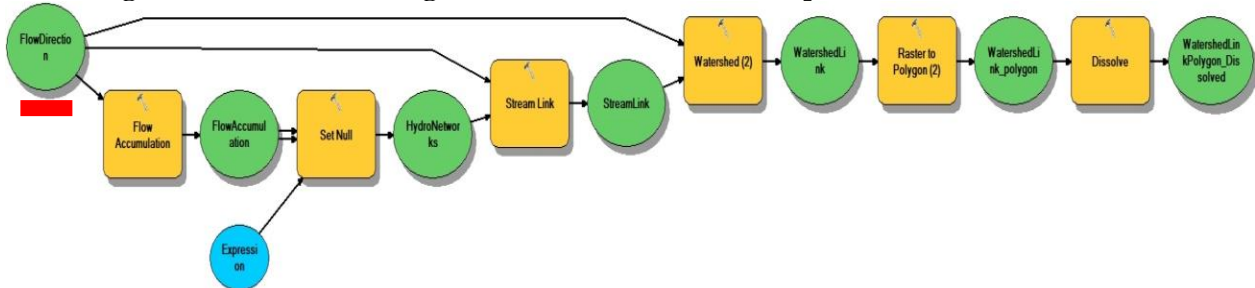


Figure 4. A model used to generate watershed polygon from flow direction raster

#### 4.2 Feature Extraction

After successfully generating projected datasets covering the area of interest only, features of interest were then extracted from the datasets.

For the bodies of water dataset which among its components included the desired Jangwani floodplain, the floodplain was selected from the layer followed by creation and storage of it into a new layer which consisted of only a single polygon, the Jangwani floodplain. The formed Jangwani polygon layer was the center of study, and all other generated features for this project were processed with respect to this generated Jangwani floodplain polygon. The workflow of this procedure is shown in Figure 5.

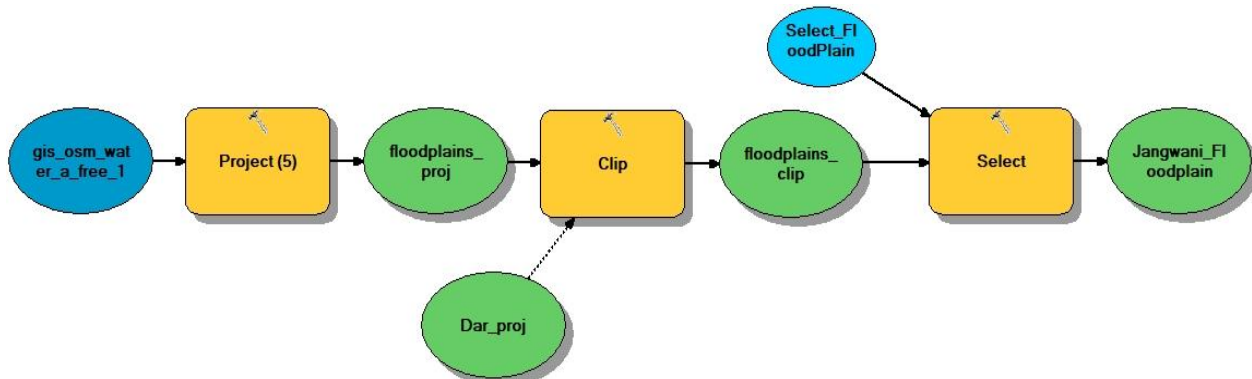


Figure 5. A model used to generate Jangwani floodplain layer from bodies of water dataset

To obtain features which had connections with the floodplain, i.e. whether they lie inside the floodplain, crosses it or borders it, selection by location was used to select all features with lied, crossed or bordered the floodplain. The attributes of the selected features were then taken and documented from their attribute tables. Figure 6 displays the flowchart of the feature generation and extraction process.

Waterways dataset consisted of rivers, streams, and drains. Rivers and streams were first selected and exported to form a single feature class of rivers and streams found in the region. Drains were then extracted using selection by SQL expression and formed a feature class of drainage systems in the area.

Roads dataset consisted of major roads which were comprised of motorway, national roads, regional roads and local roads, minor roads which were comprised of smaller local roads, residential roads, and pedestrian roads, and highway link roads. Roads of interest for this project were the major roads passing through the floodplain. Thus, the major roads were selected from the dataset through SQL expression and formed the desired feature class of roads.

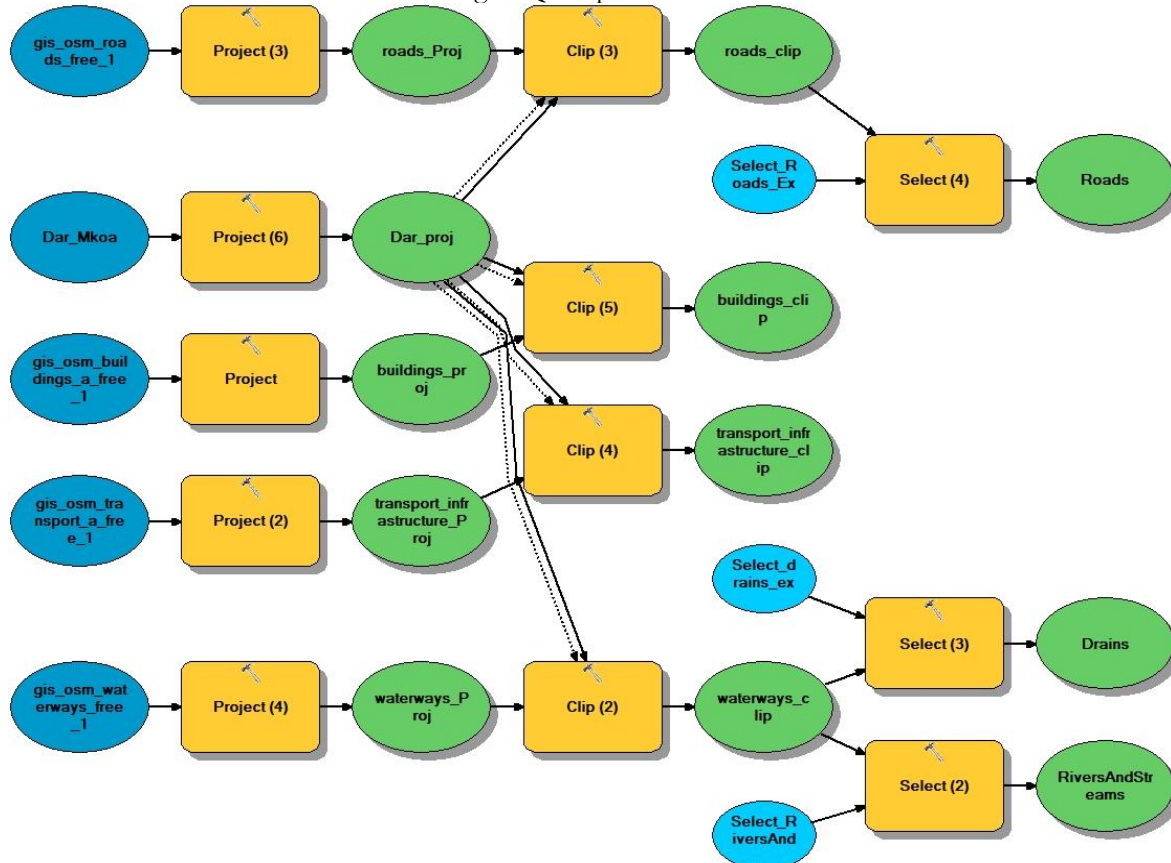


Figure 6. Models used to generate roads layer, buildings layer, transport infrastructure layer, drains layer, and rivers and streams layer from their source datasets

## 5 Results

This section outlines the results that were obtained after performing data analysis. It covers area computation of the floodplain and areas adjacent to the floodplain. The population affected by the flood plain is also estimated. The generated flow direction, flow accumulation, slope, aspect, hillshade, and contour raster data are used to discuss the nature of the floodplain.

### 5.1 Computing the area covered by the floodplain

The computed area of the floodplain by using calculate geometry geoprocessing tool (operation) was 3.29 km<sup>2</sup> and the floodplain passes through 12 divisions in Dar Es Salaam region as shown in Table 2.

**Table 2: Areas covered by Jangwani floodplain**

Division	Area (km <sup>2</sup> )	Floodplain Area (km <sup>2</sup> )	% of floodplain in the Division	Population*	Population to be affected **
Upanga Magharibi	2.14	1.032	48.2	13,476	6,499
Mchikichini	1.16	0.652	56.2	25,510	14,338
Jangwani	1.41	0.632	44.8	17,647	7,910
Magomeni	1.17	0.553	47.2	24,400	11,533
Ndugumbi	1.51	0.127	8.4	36,841	3,099
Kigogo	1.79	0.077	4.3	57,613	2,478
Mwananyamala	2.25	0.054	2.4	50,560	1,213
Hananasif	1.92	0.052	2.7	37,115	1,005
Mzimuni	1.19	0.035	2.9	21,486	632
Upanga Mashariki	1.41	0.033	2.3	11,167	261
Ilala	2.1	0.027	1.3	31,083	400
Makumbusho	2.02	0.017	0.008	68,093	573
<b>Total</b>	<b>20.07</b>	<b>3.291</b>	<b>16.4</b>	<b>394,991</b>	<b>49,941</b>

\* Tanzania census 2012 population

\*\* Population that is likely affected by the floodplain with the assumption that the population is uniformly distributed in its division.

Out of the 12 divisions, most of the area covered by the floodplain is found in four divisions which are Jangwani, UpangaMagharibi, Mchikichini, and Magomeni divisions. The total area of the floodplain in these four divisions is 2.86 km<sup>2</sup>, which is almost 87% of the total area of the floodplain. About 16.4% of the surrounding population was estimated to be affected by the floodplain during the rainy season.

### 5.2 Infrastructures, transport facilities, drains, rivers and streams which crosses the floodplain

Figure 7 shows the infrastructures, transport facilities, drains, rivers and streams which crosses the floodplain. There are four locations inside the floodplain where rivers and streams merge into a single river. The most noticeable merge is found near the mouth of River Msimbazi whereby River Ng<sup>o</sup>ombe and another stream connect to River Msimbazi. In another location near the floodplain, River China and River Kibangu merges into a single river which flows into the floodplain and later connects to River Msimbazi inside the floodplain. Also, there are 7 watersheds intersecting the floodplain with a total area of 14.53 km<sup>2</sup>. Three major roads cross over the floodplain, Morogoro road, Kawawa road, and Ali Hassan Mwinyi road. There is also Jangwani road, which is a local major road which runs through the floodplain, connecting other two major regional roads. Inside the floodplain there are service roads, footway and residential way minor roads. There are also two transport infrastructures found inside the floodplain, the BRT bus terminal, and Jangwani bus station.

There are 120 drains discharging into the floodplain. These drains are mouths formed by the connected link of drainages from roadsides, residential, public and commercial areas. There are also 8577 buildings found either completely inside or part of the building structures lying inside the floodplain. The buildings include both residential and commercial buildings.

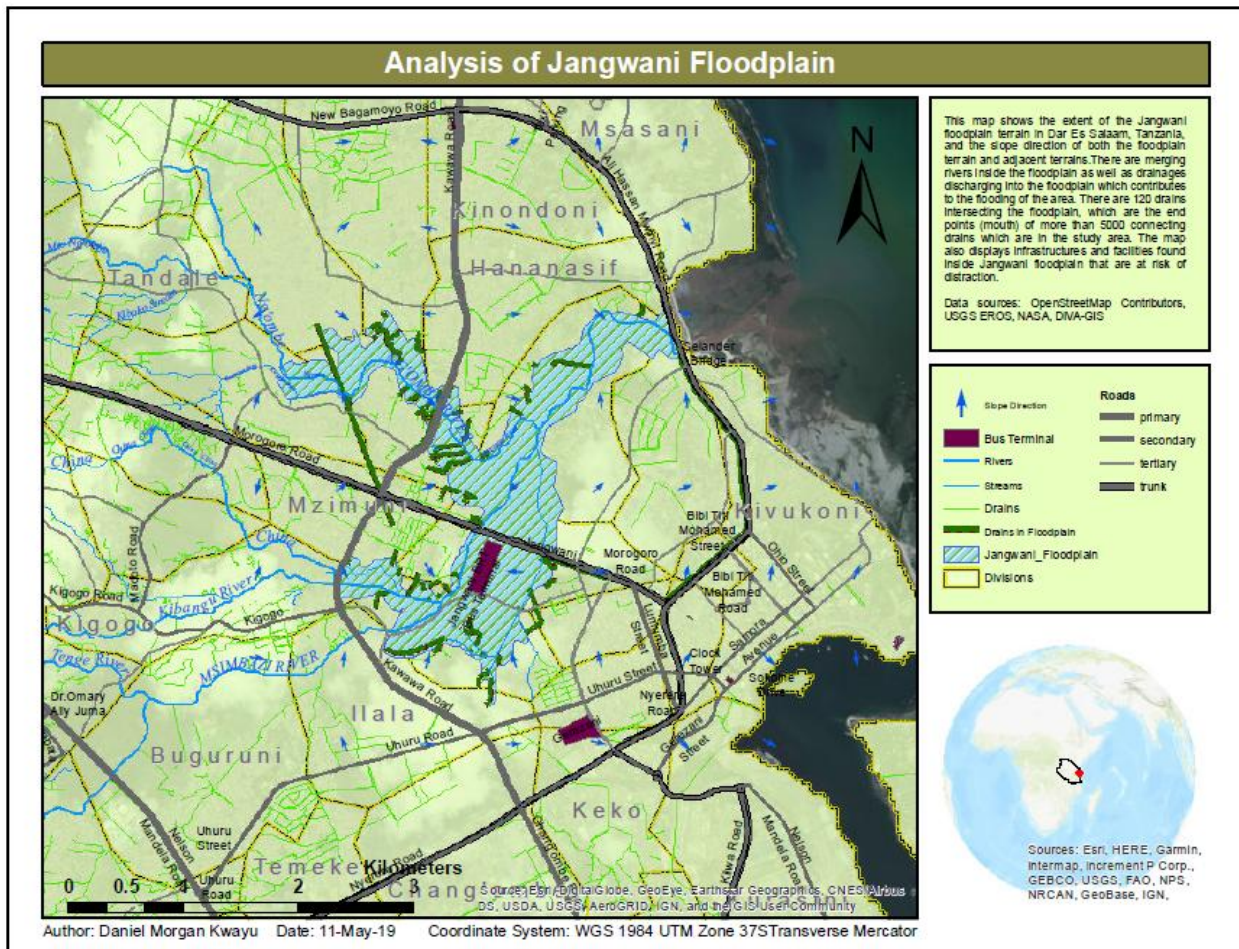


Figure 7. A map showing slope direction in Dar Es Salaam region, infrastructures, transport facilities, drains, rivers and streams found in the region which crosses the floodplain

### 5.3 The terrain of the floodplain

Figure 8 displays the generated contour map of Dar Es Salaam region using DEM layer. The map shows the elevation of the Jangwani floodplain terrain. Inside the floodplain, it's mostly flat, with slope mostly 0° and small portions with variations ranging up to 4°. Slope at the edges of the floodplain ranged from 5° to 34°. The slope direction around the floodplain i.e. on its edges and areas surrounding it by using vector fields is towards the inside of the floodplain. By using degrees, the slope direction inside the floodplain is flat (-1), on the west edge varies from 67.5° to 202.5° which is East → Southeast → South, while on the east edge slope direction varies from 202.5° to 337.5° which is Southwest → West → Northwest. Inside the floodplain, in the southern part of the floodplain the flow direction is mostly 64 which is north direction, while that of the northern part of the floodplain is 1 which is the east direction.



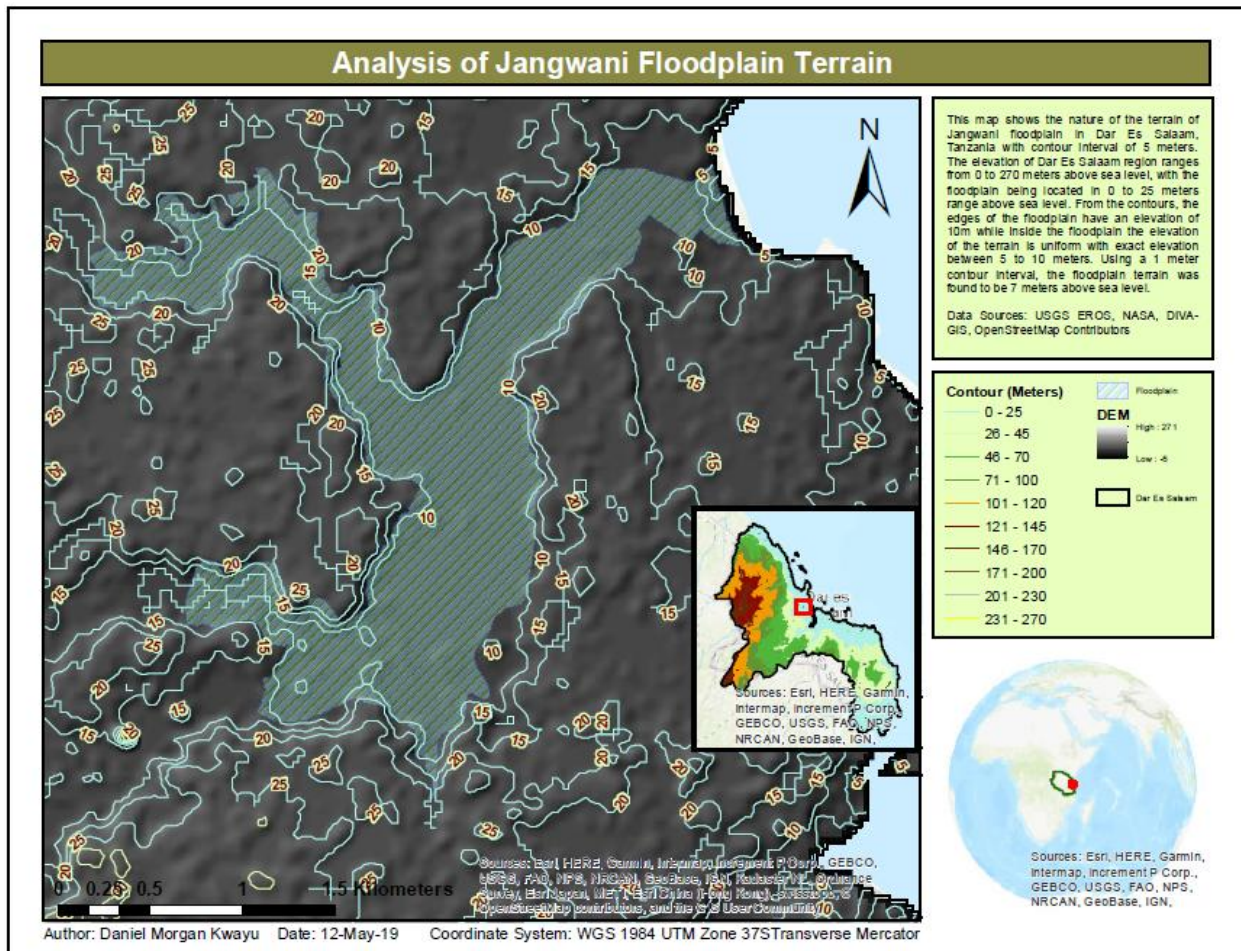


Figure 8. Contour map of Dar Es Salaam region showing the elevation of the Jangwani floodplain terrain

## 6 Discussion of Results

The analysis of the data has determined that the floodplain is flat (it has no slope) and thus, not the expected sink or bowl shaped terrain. This eliminates the expected reason for the backflow of water in the floodplain during flooding. The drains which are in the floodplain are not draining water from the floodplain as suggested, but rather they discharge water and wastes into the floodplain from higher elevated surrounding areas. The elevation in the floodplain is very low compared to the elevations and slope in the origins of the drains, which confirm the direction of flow in the drains. Furthermore, with the combination of buildings layer which displays community areas and road layer which displays the location of roads, it is vividly clear that the drains originate from community areas and roadsides, running towards the floodplain. Some of the drains discharge into nearby rivers whereby majority of these rivers merges along their paths, and still find their way into the floodplain.

The flow direction generated from the analysis indicates the natural flow of water in the floodplain. Following the flow direction given in the results of the analysis, the flow direction in the floodplain is supposed to be similar to that of River Msimbazi which is; it should be towards the Indian Ocean (the northeastern region in Figure 8). But that is not what is happening in Jangwani. The flow direction is opposite to what is expected because of the plain lower elevation and the nature of the floodplain's slopes.

Observation of the materials found inside the floodplain, at the mouth of River Msimbazi, and along the drains in the floodplain, appears that not only water is flown in these drains and rivers, but also solid waste materials. Accumulation of these solid wastes in the floodplain creates barriers within the floodplain, and in combination with the flatness of the floodplain it explains the unexpected backward movement of water in the floodplain during flooding.

In addition, mixture of solid wastes and water in the mouth of River Msimbazi where it connects to the Indian Ocean creates a sluggish product which hinders the flow of water from the floodplain in the required forward direction to the ocean just as the flow in River Msimbazi. This sluggish product act as a barrier to the forward movement of water in the plain, causing the water to flow backward since the area is flat. These sluggish products can be observed where River Msimbazi enters in the Ocean in Salendar Bridge found in Upanga area (northeastern region in Figure 7).

The elevation in the floodplain is lower than in the surrounding areas. Naturally, water flows from higher elevation areas to lower elevation areas. Therefore on occasion of heavy rainfall, water would runoff from surrounding higher elevations to the floodplain which has low elevation. Since there are barriers inside the plain, and the presence of sluggish materials blocking the discharge of water from the floodplain to the ocean, water accumulates in the floodplain, and when it is plenty enough to flow, it flow backwards in the flat plain where there are no obstacles and will only stop where elevations are higher.

Due to the wetness of Jangwani floodplain, plants have grown in the area. These plants vary in sizes to approximately 2 meters high. Though these plants can assist in drying the area by absorbing water, they create a barrier in the flow of water in the area. They slow down the flow of water in the area, and under heavy rainfall, they likely assist in preventing the quick drainage of the plain.

The presence of several merging rivers and streams into a single channel of water in the floodplain contribute to the flooding of Jangwani plain during heavy rainfall. On the occurrence of heavy rainfall, a large volume of water from all areas flow towards rivers and streams. Each river or stream individually can handle these increased amounts of water from heavy rainfall, but when they merge into a single river channel, most likely, a newly formed single channel of river can't accommodate these large amounts of water from these individual tributaries. This can explain overflowing of water from the merged riverbank into the floodplain. The presence of solid waste materials and boulders can shorten the rivers' and streams' depths which can result in overflowing of water during heavy rainfall.

The seven watersheds intersecting Jangwani floodplain are most likely to discharge in the plain due to the plain's lower slope and elevation compared to the slopes and elevations of these watersheds. The total area of these watersheds intersecting the plain (14.53 km<sup>2</sup>) is at least four times greater than the area of Jangwani floodplain (3.29 km<sup>2</sup>). Such a big area discharging in a small area can cause overflowing of water in the plain during the rainy season.

Recently, the government of Tanzania has been trying to mitigate flooding in the area by removing the solid sluggish materials from the floodplain by using backhoe loaders and bulldozers. This initiative aims at clearing the pathway of water. However, it may not be effective as it is not done throughout the floodplain to remove all the barriers formed by the sluggish waste materials. Also, rather than collecting these cleared obstructing materials and disposing them in a more favorable designated location, these materials are piled up near the edges of the floodplain. On occasion of rainfall, these materials will likely be washed back in the floodplain, and the problem will persist.

As stated in the results of the analysis section, there are buildings and transport infrastructures found in the floodplain. As the plain is a waterway, these facilities block water flow in the area and thus, assist in the accumulation of water in the floodplain. Furthermore, their presence in the flood-prone area is risky to human life. Thus, all those who use these facilities are at risk during rainy season. Any type of construction in Jangwani floodplain should be discouraged.

Currently, there is a plan proposed in 2017 to build a sewage scheme that will involve the use of waste water treatment plants, which will be installed in three city locations with one of the locations being the Jangwani plain. Even though it might be helpful in eradicating the sluggish wastes in the area due to the amount of liquid waste which will supposedly be treated per day (200,000 cubic meters), these plants might be a barrier to the flow of water in the area. Furthermore, it would influence more draining of all types of waste materials into the floodplain. With respect to the nature of the area in relation to the surrounding areas, more studies should be done on the proper locations of installing these waste treating plants in the area.

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