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THE APPLICATION OF GIS IN MAPPING OF DESIGNATED FLOOD HAZARD AND ASSESSING OF RISK IN KUMASI, GHANA.

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ABSTRACT

Flooding is one of the most dangerous natural hazards which causes economic losses and death globally. In the last three decades, there has been a rise in flooding events globally. Furthermore, it is been projected that the occurrence of flooding is expected to rise due to urbanization, haphazard development, rise in precipitation and deforestation. Floods in Kumasi have become a perennial phenomenon. This has caused significant damages to properties and financial losses. The research utilized a geographic information system through a modelling approach to map flood hazard and assess risk in Kumasi. The results reveal that in the study, 53% of the entire area was found to be highly susceptible to flooding. In addition, 35% of the population are at high risk of flooding. The high-risk zone was found to cover the north – western and the city centre. Also, the city centre was identified to be highly prone to flooding and also floods are likely to occur in the rainy season. Moreover, Bantama and Subin were identified to be at more risk of flooding as compared to the other sub- metros. The results from the flood hazard map and the risk map suggest flooding in Kumasi is of critical concern and thus flood management strategies need to be implemented.

Key words:

Flood hazard map, Flood risk map, Digital Surface Model, GIS, Flood modelling

1. INTRODUCTION

Floods are among the leading causes of natural disasters worldwide (CRED, 2015). It is stated in Ramala and Babam (2007) that flooding is the most dangerous and catastrophic act of nature. It causes damages to properties, destruction of crops, pollution of water and death globally. Every year, this phenomenon causes significant economic losses worldwide. Moreover, according CRED (2015) it is known that more people are affected by flooding than any other natural disaster.

In the last three decades, there has been a rise in flooding events globally. A recent report by the CRED and UNISDR (2015) on "The human cost of weather-related disasters" revealed that the death occurrence from flooding has risen globally. It further revealed that between 1995 and 2015, a total of 2.3 billion people were affected by floods worldwide. The stipulated figure is significantly higher than any other type of weather-related hazard. Additionally, it was postulated in the report that Asia and Africa are more influenced by floods than any other continents. Also, the importance of flood studies through assessment, mapping and predicting has been discussed in several scholarly articles (Kourgilas and Karatzas, 2011; Armenakis and Nirupama, 2014; Merkuryeva *et al*., 2014; Elkhrachy, 2015; Zhang *et al*., 2015 and Ozkan and Tarhan, 2016). Furthermore, it is projected that, the occurrence of flooding is expected to rise due to argument of urbanization, haphazard development, rise in precipitation and deforestation (Tehrany *et al*. 2014). Due to this, undertaking research on flood hazard mapping has become expedient.

According to Ozkan and Tarhan (2016) urban areas are known to be most important areas that are affected by flooding. The factors that cause flooding are numerous and varies in nature. The main causes of flooding are due to urbanisation, climate change, deforestation, land use change and construction of infrastructure across a watercourse (Kourgilas and Karatzas, 2011, and Tehrany *et al*. 2014). It can be said that urbanisation is one of the most important causes of flooding (Tehrany *et al*., 2014). Due to the concrete and paved surfaces resulting from urban growth, runoff water is not able to penetrate into the soil. The effect of this consequently increases the imperviousness. However, others have stated climate change as the primary driver for increased flooding (Ramala and Babam, 2007). It is clearly evident than before that climate change is one of the defining issues of our time (NAS, 2014). Literature has established a link between climate change and flooding. However, globally establishing a trend in the frequency of flood occurrence due to climate change is problematic. Studies have shown that the global average atmospheric temperature in 2013 was 0.75º warmer than it was at the beginning of the Century (IPCC, 2013). This indicates that the atmosphere can hold 5%-6% moisture. It, therefore, suggests that with more water in the atmosphere, the volume of water will increase when it falls. Consequently, it may cause flooding. Due to this, the role of climate change is considered as a key element in causing flooding (Ramala and Babam (2007).

Above everything else, flooding needs management. For this reason, it is stated in Associated Programme on Flood Management (2013) that the ultimate aim of flood studies is to produce a flood map. An inundation map provides information on how you could be affected by flooding. The essential flood maps for developing a flood mitigation plan and assessment are the flood hazard map and flood risk map. A flood hazard map graphically defines areas that are susceptible to flooding while the flood risk map provides information on the danger to people, infrastructure, and economic activities when exposed to floods. Over the past years, the issue of flood hazard mapping has been critically and painstakingly explored and examined by researchers.

Particularly, these studies have been done using Geographical Information Systems (GIS) (Chen *et al*., 2009; Alaghmand *et al*., 2010; Kourgilas and Karatzas, 2011; Tehrany *et al*. 2014; Elkhrachy, 2015 and Ozkan and Tarhan, 2016). In a recent study Ozkan and Tarhan (2016) discussed that the possible means of overcoming flood hazard is by simulations. Kourgilas and Karatzas (2011) and Ozkan and Tarhan (2016) in their respective studies established that the required factors for creating a flood hazard map (FHM) are elevation, land use, rainfall, flow accumulation and slope, although in some instances, there are modifications to the factors used in producing the flood hazard map. An example is Elkhrachy (2015), in this study, the causative factors used were surface roughness, geology, land use, rainfall run-off, drainage density and distance from the river channel. Generally, it can be said that creating of flood hazard maps can be considered as a subjective process that is strongly influenced by the availability of input data. Based on this understanding, the use of input data is not constant. However, there are primary and key factors that underpin every flood simulation.

Growing knowledge of mapping flood hazards reveals that elevation in the form of digital elevation model (DEM) plays a significant role. Also, for the best flood modelling results, a digital surface modelling (DSM) is needed. A DSM captures elevations of the top of reflective surface such as the buildings and vegetation. It is important to use a DSM because above ground features can greatly impact flow direction and speed, and these features are not represented in a Digital terrain model (DTM), which shows the 'bare earth' with no vegetation or buildings. The availability of detailed and accurate topographic data has a significant impact on the prediction and simulation of floods .Moreover, topography is one of the primary contributors in determining the accuracy of flood hazard map (Cook and Merwade, 2009). It has a significant role in producing hydraulic models. Generally, the overall accuracy of a flood hazard map depends on the horizontal resolution and vertical accuracy. Depending on this, many studies have concluded that flood hazard mapping is improved by high-quality topographic data. Several studies, especially in Europe and the USA, have increasingly used light detection and ranging (LIDAR) data to create flood hazards maps using DSMs (Chen et al., 2009; Cook and Merwade, 2009 and Saksana and Merwade 2015). The reasons for this are twofold: better spatial resolution and the ability to represent above ground obstruction to flow. Consequently, flood hazard maps created from LIDAR are much more accurate (Schumann et al. 2008). DSMs derived from LIDAR in terms of its horizontal and vertical resolution are highly accurate compared to DEMs derived from traditional field survey. A major problem is when gridded (regular or TIN) data are derived by interpolation from already generalised contour data, as happened in the case of Ordnance Survey Panorama raster elevation datasets. However, even though LIDAR datasets are of high accuracy and quality, due to the high cost of obtaining the data many studies are still carried out using traditional field survey data. DEMs of low or coarser spatial resolution typically but not always over predict the flood extent (Saksana and Merwade 2015). Also, a Digital Elevation Model (DEM) is the most important data input for hydrological modelling to create a flood hazard map (Elkhrachy, 2015).

Hydrological models are considered to be conceptual representations of the hydrological cycle. In hydrological modelling, two categories of models are generally used: conceptual models and stochastic hydrological models. Conceptual models apply hydrological concepts to simulate and represent the physical processes in the real world. In contrast, stochastic hydrological models use the mathematical and statistical concept to simulate without relation to system physics. Hydrological models are used for modelling water flow and in addition, the model calculates the runoff occurring from rainfall (Amir *et al*., 2013). In several studies investigated, many flood modelling and inundation mapping software tools have been used: such as HEC-RAS, LISFLOOD-FP, TELEMAC- 2D, HEC- GeoRAS, SWAT and FESWMS- 2DH (Cook and Merwade, 2009; Amir et al., 2013; Merkuryeva *et al*., 2014 and Saksana and Merwade 2015). These mapping software tools are either commercial or free packages. HEC–RAS and SWAT are both free packages with the rest being commercial packages. HEC-RAS is one of the most commonly used flood modelling software tools. An important component of HEC-RAS software is its ability to integrate with ArcGIS and QGIS as a plug-in to the GIS software, allowing both the modelling and creation of flood hazard maps within a single software interface. HEC-RAS requires topographic data, flow data and Manning's "n" values. Moreover, the output of the hydrological model is used as input for a hydraulic model. Conversely, other research studies have used integrated hydrological and hydraulic modelling packages. For example, in Amir *et al*. (2013), an integrated package called MIKE 11 was used. Currently, with rising availability and modern GIS software packages such as ArcGIS, integration of hydrologic and hydraulic models and graphic visualisations are possible (Alaghmand *et al*., 2010). The GIS tool allows simulation and graphic representation of varying scenarios.

It is increasingly evident that the understanding of flood hazard mapping bridges the gap between mapping and making informed decisions. Many past studies on flood hazard and risk mapping in Sub-Saharan cities have been focused on a historic approach, particularly in Kumasi. Thus, flood hazard and risk mapping through modelling approach in Kumasi has not been investigated (Korsah and Cobbinah, 2016). Hence, there is an incomplete picture of the way its floods are assessed.

Against this gap, the overall aim of the research is to provide a detailed map and a robust assessment of flood hazard and risk areas in Kumasi (a map of Kumasi can be seen in the materials and methods section, Fig. 1).

The research specific objectives are:

- Determination of flood prone or hazard areas in Kumasi based upon a range of causative factors of flooding
- To provide a flood risk map indicating areas of high, medium and low risk within the hazard area

The research questions are:

- Where are the flood hazard areas located?
- Where are the areas of low, medium and high risk of flooding?

According APFM (2013) there are three different approaches to develop a flood hazard map: historic approach, geomorphologic approach and the modelling approach. The most simple and easy approach is the historical approach. It provides information on past inundated areas from flooding by rainfall, rivers and sea. The historical information is mostly gained from national and regional databases, written reports (such as technical reports and newspaper), photographs and archived field data. The map is prepared by gathering all necessary flood events of an area and could either be displayed separately by depicting different layers or overlaying of all the layers. One merit associated with this approach is that the flood records can be used as a visual proof and reminder that the danger of flood inundation is real. Also, a major demerit of this approach is that the map needs to be updated periodically as when new flood inundation events are recorded. In addition, prediction of flood inundation using historic data is problematic since the conditions of the flood plain, land use or the landscape could change and as such, a similar flood inundation in future might have different characteristics. On the other hand, the geomorphic approach provides information on flood inundation based on surface features. Generally, past floods events leaves traces on a landscape. As such, it is possible to read and interpret the traces on the landscape. An advantage of this method is that it can often be used for validation of a flood hazard map produced from a modelling approach. Last but not least is the modelling approach. This modelling approach provides simulation of floods in which hydrological and hydraulic models are applied. Also, two crucial demerits identified in this approach are often in the availability and the spatial resolution of the data. Availability and spatial resolution of data affect the accuracy of the prediction. However, one major merit of this approach is that it is used for mapping accurate flood inundation. It is known to provide detailed and accurate flood assessment among the other approaches.

Hence, this study used the modelling approach for its flood mapping and assessment. The choice of this approach is greatly based on the aim of achieving accuracy in the flood mapping and assessment and to a level of extent the availability of data.

2. MATERIALS AND METHODS

A GIS approach will be applied in this study. This approach is the capturing of spatial data, storing, manipulating, analysing and displaying spatial data which are referenced to the earth (Heywood *et al*. 2006). This research illustrates through a case study of Kumasi and explains how GIS modelling is used to create flood hazard and risk maps. To achieve the objectives listed in the introduction, the methodology contains these steps; preparation of hazard map and flood risk map.

2.1 Study area

Kumasi is the second largest city in Ghana and is located between Latitude $6^{o}38'$ and $6^{o}45'$ North and Longitude $1^{o}41'$ and $1^{o}32'$ West. The city has an area of approximately 24 km^2 and the elevation ranges from 250m to 300m above sea level. Like many Sub- Saharan cities, Kumasi is plagued with growing frequency and scale of floods. Floods in Kumasi have become a perennial phenomenon. As a result, national interest on flooding has been on the increase in recent years. Recent flood events in Kumasi suggest that the impact are becoming more severe (Korsah and Cobbinah, 2016). The rapid increase in population, averaging 4.8% per annum, and expansion of settlement in Kumasi will mean high vulnerability risk (Ghana Statistical Service, 2010). Thus, an incidence of flooding will endanger a greater number of population.

Kumasi is located within the Pra basin and is divided into five sub- basins: Kwadaso, Subin, Aboabo, Wiwi and Sisai. The city is drained by a relatively dense network of rivers: Wiwi River, Subin River, Sisai River, Suatem River and Daban River (Figure 2.1). The Subin River flows from Kumasi zoo to Kaase and the Wiwi River also flows from Nsemie into Sisai River at Atonsu. The

Suatem River flows through North Suntreso to join Kwadaso River at Dakwadwom to form the Daban River. The Subin, Daban and Sisai River then joins Oda River, which is a tributary of the River Pra. Flood events that have inundated areas around the above mentioned rivers have caused property destruction and claimed lives. Hence, there is the need for flood hazard and risk mapping.

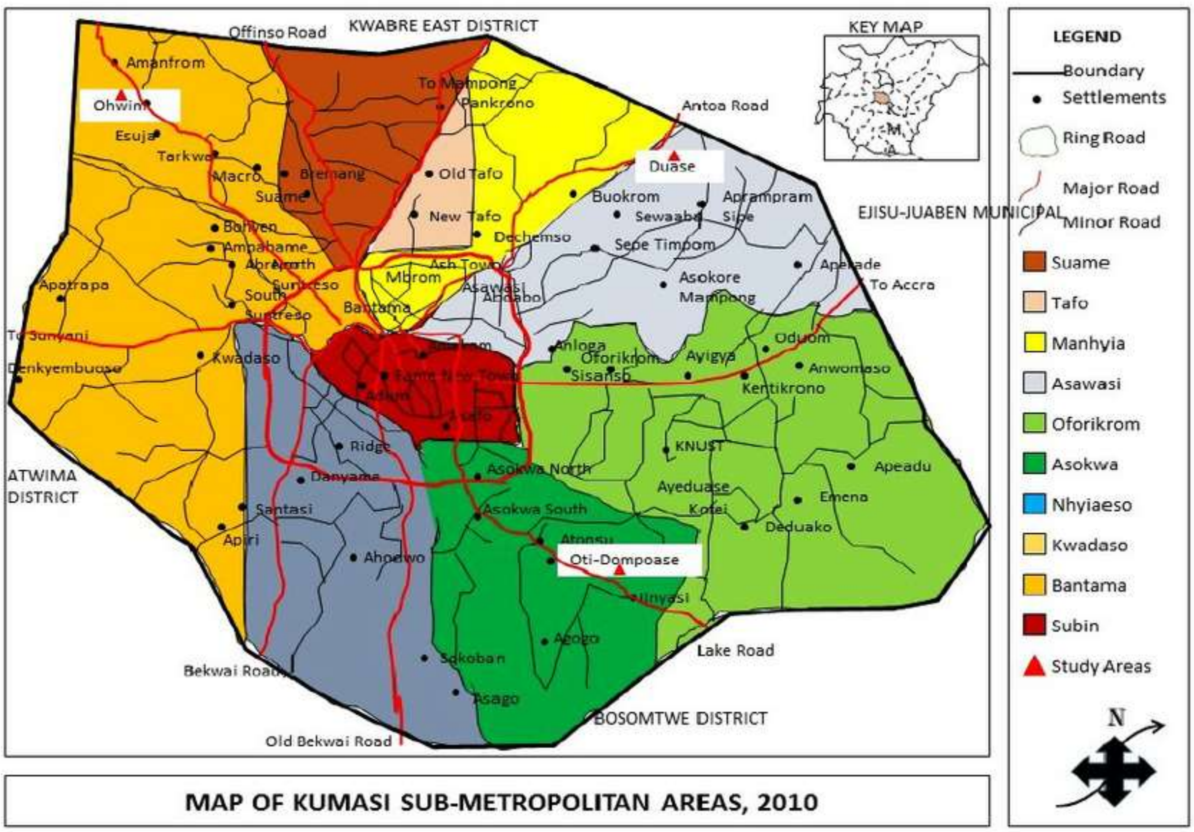


Fig 1. A map of Kumasi (Source: TCPD 2010)

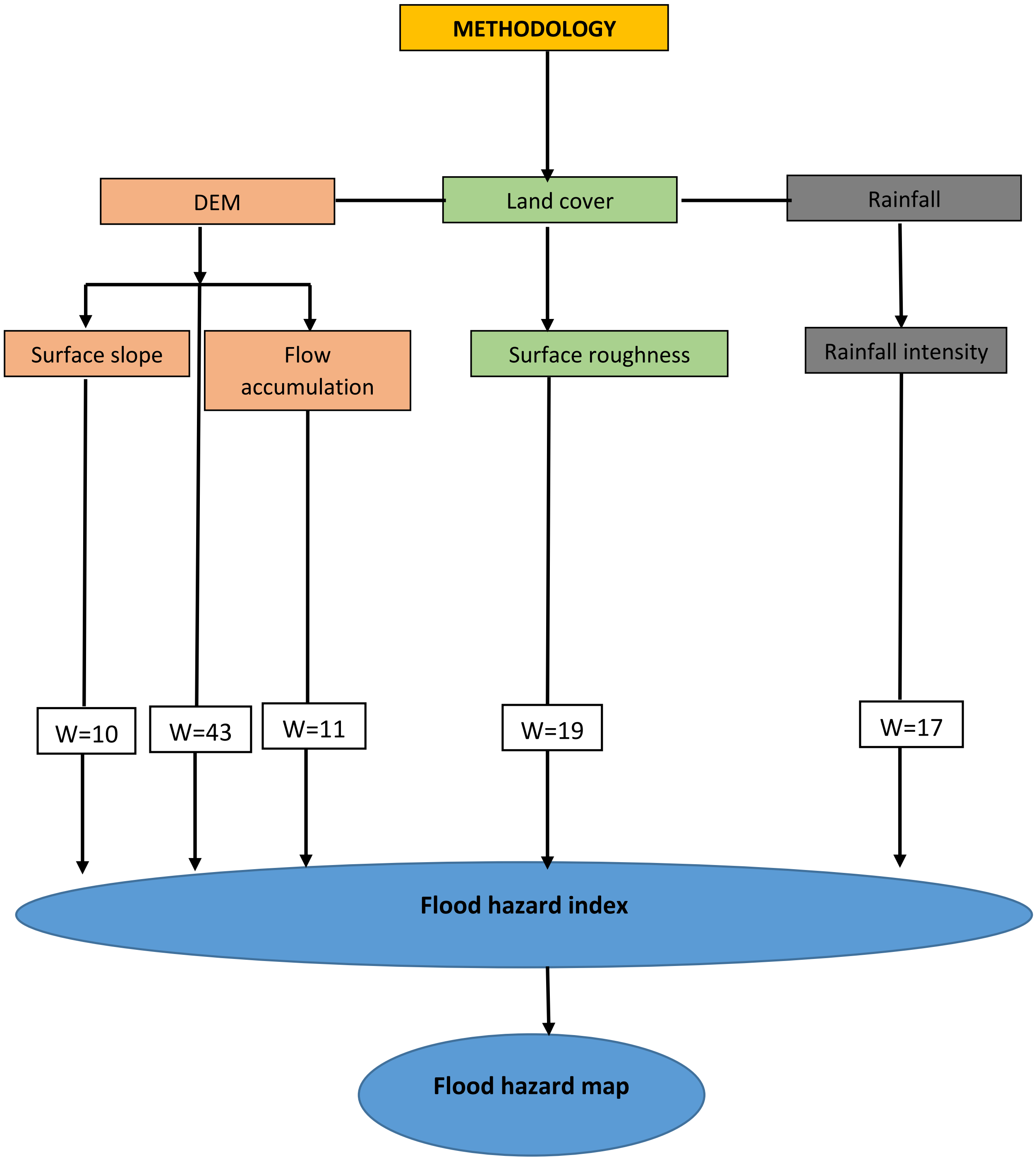
2.2 Data requirements and data sources

In order to assess the flood hazard and risk, an elevation map, land cover map, flow accumulation map, surface slope and rainfall data will be needed. These factors listed here have been selected based on different studies on flood hazard with similar characteristics.

Table 1. Data type and their sources

Data type	Organisation	Date	Spatial Resolution
Elevation data(DSM)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	2011	30m
Land cover and land use map	Interdisciplinary research in earth science (IDS) program	2010	0.5 to 0.8m
Rainfall data	Ghana Meteorological department	2005-2016	
Population	Ghana Statistical Service	2010	

2.3 Research Approach



Source: Author, 2016

Fig 2. Methodology for mapping flood hazard

2.3.1 Geoprocessing and geo referencing of data

Once the various spatial and non-spatial data are acquired, the next activity is to analyse the data. ArcGIS 10.3.1 software, a fully-developed GIS software by ESRI was used for the spatial analysis because of its technical capabilities, modeller environment and commercial maturity. One big advantage of ArcGIS 10.3.1 is that is able to automate workflow rather than run each step separately as compared to some more basic packages like QGIS. However, the analysis could be achieved in any basic GIS package. Also, the datasets were georeferenced into local UTM zone: Accra grids.

2.3.2 DEM

A Digital elevation model is the most important input in hydrological modelling and flood management (Elkhrachy, 2015; Forkuo 2011). In this study, a DSM was used to create surface slope and flow accumulation. The expected minimum requirement this study aims at is to use:

- A spatial resolution of 30m or better,
- A relative vertical height accuracy of <20m
- A minimum age of 2010

A careful search on the outlined potentially suitable data was done on various data sources such as Shuttle Radar Topography Mission (SRTM), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Global Multi-resolution Terrain Elevation Data (GMTED). The results of the search reveals that the SRTM DSM has a better spatial resolution of 30m which meets the outlined requirement. However, the date the data was acquired was 2003. Which indicates that the SRTM doesn't meet the outlined minimum age. The GMTED DSM data has 30 seconds arc with vertical accuracy between 25m and 42m and the date it was captured was 2010. This further indicate that the GMTED does not meet the outlined requirement. The DEM dataset used was the ASTER DSM data. The ASTER DSM was obtained via USGS Earth Explorer web portal. The data are at a resolution of 1 arc-second (30 metres), captured in 2011 and have a vertical accuracy of 10m to 24m. This is high spatial resolution data and more recent as compared to the other data sources. As a result, it has the potential of producing an accurate flood hazard and risk map. Also, examining the accuracy of the data is essential. In this study, the vertical accuracy of the DSM was verified with 10 Ground Control Points derived from survey- grade differential GNSS and from a Ghana Survey department map. The topography map had a scale of 1:50,000 and was prepared in 2010. The root mean square error (RMSE) was 2.04 metres. In general, the smaller the RMSE the better. Hence, the ASTER dataset has a better accuracy. The DSM was reclassified into four groups: very high, high moderate and low and was done by using regular intervals. Below is the formula for calculating RMSE

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}$$

Table 2 Root Mean Square Error

ASTER	Ground Control Point	Residual	Square of residual
246	247	-1	1
300	300	0	0
140	138	2	4
122	120	2	4
319	320	-1	1
202	200	2	4
161	160	1	1
112	115	-3	9
301	298	3	9
143	146	-3	9
RMSE	**2.049390153**		

2.3.3 Surface slope

Slope is an important element in flooding and as such the danger in floods increases as the slope increases. The DSM was used to create the slope. The output (slope) was reclassified into high and low using regular intervals.

2.3.4 Surface roughness

Surface roughness value is an important input for flood simulation. The type of land cover has an effect on the resistance of flood flow. The Manning's roughness values (coefficient) is used to calculate flow on surfaces. In this approach, roughness value "n" is assigned to each land cover. Each land cover was represented by individual pixel. The expected minimum requirement for this data aims at is to use:

- A spatial resolution of 10m or better
- Geometric accuracy of 10m or better
- A minimum age of 2010

An extensive search was done on the various data sources such as Landsat 8 OLI and Landsat 7 ETM+. The Landsat 8 OLI was identified to fall short of the outlined requirement due to a spatial resolution of 30m. Also, the ETM+ has a 30m spatial resolution and was captured from 1999 to 2003. This indicates that the ETM+ doesn't meet the outlined requirement. A suitable available datasets found was a 2010 land cover and land use (LCLU) data set obtained from Interdisciplinary Research in Earth Science (2014). The dataset was derived from high spatial resolution imagery (0.61m to 0.8m) from commercial satellites (QuickBird-2, IKONOS-2, GeoEye -1 and WorldView- 2). It has a geometric accuracy of 5m and of more recent year (2010). These data are free and have been preprocessed by IDS. This makes the data more suitable and meets the outlined requirement. The land cover and land use categories identified were buildings, road, water bodies and vegetation. The roughness values were assigned using Manning's roughness coefficient. The roughness values and its various LCLU was used to create a two- dimensional model of Kumasi. Basically, the higher the resistance of the land cover to flood flow, the higher the roughness value. Table 3 shows each land cover and its coefficient.

Table 3. Land cover and Manning's roughness values

Surface Mater	Manning's roughness coefficient "n"
Concrete (cement)	0.012
Open land (bare ground)	0.050
Water body	0.035
Vegetation	0.15

Source: Dorn *et al.,* 2014; Kalyanapu *et al.,* 2009.

2.3.5 Flow accumulation

The flow accumulation is used to create a network to show the flow in each grid cell. In order to generate the flow accumulation, it is important to determine the flow path of every cell. The drainage network is generated based on the flow of each cell. ArcGIS 10.3.1 was used to model flow accumulation from the DEM data. The initial step was to fill the sinks in the DEM data to create a new data set. This approach is to reduce the errors in the sourced data (Parmenter, 2012). Flow direction was performed on the sink filled data. This function was to identify the flow direction on the surface. The flow direction was used to create the flow accumulation. The output was then reclassified as high flow cells, moderate and low flow cells using regular intervals.

2.3.6 Rainfall intensity

Higher precipitation can lead to runoff, hence, flood hazards increases as the amount of rain at a particular location increases. The optimal requirement this study aims at is a minimum of five rainfall stations. However, in this study, the approach adopted was to use average monthly precipitation from 2005 to 2015 at two rainfall stations (Kumasi airport and Knust) to create a rainfall intensity map. The limitation to this approach was due to inadequate number of rainfall stations in Kumasi. The average monthly precipitation at these stations is shown in Tables 3.1 and 3.2.

2.3.7 Overlay

A model was adapted from Ozkan and Tarhan (2016) to assign rank to the flood hazard indicators. The model was adapted because it can be replicated in any urban area. Five flood causative factors were used to create the flood hazard map (FHM). In creating the composite FHM, a weighting approach was used. Different weight values were assigned to each factor based on the impact each factor has on flood hazard. The weight was determined by applying the methodology in Fig. 3.

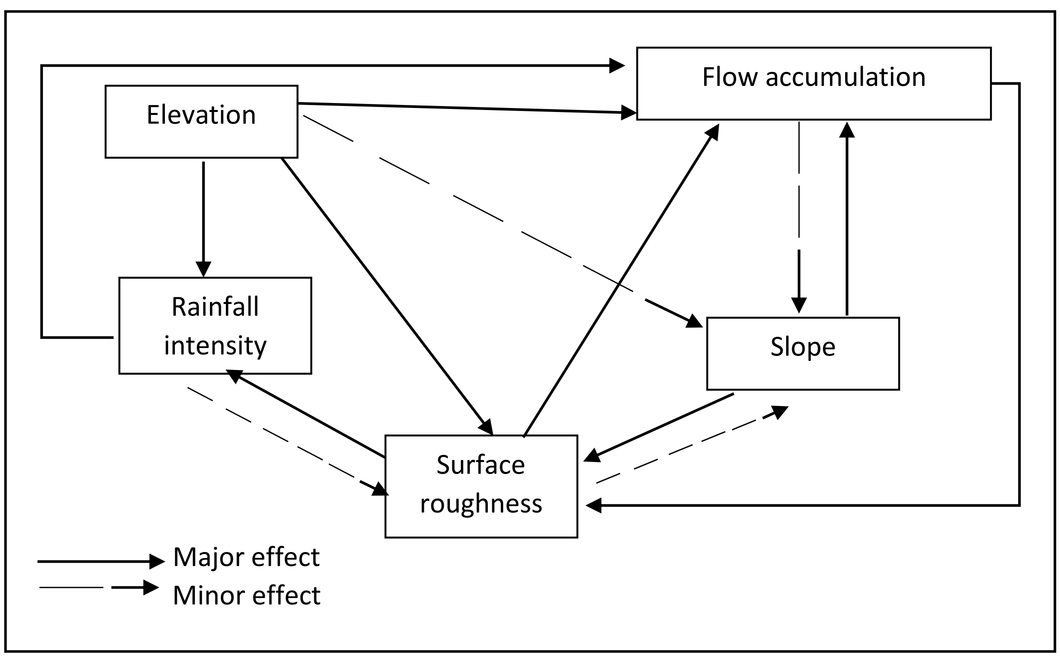


Fig. 3 schematic diagram of interaction between the causative factors of flooding
(Source: Ozkan and Tarhan (2016)

Figure 3 shows the interaction between all the factors. The solid line which links two factors indicate that one causative factor has a major effect on the factor which the arrow is pointing to. The dashed line linking two causative factors means that one factor has minor (secondary) effect on the factor which the arrow is pointing at. For instance, the elevation has a major effect on the flow accumulation and minor effect on the slope. In measuring two different effects, one (1) point was assigned to the major effect and a half point (0.5) was assigned to minor effect. The next step was to sum the points corresponding to the effects from each factor.

Table 4. Rates for the causative factors

Causative factors	**Interaction between factors**	**Rates**	**Outcome**
Surface slope	2 major + 0 minor	(2*1) + (0*0.5)	2 points
Surface roughness	1 major + 1 minor	(1*1) + (1*0.5)	1.5 points
Flow accumulation	1 major + 1 minor	(1*1) + (1*0.5)	1.5 points
Elevation	3 major + 1 minor	(3*1) + (1*0.5)	3.5 points
Rainfall intensity	1 major + 1 minor	(1*1) + (1*0.5)	1.5 points

Source: Author, 2016

Based on the result, an evaluation was carried out by combining the rate and the proposed score. This was derived by multiplying the proposed weight and the rate to give the weighted score. The weighted score was then summed to give the total weight and then expressed in percentage terms.

Table 5. Categorization and weighting of causative factors

Factors	**Domain**	**Descriptive level**	**Proposed weight (a)**	**Rate (b)**	**Weighted score (a*b)**	**Total weight**	**Percentage**
Surface slope (%)	0-80 80-100	High Low	8 2	2	16 4	20	10
Surface roughness		Very high High Moderate Low	10 8 5 2	1.5	15 12 7.5 3	37.5	19
Flow accumulation	400000-1800000 200000-400000 0-200000	High Moderate Low	8 5 2	1.5	12 7.5 3	22.5	11
Elevation (m)	0-230 230-260 260-300 300-723	Very high High Moderate Low	10 8 5 2	3.5	35 28 17.5 7	87.5	43
Rainfall intensity (mm)	123.3 115.8	High Moderate	8 5	1.5	28 7.5	35.5	17
Total						203	100%

Source: Author, 2016

In the next step, all the map layers (five layers) are combined using the weighted overlay tool in ArcGIS 10.3.1. The output was then reclassified into classes showing high risk, moderate risk and low risk areas using regular interval. The final map produced is the flood hazard map.

2.4 Assessing of risk

This assessment indicates potential threat or harm to people and infrastructure. It assesses the vulnerability of people and communities. In assessing the risk, the indicator used was population. Due to data availability, the assessment of potential harm to infrastructure was hindered.

2.4.1 Population density

Under this assessment, the total population likely to be affected was indicated. Population data from the most recent census from Ghana Statistical Service (2010) was used to create a population density map. The population density map was classified as very high, high, moderate and low using regular interval. The population density map was overlaid with the flood hazard map to ascertain the areas classified as high hazard and the estimated number of people to be affected or vulnerable.

2.4.2 Risk map

The final map created was the flood risk map. This map was obtained from assigning weighted values to the categorized population density. A weighted overlay was carried out for population density and flood hazard map. A higher percentage (60%) was assigned to population because the number of people exposed to hazard is generated by estimation of number of people in hazard areas (Maantay and Maroko, 2009). Hence, a higher percentage was assigned to population.

Table 6. Weighted values.

Indicators	Descriptive level	Proposed weight	Percentage
Population density	Very high High Moderate Low	10 6 3	60
Flood hazard map	Very high High Moderate Low	10 6 3	40

Source: Author, 2016

3. RESULTS AND DISCUSSION

In this study, the mapping and assessment of flood hazard and flood risk were based on the five factors introduced in the materials and methods. All the five factors were evaluated on a numeric value. The causative factors maps, hazard map, and the risk map have been graphically presented separately. The maps presented have been assessed and discussed.

3.1 Results

The results show the locations that are at high probability of inundation. The maps created for the causative factors are Digital Elevation Model, surface roughness, surface slope, flow accumulation and rainfall intensity map.

3.1.1 Digital elevation model

The study created a digital elevation model from an ASTER DSM data set. The model predicts areas of low, moderate, high and very high elevation which are shown in Fig. 4. From the DEM map, the areas classified as having low susceptibility to flooding are areas of very high elevation (301 – 723m). It covers approximately 3% (833.3 ha) of the total area. Areas which are classified as having a moderate susceptibility to inundation are areas with fairly high elevation (261 – 300m) and covers 39% (10834.1 ha) of the total area. Also, areas which were considered as high susceptible to flooding were having fairly low elevations (231 – 260m). This area covers 51% (14167.7 ha) of the entire study area. Furthermore, areas classified to be having very high susceptibility to flooding were areas with very low elevation (0 – 230m). This area covers approximately 7% (1944.5 ha) of the total area. It can also be seen that the areas in the low-lying areas area are found to be in the river channel. Generally, it is seen that the southern part of

Kumasi is identified to be a low lying area which indicates high susceptibility to flood as compared to the north.

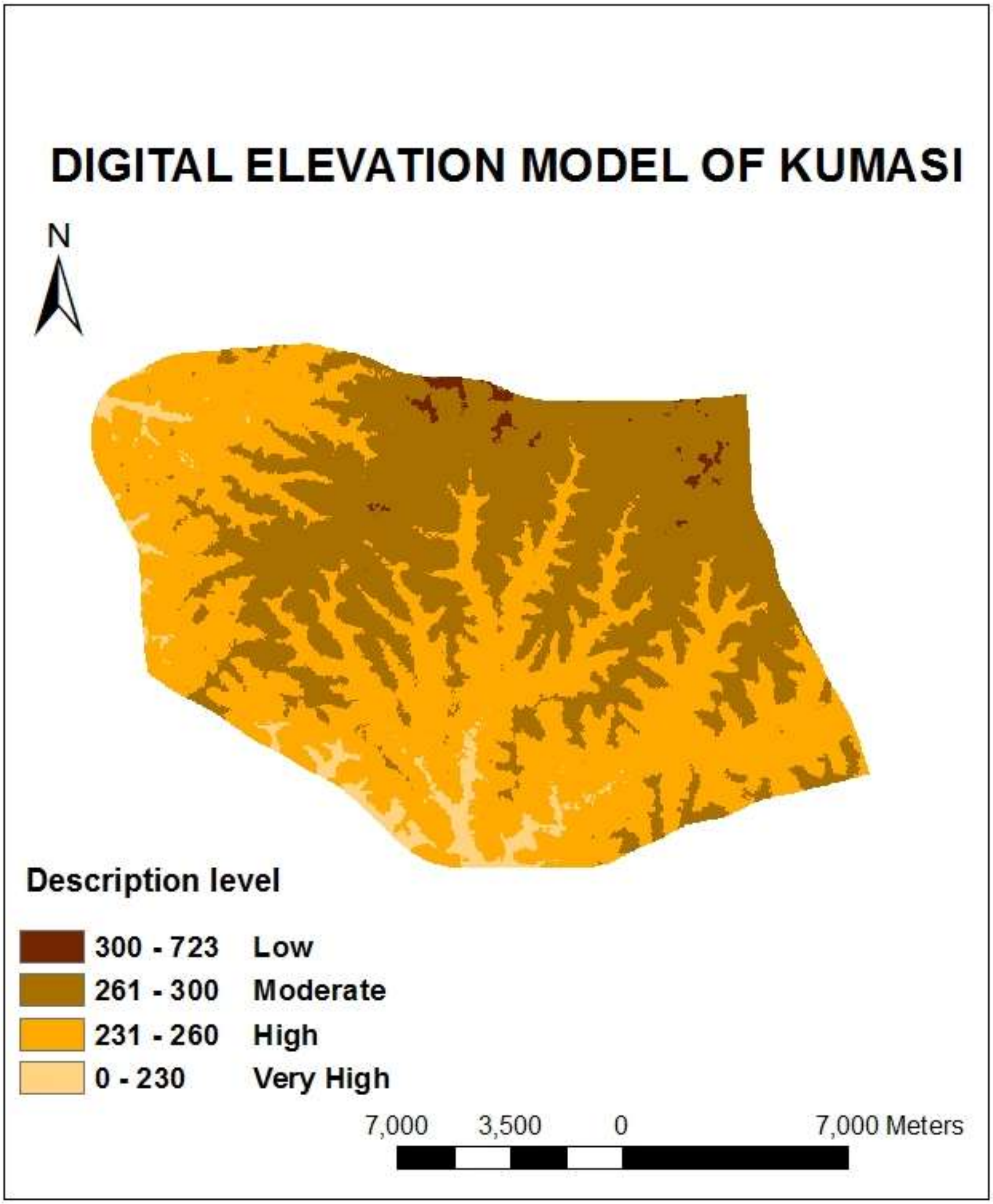


Fig 4. Digital Elevation Model of Kumasi

3.1.2 Slope

The model for slope displays areas with high and low gradient. It can be seen from the model that approximately 26% (7222.7 ha) of the area was identified to have a steep slope. This could indicate that these areas will have increase in run-off since slope increases intensity of flow. Additionally, areas classified to be low susceptibility to inundation were areas with fairly low slope. This covers an area of 20557.1 ha, which is approximately 74% of the area. Overall, it can be identified that only a smaller area (26%) can be said to be lying in a steep slope. This indicates that generally, the city does not have steep gradient.

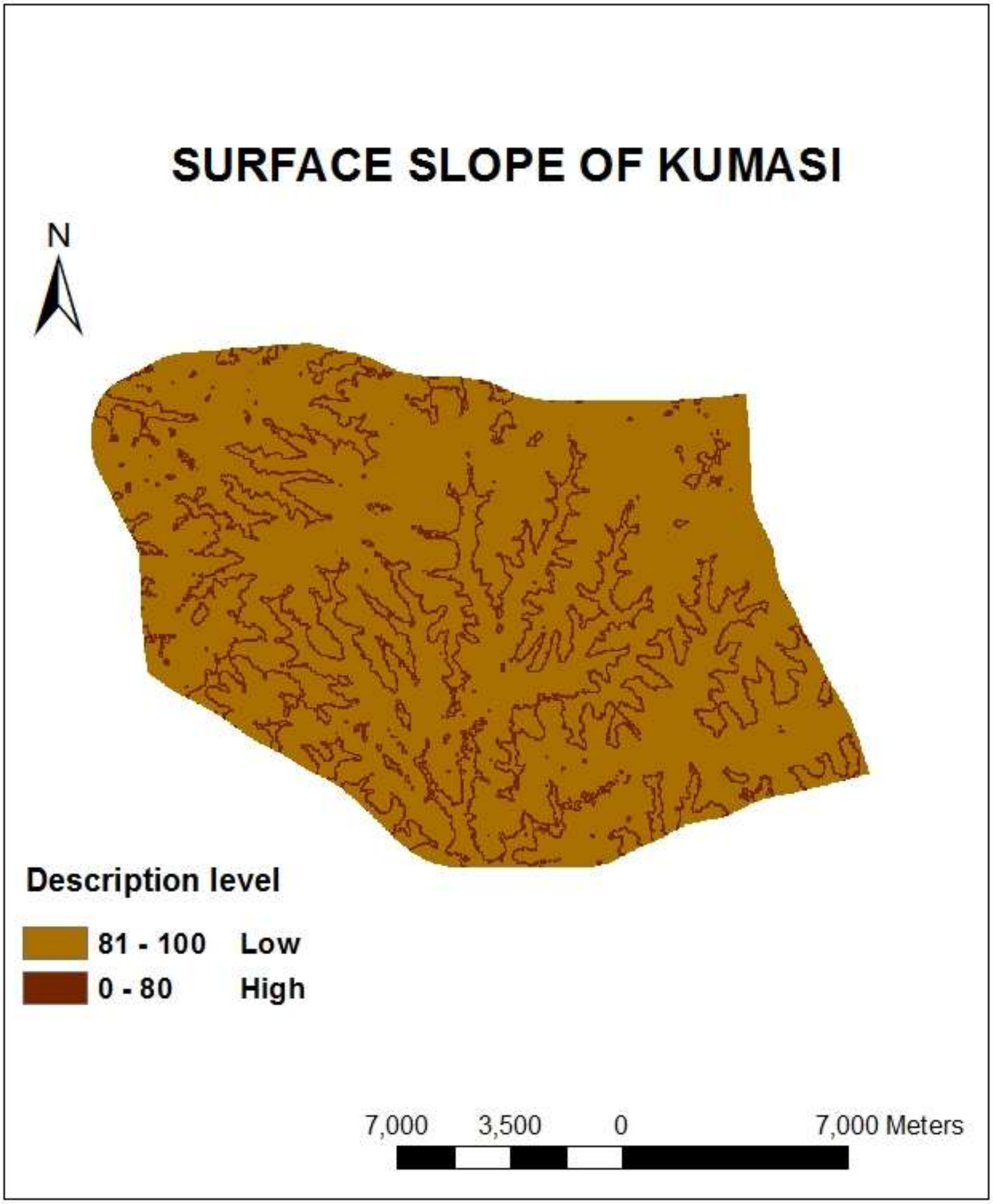


Fig 5. Surface slope of Kumasi

3.1.3 Flow accumulation

The flow accumulation was carried out to show the natural drainage pattern of Kumasi. The model displays areas within high, moderate and low susceptibility to inundation. The purple colour portion of Fig. 3 shows the catchment area with very high susceptibility to flooding. It covers the smallest area with 0.5% (138.8 ha) of the total area while the area classified as having moderate susceptibility to inundation covers approximately 1% (277.7 ha) of the area. Also, the catchment area which is considered to be low in susceptibility covers approximately 98.5% (27363.2 ha) of the area. Generally, the flow accumulation result indicates that Kumasi has a small catchment area which is at high susceptibility of flooding.

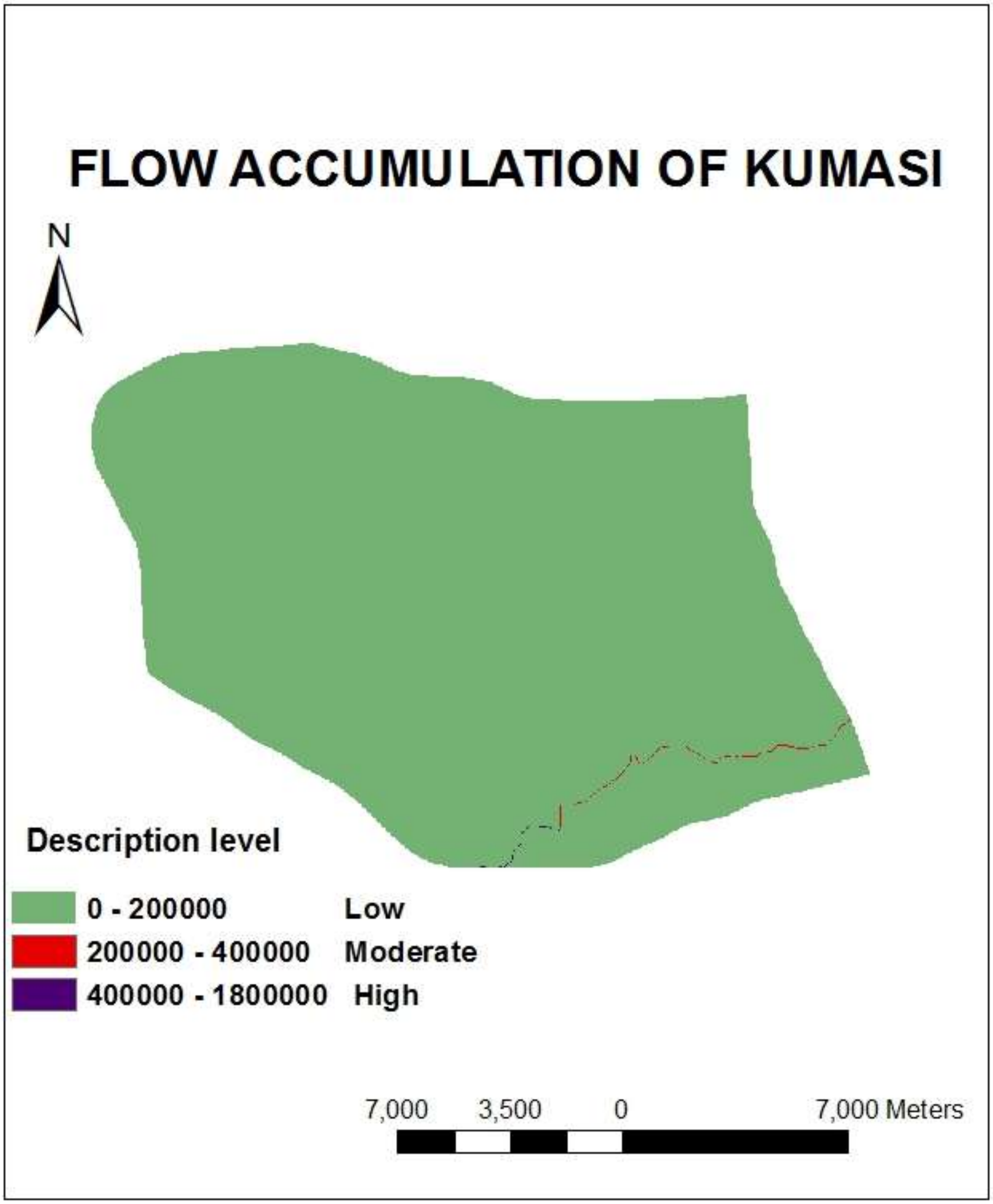


Fig 6. Flow accumulation of Kumasi

3.1.4 Rainfall intensity

The rainfall model predicted areas of high and moderate rainfall intensity. The area with high rainfall intensity had an average monthly rainfall of 123.3mm while the area with moderate rainfall intensity had an average of 115.8mm. Also, among the various months of the year: June, October, and May have the highest average monthly precipitation respectively. This indicates that there is the high probability or likelihood of flood occurrence during these months. On the contrary, December, January, and November have the lowest average monthly precipitation respectively. This suggests that flooding is not likely to occur during low or dry weather conditions.

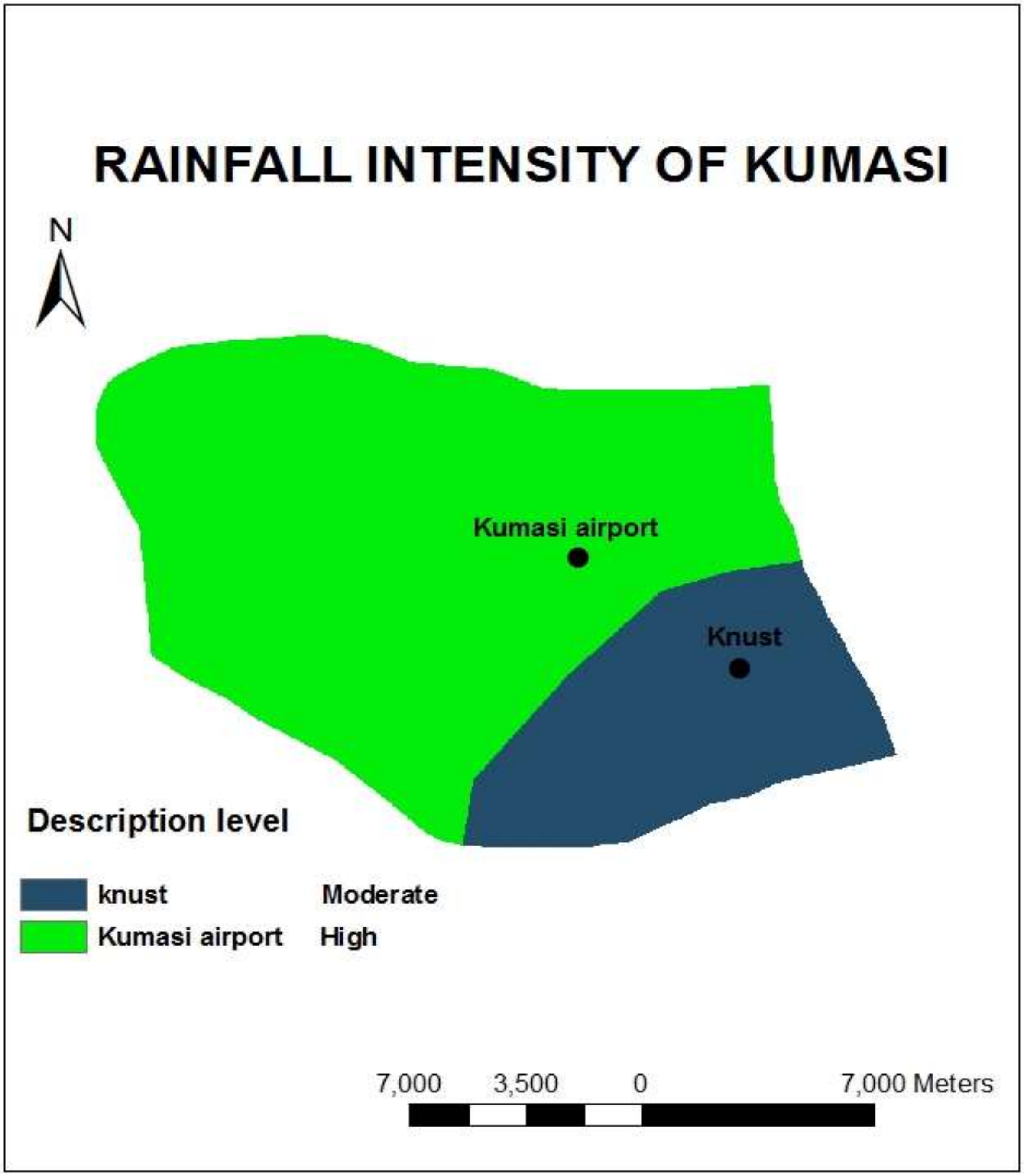


Fig 7. Rainfall intensity of Kumasi

Table 7. Monthly precipitation of Kumasi- airport station with the two highest rainfall months highlighted.

MONTHLY RAINFALL FOR KUMAI – AIRPORT												
YEARS	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
2005	12.5	48.9	84.2	146.4	272.1	121.3	18.3	36.7	174.1	236.9	49.8	29.8
2006	111.1	98.4	112.8	66.9	187.3	145.4	66.7	65.2	111.4	158.4	32.5	3.7
2007	0.2	16.9	56.2	310.9	164.2	176.0	192.9	117.7	534.5	153.9	51.7	19.8
2008	0.0	53.7	97.4	132.0	239.6	286.7	131.1	192.6	170.7	75.1	18.3	54.8
2009	0.0	131.4	110.6	139.8	164.6	376.7	273.5	17.6	99.3	138.6	45.2	33.4
2010	14.7	52.7	52.6	77.3	108.9	225.8	83.3	113.1	165.9	184.0	80.9	38.3
2011	65.8	136.4	230.5	122.8	100.1	244.4	178.6	60.6	155.6	188.1	38.9	0.0
2012	48.1	74.9	92.0	119.3	270.8	379.8	93.8	3.4	82.5	225.6	70.6	60.6
2013	74.9	54.7	107.9	167.8	207.4	114.9	138.0	6.2	219.5	209.7	80.6	42.0
2014	89.2	99.5	66.8	105.8	117.0	268.5	888.8	59.3	112.7	180.1	117.6	6.2
2015	0.0	54.0	171.6	231.5	118.4	333.4	128.4	2.9	101.7	142.2	40.7	0.0

Table 8. Monthly precipitation of KNUST station with the two highest monthly rainfall highlighted.

MONHTLY RAINFALL FOR KNUST(mm)												
YEARS	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
2005	8.1	48.4	84.6	126.4	172.1	93.0	22.8	35.6	195.6	224.6	54.5	0.0
2006	109.7	113.9	91.8	93.2	143.9	113.0	68.0	75.8	96.8	177.9	45.1	5.4
2007	8.5	65.3	76.7	189.9	84.3	244.2	374.0	127.3	539.8	237.6	48.6	2.9
2008	0.0	61.7	134.1	117.1	185.8	279.8	145.0	164.5	147.8	95.8	30.8	47.5
2009	0.0	114.9	162.9	123.9	99.0	367.9	225.2	19.0	59.7	201.7	40.4	30.0
2010	4.2	56.7	105.3	101.2	132.6	203.3	166.8	134.9	201.8	163.2	111.1	47.0
2011	20.2	101.7	256.6	157.4	149.9	197.7	247.6	71.5	229.2	247.0	44.9	0.0
2012	18.5	48.5	126.1	206.5	238.4	359.8	55.8	15.9	70.1	182.3	40.5	60.0
2013	2.0	37.0	108.6	141.6	194.1	184.8	140.8	8.0	282.3	221.3	43.6	15.8
2014	15.6	52.0	73.5	120.6	103.4	270.0	91.4	74.2	162.9	138.2	107.2	10.8
2015	2.4	53.7	108.5	183.3	144.6	206.5	103.7	10.2	56.7	163.6	21.6	0.0

3.1.5 Surface roughness

The map for the surface roughness predicted areas of low, moderate, high and very high susceptibility using Manning's roughness value. Areas with impervious surface resulting from concrete pavement, asphalt and buildings were considered to be the worst area to be affected and estimated to cover approximately 62% (17223.5 ha) of the entire area. The vegetation cover of the study area comparatively is considered to have a high roughness value compared to open land and water bodies. The vegetation cover which comprises the parks, farmlands, forest and woodlands is identified to be at high susceptibility to flooding. It covers approximately 21% (5833.7 ha) of the area. Also, the open land (bare ground) was identified to be fairly susceptible to inundation. This covers approximately 15% (4166.9 ha) of the area. It can also be seen that the water body has the smallest coverage: approximately 3% (833.3 ha) and again is considered to be lowly susceptible. Overall, it was found that higher percentage of the area (impervious and vegetation) which is approximately 83% was identified to be highly susceptible to flooding whilst 17% of the area (open land and water body) was identified to be at low susceptibility to inundation.

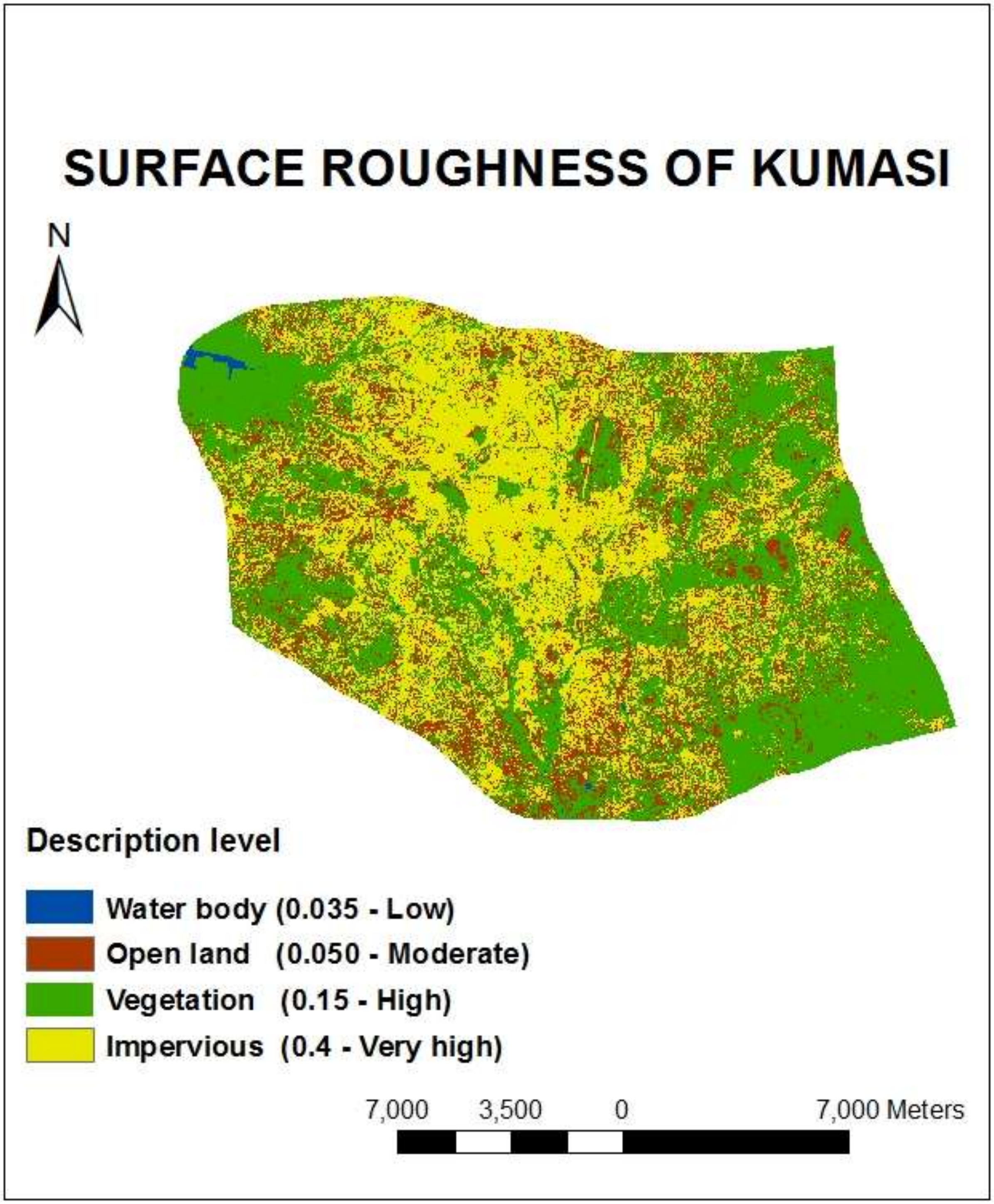


Fig. 8 Surface roughness map of Kumasi

3.2 Flood hazard map

Fig 5 displays areas which are at danger of flooding as per the causative factors stated above. From the flood hazard map, the spatial variability of hazards in the area is clear. It can be identified from the map that the southern and north – western part of Kumasi is seen to be at very high susceptibility to flooding. These areas are at very high probability of been flooded. They have very high potential of been inundated and covers approximately 8% (2222.3 ha) of the area. This category can be considered to be an area with a probability of flooding occurring at 1:10 years. In addition, 45% (12500.9 ha) of the area is identified to be at high susceptibility to flooding. This area has a probability of flooding occurring at 1:20 years. Also, from the hazard map, there are some areas which will be less endangered by flooding. Areas categorized to be moderate and low danger prone cover 36% (10000.7 ha) and 11% (3055.7 ha) and have a probability of flood occurring at 1:30 years and 1:40 years respectively. These areas are located in the North - eastern part of Kumasi. Overall, areas identified to be highly susceptible to flooding cover 53% of the entire area. This suggests that more than half of the area can be considered to be at danger of flooding and as such, large area of the city falls in danger of flooding.

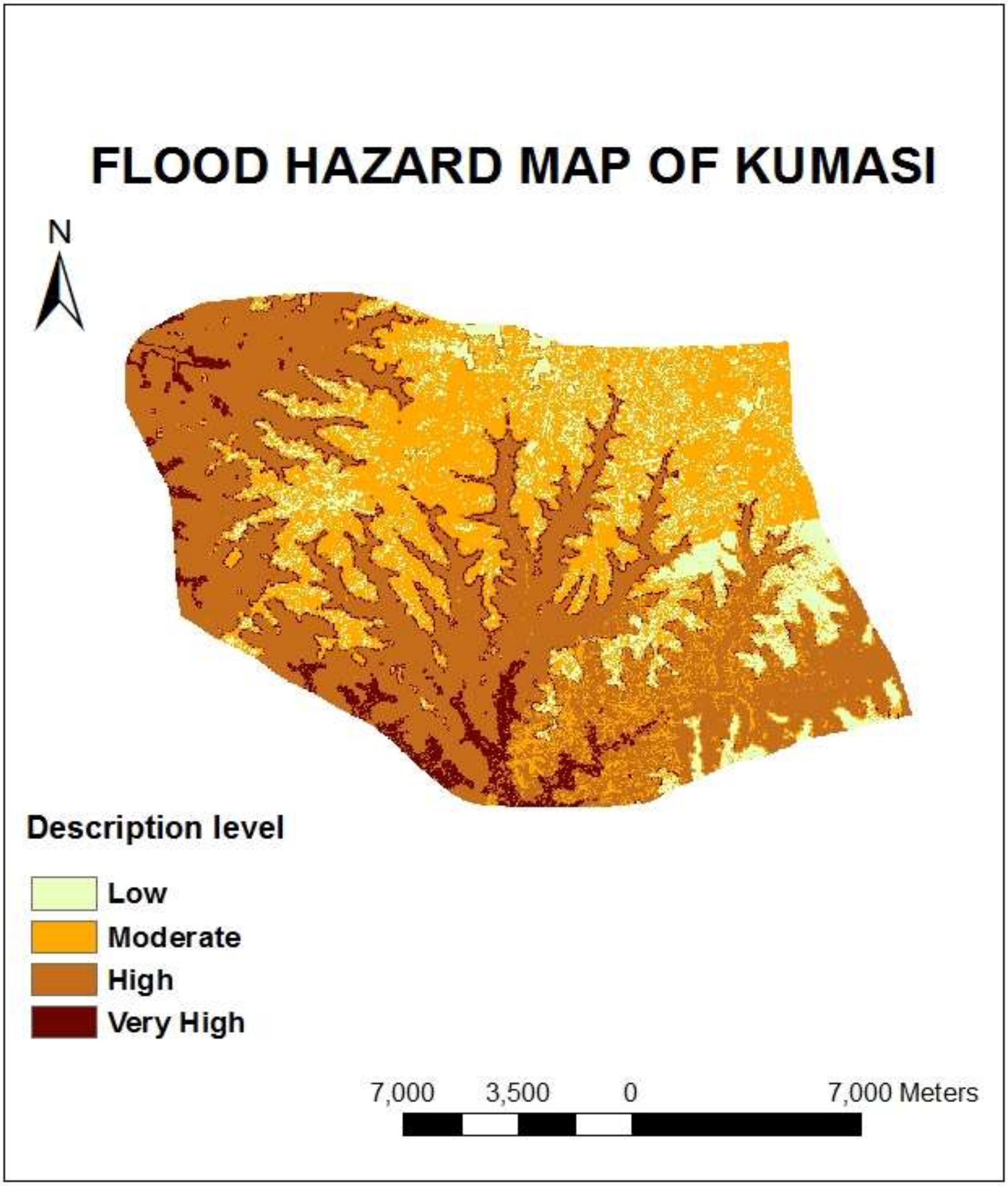


Fig. 9 Flood hazard map of Kumasi

2.3 Population density

The population density map provides insight on the population distribution per each sub – metro. The results showed that the two sub – metros: Subin and Tafo have the highest population density, averaging, 126 to 213 people per hectare. This indicates a greater population to be affected when there is the occurrence of flood. Additionally, Kwadaso, Bantama, Suame and Asawase were identified to have high population density. This zone has an average of 53 to 125 people per hectare. Also, from the Fig. 6, it can be seen that there are some areas namely: Nhyiaso and Manhyia which have moderate population density. In an incidence of flooding, this zone is likely not to affect a greater number of people. Additionally, Asokwa and Oforikrom were identified to have the lowest population density of 41 to 45 people per hectare. This connotes that few people are likely to be affected in an incidence of floods. In general, Kumasi can be said to be highly dense with about 64% (1.2m) of people living in a highly dense area. These areas are depicted in the central and North – western part of Kumasi.

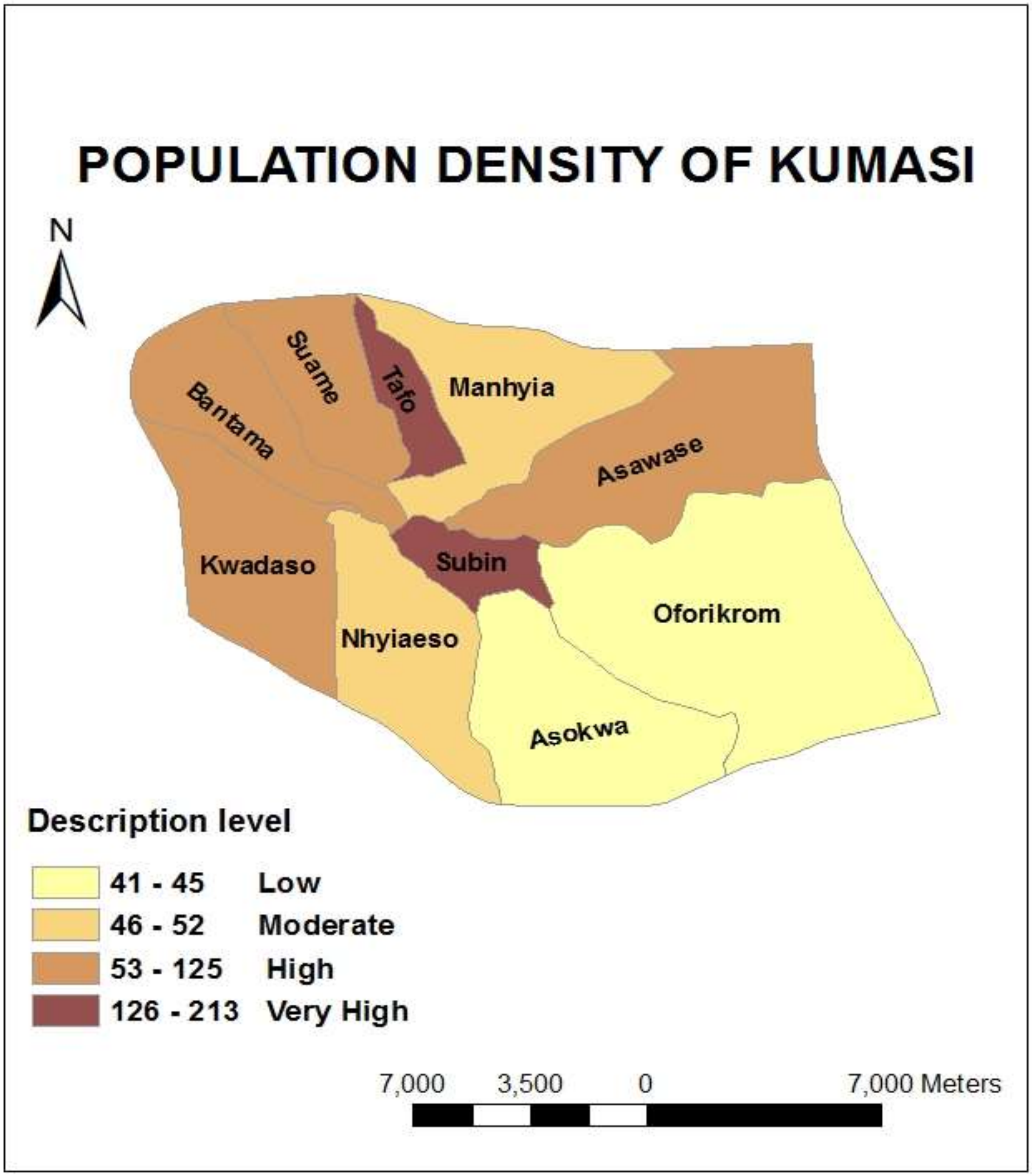


Fig. 10 The population density of Kumasi showing the sub – metros.

2.4 Flood risk map

Fig. 12 present the potential harm people are exposed in qualitative terms using indicators. Also, Table 9 present the potential harm to people in quantitative terms. The flood risk map shows high spatial variability. From the risk map, the area considered to be very high risk covers approximately 15% (4166.9 ha) of the area. This indicates that 187,272 people are at very high risk of been affected by floods and is located in the central and North – western part of Kumasi. The very high-risk zone indicates a very high probability (1:10 years) of been flooded and has a very high population density. The very high-risk category defines the zone to be an extreme risk for all. Also, the model predicted the areas which have high potential harm to people. The predicted zone covers a quarter of the entire area. On average, 522,648 people are found to be in the high-risk zone. It is also seen that the larger portion of this zone lies in the North and central part of the city. The high-risk zone defines the area to have a high probability to flooding (1:20 years) and high population density. This zone defines the area to be at slightly greater risk of flooding for all. Meanwhile, about 729,936 people are located in the moderate zone. This zone considers the population to be at a fair risk. The moderate zone indicates that the area has a fair probability of been flooded (1:30 years) and a medium population density. This category defines the zone to be at mild risk in which some will be in danger like the aged and the children. In addition, the low risk zone covers 20% (5555.9 ha) of the area. This indicates that the population in this zone are likely not to be impacted by inundation. This zone is defined as the area that has low probability (1:40 years) of been flooded and has low population density. It is classified as the area that has minimum risk of flooding for all. In general, one-third (1/3) of the area lies at high risk of flooding. Also, inundation would have a great impact on people and infrastructure on the high-risk zones.

Table 9. Population per the description level

Description level	Area (Hectare)	Population
Very High risk	2600.56	187,272
High risk	7259.47	522,648
Moderate	10138.33	729,936
Low	7781.59	560,304
Total	27779.95	2,000,160

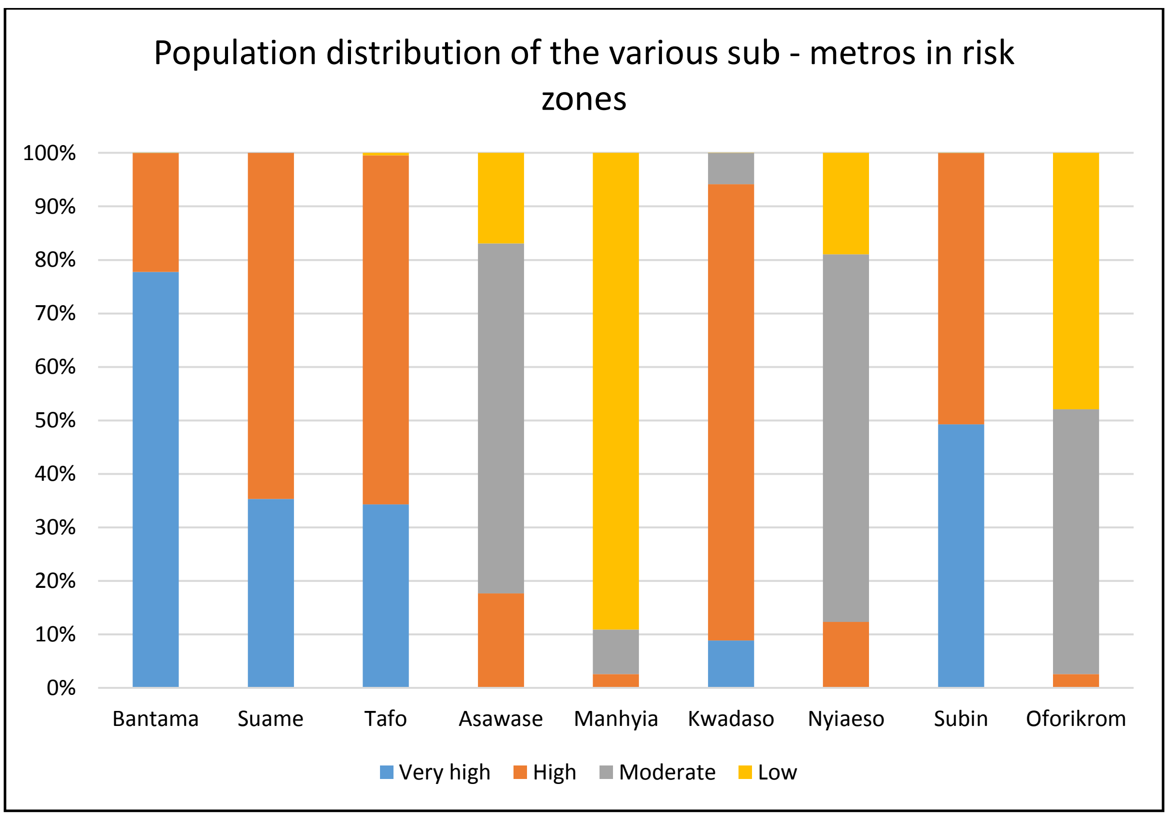


Fig. 11 Population distribution of the various sub – metros in risk zones

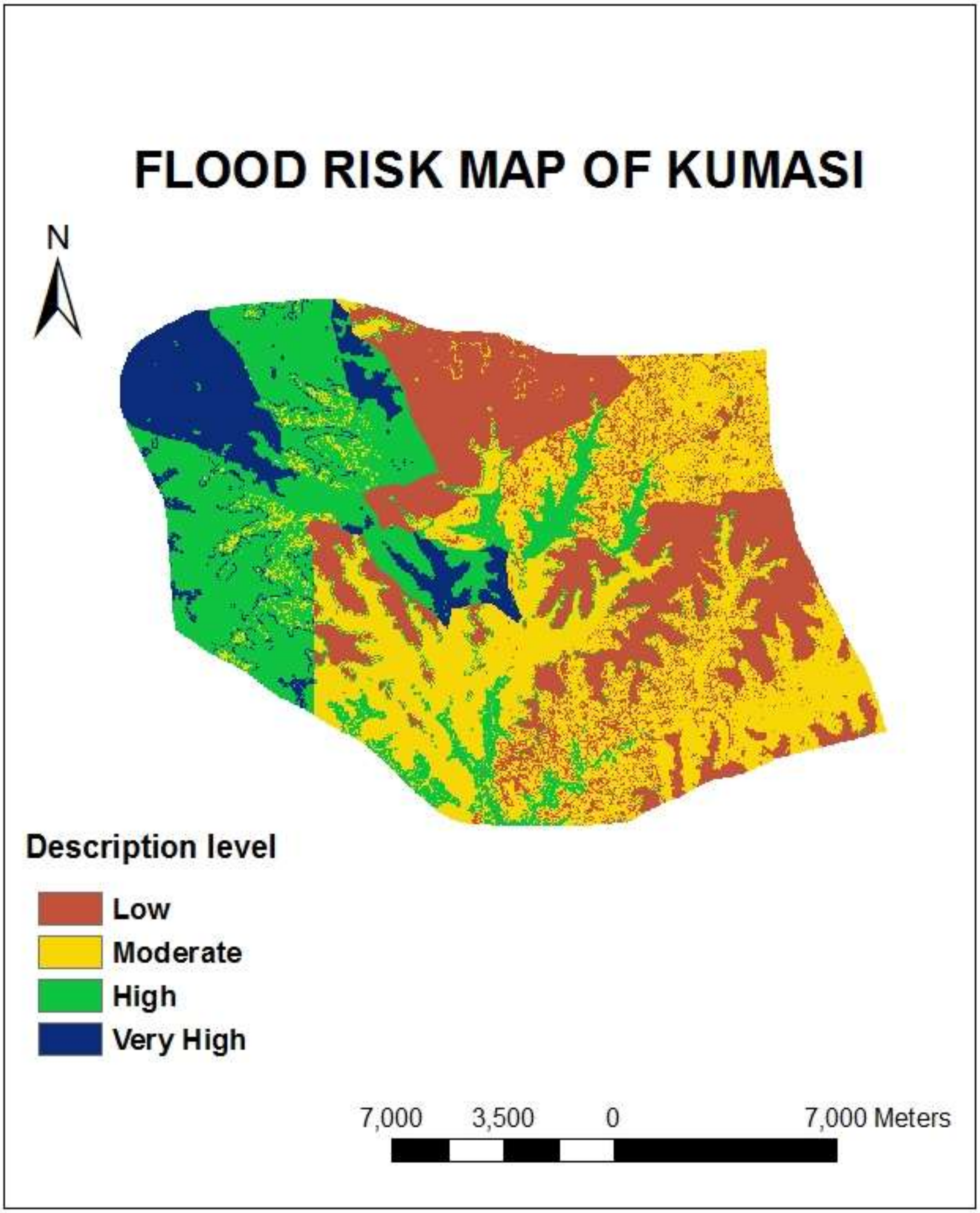


Fig 12. Flood risk map of Kumasi

2.5 Discussion

2.5.1 Flood hazard map

The results of the model revealed that there are areas that lie in the zone of high susceptibility to flooding. This ideally will require certain flood management measures to be mounted. Thus establishing an understanding of flood prediction or simulation is important in developing an effective response strategy. On the contrary, in Ghana, specifically Kumasi, it is surprising that response strategies are only on provision relief items after the occurrence of flood. (Ahazie and Proverbs, 2011).

According to the model results displayed in Fig.12, it was identified that the flood hazard map was distinct from the flood risk map. The result clearly affirms the understanding that elevation is the most important data input in creating a flood hazard map by Elkhrachy (2015). This is because there is a similarity between the output of the DEM and the output of the flood hazard map. Most notably, in the areas classified to be at very high and high susceptibility of flooding. Typically, it can be argued that areas known to be at high susceptibility in DEM will also be the similar or same areas to be identified in flood hazard map. Again, it is noted that the flood hazard map of this study also compares well with the flood hazard map of Kourgilas and Karatzas (2011) and Ozkan and Tarhan (2016). There is much similarity in the respective output. This is basically because the outputs of these studies are also characterized with similarity between the DEM output and the flood hazard map. This further emphasizes on the postulation that elevation is the most important data in flood hazard mapping. However, One striking result found in Fig. 6 was the greater percentage (53%) of the area lying at high susceptibility to flooding or areas highly prone to flooding. Results from Ahazie and Proverbs (2011) reveals that there is little or no management strategy to warn inhabitants of a potential flood in Ghana. This suggests that the percentage of people living in areas classified as highly susceptible are at great danger of unexpected flood events. This is in contrast to the western countries where effective management strategies are put in place to help reduce flood risk and minimize the impact of floods on the population.

Access to information has a crucial impact on people's awareness and response to living in a flood hazard area. From the result, it is noted that about 14723.37 hectares (53% of the entire area) are susceptible or prone to be flooded. This suggests that the people living in the flood-prone areas will have weak resilience to floods. Again, they will not be able to invest in flood insurance due to their low awareness of flooding.

The spatial variability of the classified zones in Kumasi varies across the city. Flood incidences are often likely to affect the city centre. The results in Fig. 9 tend to show that the city centre has a high susceptibility to flooding. These are due to the extensive construction of infrastructure, land use change and development on river basins. Basically, the high proportion of built-up areas in city centres increases their susceptibility to flooding in instances of high precipitation (Kazmierczak and Caven, 2011). This is consistent with the result in Fig. 9. In Williams et al. (2010) they recommended that to curb the high proportion of imperviousness in city centres causing an increase in surface flooding, an introduction of vegetation is essential. In this study, the results of Fig. 8 indicates that the city centre of Kumasi has limited green space. This could suggest an increase in runoff in the city thus leading to high susceptibility. Additionally, the contribution of weather cannot be overemphasized in this study. The results in Table 7 and 8 reveals a fluctuating average yearly rainfall. This suggests the unpredictability of precipitation in Kumasi thus could affect accurate forecasting or prediction. The fluctuating trend of rainfall might be due to one prominent reason- climate change. Also, in Table 7 and 8, it was noted for all the years (2005 to 2015) that the highest amount of precipitation recorded were all in the rainy season (Mid-April to November), except in 2011. This could back the frequent occurrence of flood events in the rainy seasons.

2.5.2 Flood risk map

Flood risk is a multi-faceted phenomenon which is associated with population, infrastructure, and economic activities. However, this assessment focused on the population as it was the only available data.

The research findings in the study reveal that there are different facets of risk associated with people. The method used here evaluates where people are at higher risk of flooding. Also, the diversity aspect of flood risk to people reflects the population density in urban areas. Particularly, areas with higher population density are more likely to be at higher risk of flooding. Although the zones classified as having very high and high risk of flooding mean high risk for all, there are particular groups which are identified to be at more risk. In this study, the result indicated that high-risk zones were found in the city centre and the northern part of the city. This is synonymous with a study done by Kazmierczak and Cavan (2011). Their result indicated that urban centres are more vulnerable to flooding and also the poor and the migrant from other regions within Ghana are more associated with the urban centres. Consequently, it can be said that the city centre of Kumasi has an appreciable number of migrants from the other regions in Ghana. It also has suburbs which are considered as slums by UN habitat. Most importantly, there are a large number of people who are homeless in the city centre. The agglomeration of all these facts raises the risk level of the city centre to flooding. The proportion of area at risk of inundation in the city centre is higher than all the areas. This suggests that loss of lives and material loss will be exacerbated and the most vulnerable in the Kumasi city centre (the poor, aged and children) will be affected more.

4. CONCLUSION AND RECOMMENDATION

Flooding is a perennial problem in Kumasi. This study has helped describe an approach in delineating flood hazard zones and generation of a flood risk map. It has also helped identify the causative factors in flooding and the inter-relationship between these elements. Furthermore, it has helped identify areas of very high, high, moderate and low hazard and risk. This indicates that the extent to which the outlined objectives were achieved could be considered as good. This is because all the outlined objectives were achieved. The findings of this study reveal that the high-risk zone was found to be at the north – western and the city centre. Particularly, in the city centre, the poor, the homeless, children and the aged are more vulnerable to be affected and are at higher risk. Also, the susceptibility zone to flooding was mainly influenced by elevation. This suggested that there was a strong correlation between the DEM and the hazard map. Thus elevation is the most important data in flood hazard mapping. Again, in the study, 53% of the entire area was found to be highly susceptible to flooding. This suggested that large portion of the area are in danger of been inundated. Also, 35% of the population are at high risk of flooding. In addition, the city centre was identified to be highly prone to flooding and also at high risk to people in events of floods. It was also revealed that floods are likely to occur in the rainy season due to high precipitation volume which will cause an increase in run-off. Specifically, June, October, and May are the months that receive high volume of rains and inundation is likely to occur in such months.

The results from the flood hazard map and the risk map suggest flooding in Kumasi is important and thus flood management strategies needs to be implemented. Access to information on flood inundation, prediction, and risk assessment is important and should be made readily available to people. The flood risk management strategies should be made clear and most importantly will need further development. Thus emergency planning and management, early warning systems, spatial planning and insurance need to be developed and implemented. Moreover, to the large extent, this study will be beneficial to authorities in order to help develop responses tailored to Kumasi.

Future studies on the flood hazard and risk mapping will consider the assessment of infrastructure and land use, and economic activities since an accurate and detailed risk map is obtained from such data input.

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Appendix A

Future research

Based on the research findings, future studies on the flood hazard and risk mapping will consider the assessment of infrastructure and land use, and economic activities since accurate and detailed risk map is obtained from such data input. Also, it will provide detail analysis and assessment of flood risk.

Limitations

The main limitation is the availability of datasets to create the models. Especially, infrastructure and land use datasets were difficult to acquire. Moreover, there was limited rainfall station. The rainfall data was obtained from only two stations, hence it doesn’t improve the accuracy of the rainfall intensity map. In general, there was limitation on the modelling since models have some degree of uncertainty.

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