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Flood Hazard Assessment Using Multi-criteria Evaluation Approach in Dembiya Woreda, Amhara Region, Ethiopia

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Abstract

The current climate change scenario and various studies in the past related to climate change have shown that flood impact has increased vulnerability of people in the flood plains. The aim of this study was to examine the spatial distribution of flood hazard severity in Dembiya Woreda in Amhara Region using GIS and remote sensing techniques. The study employed the multi criteria evaluation (MCE) based flood hazard severity to examine the extent and magnitude of flood hazard severity in the study area. The flood hazard mapping was undertaken using GIS and remote sensing technique to show spatial distribution of flood hazard severity hotspots in the study woreda. The flood hazard map obtained from the overlay analysis of flood causative factors in the study area soundly agrees to each other. The flood hazard severity map indicated that about 40777ha (32.8%) and 81350ha (65.4%) of land were subjected to high and moderate flood hazard severity, respectively. These could have a tremendous impact on crop production in areas that are frequently being hit by flood hazards. Therefore, multi-criteria based flood hazard assessment is vital to show spatial distributions of different severity levels of flood hazard so that the required mitigation and adaptation strategies can be implemented.

Keywords: *MCE, flood hazard severity, hazards mapping, GIS, Remote sensing, mitigation and adaptation strategies*

Introduction

Background of the Study

Flooding is defined as the spilling over of the normal limits for example river, lake, sea, stream or accumulation of water as a result of heavy precipitation through lack or exceeding of the discharge capacity of drains, or snow melt, dams or dikes break affecting areas which are normally not submerged (Douben and Ratnayake, 2005). Flood is still an occurrence in this age and cannot be eliminated, as it is a natural phenomenon. Floods are natural phenomena that has become a cause for serious concern when they exceed the coping capacities of affected communities, damaging lives and properties (Abhas et al., 2011). Floods are the most common and widespread of all weather-related natural disasters that cause over 20,000 lives and adversely affect around 75 million of people worldwide every year. The relation lies in the wide spread geographical distributions of river flood plains and low-lying coasts, together with their long-standing attractions for human settlements (Smith, 2001).

Climate change may increase the frequency, magnitude and the seasonality of extreme events such as flood, which means that concurrent flood hazard of importance to urban flood risk management, may occur more frequently in the future (Danumah et al., 2016). In Africa, the situation is very likely to worsen as the intergovernmental panel on climate

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change (IPCC) has projected higher frequencies and intensities of floods and droughts for the continent as a consequence of climate change (Bernstein et al., 2008). Floods that are resulting from extreme hydrological and meteorological events take place in unexpected magnitudes and frequencies cause loss of lives, infrastructure and livelihoods.

The need to study the cause and effect of flooding has begun since flooding has become a problem to society as people and their valuables are affected (Alam, 2008). Water-related extremes, such as floods and storms, that account for the greatest share of natural disasters' have inflicted economic damage and death toll at the global level in both developed and developing countries (Jonkman and Kelman, 2005; Osti et al, 2008; UNISDRS, 2009). However, the magnitude of flood hazard risk in developing countries is more severe when compared to the developed countries. This is particularly due to the resilience capacity due to Between 2000 and 2008 East Africa has experienced many episodes of flooding (CRED, 2008). Almost all of these flood episodes have significantly affected large parts of Ethiopia (FDPPA, 2007).

The Third World Water Forum indicated that in recent years, floods have become more frequent and of increasing severity resulting in loss of life, injury, homelessness, damage to infrastructure and environment (Guha-Sapir et al., 2012). Globally, about 200 million people were affected by floods in the 1990s with about US$ 63 billion loss in terms of market value of damaged properties. Crop production is affected by increased intensity and frequency of extreme weather events such as drought and floods (Bernstein et al., 2008). Its negative impact is much higher in areas where rain-fed agriculture dominates. For instance, frequent droughts not only reduce water supplies but also increase the amount of water needed for evapotranspiration by plants.

Flood hazards are natural phenomena, but damage and losses from floods are the consequences of human action. Flooding of property and land again can be a result of unplanned growth and development in floodplains, or from the breach of a dam or the overtopping of an embankment that fails to protect planned developments (Jeyaseelan, 2003). The floods have removed a significant amount of topsoil large area of farm land. Some parts of the landscape have lost significant amounts of topsoil both from the sheet erosion as rain falls on wet soils. However, the removal of topsoil is always a loss to agricultural productivity as it is the part of the soil horizon with higher level of organic matter and nutrients and generally better structure (USDA, 1993).

Floods and flash floods cause loss of life and property damage in Africa (Danumah et al., 2016). The most immediate impact of floods in Africa is on infrastructure, social and the undermining of crop production (Kotir, 2011). In Africa, crop yields are affected and it means that household and national level agricultural income derived from crop sales have declined due to the floods hazards. The impact of flood hazard on food security is more serious particularly on those whose livelihoods are directly relying on agriculture for their income or direct food supplies (Guha-Sapir et al., 2012).

In Ethiopia context, the rainy season is concentrated in the three months between June and September when about 80% of the rains are received where the torrential down pours are common in most parts of the country (Daniel, 2007). Among most severe natural disasters during the last century in Ethiopia, flood and drought accounts for major proportion in terms of loss of life and associated damages to people and property (EM-DAT, 2010). Flooding in Ethiopia is mainly linked with heavy rainfall and the topography of the highland mountains and lowland plains with natural drainage systems formed by the principal river basins. In recent years, floods in Ethiopia have become more frequent and of increasing severity. In 2006, flood has resulted in a damage of 18,150 hectares of farmlands in different parts of Ethiopia. This resulted in a 20% reduction in crop production mainly as a result of water lodging on the farmlands (FDPPA, 2006). For instance, Awash River basin is one of the major rift valley basins, which has serious recurrent occurrences of flooding problem located in the downstream portion of the river. Over irrigation in the middle and lower course of the main river coupled with the topographic nature is attributed to flooding where about 200,000-250,000 ha is subject to flooding during high flows (Daniel, 2007).

Terrain characteristics of land and meteorological properties are the main natural factors for causing flood disaster (Elsheikh et al., 2015). The demands of the growing population pressure in rural areas and urbanization lead to severe land use change, which aggravated flooding (Danumah et al., 2016). Land degradation, deforestation of catchment areas, poor land use planning and control of flood plain development, and inadequate drainage are the major factors aggravating flood hazard vulnerability (Elsheikh et al., 2015). Therefore, flood risk mapping using GIS and multicriteria methods could have been an essential approach for identifying flood hazard severity hotspots, monitoring and spatial multicriteria decision analysis.

Statement of the Problem

Flood is probably the most devastating, widespread and frequent natural hazard in the world. According to UNEP (2002), the major environmental disasters in Africa are recurrent droughts and floods. Their socio-economic and ecological impacts are devastating to African countries due to lack of real time forecasting technology or resources for post-disaster rehabilitation. This problem is more acute in highland areas like Ethiopia, which are under strong environmental degradation due to population pressure. Extensive flooding due to heavy rains in Ethiopia has affected thousands of people. Rainfall has caused several rivers and streams in Ethiopia to burst their banks and overflow, resulting in extensive flooding in many areas and subsequent loss of life (WFP, 2014). Flooding, as a natural phenomenon, has been occurred in many parts of Ethiopia. FDPPA (2007) reported that more than 500,000 people were vulnerable and about 200,000 people had been affected with 639 deaths, thousands of live stocks were killed, 228 tons of harvested crops were washed away, 147 tons of export coffee beans were lost, and 42,229 hectares of crop land were inundated.

Dembia woreda is drained by two major rivers, namely Megech and Derma. It totally lays in Megech-Derma Watershed, which is part of the Lake Tana Basin. This Catchment encloses big flat to gently sloping plains located in the Northern and Northeastern side of Lake Tana. The study area is particularly found in the downstream part of the Megech and Derma catchment, which is known as one of the flood prone areas of the basin. The overflow of Megech and Derma Rivers and the backflow of Lake Tana have affected about 9200 people and displaced 4300 in Dembiya woreda during summer (Kebede, 2012).

Megech and Derma Rivers flood much of the plains in the study area. In 1998, Megech River changed its course and created a new course over the lower reaches of Lake Tana, flooding the small rural town called Robit and the villages around it. Parts of the new Megech river course do not have a well-defined channel. It flows in many different routes in the Dembiya plain. This aggravates the flooding problem. Following the severe flooding experienced in 2006, areas without dikes are still affected by the flood. In the southern part of Dembiya, eleven rural kebeles, with thousand people, are affected by flooding (Yirga, 2007).

In the year 2016, in Tana Woina kebele of Dembiya woreda 575 households lost about 258.5 hectare of cultivated land with various crops caused by the backflow of Lake Tana and overflow of its major tributaries at times of heavy rainfall (DWEPPC, 2017). Consequently, in Seraba-dabelo kebele from a total of 2082 hectares, about 127 hectares of cultivated crop lands were affected. Similarly, from a total of 1564 hectares of lands, 61 hectares cultivated crop lands were affected by flood in Chenker-cherkose kebele (DWEPPC, 2017).

Sufficient studies investigating the impacts of flood hazard on crops and livelihoods which is common in Dembiya woreda were absent. Wubet (2007) reported the recurrent occurrences of flooding and map flood hazard severity hotspot areas in Fogera woreda, but absent in the study area. There were also scarce empirical evidences that show about the existing impacts of flood on crop production in flood prone areas of the study area. On the other hand, frequent flooding is still occurring where many rural households at risk of loss of life and property in the study area. Thus, this study will have its own contribution in filling gaps in the literature in relation to flood hazard severity mapping so that possible mitigation strategies can be recommended and farmers' vulnerability to flood hazard risk will be minimized. This research can provide flood hazard severity hot spots where the required flood control structures can be implemented. Therefore, this study aimed at examining spatial distribution of the flood hazard severity mapping of Dembiya Woreda using MCE approach.

Materials and Methods

Description of the Study Area

The study was conducted on Dembiya woreda located in North Gondar zone of Amhara Region. The woreda shares borders with Gondar town and Lay Armachiho in the North, Gondar Zuria in the east, Chilga and Takusa woreda in the west and part of Lake Tana in the south. Dembiya woreda has 45 kebeles of which five are urban centers (DWARDO, 2017). The area is located between 12° 11' 33" and 12° 37' 16" N latitude and 37° 03' 21" and 37° 29 07" E Longitude (figure 1).

Topography

Topographically the study area lies in the vicinity of Lake Tana with altitude ranging between 1563 – 2469 meters above sea level (a.s.l). The largest area is found in southern and south central portions of the study area with an altitude range of 1760-1859 meters a.s.l. Areas with the altitude ranges from 1969 – 2469 comprise the northern and northwestern portions of the catchment while areas with altitude between 1860 – 1968 comprise the narrower portions and extends from east to west and to the southern portions of the study area. Generally, plains dominate much of Dembiya, i.e., 87.8%, while the mountain slopes and valley bottoms account for 12.2% (DWARDO, 2017).

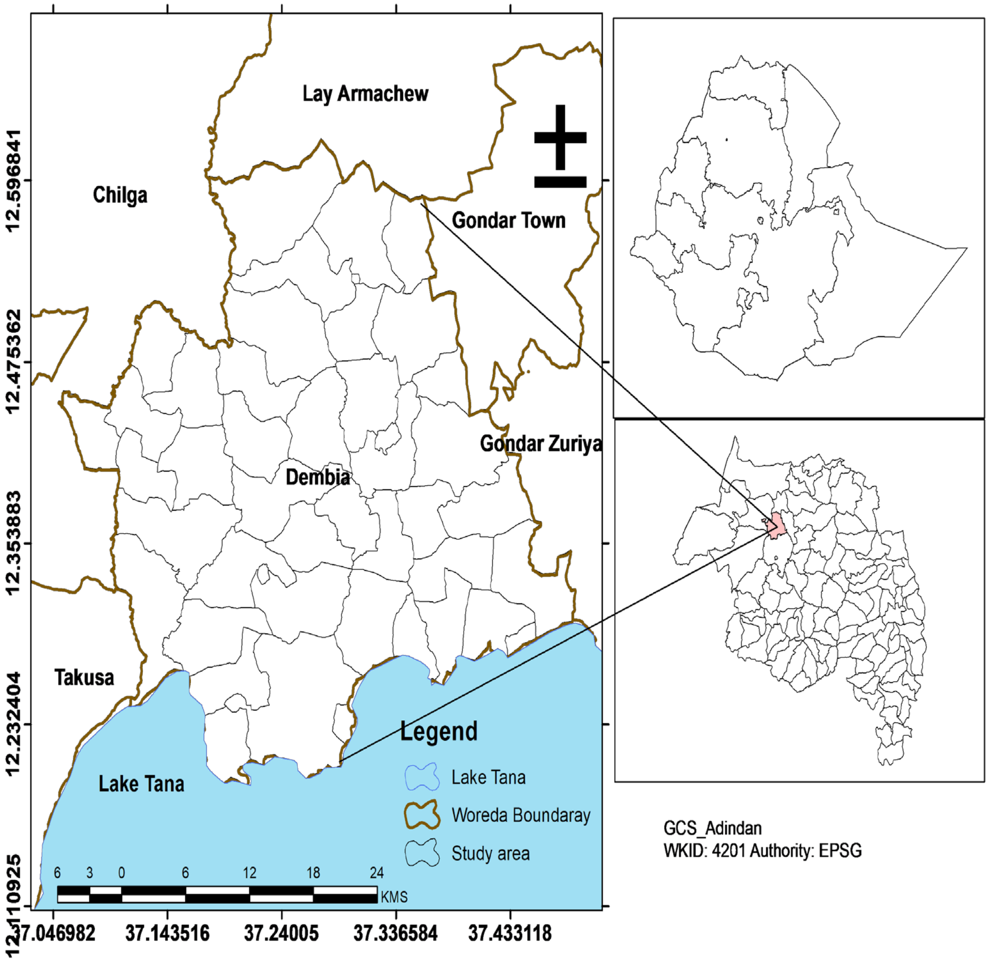
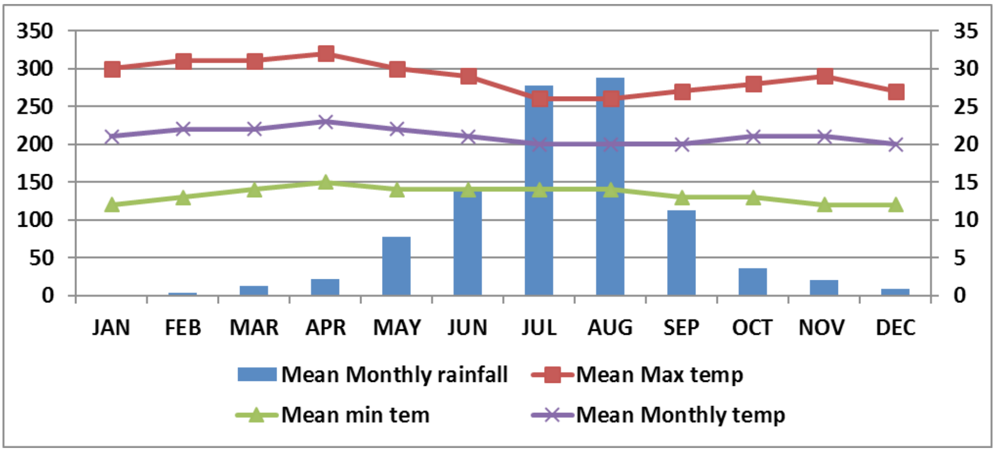


Figure 1: *Location Map of the study area (CSA, 2007)*

Climate

Figure 3 shows that the mean monthly rainfall and temperature values of Gorgora, Chuahit, Koladiba, Maksegnit and Tseda meteorological stations found in and around the study area. These are the closest weather stations that can represent the study area. The type of climate in Dembiya plains is traditionally Woinadega (sub-tropical) with average total annual rainfall amounting to 1000 mm (Hurni, 1998). The available rainfall records for the period between 2009 and 2016 records have shown that the pattern is predominantly unimodal. The main rainy season extends from early June to late September, which accounts for about 90% of the total annual rainfall (Figure 2). The highest mean monthly temperature (32°C) is recorded in April whereas the minimum (12 °C) in December with a mean monthly range of 6 °C.



Note: *It is based on the records of Kolladiba station (2009-2016) from National Meteorological Service Agency, Bahir Dar Branch office, Ethiopia*

Figure 2: *Mean monthly rainfall and mean monthly temperature records of study area*

Soil

Major soil types in the study area include Eutric Regosols,Vertisols, Solonchalk, and Calcic-xerosols. These soil types in Dembiya Woreda exhibit a general relationship with altitude and slopes. Vertisols are generally dominating the Woreda particularly the flat plains, valley bottoms and river terraces. According to FAO (1997), the three major soil types comprised about 89% of the study area that is Orthic solonchaks (10.7%) Eutric regosols (46.6%), and Chromic vertisols (32.5%). The woreda is also drained by two perennial streams, namely Megech and Derma River used for irrigation purpose in the downstream.

Methodology

Data sources and method of Flood hazard severity mapping

GIS and remote sensing approaches were employed to identify the hotspot areas of flooding hazard. The nature of land use/land cover patterns, nature of soil, topography, rainfall and drainage density; which are the major flood causative factors affecting the magnitude and duration of the hazard, were developed and weighted (Wubet, 2007). However, in this study, the effect of land use and drainage density on flood magnitude is excluded due to the lack of input data for the study area. Thus, the parameters in the form of thematic map layers considered in the analysis were soil type, topography (elevation and slope), and mean annual rainfall. Topographic factor was obtained from Shuttle Radar Topographic Mission (SRTM) image with ground resolution of (30m×30m) to generate elevation and slope map using spatial analyst tool of ArcGIS 10.1.

Soil data layer was generated from soil map of Ethiopia (1:1,100,000) for the study area clipped using spatial analyst tool of ArcGIS 10.1 (FAO, 1997). Finally, rainfall data layer was interpolated from mean annual rainfall values of Gorgora, Chuahit, Koladiba, Maksegnit and Tseda meteorological stations using spatial interpolation techniques of ArcGIS 10.1. The flood hazard factor rating values for each layer were assigned based on Woubet (2007) and FAO (2006) flood hazard ratings (Table 1). Finally, these data layers were arranged in raster formats for weighted overlay analysis where the resultant flood hazard map representing the study area has been produced in multi-criteria evaluation technique (MCE) as shown in Figure 5.

Table 1: Scaled and weighted flood hazard inducing factors modified after (Woubet, 2007)

Factors	Weight	Sub-Factors	Scale (Hazard)
1.Slope (percent)	37%	0 – 9% 0.91 – 6.4% 6.5 – 13% 14 – 23% 24 – 41%	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)
2.Soil (based on drainage capacity)	31%	Chromic Vertisols Eutric Regosols Calcic Fluvisols; Orthic Solonchaks Calcic Cambisols; Leptosols; Calcic Xerosolsand CalcaricFluvisols	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)
3.Elevation (meter)	10%	1563 – 1759 1760 – 1859 1860 – 1968 1969 – 2130 2131 – 2469	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)
4. Mean Monthly Rainfall (mm)	22%	1051 – 1119 1006 – 1050 957.4 – 1005 906.3 – 957.3 842.0 – 906.2	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low

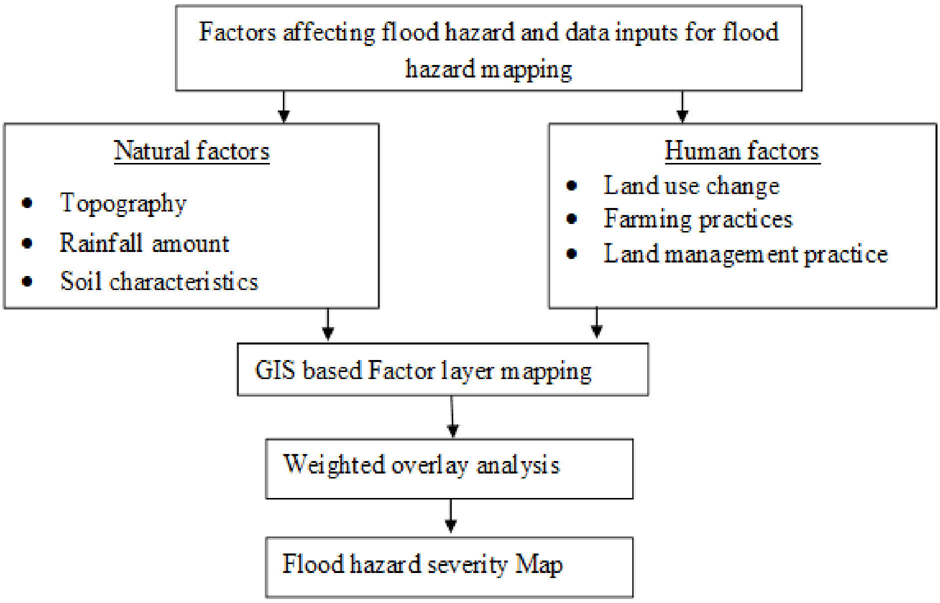


Figure 5: Methodological flow of flood hazard potential mapping in the study area

Results and Discussion

Flood hazard factor mapping

Flood causative factors particularly in Dembiya Woreda were identified from field survey and literature. Accordingly, standardized values for the relative importance of slope steepness, soil type, elevation, and rainfall on flood hazard potential were considered in the reclassification process.

Slope Factor

Slope has a great influence on flood hazard. The flatter the slope, the higher is the probability of the area to be flooded. Slope feature class was further converted to raster and the raster layer was further reclassified in five sub groups using standard classification schemes namely Quantiles. This classification scheme divides the range of attribute values into equal-sized sub ranges, allowing one to specify the number of intervals (Woubet, 2007). Finally, the slope was reclassified into continuous scale in the order of flood hazard rating. The slope gradient map of the study area were 0 – 9%, 0.91 – 6.4%, 6.5 – 13%, 14 – 23%, 24 – 41%, and it is reclassified into very high, high, moderate, low, and very low flood hazard severity ratings, respectively (Figure 6 a and b). Slope steepness has the dominance of the other causative factors of flood hazard severity in the study area because it has nearly 47% of weight.

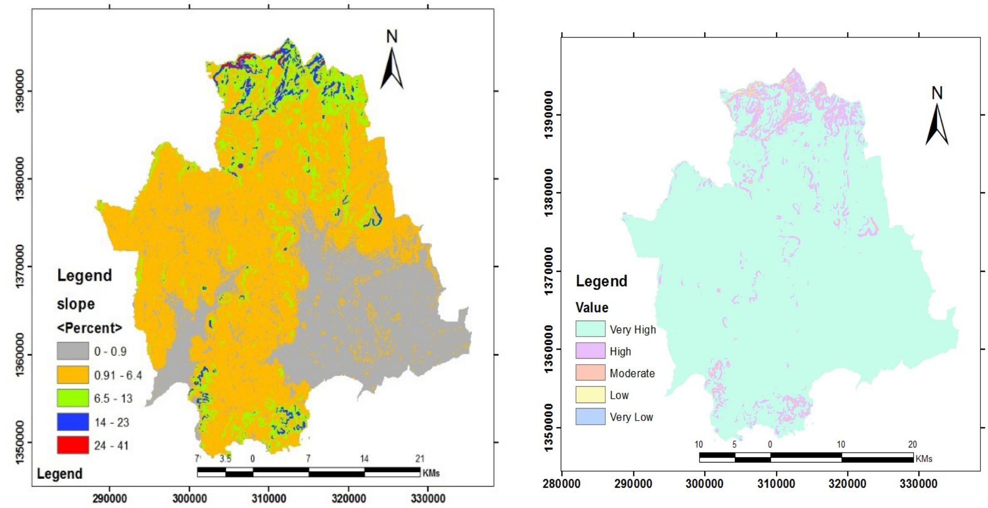


Figure 6: Slope gradient map of the study area (a) and reclassified slope factor map (b)

Soil factor

Soil type is a very important factor in soil drainage, which refers to the rate and extent of water movement in the soil, including movement across the surface as well as downward through the soil. Other factors include texture, structure, and physical condition of surface and subsoil layers. These soil types are converted to raster format and finally reclassified based on their water infiltration capacity. The vertisols, commonly known as black cotton soils and locally termed walka, are dominantly clayey and generally poorly drained with relatively slow infiltration and permeability. When dry, they crack deeply but when wet they swell and become essentially impermeable. They have a very limited range of moisture conditions when cultivation is possible using traditional implements, and they are highly erodible. Vertisols and Eutric Regosols are the dominant soil types of the study area which accounted for the largest portion with poor infiltration capacity. Therefore, major soil types in the study area are reclassified into very low (0.24%), low (0.22%), moderate (2.5%), high (7.2%) and very high (32.5).

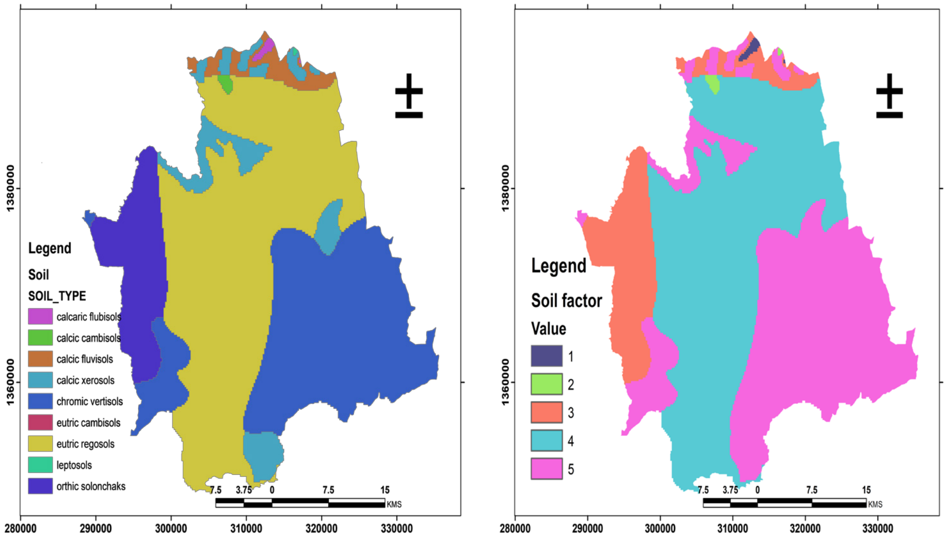


Figure 7: Soil map of the study area (a) and reclassified soil factor map (b).

Elevation factor

All the processes for the development of the elevation factor are as explained above in the slope factor development. The raster layer is then reclassified into a common scale according to their influence to flood hazard (Figure 8b). The study area has a diverse altitudinal difference which ranges from 1563 to 2469 meters above sea level. The lower the elevation, the higher will be its vulnerability to flooding. Therefore, the altitude ranging between 1563 and 1759 meters above sea level (very high) indicated that the northern parts of the woreda, 1760-1859 meters above sea level (high) located that the eastern and the southern parts, 1860-1968 meters above sea level (moderate) show that the central and western areas, 1969-2130 meters above sea level (low) located in the northern parts and 2131-2469 meters above sea level (very low) shows that the northern areas of the study area (Figure 8 a and b).

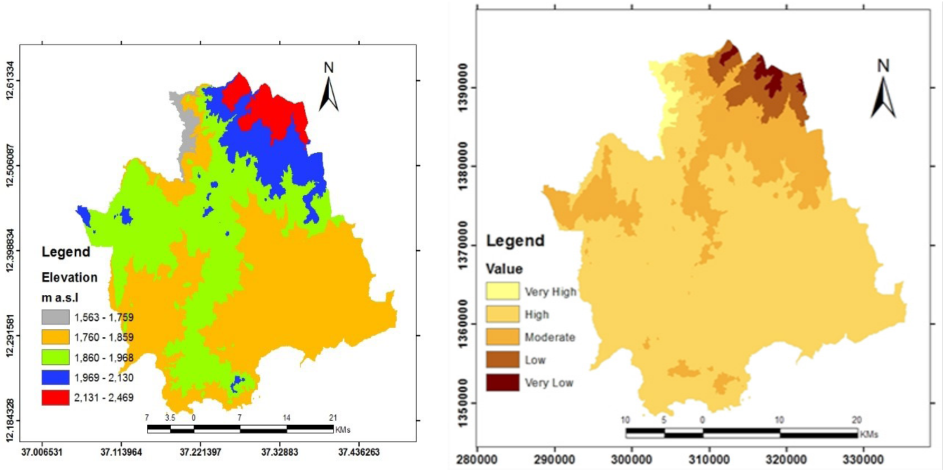


Figure 8: Elevation map of the study area (a) and reclassified elevation factor map (b)

Rainfall Factor

Flood hazard and risk assessment for rainfall factor requires an aerial rainfall intensity data. The rainfall data layer was interpolated from mean annual rainfall values of Gorgora, Chuahit, Koladiba, Maksegnit and Tseda meteorological stations. However, Ethiopian National Meteorological Service Agency (NMSA) only provides point rainfall data from five stations within and around the study area and the available rainfall records for the period between 2009 and 2016. In addition, even though rainfall intensity is the best data for flood hazard analysis, this type of data is not available for most of the meteorological stations in Ethiopia. The point data are converted to surface layer data using Kriging technique of interpolation that weights the surrounding measured mean annual rainfall values to derive a prediction for an unmeasured location. This rainfall surface was then reclassified into common scale in the assumption that the higher the rainfall amount, the higher the flood hazard (Figure 9 a and b).

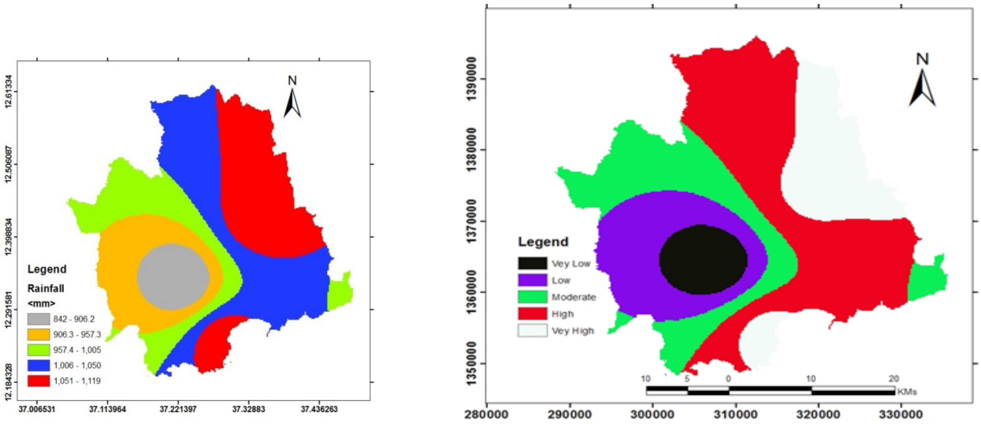


Figure 9. Interpolated rainfall map (a) and reclassified rainfall factor map (b)of the study area

Flood hazard severity analysis

Multi-criteria Evaluation technique was used to assess flood hazard analysis, which is a procedure which needs several criteria to be evaluated to meet a specific objective. The procedure was used in the study where continuous criteria (factors) were standardized to a common data model that was raster layer with a resolution of 30 m cell size, and then combined by means of a weighted overlay Analysis (Source). The result is a continuous mapping of flood hazard and the standardized raster layers were weighted using values showing the relative significances of each factor layers to the contribution of flood hazard and in the final flood hazard severity mapping. The flood hazard map (Figure 10 a and b) below shows that about 40777.4 ha (32.8%) and 81350.3 ha (65.4%) of the study area was subjected to high and moderate flood hazards severity classes, respectively. However, only, small portions of the study area are subjected to low to very low flood hazard severity classes, which accounted <2% of the study area.

Table 4.6: Flood Hazard Severity Level of the study area

Flood Hazard Severity Level	Area (ha)	%
High	40777.4	32.79
Moderate	81350.3	65.42
Low	2184.7	1.76
Very Low	31.4	0.03
Total	124343.7	100.0

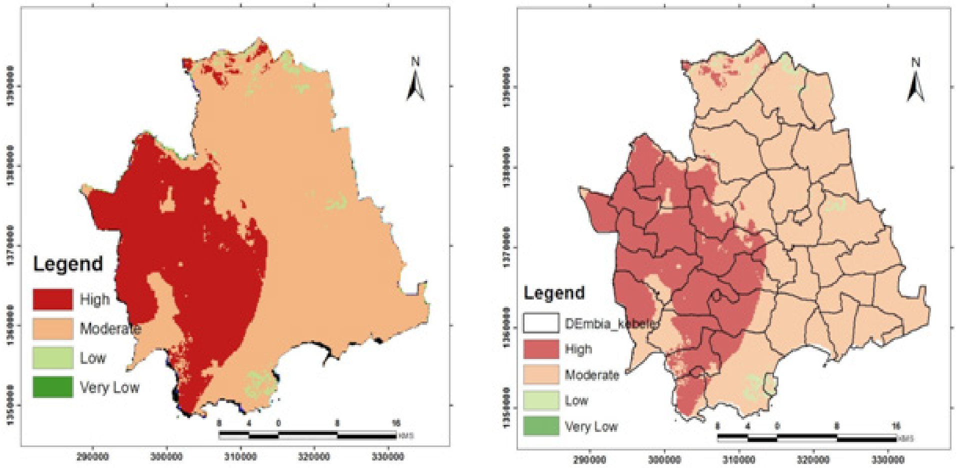


Figure 10. Flood hazard severity map (a) and map overlaid with kebele boundary (b) of the study area

The simple vector overlay analysis of flood hazard severity map and rural kebele map of the study area have shown that high, moderate, low, and very low flood hazard category (Figure 10 b). The Central part of Dembiya or the rural kebeles of Mange, Gurandi Wenbebiha, Darna Gawirna, Miskele Kirostos, Jenda Kobela, Semera Kekeza, Abawiram, Fenja Barcha, Wawicha Chegen and Chenkela Iyesus fall under very low flood hazard category. Fentaye Narichacha, Jeri Deberga, Hana Mariam, Chenkela-Abo, Guntir, Senbet Debir, Dirmara and, Chenker-cherkose (Northern and Western parts of Dembiya) fall low flood hazard category of rural kebeles. Sufeankara, Gebeba Chilo, Guramba Michale, Guramba Bata, Wekerako Dalko, Jarjar Abanov, Tana Woiyna, Deber Zuria, Achera and Seraba Dabelo (Southern and Eastern parts of Dembiya or located on the northern side of Lake Tana) show that moderate flood hazard category. In addition to this moderate flood hazard category areas lie in the downstream part of Megech and Derma rivers where they join to Lake Tana. Ghana Yohannes and Mequamia Mariam (Northern tip of Dembiya woreda) has a small patch of high flood hazard category of rural kebeles of Dembiya woreda.

According to Dembia Woreda Emergency Prevention and Preparedness Committee (DWEPPC) report, flooding regularly occurs in the plain areas of Arebiya-Abalebanos, Guramba-Bata, Guramba-Michale, Tana-Woina, Achera, Seraba-Dabelo, Deber-Zuria, Chenker-Cherkos, Jarjar Abanov, and Jangua-Kebrahel rural kebeles of (Southern and Eastern) DembiaWoreda. The Central part of Dembiya is located in a very low flood hazard category. In addition, investigations done by 2006 in the study area indicated that about nine rural kebeles with a total of about 69 thousand people were experienced severe flooding. The kebeles include Tana-Woina, Debrezuria, Arebeyadiba, Achera, Guramba-batachaniqua, Guramba-Michael, Seraba-dabiloand and Sufanqiragubaya. These are mostly found in the lower part of the Dirma, Megech and Shenzeli rivers (DWEPPC, 2011). According to Dembia Woreda Emergency Prevention and Preparedness Committee (DWEPPC) report, during and after the rainy season as the Megech, Dirma and Shenzeli Rivers began to overflows its banks and floods the study area.

Conclusion

The result of flood hazard severity analysis is consistent with Dembia woreda DWEPPC report. Thus, the eastern and southern parts of Dembiya have been highly affected with the recurrence occurrences of flood hazard. In addition, the observation result also showed that the plain areas of Dembiya woreda (Southern and Eastern parts) are more vulnerable to flood hazard areas compared with Central, Northern and Western parts the study area. To deal effectively with recurrent occurrences of floods and flood emergencies, an appropriate mechanism and capacity needs to be established in order to put in place them at national, regional and district level is vital.

Continuous awareness creation programs need to be provided for local community who are vulnerable to flooding hazards. Mechanisms to minimize the aggravating factors of and building community resilience on flood hazard through community-based flood control and other land management practices could be promoted. The responsible bodies of the Woreda as well as of the regional government should also incorporate flood hazard risk assessment studies in their development plans. Conducting integrated watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters through proper land use planning in the study area. Therefore, multi-criteria-based flood hazard assessment is vital to show spatial distributions of different severity levels of flood hazard so that the required mitigation and adaptation strategies can be implemented.

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