International Journal of Environmental Monitoring and Analysis
2023; 11(1): 1-14
http://www.sciencepublishinggroup.com/j/ijema
doi: 10.11648/j.ijema.20231101.11
ISSN: 2328-7659 (Print); ISSN: 2328-7667 (Online)

Flood Hazard and Risk Area Identification: A Case of Gelana River Watershed, Southern Ethiopia

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To cite this article:

Wendafiraw Abdisa Gemmechis, Daba Biru Leta, Hindesa Danisa Bunda. Flood Hazard and Risk Area Identification: A Case of Gelana River Watershed, Southern Ethiopia. *International Journal of Environmental Monitoring and Analysis*. Vol. 11, No. 1, 2023, pp. 1-14. doi: 10.11648/j.ijema.20231101.11

Received: October 3, 2022; **Accepted**: December 26, 2022; **Published**: February 6, 2023

Abstract: Floods are among the most devastating natural disasters in the world, claiming more lives and causing more damage to properties than any other natural phenomena. This study specifies flood hazard areas as well as flood risk areas of Gelana River Watershed. It specifically aims to investigate factors that create good conditions for flood hazard, generate flood hazard and risk areas from environmental and socio-economic factors using integration of Multi-Criteria Evaluation (MCE) and Geospatial Techniques. The research was conducted using quantitative research approach. Therefore, slope, elevation, soil type, land use land cover (LULC), and drainage density were the environmental factors developed for the generation of flood hazard. In addition, flood hazard, LULC and population data factors were developed to generate flood risk areas of Gelana river watershed. As the result, flood hazard map reveals 64.68, 1769.48, 1345.38, 244.37, 10.73 square kilometers of Gelana river watershed, is subjected to very high, high, moderate, low and very low flood hazardous respectively. It is revealed that 46.52% of the watershed has very high to high flood risk. The rest 47.20%, 6.24%, and 0.05% of the study area has medium, low and very low flood risk respectively. Therefore, the area incorporated under very high and high hazardous and risk areas are located around the Main River and lower course of the watershed.

Keywords: Flood, Hazard, Risk, Gelana River Watershed, Flood Hazard and Risk, Southern Region, Vulnerable and Livelihoods

1. Introduction

Floods are among the most devastating natural disasters in the world, claiming more lives and causing more damage to properties than any other natural phenomena, as well as being the most widespread. With more than 2.8 billion people affected since 1990 around the world [1], flooding is the phenomenon with the most impact on human population worldwide [2]. However, it is more of an economic risk because of the material damage caused rather than a lethal risk for the affected population [3], estimated that more than one-third of the world's land area is flood-prone affecting over 82 percent of the world's population. Similarly, UNDP reported about 196 million people in more than 90 countries were exposed to catastrophic flooding, and that some 170,000 deaths were associated with floods worldwide between 1980 and 2000 [4].

In Ethiopia, a total of 524,400 people were vulnerable to flood disaster throughout the country. Out of this population, 199,900 people are actually affected by flood disaster in various regions of Ethiopia [5]. According to Tesfaye, the flood hazard map indicates that 2103.34, 35406.63, 59271.09, 162827.96, and 1491.66 km^2 corresponds with very high, high, moderate, low, and very low flood hazard, respectively [5]. The frequency and consequences of extreme flood events have increased in recent times, having huge impact on the socio-economic well-being of nations with the most significant impact being felt at the community level [6].

A wide range of flood risk management can reduce this destruction, and managing flood risks requires the estimation of flood hazards and the impacts that they can cause. Proper estimation of risk is challenging and requires careful consideration of a number of factors, including watershed properties such as size, topography, and land use, the types and characteristics of storms that produce rainfall and flooding in the region, and the number, location, and types of buildings and other assets that could be damaged [7].

First and foremost, maps can tell us the where aspect of a disaster— where are buildings damaged, where are roads open for evacuation, where are the areas that are most susceptible to flooding impacts, where should supplies be stationed for planning purposes [8]. For many users of mapping tools in disaster management, the where aspect of maps is the most important function a map can serve. Increasingly in the US, disaster management officials are making the role and functions of GIS more accessible during disasters to provide real-time situation awareness—in disaster response in particular, but also during disaster planning and training exercises. GIS is the best assemblage of computer equipment and a set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis, and display (soft copy) and printing (maps) of the factors (spatial data) affecting flood hazard. One of the most common approaches in the flood risk and flood hazard study in other countries is using multi-criteria analysis approach in Geographic Information System (GIS).

This study was carried out by integrating Multi-Criteria Analysis and geospatial techniques. Flood hazard map was generated from physical factors like elevation factor, slope factor, land use land cover factor, drainage density factor, and soil factor and socio-economic factors population data, and land use are integrated with flood hazard map were produced flood risk map. In addition to flood hazard map and flood risk map the impact of flood in the livelihoods of the community was analyzed by using survey data collected from the field by using questionnaires, and interview.

2. Materials and Methods

2.1. Study Area

The study area is located in Southern Ethiopia; the watershed was located in two zones one zone is Oromia regional state, and the rest zone is Southern Nation Nationality Peoples (SNNPs) namely West Guji zone and Gedio zone particularly in the Abeya, Gelana, Gerba, Bule Hora, Erga Chefe, and Wonego Woredas. It lies within latitudes 5° 25’00'N up to 6°20'N, and longitude 37°45'00”E up to 38°25'00”E with an area of around 3438 km^2 (Figure 1). Gelana is one of the nine Woredas in West Guji Zone; the livelihood of the woreda is mainly pastoralism and farming. The woreda has 26 kebeles out of which 17 were affected by the flood. The woreda is recurrently affected by flash flood and river over flow; caused by heavy rain. Moreover, the rivers that often overflow and cause the flooding are Gelana and its tributaries like Abas, Worki, Dilalessa, and Jalo. These rivers cross the woreda; most of these rivers flow from high lands of Gedeo Zone, SNNPR and West Guji zone of Oromia region and all of them are tributaries of Gelana River. The rivers are coupled with the catchment which creates wide watershed makes most of the kebeles vulnerable to flood. The recent flood disaster during this year is significant in scale and severity; the actual flood started from May 09, 2020 and continued. According to the woreda early warning task force, about 8,929 HHs (63,601 people) are displaced and other social infrastructures and individual properties were damaged by the flood disaster in the affected kebeles. The flood took the lives of three children in Bore Kebele.

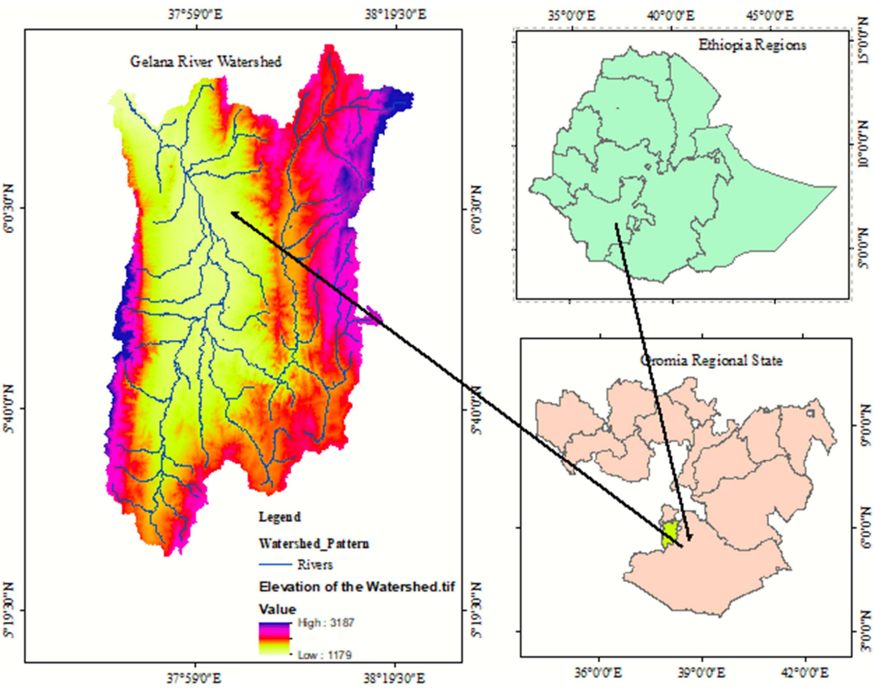

Figure 1. *Locational map of study area.*

In Abaya Woreda is one West Guji woreda, Ledo kebele is the most affected kebele of Abaya woreda by flood; the kebele is recurrently affected by overflow of Gelana River, which cross both Gelana and Abaya woredas. The flood displaced about 585HHs (3,980 individuals). About 88 houses are completely damaged while 497 houses are flooded and not live-able right now.

2.2. Research Methods

This paper was carried out by using mixed research approach such as Vulnerability risk analysis and descriptive research methods. The flood hazard and risk area mapping were carried out using Multi Criteria Evaluation (MCE) and geospatial techniques. To carry out the MCE, weight for the factors depending on their suitability for flood hazard and risk were gave in IDRISI software. Then the overly analysis conducted using IDRISI Software. Finally, the flood hazard and risk map were produced using similar procedures, the flood hazard map produced by including slope, elevation, land use, drainage density and soil types of the study area. As well as flood risk map was generated from population density, land use and malaria hazard map factors. The flow chart of the overall methodology was presented in figure 2 below.

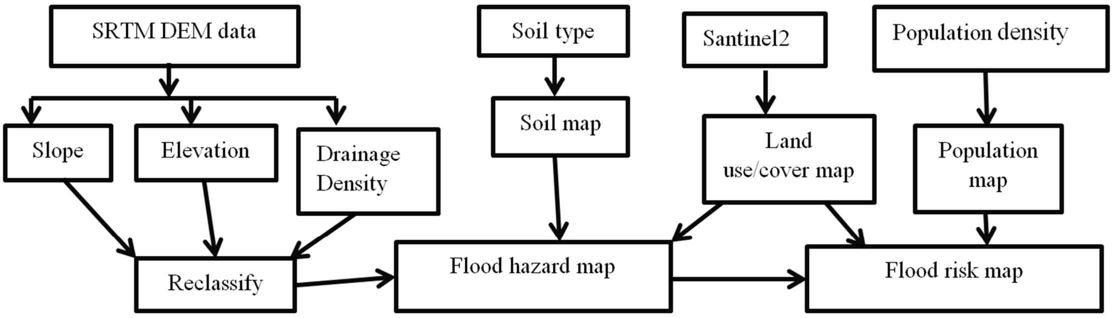

Figure 2. *Workflow chart of Research Methodology.*

2.2.1. Methods of Spatial Data Collection and Software Needed

Remote Sensing and GIS technology was the effective methods of identifying flood hazard and risk areas for decision making as well as protection. SRTM DEM was downloaded from United State Geological Survey (USGS) to generate the selected flood hazard factors like slope, elevation, and drainage density of the study area and they were processed in ArcGIS 10.8 software. Santinel2 imagery was downloaded from USGS, with band 8, 5 and 4, composited on ENVI (version 5.0) software where various region of interest (ROI) was created to form the basis for land use classification. Soil data was taken from Geological Survey Office of Ethiopia and Population data of the study area was from Central Statistical Agency then they were converted to shape file in ArcGIS 10.8 v. software specifically using spatial analyst tool. Sources of the data and data types that used for the study was presented in the Table 1, below.

Table 1. *Data collection Specifications.*

Data type	Year	Path/ Row	Date of Acquisition	Resolution	Source
Santinel2 Satellite Image	2021	168 & 056	December 2021	30m	USGS
SRTM DEM	2021	168 & 056	December 2021	30m	USGS
Study area ShapaAAAae file	2021	-	2021		From DEM
Soil data	2021			Converted to 30m	FAO
Population data	2021	-	2021	Converted to 30m	CSA

2.2.2. Methods of Data Analysis

According to Victor Onyewuchi Flood causative factors influence in contributing to flood hazard was determined by integrating and calculating the mutual interaction ratios for most reviewed flood causative factors [9]. As it mentioned above, flood hazard map generated from the integration of slope, soil, land use, elevation, and drainage density parameters. They are appropriate factors to investigate potential sites of flood hazard of the study area.

In this study fluvial floods along large rivers occur in large catchments are common. They cover the largest areas by flooding large floodplains at the lower end of catchments during prolonged periods, but can be foreseen days ahead allowing time for warning and are characterized by slow rise. Therefore, for this study flood risk map was generated from the following factors flood hazard, population density and land use factors.

(i). Environmental and Socio-Economic Factors

i. Slope factor

Slope plays a major role in flood hazard mapping. It has a great influence on flood hazard assessment because it governs the amount of surface runoff produced the precipitation rate and displacement velocity of water over the equi-potential surface [10]. Practically high rating is assigned to low slopes for the gentle gradient of the floodplain whereas low rating is assigned for high slopes. The slope of the study area was derived from 30 meter SRTM data and reclassified in to five classes like the other parameters using natural break standard reclassification technique. For this study slope was classified, according to [9] the classes (0-5.5°, 5.5-15.5°, 15.5-25.5°, 25.5-45.5°, 45.5-69°) in the reclassified slope layer and was described as very high, high, moderate, low, and very low respectively based on the relative degree of suitability of the slope class for flood hazard.

ii. Elevation Factor

Ethiopia has a lot of rugged and mountainous topography with altitudes that range 4650 meter above sea level to 420 meters below sea level [1]. The rainfall also varies from place to place it reaches at average 2400mm/year in the south west and not greater than 150mm/year in the northern part [1]. Flooding is common in Ethiopia during rainy season between June and September and the major type of flooding which Ethiopia is experiencing are; Flash flood and river floods. Elevation generally correlates positively with precipitation and negatively with temperature and can be used as surrogate indicator [11]. So, the study only considers elevation rather than temperature and rainfall for modelling hazardous sites. The higher ground area is considered more the less hazardous than the lowest or gentler area.

For the study, the elevation layer was reclassified based on the extent of flood hazard at different altitudes. The layer was reclassified in to five classes they are very high, high, moderate, low, and very low and values is given to elevation ranges of 1179-1300m, 1300-1700m, 1700-2000m, 2000-2300m, and 2300-3187m respectively.

iii. Soil Type

Different soil types have different capacities to infiltrate water. Morgan (1995) stresses that "infiltration is a key component that significantly influences the rainfall -runoff process and plays an important role in controlling the amount of water that will be available for surface runoff after a rain storm event" [12] (p. 198). The soil factors influencing the rate of infiltration are: the total amount of pores (soil porosity), the particle size distribution and the structure of pores (grain size distribution), soil structures (size distribution and structure of aggregates) and organic matter content of the soil [13-15].

The major soil types of Gelana river watershed exhibit a general relationship with altitude and slopes. Shallow and infertile soils being the characteristics of the mountains and hills where as the deep and fertile soils are the major properties of valley bottoms, river terraces and flat plains. Generally, the soils of the valley are developed on recent alluvial colluvial sediments derived from the adjacent mountain ranges. Fluvisols, vertisols and xerosols are generally dominating the watershed and particularly around river valley and lowland flat plains and they are classified as very high for flood hazard. Texturally these soils are sandy loam, clay and sandy clay respectively. Cambisols, and solonchaks soils are classified as high flood hazard, acrisols, and luvisols are considered as moderate suitable for flood hazard, gleysols and leptosols were classified as low suitable and nitisols and regosols were classified as very low suitable for flood hazard.

iv. Drainage Density

Drainage is an important ecosystem controlling the hazardous as its densities denote the nature of the soil and its geotechnical properties [16]. Drainage system, which develops in an area, is strictly dependent on the slope, nature of altitude and on the regional and local fracture pattern [17]. Drainage density is an inverse function of infiltration [18]. Greater drainage density indicates high runoff for basin area along with erodible geologic materials, and less prone to flood. Thus the rating for drainage density decreases with increasing drainage density. DEM data was used to extract the drainage network, to calculate the drainage density of the watershed. Arc GIS 10.8 Software, was used to generate drainage network map of the watershed. Using the spatial analyst, density, line density module was used to compute drainage density of the watershed.

v. Population Density

Since socio-economic vulnerability relates to the adaptive capacity of the population to that hazard, an area can be considered highly vulnerable, if the population within the area has less capacity to resist the impact of the natural hazard and to recover from its long term or short term effects [19]. Populations have experienced increasingly important phenomena of floods, with its effects such as death, damage to property and population exodus. Heavy rainfall is the main natural hazard which causes loss of many lives; destruction of infrastructures, and the displacement of people during the rainy season. Population density risk map was classified, as the following classes (<7900; 7900-8700; 8700-9500; 9500-10400; >10400) in the reclassified population density sparsely populated areas were low risk as well as high populated areas were high risk and it was described as very low, low, moderate, high and very high respectively based on the relative degree of suitability of the population density for flood risk.

vi. Land use change Factors

Knowing the changes in land use/cover could be taken as a good indicator of ecosystem health that includes biodiversity. Therefore, mapping the land use/cover can be considered as bench mark for land use/cover change detection in the future and it could be a pillar for different land use planning. Hence, it becomes important to undertake studies of land use/cover changes to see the severity of the changes with time. According to Yirga, land use land cover Wetland, built-up and rock out crop were classified as very high hazardous; cultivated land and exposed sound as high suitable flood areas; grassland medium hazardous; woodland, shrub & bush land as low hazardous and forest land and riverine forest land considered as very low hazardous areas [10]. Therefore, Land use land cover of the watershed were reclassified into five land classes like water body and agricultural land; Settlement Area; Grassland and Bare land Area; Agroforestry and Forest land and assigned as very high, high, moderate, low and very low flood hazardous respectively.

(ii). Flood Hazard Analysis Methods

Weighted sum overlay tool was used to analysis flood hazard of the study area, it was developed from slope, elevation, land use/cover, drainage density, and soil type factors. The weights for each factor were given through Multi-criteria evaluation using pair wise comparison methods in IDRISI software. The techniques used in this study was pair wise comparisons developed by [20] and implemented in IDRISI Selva software, in that the decision process is known as the Analytical Hierarchy Process (AHP) [10], the AHP is based on Multi-criteria decision making approaches.

The principal Eigen Vector of a square reciprocal matrix of pair wise comparisons between each criteria weight can be derived using Saaty's technique. The standardized raster layers were weighted using Eigen Vector that is important to show the importance of each factor as compared to other in the contribution of flood hazard.

(iii). Flood Risk Analysis Methods

Flood risk area identification was done using the flood hazard layer and the two elements at risk, (population density and land use/cover). For these three factors reminded to be at equal vulnerability, assuming to be one in the weighted overlay process. Flood risk assessment and mapping were done for Gelana river watershed by taking population and land use elements that are at risk combined with the degree of flood hazards of the watershed.

3. Result and Discussion

Flood hazard and risk area mapping and its causing factors are analyzed through the integrated application of MCE and geospatial techniques.

3.1. Environmental Factors Analysis

i. Level of flood hazard and slope

Moreover, steeper slopes are areas where there is a rapid flow of surface water, and such places are incapable to retain or accumulate surface water, as it easily runs away to rather flatter areas. These areas are also not suitable for human settlement. As a result steepest areas of the watershed are considered areas not vulnerable to flood hazards. In Contrast, horizontal slopes are areas where there is little or no flow of surface water, which often leads to a situation of flooding and inundation through an excess accumulation of surface water. This means that flat areas of the watershed are considered as areas vulnerable to flood hazards. Moreover, areas with flat surfaces are suitable for human settlement, and this leads to a situation where flood hazard damages wealth of the community surrounding the watershed. Slope map was classified, according to [9] the classes (0-5.5°, 5.5-15.5°, 15.5-25.5°, 25.5-45.5°, 45.5-69°) in the reclassified slope layer and was described as very high, high, moderate, low, and very low respectively (Figure 3).

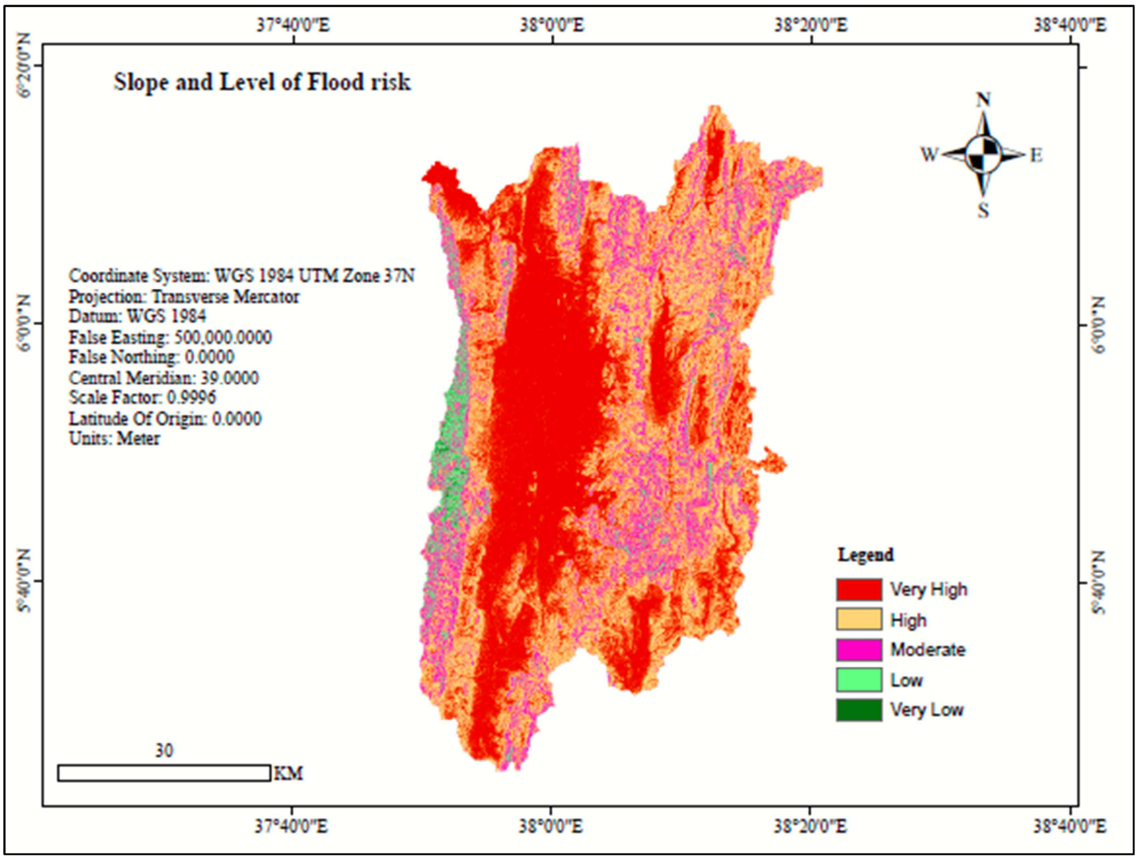

Figure 3. *Slope based flood hazard map.*

Based on the suitability of the slope for flood hazard, the reclassified slope map of Gelana river watershed shows that about 41.40% of the water shade has very high risk of flood hazard. From the remaining area of the watershed 41.53% has high; 12.84% has moderate; 3.96% has low, 0.27% has very low risk of flood hazard (table 2). This shows that more than 80% of Gelana river watershed has high or very high risk of vulnerability to flood hazard. These areas are the more flat areas of the watershed which accumulate excess surface water as heavy rainfall showers the area.

ii. Level of flood hazard and elevation

Flood hazards are largely determined by the altitude or elevation of the area. Altitude affects the distribution of the flow of surface water through its effect on temperature and rainfall. All the processes for the development of the effect of elevation factor on flood risk was generated from DEM using reclassifying tools in ArcMap 10.8 version, which is provided in figure 4 below.

Elevation map was generated from the raster layer and reclassified depending on its influence on flood hazard. Accordingly the reclassified elevation map of the watershed shows that 8.64%, 40.62%, 30.15%, 13.30%, and 7.29% of the total area has very high, high, medium, low, and very low level of flood hazard respectively (table 2). According to the elevation map, half of the area of Gelana river watershed has elevation less than 2000m asl. This indicates that half of the area of Gelana river watershed has from high to very high vulnerability of flood hazard.

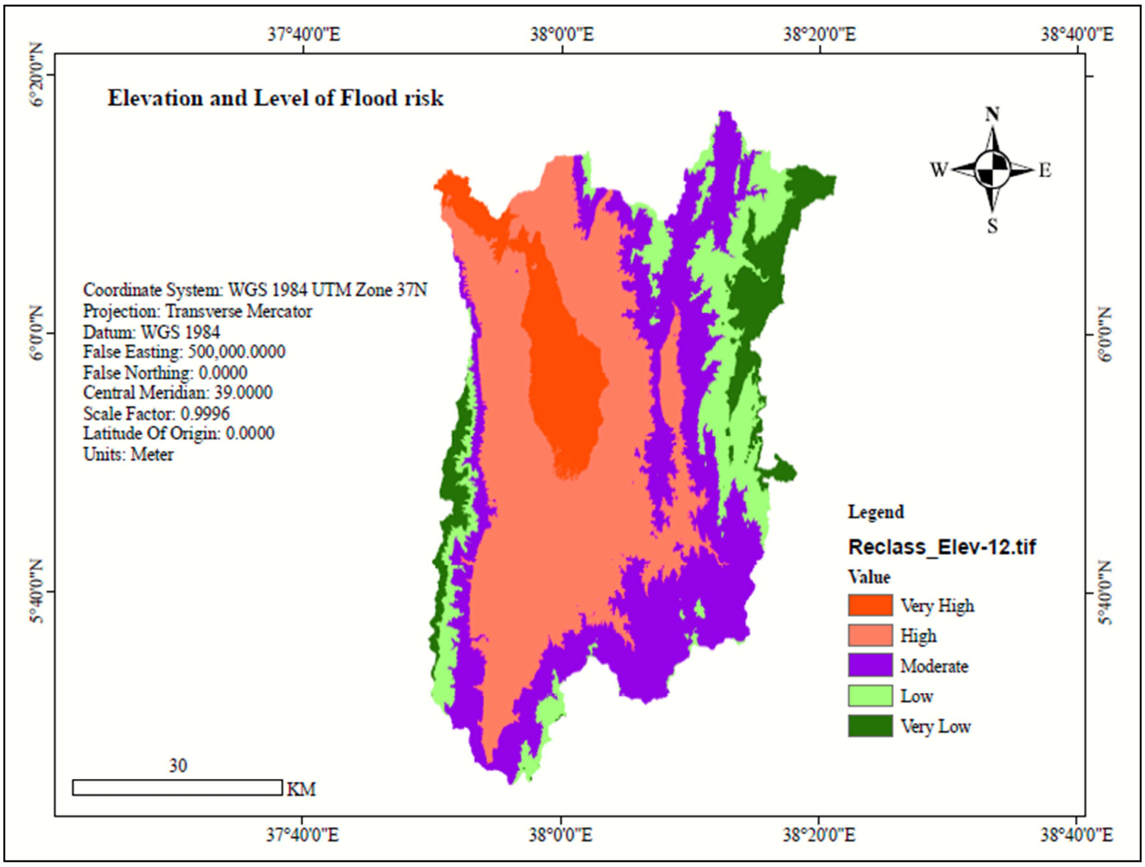

Figure 4. *Elevation based flood hazard map.*

iii. Level of flood hazard and soil type

Based on their physical properties, different soil types have varying degree of vulnerability to flood risk. Physical properties of the soil, particularly soil texture, soil porosity, and soil structure are considered to determine the soil type factor. As it is depicted in figure 5 below, the soil types of Gelana river watershed are classified based on the soil texture of the watershed and converted to raster format which are reclassified based on their water infiltration capacity into flood rating result for soil factor map.

Gelana river watershed has around 11 soil types which are further classified in to five major categories based on their similarities in terms of water infiltration. These major soil type categories are then used to generate the flood hazard map. Among the five soil type categories, Vertisols, fluvisols and Xerosols, which make about 44.89% of the watershed are found around lower slopes, and are reclassified under areas of very high flood hazard. On the other hand, Cambisols, and Solonchaks soil types, covering 10.53% of the watershed, are reclassified as areas of high flood hazard; Acrisols and Luvisols, making up 10.41% of the watershed, are reclassified as medium flood hazard area; Gleysols and Leptosols, covering 1.21%, are reclassified as low flood hazard area; and Nitosols and regosols, which cover 32.95% of the watershed, are classified as areas of very low flood hazard (table 2).

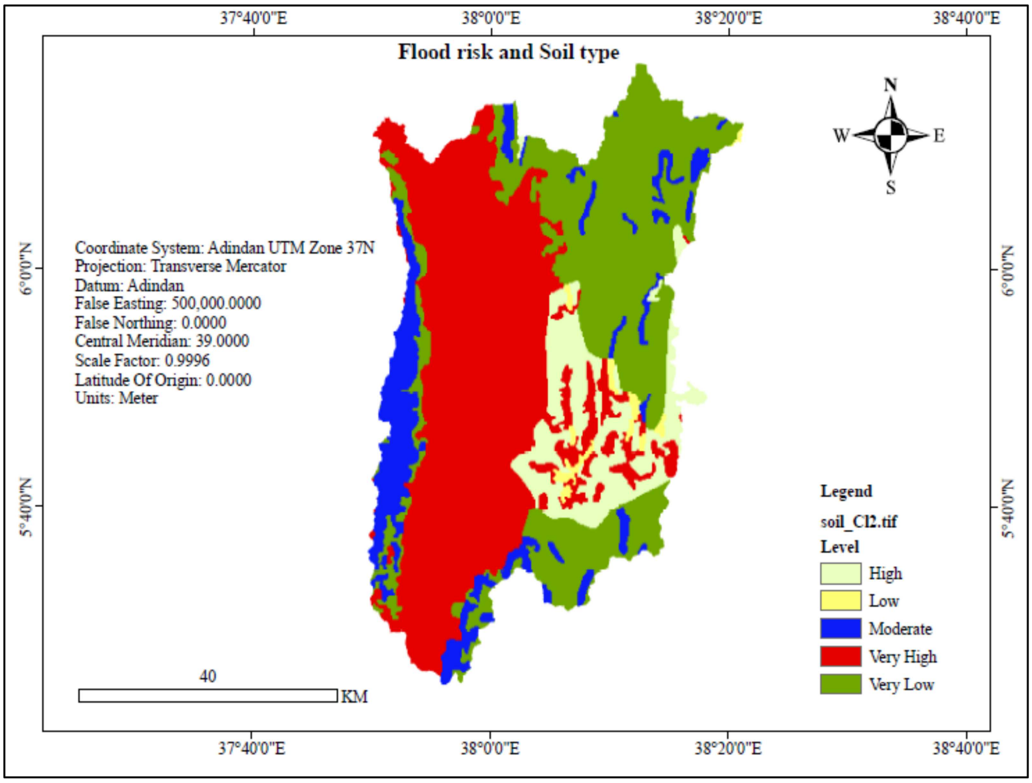

Figure 5. *Soil based flood hazard map.*

iv. Level of Flood Hazard and Drainage Density

Drainage system, which develops in an area, is strictly dependent on the slope, the nature and attribute of bedrock and on the regional and local fracture pattern [17]. Drainage density (DD), a fundamental concept in hydrologic analysis is defined as the ratio of the length of drainage to the watershed area. Drainage density is controlled by permeability, erodability of surface materials, vegetation, slope and time.

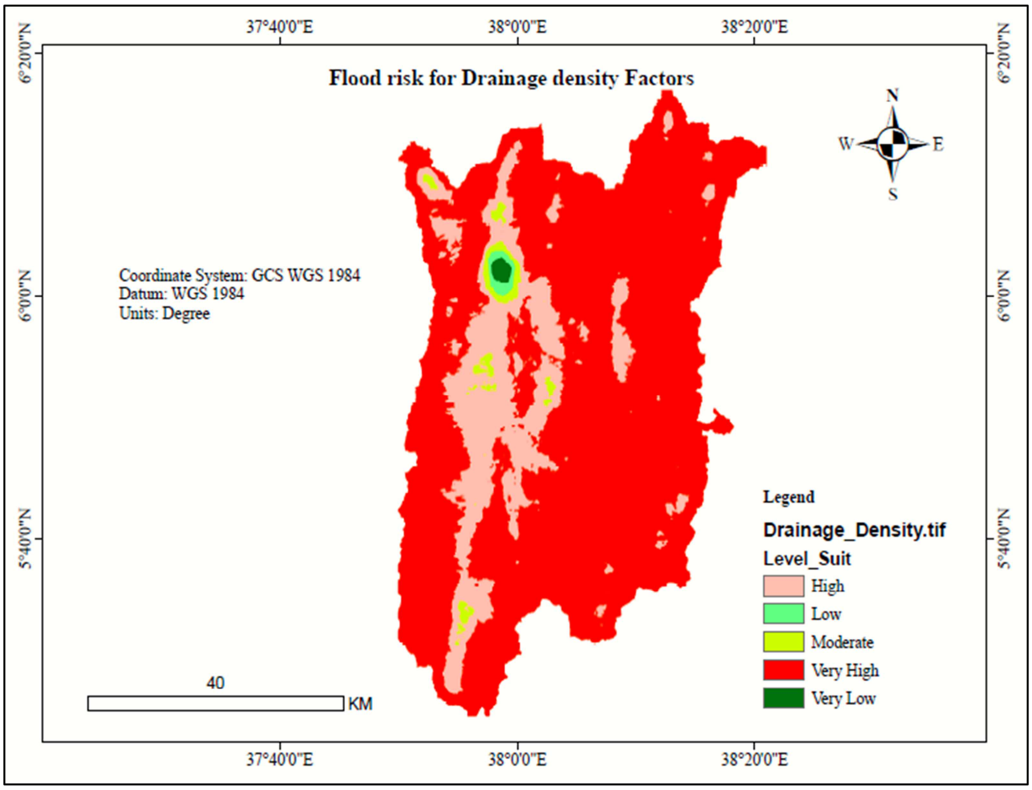

Figure 6. *Drainage density based flood hazard map.*

As it is depicted in Figure 6 and table 2, more than 3/4th of Gelana river watershed has very high drainage density; whereas, nearly 1/5th of the watershed has high drainage density. Therefore, on the basis of drainage density analysis, about 97% of Gelana river watershed has high to very high vulnerability to flood hazard.

Table 2. *Environmental and Socio-economic sub-factors area coverage.*

No	Factors	Naming	Sub-factors	Area in M^2	Area in KM^2	Percent
1	Slope	Very High	< 5.5^0	1421782.2	1421.78	41.40
		High	5.5^0 - 15.5^0	1426575.6	1426.58	41.53
		Moderate	15.5^0 - 225.5^0	441069.3	441.07	12.84
		Low	25.5^0 - 45.5^0	135848.7	135.85	3.96
		Very Low	> 45.5^0	9365.4	9.37	0.27
		Total		3434641.2	3434.64	100.00
2	Elevation	Very High	1179m-1250m	296867.58	296.87	8.64
		High	1250m-1400m	1395240.27	1395.24	40.62
		Moderate	1400m-1700m	1035499.52	1035.50	30.15
		Low	1700m-2000m	456700.11	456.70	13.30
		Very Low	2000m-3187m	250333.72	250.33	7.29
		Total		3434641.20	3434.64	100.00
3	Soil	Very High	Vertisols, fluvisols and Xerosols	1541645.1	1541.65	44.89
		High	Cambisols, and Solonchaks	362086.2	362.09	10.54
		Moderate	Acrisols, and Luvisols	357529.5	357.53	10.41
		Low	Gleysols and Leptosols	41650.2	41.65	1.21
		Very Low	Nitosols, and regosols	1131730.2	1131.73	32.95
		Total		3434641.2	3434.64	100.00
4	Land use/cover type	Very High	water body and agricultural land	646275.6	646.28	18.82
		High	Grassland and Bare land Area	674230.5	674.23	19.63
		Moderate	Settlement Area	542246.4	542.25	15.79
		Low	Agroforestry	1179919.8	1179.92	34.35
		Very Low	Forest land	391968.9	391.97	11.41
		Total		3434641.2	3434.64	100.00
5	Drainage Density	Very High	0.67-1.8	2753224	2753.22	80.16
		High	1.8-2.5	613786	613.79	17.87
		Moderate	2.5-3.5	45233	45.23	1.32
		Low	3.5-4.8	13282	13.28	0.39
		Very Low	4.8-6.13	9116.2	9.12	0.27
		Total		3434641.2	3434.64	100.00
6	Population Density	Very High	>10400	2140147.2	2140.15	62.31
		High	9500-10400	815808	815.81	23.75
		Moderate	8700-9500	251654	251.65	7.33
		Low	7900-8700	168782	168.78	4.91
		Very Low	<7900	58250	58.25	1.70
		Total		3434641.2	3434.64	100.00

3.2. Socio-economic Factors

i. Level of flood risk and Land use land cover

Land use/cover types of Gelana river watershed are reclassified into a common scale considering their rain water abstraction capacities for the flood hazard analysis which is converted into flood rating result to produce the land cover factor map (figure 7).

The result shows that 18.82% of Gelana river watershed is covered by water bodies and agricultural land, which is considered to have very high risk of flood hazard; whereas, 19.63% of the watershed is covered by settlement with high risk of flood hazard; grassland and bare lands, covering 15.79% have medium risk of flood hazard. The result also shows that, from the remaining area of Gelana river watershed, 34.35% and 11.41 is covered by Agroforestry and forest land, which have low and very low risk of flood hazard respectively (Table 2).

Moreover, agroforestry areas are located in the upper course of the watershed which are mainly located in Gedeo zone, while forest areas are, in contrast, found in the river valley of the main river and its tributaries. Therefore, the land use/cover analysis shows that areas which have very high to high risk of flood hazard are mostly located at the lower course of the watershed.

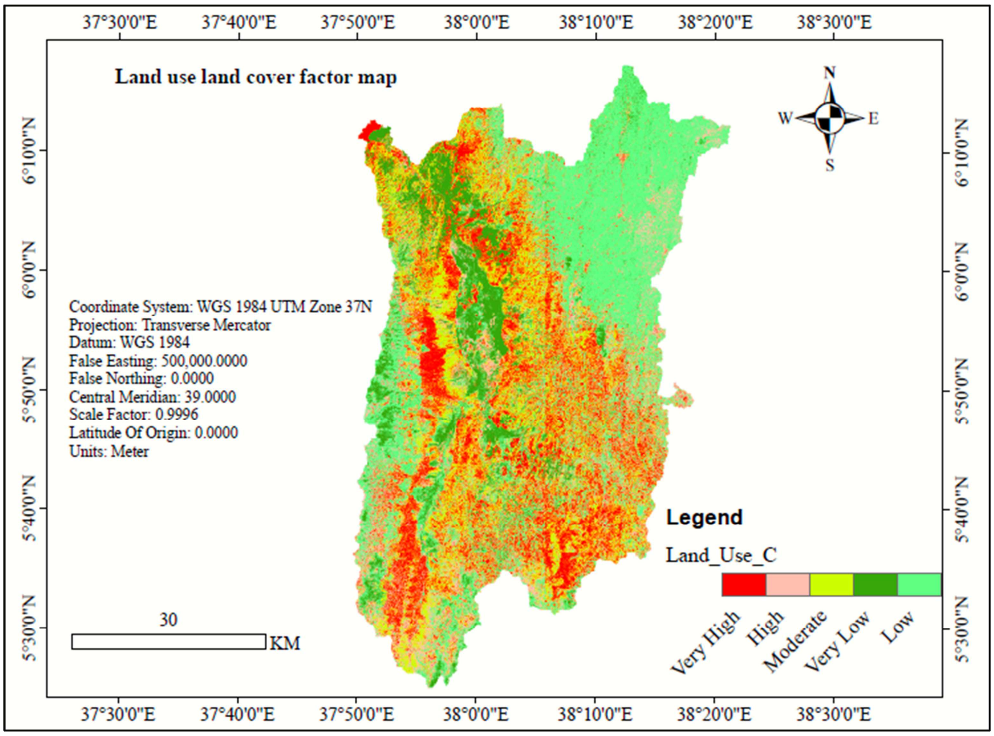

Figure 7. *Land use based flood hazard map.*

ii. Flood Risk level and Population Density

The reclassified population map shows density of the population per square kilometers and the vulnerability of areas to flood risk described as very high, high, moderate, low, and very low based on the relative degree of suitability of the population density for flood risk. The densely populated areas are associated with high flood risk, while sparsely populated areas are associated with low flood risk.

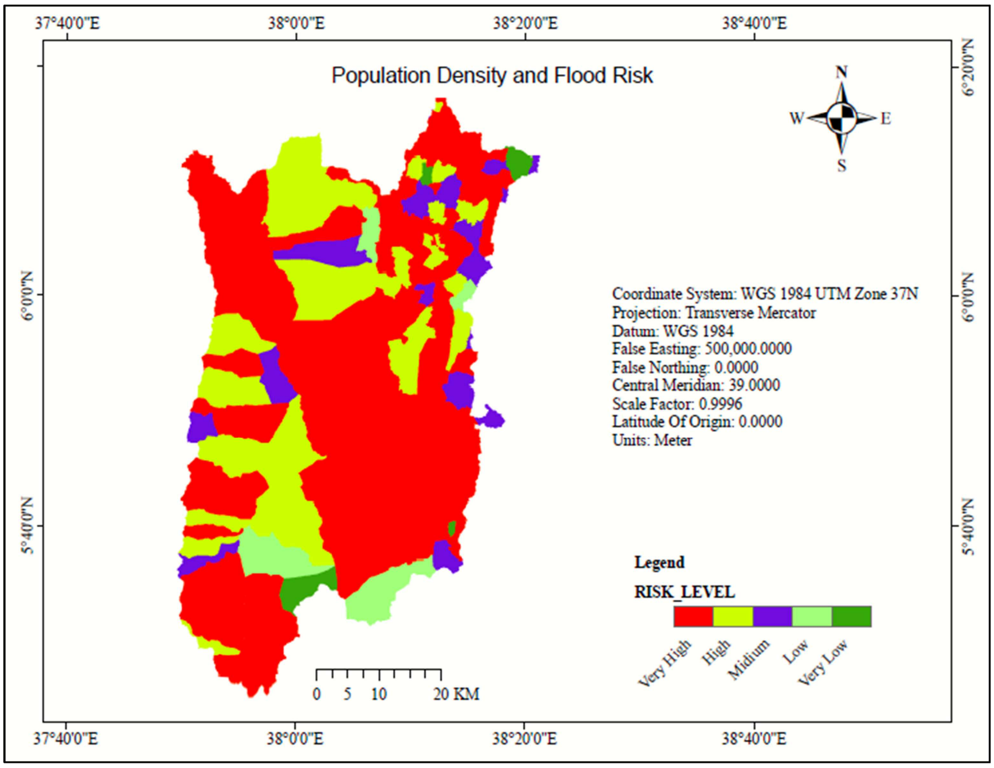

Figure 8. *Population density based flood risk map.*

The result of population density reveals that about 62.31% of Gelana river watershed is densely populated, which is also the area of very high flood hazard. The remaining 23.75%, 7.33%, 4.91% and 1.70% the watershed are classified as areas of high, moderate, low and very low population density and flood hazard respectively (Table 2).

3.3. Flood Hazard and Risk Mapping

3.3.1. Flood Hazard Mapping

The determination of the hazard, i.e., the identification of the flood zones and the evaluation of the return period associated with submersion, the depth and duration of submersion, and the speed of the current, presuppose the analysis of several characteristics of the catchment area. Rainfall regime, land use and vegetation influence the formation of runoff, while physical, topological, topographical and geological features affect the concentration of runoff [3].

The Eigen Vector of the weight of the factor was computed in IDRISI Selva Software in GIS Analysis menu of the decision support module weight tool based on the given pair-wise comparison (Table 3). The weighted module was fed with the pair wise comparison nine point continuous scale. Then the principal Eigen Vector of the pair wise comparison matrix using the factors affecting flood hazard was calculated. A consistency ratio values less than 0.1 is acceptable [10]. The consistency ratio of the calculated Eigen Vector was 0.03 that indicates that the given pair-wise weights are accepted.

Table 3. *The Eigen Vector Weights of each flood factors obtained from pair-wise comparison.*

The eigenvector of weights	
Factors	Weight
Slope	0.5128
Elevation	0.2615
Land use/cover	0.1290
Drainage Density	0.0634
Soil type	0.0333

Weighted sum overlay tool was used to generate flood hazard of the watershed, it was developed from slope, elevation, land use/cover, drainage density, and soil type factors (Table 4). The computed Eigen vector was used as a coefficient for the respective factor maps to be combined in weighted Overlay tool in the Arc GIS environment using the following equation:

$$\text{Flood hazard} = 0.5128 * (\text{Slope}) + 0.2615\times*(\text{Elevation}) + 0.1290*(\text{Land use/cover}) + 0.0634*(\text{Drainage Density}) + 0.0333\times(\text{Soil type})$$

Table 4. *Weighted Flood Hazard sub-factors Ranking.*

No	Factors	Naming	Sub-factors	Ranking	Weight
1	Slope (Degree)	Very High	< 5.5^0	5	0.5128
		High	5.5^0 - 15.5^0	4	
		Moderate	15.5^0 - 225.5^0	3	
		Low	25.5^0 - 45.5^0	2	
		Very Low	> 45.5^0	1	
2	Elevation (Meter)	Very High	1179m-1250m	5	0.2615
		High	1250m-1400m	4	
		Moderate	1400m-1700m	3	
		Low	1700m-2000m	2	
		Very Low	2000m-3187m	1	
3	Soil type (based on Porosity)	Very High	Vertisols, fluvisols and Xerosols	5	0.0333
		High	Cambisols, and Solonchaks	4	
		Moderate	Acrisols, and Luvisols	3	
		Low	Gleysols and Leptosols	2	
		Very Low	Nitosols, and regosols	1	
4	Land use/cover (based on flood abstraction)	Very High	water body and agricultural land	5	0.1290
		High	Grassland and Bareland Area	4	
		Moderate	Settlement Area	3	
		Low	Agroforestry	2	
		Very Low	Forest land	1	
5	Drainage Density (KM/KM2)	Very High	0.67-1.8	5	0.0634
		High	1.8-2.5	4	
		Moderate	2.5-3.5	3	
		Low	3.5-4.8	2	
		Very Low	4.8-6.13	1	

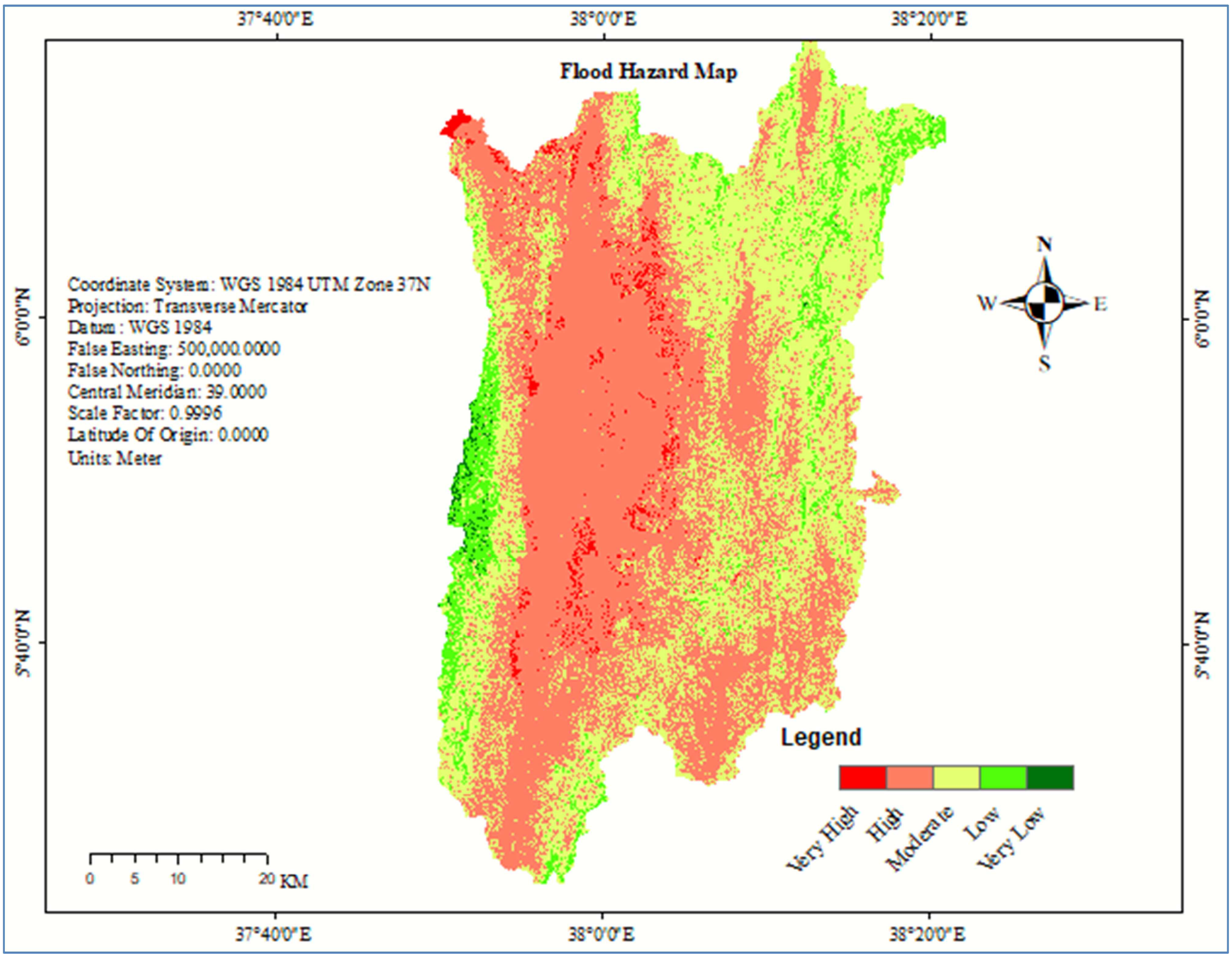

Figure 9. *Flood Hazard Map of Abaya river watershed.*

The flood hazard map in figure 9 above and table 5 below show that 64.68, 1769.48, 1345.38, 244.37, and 10.73 square kilometers of Gelana river watershed, are subjected to very high, high, moderate, low and very low flood hazards respectively (Table 5). The areas categorized under very high flood hazard are those which dominantly cover around the Major River and gentler slope. This is the area where the flood is more common and repeatedly affects the community in the area. Furthermore, as it is evident in the flood hazard map, the level of the flood hazard increases toward the lower areas of the watershed.

The result generally shows that slightly more than 50% of Gelana river watershed is under high risk of flood hazard, whereas 39.17% of the area is categorized under moderate vulnerability to flood hazard. The remaining 7.11% and 0.31% of the total area of the watershed respectively have low and very low risk of flood hazard, as they are located around highly elevated areas of the watershed (Table 5).

Table 5. *Flood Hazardous area in kilometers and percent's.*

No	Rating of flood hazard	Pixel Count	Area in KM^2	Percent
1	Very High hazardous	71900	64.68	1.88
2	High hazardous	1966084	1769.48	51.52
3	Moderate hazardous	1494872	1345.38	39.17
4	Low hazardous	271518	244.37	7.11
5	Very Low hazardous	11922	10.73	0.31
	Total	3816296	3434.64	100

3.3.2. Flood Risk Mapping

Flood risk assessment for Gelana River watershed was done by using the flood hazard layer and the two elements at risk, namely population and land use (Figure 10). These three factors were given weight depending on equal importance (Table 6), and processed and analyzed by weighted overlay tool. Flood risk assessment and mapping was done by taking in to account population data and land use elements, that are element at risk combined with the degree of flood hazard of the study area.

Table 6. *Weighted Flood Risk Ranking.*

No	Factors	Naming	Sub-factors	Ranking	Weight
1	Flood Hazard (Based on hazardous level)	Very High	Very High	5	0.3334
		High	High	4	
		Moderate	Moderate	3	
		Low	Low	2	
		Very Low	Very Low	1	
2	Population Density (Population number)	Very High	>10400	5	0.3333
		High	9500-10400	4	
		Moderate	8700-9500	3	
		Low	7900-8700	2	
		Very Low	<7900	1	
3	Land use/cover (based on flood abstraction)	Very High	water body and agricultural land	5	0.3333
		High	Grassland and Bare land Area	4	
		Moderate	Settlement Area	3	
		Low	Agroforestry	2	
		Very Low	Forest land	1	

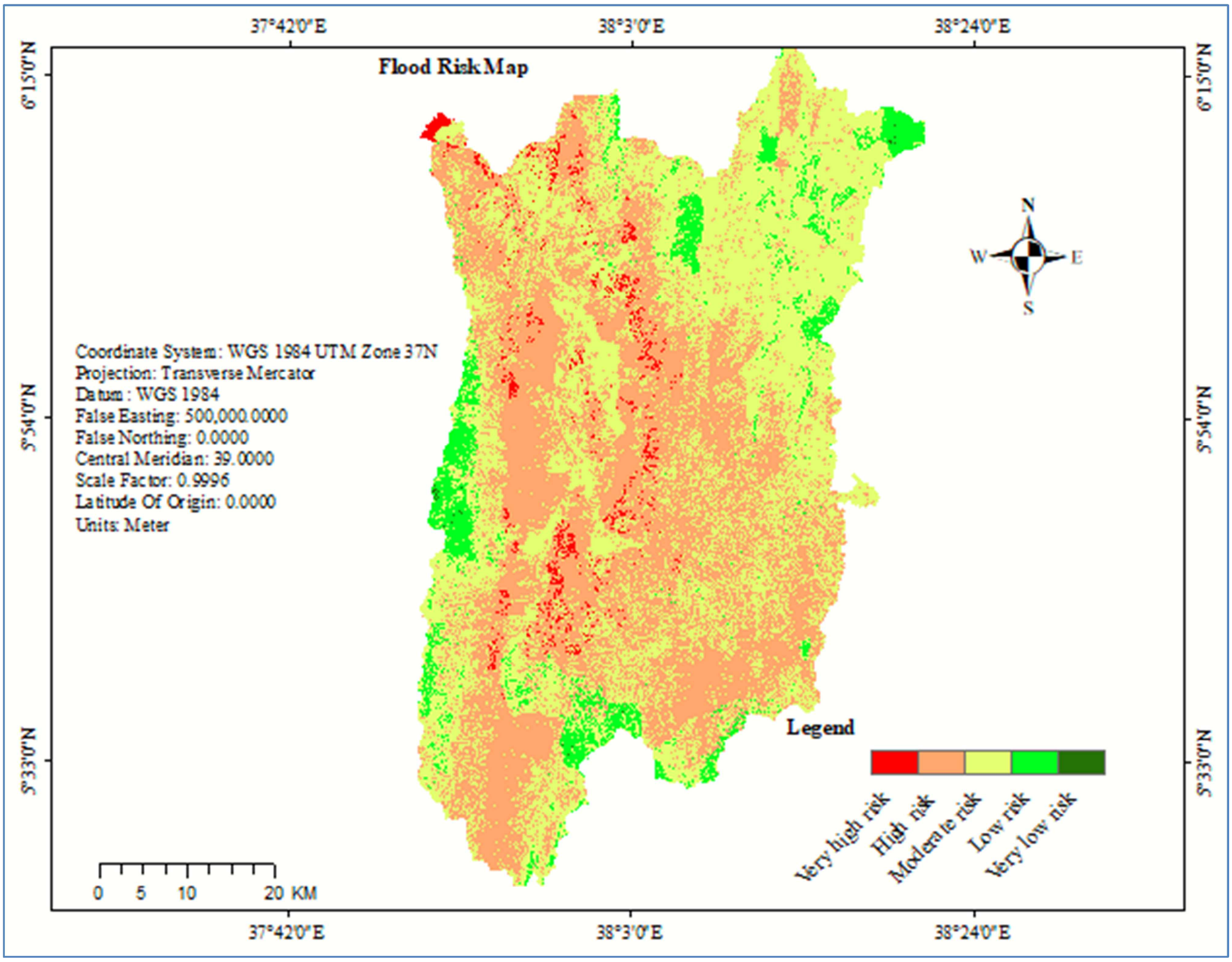

Figure 10. *Flood risk map of Gelana River Watershed.*

The result shows that 1.91% of Gelana river watershed falls under the category of areas with very high risk of flood hazard; while slightly over 44.61% of the watershed is under high risk of flood hazard. The remaining 47.20%, 6.24% and 0.05% of the study area is under medium, low and very low risk of flood hazard respectively (Table 7). These results indicate that areas categorized under very high and high risks of flood hazard are those located around the Main River and lower course of the watershed. This specifically implies that most kebeles in Gelana and Abaya Woredas, which are located in the lower course of Gelana river watershed, including Ledo, Meteri, Chuketa, Shamole, Bore, Odo Derba and Kersa are under high to very high risk of flood hazard.

Table 7. *Flood risk rating area coverage and percentage.*

No	Rating of flood risk	Pixel Count	Area in KM2	Percent
1	Very High	72800	65.52	1.91
2	High	1702391	1532.15	44.61
3	Moderate	1801207	1621.09	47.20
4	Low	238074	214.27	6.24
5	Very Low	1792	1.61	0.05
	Total	3816264	3434.64	100

4. Conclusion

The study has identifying flood hazard and risk areas of Gelana river watershed, which is a major river that has serious flood problems in West Guji zone using MCE and Geospatial techniques. The study was carried out using quantitative research approach, as a result flood hazard and risk maps were generated using geospatial and MCE techniques. Vulnerability analysis is a critical element in determining areas suitable for some specific purposes such as flood hazard and risk development. However, proposing suitable sites for flood hazard and risk development using suitability analysis is a cumbersome job involving multi-criteria decision analysis steps.

Therefore, for this study flood hazard map was generated from environmental and socio-economic factors like; slope, elevation, land use, drainage density, and soil type and flood risk map was generated from flood hazard, population density and land use factors.

As the result of flood hazard maps reveals 64.68, 1769.48, 1345.38, 244.37, 10.73 square kilometer of Gelana river watershed, were subjected to very high, high, moderate, low and very low flood hazardous respectively. The very high and high hazard areas were dominantly covers around the lower course of the river. Moreover, around the half of the Gelana River watershed was high flood risk areas. 65.52 km^2 (1.91%) and 1532.15 km^2 (44.61%) of the watershed were included under very high and high flood risk respectively. As a result, the community lived in the lower course of the river were displaced in to neighboring areas and vulnerable to food stocks.

5. Recommendation

The researcher suggests the following recommendations:

1) Land use planning can play very important role to reduce the adverse effects of flooding due to that concerned bodies should have to adopt an appropriate land use planning in flood prone area.
2) Government and key stakeholders should convince communities in flood prone areas in order to move them permanently to less flood risky areas. The relocation should go with the provision of all the necessary social amenities such as schools, hospitals, and infrastructures like water, roads, and agricultural support centers for the resettled households. Consideration should also be made to introduce alternative livelihood strategies that could improve the livelihood and food security the relocated communities.

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