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Research Article

The application of GIS in mapping of flood hazard areas 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 has 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.

Keywords
Digital Elevation Model–GIS–Flood modelling–Flood hazard map–Flood risk map.

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Contents

1. Introduction

Floods are among the leading causes of natural disasters worldwide [1]. It is stated in [2] 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 to [1] 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 [3] 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. 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 [4]. Due to this, undertaking research on flood hazard mapping has become expedient.

1.1 Review on flood hazard mapping

According to [5] urban areas are known to be most important areas that are affected by flooding. The factors that causes 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 [6] and [4]. It can be said that urbanisation is one of the most important causes of flooding [4]. Above everything else, flooding needs management. For this reason, it is stated in [7] that the ultimate aim of flood studies is to produce a flood 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. In a recent study [5] discussed that the possible means of overcoming flood hazard is by simulations. [6] and [5] 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 [8], 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. 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 [9]; [10] and [11]. 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 [12]. 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 [11].

2. Materials and Methods

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 km2 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 [13]. The rapid increase in population, averaging 4.8% per annum, and expansion of settlement in Kumasi will mean high risk [14]. Thus, an incidence of flooding will endanger a greater number of population.

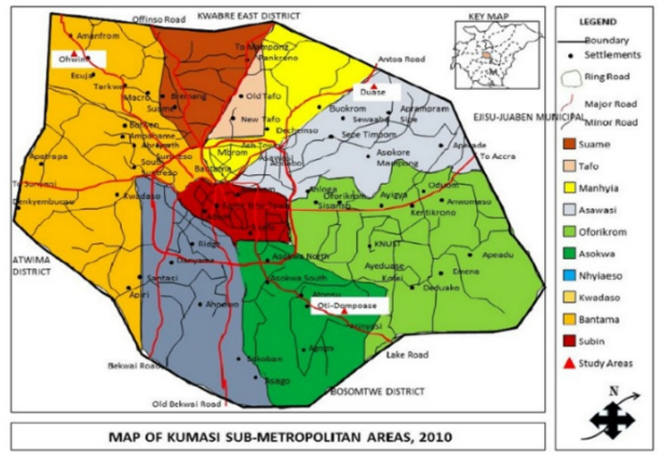

Figure 1. A map of Kumasi

2.2 Methodology

A GIS approach was applied in this study. This research illustrates through a case study of Kumasi and explains how GIS modelling is used to create flood hazard and risk maps.

2.2.1 Research Approach

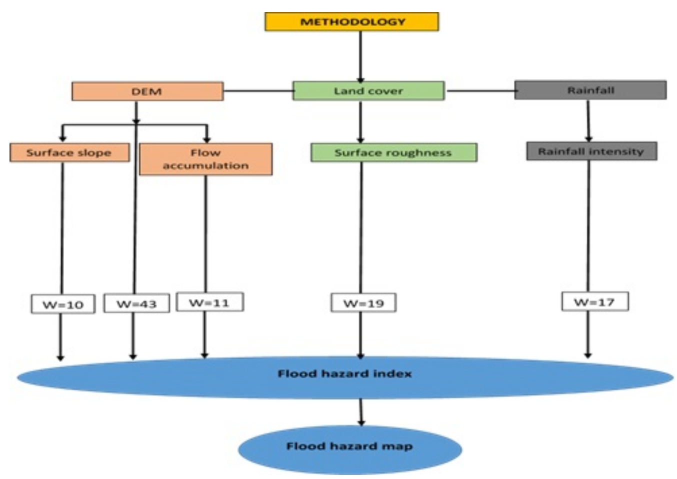

Figure 2. Methodology for mapping flood hazard

2.2.2 Data requirements

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

2.2.3 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. Also, the datasets were georeferenced into local UTM zone: Accra grids.

- Digital Elevation Model.

  In this study, a DEM 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 and a minimum age of 2010 The DEM dataset used was the ASTER DEM 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.

- Surface slope.

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

- Flow accumulation.

  The flow accumulation is used to create a network to show the flow in each grid 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 [15]. 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.

- Surface roughness.

  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. 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 and its various LCLU was used to create a two- dimensional model of Kumasi.

Table 1. Land cover and Manning's roughness values

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

Source: [16]; [17]

- 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.

2.2.4 Overlay

A model was adapted from [5] to assign rank to the flood hazard indicators. Five flood causative factors were used to create the flood hazard map (FHM). The weighting was determined by applying the methodology in Fig. 3.

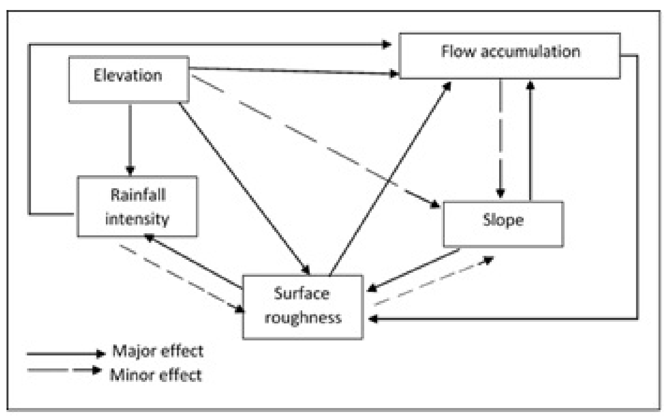

Figure 3. Schematic diagram of interaction between the causative factors of flooding (Source: [5])

Fig. 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 2. 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

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.

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 very high risk, high risk, moderate risk and low risk areas using regular interval. The final map produced is the flood hazard map.

Table 3. 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	High	8	2	16	20	10
	80-100	Low	2		4		
Surface roughness		Very high	10	1.5	15	37.5	19
		High	8		12		
		Moderate	5		7.5		
		Low	2		3		
Flow accumulation	400000-1800000	High	8	1.5	12	22.5	11
	200000-400000	Moderate	5		7.5		
	0-200000	Low	2		3		
Elevation (m)	0-230	Very high	10	3.5	35	87.5	43
	230-260	High	8		28		
	260-300	Moderate	5		17.5		
	300-723	Low	2		7		
Rainfall intensity (mm)	123.3	High	8	1.5	28	35.5	17
	115.8	Moderate	5		7.5		
Total						203	100%

2.2.5 Assessing of risk

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

- 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.

- 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 [18].

3. Results and Discussion

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. In addition, 45% (12500.9 ha) of the area is identified to be at high susceptibility to flooding. 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) 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.

Furthermore, 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 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. 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. 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 and about 560,304 people are at low risk of suffering from flooding. This indicates that the population in this zone are likely not to be impacted by inundation. 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.

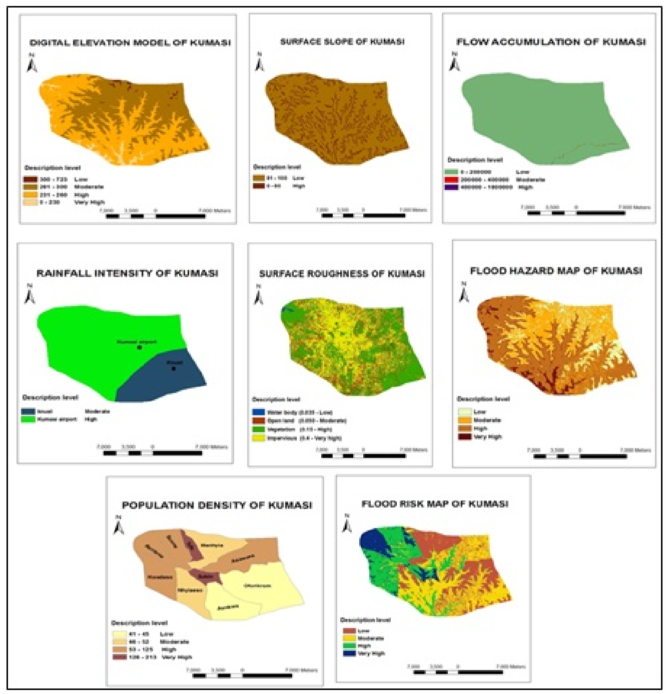

Figure 4. Maps showing the causative factors for flooding

3.1 Discussion

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 of relief items after the occurrence of flood [19].

One striking result found in Fig. 4 was the greater percentage (53%) of the area lying at high susceptibility to flooding or areas highly prone to flooding. Results from [19] 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. 4 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 [20]. Due to 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 land cover and land use map (Fig.4) indicate that the city centre of Kumasi has limited green space. This could suggest an increase in runoff in the city thus leading to its high susceptibility.

Furthermore, 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 [20]. 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

Flooding is a perennial problem in Kumasi. The findings of this study reveal that the high-risk zone was found to be at the north – western and the city centre. Also, large portion of the area are in danger of been inundated and thus are at high risk to people in events of floods. 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.

References

[1] Centre for Research on the Epidemiology of Disaster (CRED) (2015). UN report on the human cost of national disasters: a global perspective. Available from http://reliefweb.int/report/world/human-cost-natural-disasters-2015-global-perspective [accessed 10 June 2016].

[2] Ramala, B. and Babam, S.M.J. (2007). Developing a GIS base integrated approach to flood management in Trinidad, West Indies. *Environmental Management*, 88, 131-140.

[3] Centre for research on the Epidemiology of Disasters (CRED) and The United Nations Office for Disasters Risk Reduction (UNISDR) (2015). UN report on the human cost of weather related disasters 1995- 2015. Available from http://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf [accessed 10 June 2016].

[4] Tehrany, M.S., Pradhan, B. and Ahmad, N. (2014) Flood susceptibility assessment using GIS-based support vector machine model with different kernel types. *Catena* 125, 91-101.

[5] Ozkan, S.P. and Tarhan, C. (2016). Detection of flood hazard in urban areas using GIS: Izmir case. Procedia Technology, 22,373- 381.

[6] Kourgialas, N.N. and Karatzas, G.P. (2011). Flood management and a GIS modelling method to

assess flood hazard areas – a case study. Hydrological Science, 5(2), 212- 225.

[7] Associated Programme on Flood Management (APFM) (2013). Integrated flood management tools series: flood mapping. Available from http://www.apfm.info/news/2013/APFM_FinalReport_2013.pdf [accessed 1 July 2016].

[8] Elkhrachy, I. (2015). Flash flood hazard mapping using satellite images and GIS tools: a case study of Najran city, Kingdom of Saudi Arabia. *Egyptian Journal of Remote Sensing and Space Sciences*, 18, 261- 278.

[9] Chan, J., Hill, A. A. and Urbano,L.D. (2009). A GIS – based model for urban flood inundation. *Hydrology*, 373, 184- 192.

[10] Cook, A. and Merwade, V. (2009). Effects of topographic data, geometric configuration and modelling approach on flood inundation mapping. *Hydrology*, 337, 131- 142.

[11] Saksena, S. and Merwade, V. (2015). Incorporating the effects of DEM resolution and accuracy for the improved flood inundation mapping. *Hydrology*, 530, 180- 194.

[12] Schumann, G., Matgen, P., Cutler, M.E.J., Black, A., Hoffmann, L. and Pfister, L. (2008). Comparison of remotely sensed water stages from LIDAR, topographic contours and SRTM. *Photogram Remote Sense*, 63(3), 283- 296.

[13] Korsah, P. I. and Cobbinah, P.B. (2016). Juggling through Ghanaian urbanisation: flood hazard mapping of Kumasi. Geojournal, 10, 1 - 18.

[14] Ghana Statistical Service (2012). Population by region, District, age, groups and sex, 2010. Available from: http://www.statsghana.gov.gh/pop_stats.html (accessed 2 August 2016).

[15] Parmenter, B. (2012). Watershed and drainage delineation by Pour Point in ArcMap 10. Available from:http://sites.tufts.edu/gis/files/2013/11/Watershed-and-Drainage-Delineation-by-Pour-Point.pdf (accessed 28 July 2016).

[16] Dorn, H., Vetter, M. and Hofle, B. (2014). GIS base roughness derivation for flood simulations: A comparison of orthophotos, LIDAR and crowdsourced geodata. *Remote Sensing*, 6, 1739-1759.

[17] Kalyanapu, A.J., Burian, S. and Mcpherson, T.N. (2009). Effect of land use- based surface roughness on hydrologic model output. *Spatial Hydrology*, 9(2), 51-71.

[18] Maantay, J. and Maroko, A. (2009). Mapping urban risk: Flood hazard, race and environmental justice in New York. *Applied Geography*, 29,111- 124.

[19] Ahadzie, D. K. and Proverbs, D.G. (2011). Emerging issues in the management of floods in Ghana. *Safety and Security Engineering*, 1(2), 182 – 192.

[20] Kazmierczak, A. and Cavan, G. (2011). Surface water flooding risk to urban communities: Analysis of vulnerability hazard exposure. *Landscape and Urban Planning*, 103, 185 – 197.