



Flood Hazard and Flood Risk Vulnerability Mapping Using Geo-Spatial and MCDA around Adigrat, Tigray Region, Northern Ethiopia

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ABSTRACT

In Ethiopia, urban floods incidents are becoming a serious problem in recent years. They are mainly associated with poorly designed urban drainage system and land use planning. Combined to it, lack of early warning system and organized flood disaster mitigation measures at national and local level further increases the gravity of the problem. Adigrat is one of the north Ethiopian towns which is frequently attacked by these floods. To understand and address the issue, a study was conducted around Adigrat town with the aim to spatially delineate the flood hazard and risk with the help of geo-spatial and multi-criteria decision analysis (MCDA) tools. Baseline maps were developed using Landsat satellite images, DEM, aerial photographs, rainfall data and census population data. Different variables like slope, elevation, rainfall, water table, flow direction and flow accumulation, LULC, population density, building density and road density were considered for developing a model. After the data is collected and organized, Erdas Imagine and ArcGIS software were used to process and prepare the model, and finally weighted overlay model was adopted to stimulate the prototype. Each baseline maps was weighted against its impact since all factors have no the same importance. Accordingly, slope, LULC, elevations; and population density, flood hazard and LULC were found the most important factors. The flood risk areas are delineated based on flood hazard, LULC, population density, road and building density. The results indicate that the Kebeles 03, 04 and 05 (center of the town) with flat slopes, low altitudes, more population and significant amount of built up area are found to be the most vulnerable for flood hazard. On the other hand, the Kebeles 01, 02 and 06 lying southwest and west of the study area are least affected by flood due to steep topography and high altitudes. It is suggested that similar type of inter-disciplinary studies are essential to minimize the damages and assure sustainable urban development.

Keywords: Geo-spatial, Flood hazard, Flood risk, Vulnerability mapping, Adigrat town, Ethiopia.

1. INTRODUCTION

Among the natural hazards capable of causing disaster, flood is by far is the most hazardous, frequent and widespread catastrophic event throughout the world (Emmanuel et al., 2015; Kebede, 2012; Moges, 2007). This makes flooding an important subject of study, particularly in the less developed countries. According to Associated Program on Flood Management (APFL, 2008), flood impact tends to be very severe in African cities where urbanization has taken place with improper land use planning and lack of early warning systems. It is the second and the most worst

environmental disaster next to the recurrent droughts in Africa. Almost all countries in Sub-Saharan Africa are exposed to one or multiple of the natural hazards. Flood usually affects large river basins such as the Congo, Niger, Nile, and Zambezi basins. The disproportionate impact of natural disasters on the poor Sub-Saharan African countries are not been well documented (UNISDR, 2009). Population growth, poverty, food insecurity, improper use of natural resource and rapid urbanization are among the driving factors behind the increased exposure of Sub-Saharan Africa to natural hazards (Ashok and Saroj, 2005).

Ethiopia is one of the natural hazard- prone (drought, flood etc.) countries in Sub-Saharan Africa. The impact of drought and flood coupled with poverty and high population growth let many people become victims for various disasters (ERCS, 2012). Published literature suggests that the magnitude and frequency of flooding increased rapidly in recent years in the country. It is clearly indicated by the dramatically increased number of people and areas affected; number of deaths; and infrastructure and property loss. Manifestation of climate change in the form of erratic rainfall, frequent and severe floods; and droughts have grave consequences on the livelihood, security of smallholder farming communities, and making them more vulnerable in countries like Ethiopia (Gizachew and Shimelis, 2014).

Different parts of the country are threatened by the quite unprecedented and abnormal magnitude of flooding. For example, in 2006, more than 357,000 people were affected by flooding (out of which 600 died, 200,000 became home-less) and the country lost about 40 million Ethiopian Birr (UNOCHA, 2006). The problem is more acute in the river basins and urban areas. For example, in 2006, flooding in South Omo and Dire Dawa has killed 300 people in Dire Dawa city. Consequently, many are also affected before the actual information is submitted to the appropriate decisions makers. The information that is produced in accordance with the conventional approach is usually highly uncertain for employing rescue missions. Therefore, producing reliable and timely information for decision makers is essential.

Although, flooding has been remaining one of the severe natural catastrophic in the country, only few studies have been conducted, for example, Dire Dawa city, Oromia Region in Dugeda Bora Woreda; Addis Ababa City; Gambella, and Amhara Region in Fogera Woreda (Daniel, 2007; Woubet and Degnaw, 2011; Wakuma et al., 2011; Kebede, 2012).

Adigrat is one of the developing towns in northern Ethiopia, the study area, is frequently, almost annually, affected by flooding. For example, in 2006, one private Flour Factory was

destroyed and lost 3million Ethiopian Birr (Zuluboy, 2011). But, flood hazard-related studies are quite limited. Ministry of Work and Urban Development (2006) has reported that the flood has remained one of the major environmental problems in the town that has hindered its development. Zuluboy (2011) evaluated the effectiveness of flood disaster mitigation measures and concluded that the town needs to adopt disaster preparedness plan and weather forecasting supported by flood mapping zones; and reported on the poor infrastructure as panacea of flood management. Zuluboy (2011) have noted that the cause of flooding in the town is primarily due to the steep topography, improper land use zoning and land degradation. Cunningham et al. (2005) have reported that the river which forms the main drainage outlet of the town due to its shallow depth the runoff often overflows the riverbanks and creates flooding in the town. Keeping the available data in view, a study was conducted to produce spatial flood modeling and mapping for Adigrat town and the results are presented in this paper.

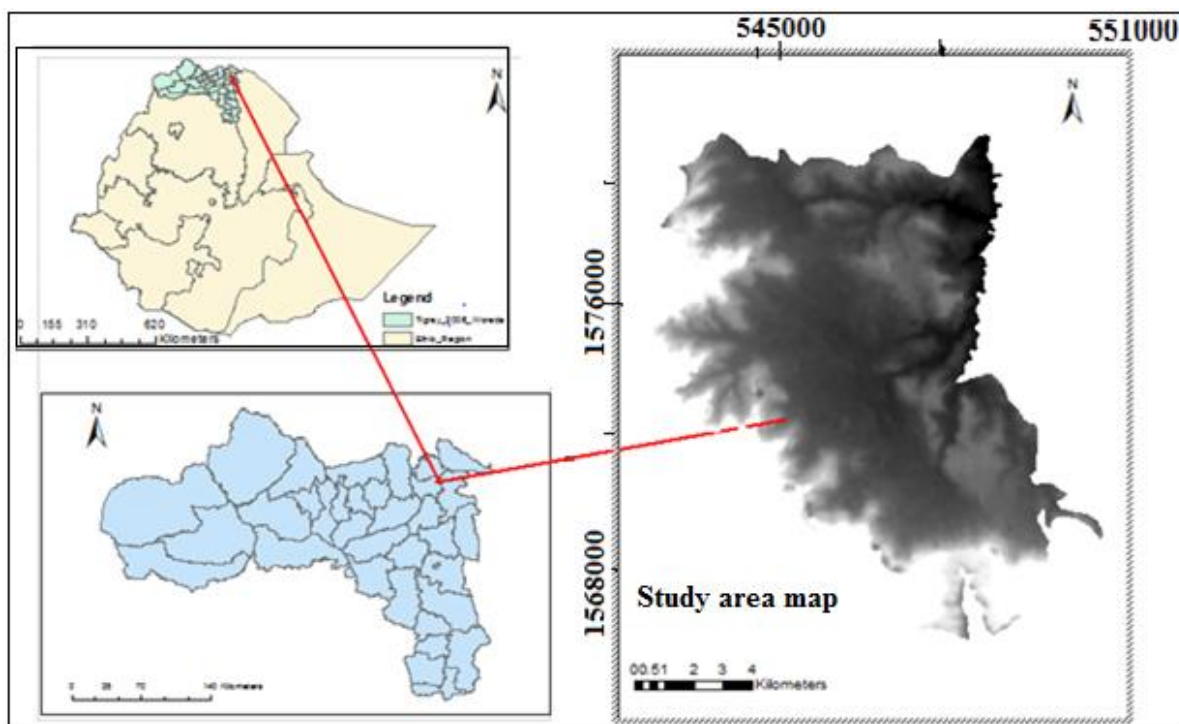


Figure 1. Map of the study area, Ethiopia.

1.1. Study Area Description

The study area, Adigrat Town is located at $14^{\circ}20'$ North latitude and $39^{\circ}29'$ East longitude. It is about 898 kilometers north of Addis Ababa, the capital of the country. Adigrat is capital city of Eastern Tigray Zone. The altitude ranges between 1500 to 25000 m.a.s.l. The town is situated on

the flat topography varying between 2530 m.a.s.l. in the southeast and 2660 m.a.s.l. in the western part of the town (MWUD, 2006). The town is hosting more than 73,000 people and is the second largest town in Tigray Region next to Mekelle city.

2. METHODOLOGY

2.1. Data Collection

The primary data used in this study are collected using GPS to collect ground control points (GCP), personal observation and discussion with experts and head of Adigrat Town municipality. The secondary data used include water table, rainfall data, Landsat Satellite image, DEM, population density and administrative boundary. After collecting the field data and the existing maps; the data preparation, processing and analysis is carried out using Arc GIS 9.3, ERDAS 9.2 and EDRISI software. Based on the data, different thematic maps like slope, flow direction, flow accumulation, rainfall, water table, land use and land cover (LULC), road density, building density and population density were prepared. All the baseline data are independent variables affecting the flood hazard and probability of its occurrence.

Table 1. Data type and sources.

<i>No.</i>	<i>Type of Data</i>	<i>Source of data</i>	<i>Scale/resolution</i>	<i>Date Acquired</i>
1	Landsat Image	Adigrat Municipality	15m	2014
2	Aster Image	USGS	30m	2008
3	Population	Adigrat Municipality	-----	2013
4	Water table	Adigrat Water Supply	Point data	-----
5	Rainfall	Metro station Adigrat	Point data	2004-2014

To start with LULC map is prepared applying supervised classification for Landsat satellite image with 30m resolution (of 2015) using ERDAS software. After processing of the image, 20 samples of GCP collected randomly from the existing LULC were used for validation and accuracy assessment. The road, built up and parcel maps are digitized from the existing maps using ArcGIS software while the water table map is prepared using 46 water samples collected from the boreholes and hand dug wells. Since, the data type is point data, the geo-statistical method, kriging interpolation were used to create surface map of water table.

The other important baseline maps such as road density, building density and population density were prepared using ArcGIS software 9.3. After the road and building maps were prepared, road and building densities were calculated using spatial analysis of ArcGIS software while the population density map using Raster calculator by dividing population to area coverage of each Kebele.

The landscape and topography of a given watershed highly affects the occurrence and also vulnerable for flooding. So, delineation of watershed needs to be done carefully using the recommended data. Most flood plain delineation involves the use of GIS with a digital elevation model (DEM) coupled with hydraulic software (Ilorme, 2007). In the present case, DEM of 2013 with spatial resolution of 20m is used to derive drainage networks like sink flow, flow direction, flow accumulation, slope, elevation, 3D view and used to delineate the watershed of the study area using the Arc Hydro extension of ArcGIS software.

2.3 Data Analysis

The independent variables affecting flood hazard vulnerability were organized and used as inputs to develop flood hazard model. Flood causative factors such as slope, rainfall, elevation, LULC, water table and flow accumulation and flow direction were developed and weighted using ArcGIS to generate flood hazard map (Wubetand Dagnachew, 2011; Getahun and Gebre, 2015). In the present case, variables such as slope, elevation, rainfall, flow direction, flow accumulation, water table and LULC maps were used as shown in the figure 2A-F. The standardized raster layers were weighted using eigenvector that is important to show the importance of each factor as compared to each other in the contribution of flood hazard. The weightage for each factor is given based on the literature.

Risk refers to as the product of hazard (the physical agent and its impact) and vulnerability (the susceptibility to damage or injury) (Alexander, 1997). To develop flood risk model, it involves two steps: hazard assessment and vulnerability assessment. Hazard assessment deals with the characteristics of the event itself in terms of magnitude and frequency. While vulnerability assessment takes into account the effects of the event on the population, considering social, economic, and environmental aspects and impacts on transportation infrastructure (Ilorme, 2007). To determine flood risk of the study area, the following risk equation (Shook, 1997) is applied.

$$\text{Risk} = (\text{Elements at risk}) * (\text{Hazard} * \text{Vulnerability}) \dots \dots \dots (1)$$

✓ *Elements at risk - refers to elements which are at risk*

- ✓ Hazard - refers to the probability of happening flood in an area
- ✓ Vulnerability - refers to the degree of exposure with max. value

The flood hazard analysis is computed using multi criteria evaluation (MCE) by taking into account the different parameters which are listed in the diagram above. MCE is a procedure which needs several criteria to be evaluated to meet a specific objective (Malczewski, 1999).

GIS integrated with Multi-criteria Decision Analysis (MCDA) provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors causing flooding (Yahaya, 2008). So, finally flood hazard map was produced which was used as one factor input for modeling flood risk as stated in the above equation (1). Then, finally weighted overlay technique was applied in ArcGIS Model Builder, to generate flood risk map by taking into account elements at risk layer which are listed in the below diagram two. However, since all the variables didn't have equal value in determining both flood hazard and flood risk, determining variables weighted influence were done before making modeling. And this was done by asking experts in the area of discipline based on their experience and literature reviews so that variables value impact was easily determined. And finally Liner Combination Formula was applied using Saaty (2008) formula which is stated below.

$$W_j = (n-r_j + 1) / \sum (n-r_k + 1) \dots \dots \dots (2)$$

Where, w_j is normalized weight for the j^{th} criterion
 n is the number of criterion under consideration ($k=1,2,3 \dots \dots \dots n$)
 r_k is the ranking position of the criterion

Each of these criteria are weighted by $(n-r_j+1)$ and normalized by the sum of all weights which is $\sum(n-r_k+1)$. Finally, percentage of influence of variables is determined by multiplying parameters normalized weighted value (PNWV) by hundred percent and is abbreviated as $PNWV * 100\%$. As shown in figure 2, flood hazard, LULC, building density, road density and population density were used to develop the flood risk model of the study area.

To develop a model of flood hazard mapping, identification and ranking of causative factors is essential. In the present case, the basic elements of flood hazard were identified through literature review and field observation. Some of the variables considered important such as elements of flood hazard and risk map with their weighted values; and percentage of influence of variables for both flood hazard and risk are given in table 2.

Table 2. Flood hazard and risk variables.

<i>Elements flood hazard</i>	<i>Straight Rank</i>	<i>Weight</i>	<i>Normalized weighted</i>	<i>Influence (%)</i>
Slope	1	7	0.25	25
Elevation	3	5	0.214	21.4
Flow accumulation	4	4	0.1785	17.85
LULC	2	6	0.1428	14.28
Flow direction	5	3	0.1071	10.71
Annual precipitation	6	2	0.0714	7.14
Water table		1	0.03571	3.57
Sum	28	28	1	100%
<i>Elements of Flood Risk</i>	<i>Straight Rank</i>	<i>Weight</i>	<i>Normalized Weighted</i>	<i>Influence %</i>
Population density	1	5	0.333	33
LULC	3	3	0.2	20
Built up density	4	2	0.133	13.3
Road up density	5	1	0.0667	6.67
Flood hazard map	2	4	0.267	26.7
Sum	15	15	1	100%

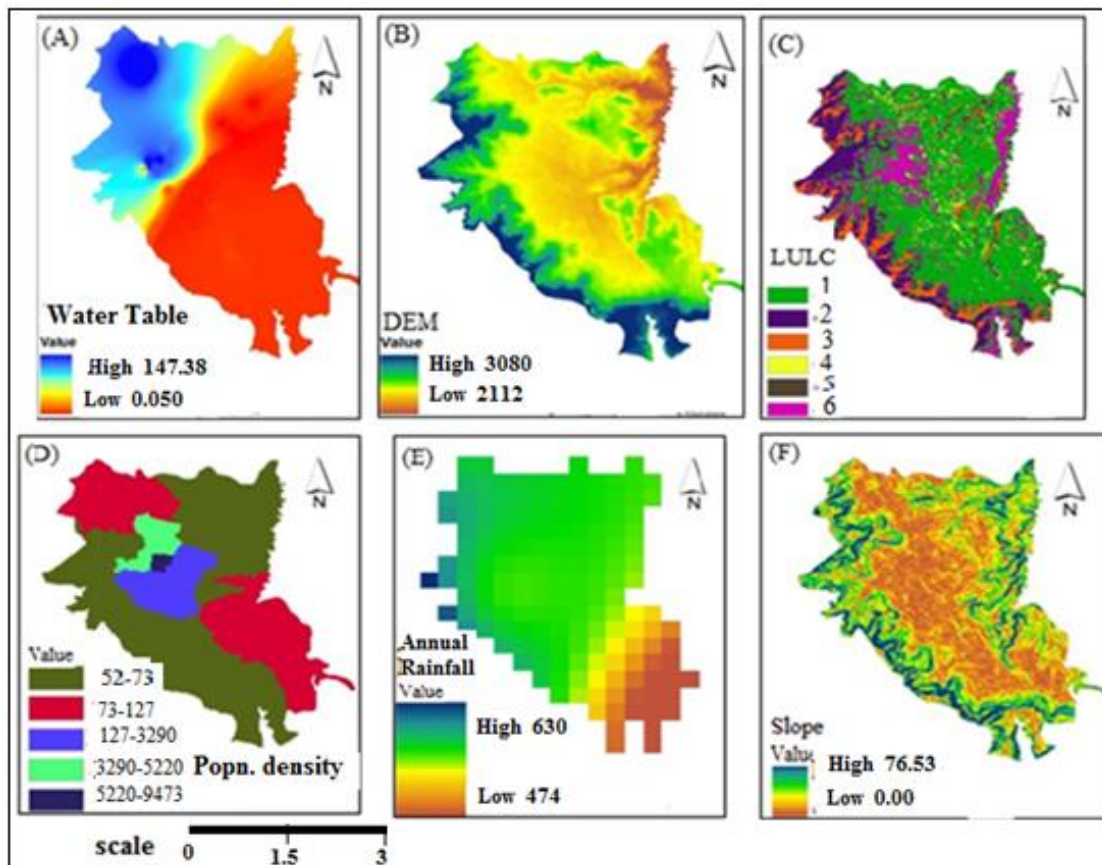


Figure 2. Baseline maps of the study area, A) water table (m), B) elevation map (m), C) land use and land cover, D) population density, E) annual rainfall (mm), and F) slope (%) (**Note:** Numbers 1 to 6, in “C”, land use land cover (LULC) map, represent cultivated land, bush land, shrub land, plantation, grass land and Built up area respectively).

3. RESULTS AND DISCUSSION

3.1. Flood Hazard Mapping

GIS is an important tool for delineating flood hazard and flood risk vulnerability mapping by taking into account the determinant factors (Navarro, 1994; Nguyen and Vogel, 2007). Flood hazard in a given area depends on physical and socio-economic factors. To delineate flood hazard areas, thematic layers such as topographic factors and environmental data are developed and weightage for different variables is determined carefully using methods suggested by different workers (Sidayao et al., 2014; Ismail1 and Saanyo, 2013). In the present case, seven important factors were considered while developing the flood hazard map (Fig 3). The flood hazard map has five field class values namely very low, low, medium, high and very high. The very high and high flood hazard areas are represented by red and yellow colors respectively. The areas are mostly covered by built up and cultivated lands.

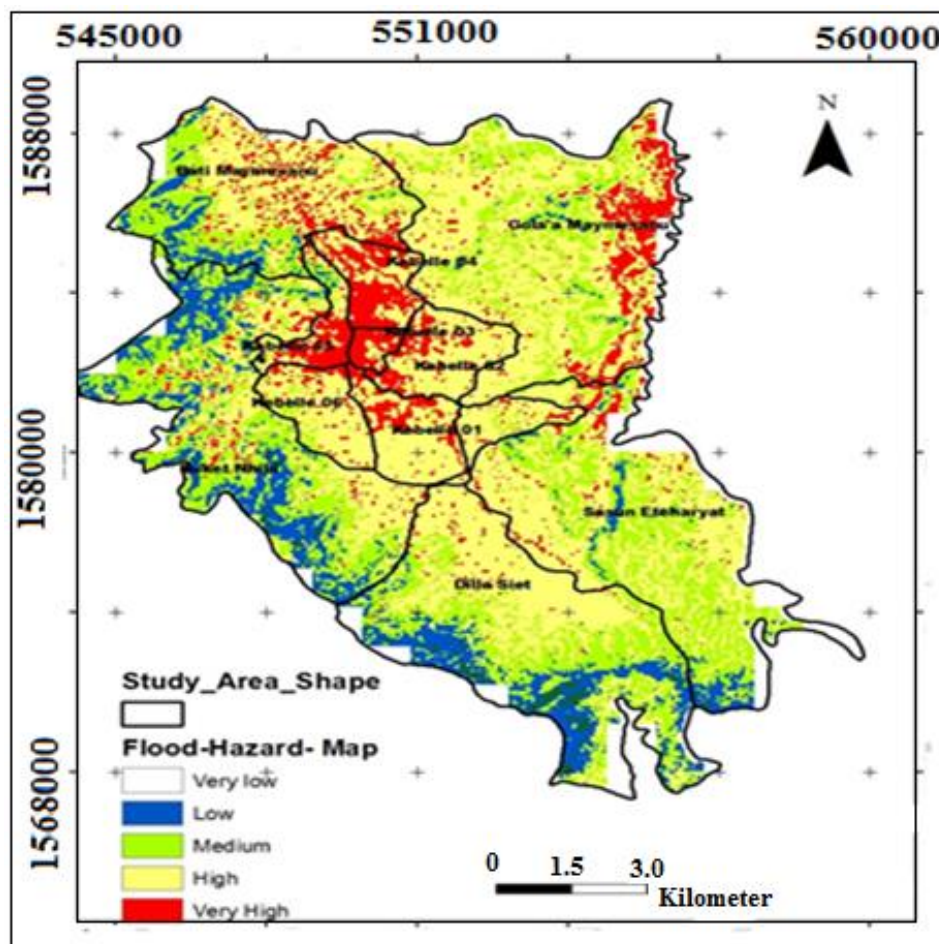


Figure 3. Flood hazard map of the study area.

Kebelle 03, 04, 05 of Adigrat town, and some parts of Bati Maymesanu and Gola Genahiti are found in the most sensitive to flood hazard zone. Here, the drainage outlet passes through these kebeles and other out let is also found in the in Bati Maymesanu and Gola Genahiti where, there is high flow accumulation. Drainage network map indicates presence of four main streams (Figs 3 and 4). One stream located at Bati Maymesanu in northwest, and others in the center next to Bati Maymesanu, at Kanadro and Buket and Dibla Siet. Except that of Bati Maymesanu, all other streams together form Huga drainage and flow towards east forming an outlet for flood water.

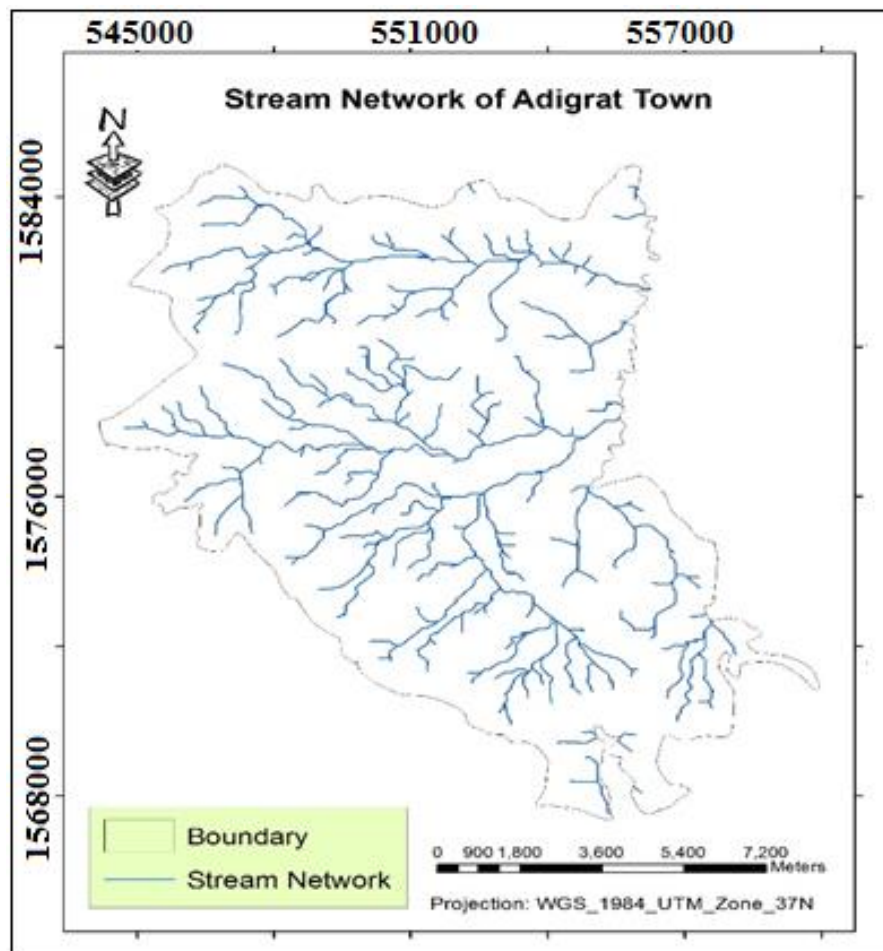


Figure 4. Stream network map of the study area.

Flash flood is the principal source of flooding in the area which is caused by runoff of rain from the nearby mountains. Generally despite flood is a natural disaster, human activities in many circumstances change flood behavior due to some activities in the catchment such as land clearing for agriculture (Kebede, 2012). Most of the flood hazard areas are located in the central and eastern

parts of the study area because of Huga drainage which passes through the center of the town and as an outlet towards east. Parts of kebeles 01, 02, and 06 are also found within the high flood hazard as shown in the figures 5 and 6. Even though, the main drainage Huga lies in Buket, Nhibi kebeles, the areas found along it are less exposed to flood vulnerability. This is because the drainage here is deep and wide water flowing area than the Kendaro drainage which crosses kebeles 04, 03 and 05. The areas where the drainage channel is very shallow, the runoff overflows to the nearby resident areas. As the map demonstrated (Figs 5 and 6), major part of the town covered by built up area is exposed to very high and high magnitude of flood hazards. Cultivated lands also lie within the high level flood hazards. In contrast, the medium and low flood hazard areas are found in Dibla Siet, Nhibi Buket, Sashun Eteharyat and small part of Bati Maymesanu. These areas in general are village areas, steep and high in elevation and covered with shrubs. The areas lying in the western and southeastern part of the study area are least flood exposed due to higher elevation and characterized by the presence of continuous chain of mountains (Fig 5).

However, the areas found with high and very high flood hazard are characterized by gradient slope, built up land use type, less altitude and high flow accumulation. Topography affects the flood severity, flow size and direction (Saini and Kaushik, 2012). Normally, areas with lower elevation are affected by flood more than the lands with higher elevation. In addition, water remains in the lower area for a long period of time (Fernández and Lutz, 2010; Saini and Kaushik, 2012). Runoff will remain in flat area for longer period of time and increases the damages. Flood risk mapping is a vital component for appropriate land use planning in flood-prone areas and it can be used by administrators and planners to identify areas at risk and prioritize their mitigation and response efforts (Emmanuel et al., 2015).

Areas with sharper slopes cause more rapid flow than the steep areas (Smyth and Royle, 2000; Fernández and Lutz, 2010; Kia et al., 2012; Saini and Kaushik, 2012). Present study suggests that many part of the town are vulnerable to flooding from medium to very high magnitude of flood hazard. Hence, the output map can be used as an effective tool in planning for future development of the town and also for identification of the areas where and how the infrastructure services have to be constructed. Due to the destructive flood impact and urbanization, mapping flood hazard is crucial for mitigation and disaster planning (Keewook et al., 2014; Stefanidis and Stathis, 2013).

3.2. Flood Risk Mapping

Flood risk is the combination of flood hazards and vulnerabilities at a particular location. So, it needs systematic assessment, collection and analysis of variables. GIS has emerged as an essential tool in flood mapping and analysis because it enables preparation of maps inundated areas (Bera and Bandhopadhyay, 2012). Flood risk map for the study area is developed based on LULC, flood hazard and population density. However, like the flood hazard map model, the variables weighted impacts were estimated based on the literature. Accordingly, population density, flood hazard and LULC were found with a score value of 40%, 35% and 25% respectively. As shown in the figure 6, the most risk vulnerable areas are found in the center of the town. In fact, these areas are found within the urban land cover and have more population density. Among the LULC, built up and cultivated lands lie with the most risk areas.

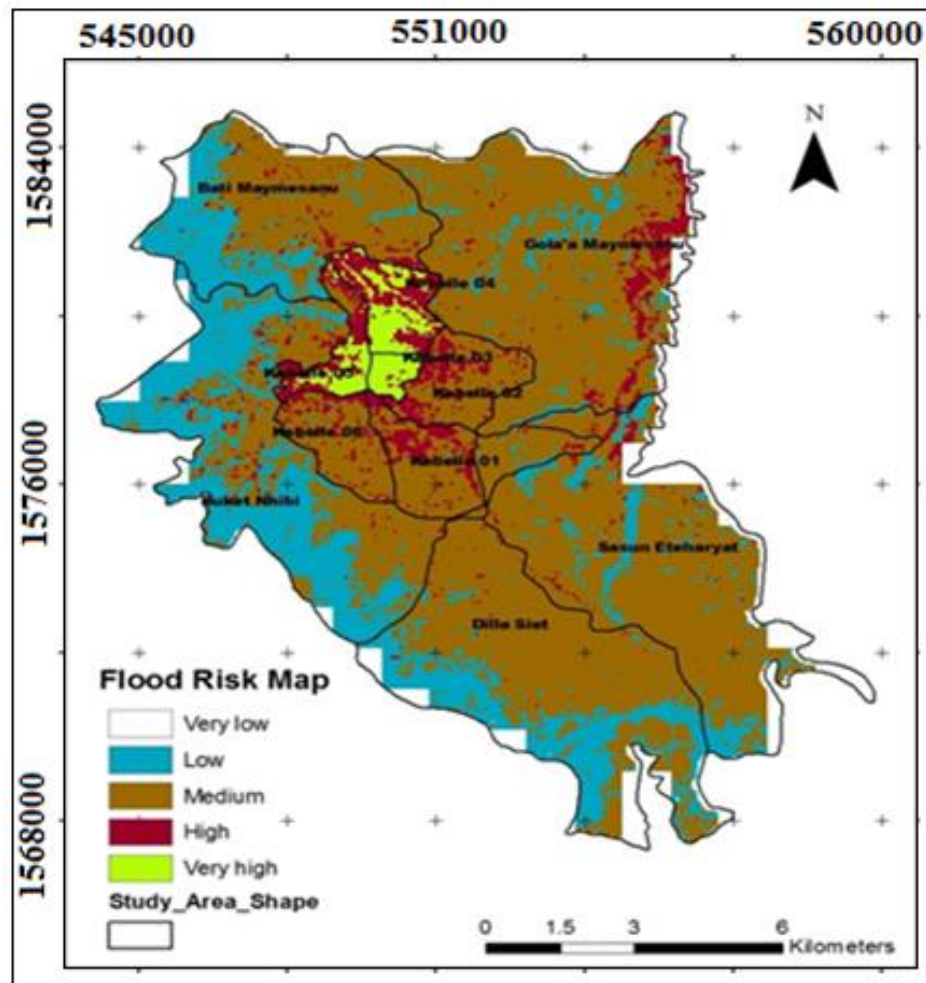


Figure 5. Flood risk map of the study area.

Flood risk map (Fig 5) shows the actual socioeconomic damage that could happen in a given community or society. In the present case, the areas with high population density and built up area are more highly exposed to the possible damages. Flood risk map shows probability of occurrence and degree of potential consequences. There are various variables and indicators associate with flood risk (Ologunorisa and Abawua, 2005; Shimokawa and Takeuchi, 2006). In other words, the least flood risk vulnerable areas lie in the western, southwestern and some parts of northeastern part of the study area compared to the surrounding areas which lie in the least flood hazard areas. These least affected areas are characterized by less population density, and covered by shrubs and bushes. Thus suggesting that the flood risk vulnerability further increases with increasing population density and urban land use cover in which the economic goods like roads and buildings are concentrated. The flood risk vulnerability has been particularly severe among the low income groups of the town who generally settle in fragile and flood prone areas along the river banks (Zuluboy, 2011).

Flood can affect directly or indirectly the environmental, social and economic aspects of society (Levy and Hall, 2005). More people will be put in jeopardy of flooding due to increasing levels of urbanization (Alderman et al., 2012). In countries like Ethiopia where urbanization is taking place without proper land use planning are at more risk. Figure 5 indicates that most of the risk areas are located in Kebele 03, 04 and 05 and were found to be the most vulnerable flood hazard areas. Moreover, these areas are characterized by high population density and high infrastructure development. Of course, there is one drainage (Kendaro drainage) crossing these kebeles with a very shallow area flow. Similarly, the reports of the municipality, personal observation and discussion with head municipality indicated these areas reported the most victims of flooding in addition to property loss (Zuluboy, 2011). In areas with higher population density, more people and infrastructure are likely to be affected by flooding (Chang and Franczyk, 2008; Paquette and Lowry, 2012; Saini and Kaushik, 2012).

The risk of flooding increases due to the change in land use type and intensive constructions in built up areas (Yeganeh and Sabri, 2014). In general, urban flood risk map can help urban planners and decision makers in evaluating the effectiveness of drainage infrastructure and development efforts. It requires the knowledge about the elements of risk in respective parts of municipality to be effective tool for urban planning and hazard management.

The result of the risk map as shown above, the most risky areas are found in kebeles 03, 04 and 05 represented by red and yellow colors. Both flood hazard and flood risk vulnerability especially are very important to urban planner and other concerned organization. Hence, urban flood susceptibility maps can be used as appropriate tools for urban regional planning and growth management (Fernández and Lutz, 2010). Furthermore, having knowledge about the risk areas is important as urban flood management is one of the major themes in addressing urban issues which could help urban planning and policy makers (Esmail et al., 2013).

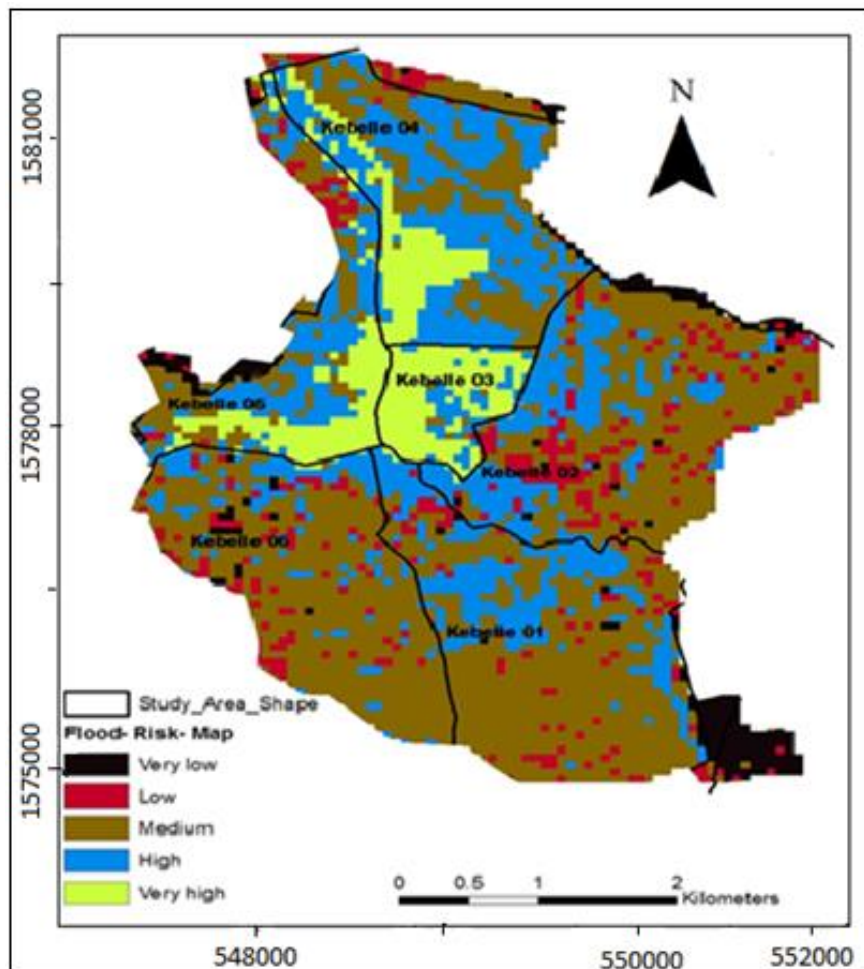


Figure 6. Flood risk map of Adigrat Town.

Of course, these areas also the most victims of flood hazard and characterized by very high populations. In contrast, the less flooded risky areas are found in kebeles 01, 02 and 06 which are characterized by less population density. Generally, the high and very high risk flood areas are concentrated where there is high road and building density, high population density and flood

hazard vulnerability and urban land cover land use. Accordingly, many parts of the town are highly exposed to the flood risks. Figure 6 shows the flood risk map of town only unlike of the figure 6, as the road density and building density data were not easily accessed. So, the road density and building density were used in combination with flood hazard, population density and LULC to detect the flood risk areas of the town only as shown figure 6. Thus, the concerned stakeholders have to take series of measures to cope up with the possible damages that can happen. Developing flood risk susceptibility map can be used to understand different levels of risk and to find out effective variables for sustainable development. One of the possible solutions could be adopting disaster preparedness and early warning system.

3.3. Model Validation

In order to validate the generated flood susceptibility map, historical records related to the previous floods are compared with the maps (Yeganeh and Sabri, 2014). In the present case, the model validation is done against population density, GCP samples and LULC in addition to the information obtained from municipality records. The information obtained compare well with the developed model. The information, had it been obtained from the aerial photograph showing the flood events, would have been appropriate to validate the model. Since, such type of data accessing is expensive, data related to GCP, LULC, population density, and flood hazard map are used to check accuracy.

4. CONCLUSION

Recent incipient technologies such as GPS, GIS, Remote Sensing and photogrammetric are certainly important tools for evaluation and monitoring flood hazard phenomena. Knowing the trend and status of such events will the help of these technologies will play a significant role in reducing the likely deaths and property damages through dissemination of information to the stakeholders. The results indicate that Adigrat town and surrounding areas are highly exposed for both flood hazard and flood risk. Flood hazard is most severe in Adigrat town particularly in the areas that are covered by urban land built up, high flow accumulation and with flat topography. Hence, these areas are highly subjected to flood hazards in contrast to the flood risk areas that are concentrated only in the urban areas in kebeles 04, 05 and 03. Flood risk is the probability of causing likely damages on people's livelihood and property. The areas described under this category have high population, vulnerable to flood hazard and covered by built up areas and road

networks. Flash flood is the type of flood common in the study area which is caused by high runoff from the surrounding mountains. Hence, it is advisable to rehabilitate and undertake plantation to minimize the problem. Further, the existing drainage network of the town is very poor and it needs to be strengthened to sustain high runoff. Flood hazard map can be used by the town municipality and policy maker for the purpose of flood disaster preparedness and early warning system. Therefore, damages that can lead to loss of human being and property could be highly reduced. Finally, this research could be used as panacea to undertake further similar comprehensive and detail research studies to explicitly define and address the problem.

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