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Geographic information system (GIS)-Based multicriteria analysis of flooding hazard and risk in Ambo Town and its watershed, West shoa zone, oromia regional State, Ethiopia

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ABSTRACT

The purpose of the study was to analyze flooding hazard and risk from Geographic Information Systems (GIS)-based multicriteria perspective in Ambo town and its watershed and proposes strategic measures for sustainable flooding disaster risk management in urban watershed. Land use/land cover, elevation, slope, drainage density, soil, and rainfall were considered as important flooding hazard factors. Analysis of flooding risk was undertaken for Ambo town's watershed using flooding hazard layer and the two elements at risk, namely human population and land use. Weighted linear combination (WLC) method was used in the process of criteria map aggregation for both flooding hazard and flooding risk. The result of the flooding hazard in the watershed reveals that more proportion of the watershed is high and very high flooding hazard area (60.58%). Moreover, more proportion of the town is high and very high flooding hazard area (66.87%). The result of the flooding risk in the watershed reveals that more proportion of the watershed is high and very high flooding risk area (41.76%). Moreover, half of the town is high and very high flooding risk area (50.09%). An integrated basin wide approach to flood management should be practiced as it is essential to address multiple water related issues at watershed level. Moreover, environmental education should be emphasized to build civic responsibility among the citizens.

1. Introduction

Scholars of sustainable disaster risk management assert that spatial planning plays a significant role in integrated disaster risk management, particularly through its potential contribution to long term disaster mitigation (Basawaraja et al., 2011; Steinberg and Lindfield, 2012; Wapwera and Egbu, 2013; Watson and Agbola, 2013; UNDP, 2015). In other words, effective risk-based planning aims to minimize damages to people and assets before a disaster strikes, but its performance in disaster mitigation requires a high level of technical and political cooperation and coordination, and equally a commitment from other societal stakeholders as partners in sustainable development (Onyenechere, 2010; Sutanta, 2012; Watson and Agbola, 2013).

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Spatial planning is increasingly being considered as an important mechanism in coping with flood risk (Schmidt-Thomé, 2006; A. Dewan, 2013; A.M. Dewan, 2013; Khailani and Perera, 2013). One of the reasons for this is that engineering approaches are increasingly expensive and cannot provide complete certainty of protection against flooding risk. In other words, planning is considered as the regulation of physical implementation as well as the process of policy-making that guides spatial development. This process is claimed to mainly involve the interaction and collaboration between actors (both public and private) (Kazmierczak and Cavan, 2011; Lu, 2014). However, spatial Planning is absent in most developing countries due to the stronghold by the traditional master planning approach to achieve controlled urban development and its management (Watson, 2009; Wapwera and Egbu, 2013).

It is vital to appreciate the role of geographic information system (GIS) and remote sensing technologies in planning for flooding disaster risks in urban watersheds. For instance, geospatial technology provides the best potential to analyze and provide results required for prompt and effective decision-making on floods (Dewan and Yamaguchi, 2009; Manfreda et al., 2011; Suriya and Mudgal, 2011; Albano et al., 2014; Samela et al., 2016, 2017b).

Given that flood hazard is spatial phenomenon, the application of GIS and Remote Sensing techniques are essential to the flood hazard/risk management process. For instance, Geographical Information Systems (GIS) with their ability to handle spatial data are an appropriate tool for processing spatial data on flood risk (Alfasi et al., 2012; Uddin et al., 2013; Samela et al., 2018). Moreover, flood hazard and risk maps are effective tools for reducing flood damage (Zerger and Smith, 2003; Marchi et al., 2010; Sayers et al., 2013; Wondim, 2016). Hazard zoning is also appreciated by scholars of disaster risk management in urban watersheds as it provide a detailed overview of the hazard situation and a basis for spatial planning processes (Balaban, 2009; Adedeji et al., 2012; Sutanta, 2012; Santato et al., 2013). Despite the aforementioned benefits of spatial planning for sustainable disaster risk management in urban watersheds in developing countries, lack of proper spatial planning and land use management coupled with poor adaptive capacity of governments to ensure good urban governance exacerbate the cases of urban flooding disaster risk.

Multi-criteria analysis methods are claimed as decision support tools for dealing with complex decision constellations where technological, economical, ecological, and social aspects have to be covered. These methods have been repeatedly combined with geographical information systems (GIS) and are therefore suitable to optimize the landuse planning (Levy, 2005; Wang et al.,2011; Bathrellos et al., 2012; Chowdary et al., 2013; Li et al., 2013; Yang et al., 2013; Guo et al., 2014). Spatial multi-criteria decision assessment/analysis (MCA) or multi-criteria evaluation (MCE) has received renewed interest because of the following: (1) it allows improved decision making; (2) it supports developing and evaluating alternative plans; and (3) it is predominantly appropriate for spatial decision making, as the data that the decision makers rely on are mostly related to space (Kubal et al. (2009);Chen et al., 2011; A. Dewan, 2013; A.M. Dewan, 2013; Zhiyu et al., 2013; Rahmati et al., 2016). The GIS-multi-criteria decision analysis (MCDA) approach is claimed to use the capabilities of GIS in the management of geospatial data and the flexibility MCDA to combine factual information (e.g., land use, slope, drainage system, etc.) with value-based information (e.g., expert opinion, standards, surveys, etc.) (Yahaya et al., 2010; Wang et al., 2011; Stefanidis and Stathis (2013); Zou et al., 2013; Gigovi´c et al., 2017; Rimba et al., 2017; Seejata et al., 2018).

Ethiopia is located in northeast Africa between 3° and 18 °North latitude and 33° and 48 °East longitude. Elevations range between 100 m below and 4600 m. above sea level. It has a land area of about 1,100,000 sq. km (Achamyeleh, 2003). The rainy season in Ethiopia is concentrated in the three months between June and September when about 80% of the rains are received. Torrential down pours are common in most parts of the country. As the topography of the country is rather rugged with distinctly defined watercourses, large scale flooding is rare and limited to the lowland areas where major rivers cross to neighboring countries. However, intense rainfall in the highlands could cause flooding of settlements close to any stretch of river course (Achamyeleh, 2003; Chibssa, 2007; Alemu, 2011; Dessie and Tadesse, 2013; Alemu, 2015; Getahun and Gebre, 2015).

Previous studies undertaken on the environmental problems of Ambo town and its watershed identified: low infiltration of rain Water, storm water occurrence, inundation of low gradient areas, incidence of sheet and gully erosion, inefficient and uncoordinated utilization of potential site and resources; sanitation problem associated with lack of waste collection system and disposal site for both solid and liquid waste, mixed waste disposal in open spaces and rivers, water stress, urban heat island effects, wind storms, dust storms, flash flood, growing water and air pollution, and unplanned expansion and deforestation as critical environmental challenges for urban development in Ambo town and its watershed (Ambo Town Administration Office, 2013; Ogato, 2013a). Moreover, UN-HABITAT (2008) affirms that the environment of Ambo town and its watershed has been in a constant decline characterized with most of the solid waste not properly collected, lack of environmental regulations and sanitation, absence of sewerage system in place, and lack of sanitary dumping site.

UN-HABITA (2008) further contends that the municipality of Ambo town is not in a position to address the aforementioned problems due to resource and capacity limitations. Furthermore, Ogato (2013a) and Ogato et al.(2017) assert that Ambo town and its dwellers are vulnerable to the negative impacts of climate change related hazards and mainstreaming climate change adaptation into urban planning is vital. This paper focuses on analyzing flooding hazard and risk from Geographic Information Systems(GIS)-based multicriteria perspective in Ambo town and its watershed and proposes strategic measures for sustainable flooding disaster risk management in urban watershed.

2. Research methodology

2.1. Description of the study area

Huluka watershed is located in West Shoa Zone, Oromia Regional State, Ethiopia. Geographically, it is located between 8°49′26″ to 8°55′22″N lat. and 37°49′50″ to 38°8′08″E long (Fig. 1).The total land area of the watershed is about 81,237 ha and composed of

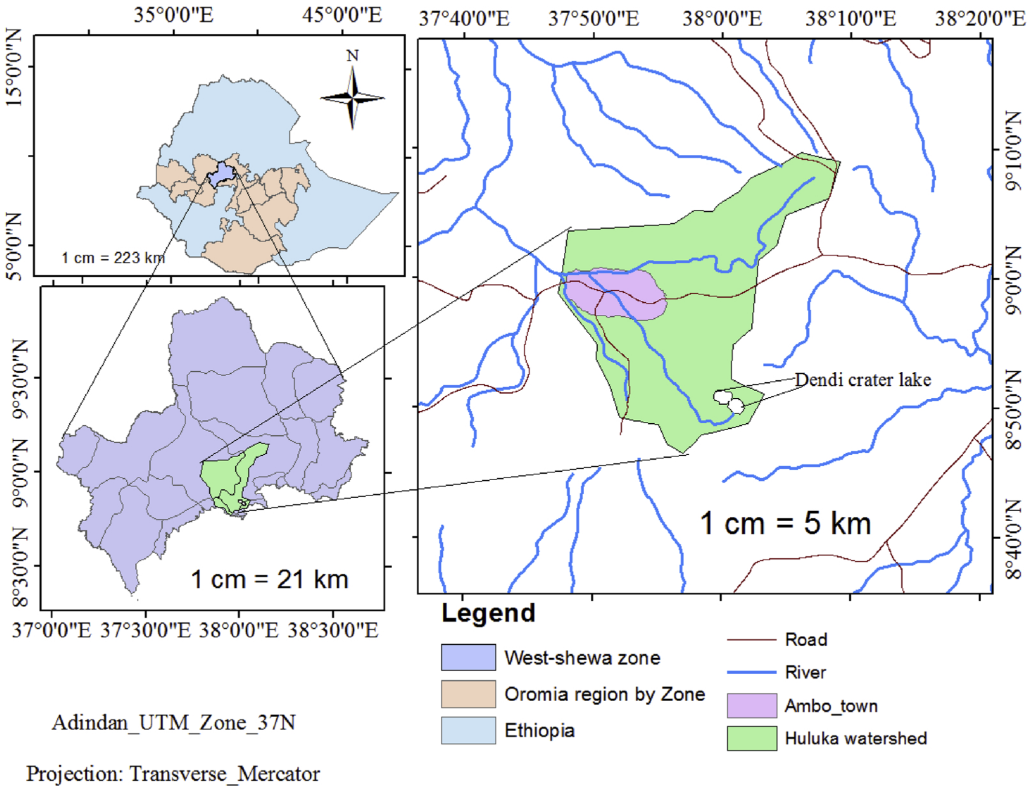

Fig. 1. Geographical location map of Huluka watershed.

villages mainly from Ambo, Dawo, Dendi, Elfeta,Jeldu, TokeKutaye and Wonchi districts and Ambo town. The total human population of the watershed is about 303,416 in the year 2017.

Seven land use/land cover types were identified in the watershed in the year 2017. The identified land use/land cover types in the watershed were: forest area, cultivated land area, urban built-up area, bush/shrub land area, bare land area, grassland area, and water area (Fig. 2).

Forest land covered 4232.253 ha (5.2%) in 2009 and 4298.85 ha(5.3)% in 2017. It increased by 1.6% between 2009 and 2017. Cultivated land covered 43,833.98 ha (54%) in 2009 and 51329.96 ha (63.2) % in 2017. It increased by 17.1% between 2009 and 2017. The increase of cultivated land in the watershed was attributable to the transformation of other land use/land cover types into cultivated land use/land cover type. Urban built-up area covered 425.79 ha (0.5%) in 2009 and 790.74 ha (1%) in 2017. It increased by 85.7% between 2009 2017. Bush/Shrub land covered 7907.733 ha (9.7%) in 2009 and 5635.09 ha (6.9%) in 2017. It decreased by 28.7% between 2009 and 2017. Bare land covered 431.46 ha (0.5%) in 2009 and 513.97 ha (0.6%) in 2017. It increased by 19.1% between 2009 and 2017. Water body covered 748.44 ha (0.9%) in 2009 and 749.07 ha (0.9%) in 2017. It increased by 0.1% between 2009 and 2017. Grassland covered 23657.14 ha (29.1%) in 2009 and 17919.11 ha (22%) in 2017. It decreased by 24.3% between 2009 and 2017 (Ogato, 2019).

The highest elevation in the watershed is 3253 ms above sea level while the lowest elevation of the watershed is 1834 m above sea level. The slope of the watershed ranges between 0% and 32.5%. The seven soil types dominating the watershed include: Chromic Luvisols, Chromic Vertisols, Eutric Cambisols, Eutric Nitisols, Leptosols, Orthic Luvisols, and Pellic Vertisos (Ogato, 2019). The watershed is drained by perennial major rivers (Huluka, Debis and Taltale); minor seasonal rivers (Aleltu, Awaro, Boji, Dobi, Kerise, Chafe Jara, Jalina, Maja, solbe, Jabdu and Sankale; and a number of intermittent or seasonal streams within the watershed (Ogato et al., 2017). The rainfall of the area is bimodal, with unpredictable short rains from March to April and the main season ranging over June to September. The highest mean total annual rainfall of the watershed over 32 years (1984–2015) was 1181 mm while the lowest was 1036 mm. The lowest and highest annual average temperature are 13 and 27 °C, respectively (Atnafe et al., 2015).

Ambo town in the watershed represent the urban feature of the watershed. The human population of Ambo town has been growing rapidly over the past few years. According to CSA (2017), the population of the town was 76,544 with the growth rate of 2.5%. The poor quality of housing and inability of the administration to increase supply could be taken as key indicators that a wide reform is necessary for Ambo town. Ambo is one of the oldest towns in Ethiopia (Established in 1889). It is among a few privileged towns of its time to have its own municipal administration since 1931, and a master plan since 1983 (United Nations Human Settlements Programme (UN-HABITAT), 2008; Ogato et al., 2017).

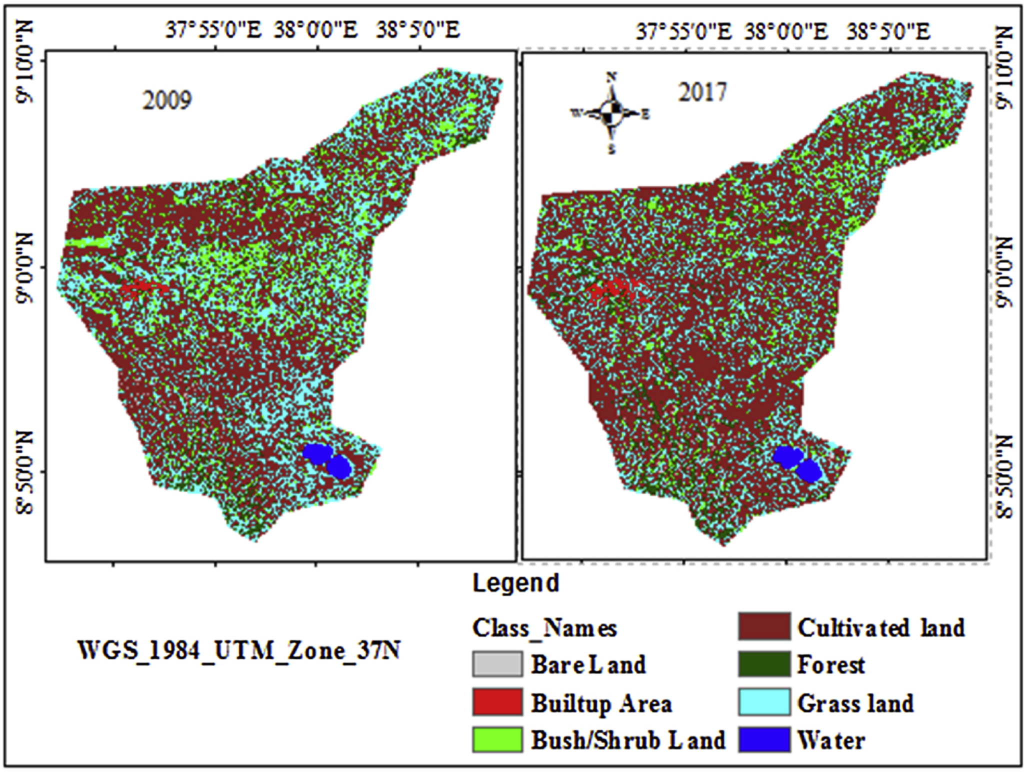

Fig. 2. Map of Land Use/Land Cover for the Watershed (2009 and 2017).

2.2. Methods of data collection

Landsat images of 2015; digital map on shape file with the scale of 1:50,000 from Ethiopian Mapping Authority; rainfall data (1984–2015) for the study watershed from the Ethiopian Metheorology Agency, Digital Elevation Model (DEM) of the watershed; soil types of Ethiopia; human population, and flood points in the watershed were the type of data used for the study. The sources of data included: Central Statistical Authority (CSA) of Ethiopia, Ethiopian Mapping Agency (EMA), Ethiopian Meteorology Agency, Landsat website of www.glovis.USGS.gov, urban and rural communities in Huluka watershed, urban planners of Ambo town, and land use planners and managers in the watershed. To collect relevant data to analyze flooding hazard and risk in the watershed, online Satellite Imagery (Monkkonen, 2008; Gondo and Zibabgwe, 2010); field observation; and document review were employed.

2.3. Methods of data analysis

2.3.1. Flooding hazard factors

The flooding hazard factors were determined by literature review, personal observation, and discussion with experts and local residents. As far as the key informants (experts and local residents) are concerned, 15 experts and 15 local elders were interviewed to decide the important factors causing flooding hazard. Accordingly, Land use/land cover, elevation, slope, drainage density, soil, and rainfall were considered as important flooding hazard factors in Ambo town's watershed.

1. Land Use/Land Cover Factor

Many scholars in the field of flooding risk management attest that land use/land cover change is one of the major contributor of flooding as urban expansion increases, impervious cover increases and forest cover decreases in urban areas contributing to increase in run-off (Tucci, 2007; Jha et al., 2012; Fura, 2013; Mngutyo and Ogwuche, 2013; Hall et al., 2014).

The existing land-use classes of the area were further reclassified into five groups in order of their capacity to increase or decrease the rate of flooding from very highly susceptible to very low susceptible. Accordingly, water body was ranked with the value of 5 as it is very highly susceptible to flooding hazard. Built-up area land use/land cover type was assigned the value of 4 as it is highly susceptible to flooding hazard. Cultivated land use/land cover type was assigned the value of 3 as it is moderately susceptible to flooding hazard. Grassland land use/land cover type was assigned the value of 2 as it is low susceptible to flooding hazard. Forest land use/land cover type was assigned the value of 1 as it is very low susceptible to flooding hazard.

2. Elevation Factor

Elevation has a key role in controlling the movement of the overflow direction and in the depth of the water level (Gigovi´c et al., 2017).

For elevation factor, the elevation raster map was prepared using the digital elevation model (DEM) and slope generation tools in ArcGIS software. The elevation raster layer was further reclassified into five sub groups using standard classification schemes namely Equal Interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, specifying the number of intervals while Arc Map determines where the breaks should be and new values re-assigned in order of flood hazard rating. In this classification process, the lowest elevation category is ranked to the value of 5 as it has very high susceptibility to flooding hazard while the highest elevation category is ranked to the value of 1 as it has very low susceptibility.

3. Slope Factor

The slope is the ratio of steepness or the degree of inclination of a feature relative to the horizontal plane (Rimba et al., 2017). Slope is an important indicator of surface zones, which are highly prone to flooding. Slope is a major factor in determining the rate and duration of water flow. On the flatter surface, water is moving more slowly, collects longer and accumulates so these areas are riskier with respect to the occurrence of floods in relation to the steeper surfaces (Gigovi´c et al., 2017; Rimba et al., 2017).

For slope factor, the slope raster map was prepared using the digital elevation model (DEM) and slope generation tools in ArcGIS software. The slope raster layer was further reclassified into five sub groups using standard classification schemes namely Equal Interval. This classification scheme divides the range of attribute values into equal-sized sub ranges, specifying the number of intervals while Arc Map determines where the breaks should be and new values re-assigned in order of flood hazard rating. In this classification process, the lowest slope category is ranked to the value of 5 as it has very high susceptibility to flooding hazard while the highest slope category is ranked to the value of 1 as it has very low susceptibility.

4. Drainage Density Factor

Drainage density (DD) a fundamental concept in hydrologic analysis is defined as the ratio of the length of drainage per basin area. Drainage density is controlled by permeability, erodability of surface materials, vegetation, slope and time. Flooding in Africa has been attributed to inadequate drainage causing overland flow and poor waste collection which can block drainage and water channels causing overland and river (fluvial) flooding (Few et al., 2004; Tucci, 2007; Rimba et al., 2017). Drainage density is an inverse function of infiltration. 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 (Chibssa, 2007; Wondim, 2016). Drainage density map could be derived from the drainage map. *i.e.*, drainage map is overlaid on watershed map to find out the ratio of total length of streams in the watershed to total area of watershed and is categorized.

The drainage density of the watershed is calculated as (Ouma and Tateishi, 2014):

$$D = L / A$$

, where, D = drainage density of watershed; L = total length of drainage channel in watershed (km); A = total area of watershed (km^2).

For drainage density factor, DEM was used to extract the drainage network from which the drainage density of the streams was calculated. Using the Spatial Analyst extension in ArcGIS environment, line density module was used to compute drainage density of the waterhsed. Line density module calculates a magnitude per unit area from polyline features that fall within a radius around each cell. The density layer is further reclassified into five sub group using standard classification schemes namely Equal Interval. In this classification, the highest drainage density category is ranked to 1 as it has very low susceptibility to flooding hazard while the lowest drainage density category is ranked to 5 as it has very high susceptibility.

5. Soil Factor

Soil characteristics in a watershed such as soil layer thickness, permeability, infiltration rate and the degree of moisture in the soil before the rain event have a direct effect on the rainfall-runoff process (Zhiyu et al.,2013; Rimba et al., 2017). The structure and infiltration capacity of soils will also have an important impact on the efficiency of the soil to act as a sponge and soak up water. Different types of soils have differing capacities. The chance of flood hazard increases with decrease in soil infiltration capacity, which causes increase in surface runoff. When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves down slope as runoff on sloping land, and can lead to flooding (Ouma and Tateishi, 2014).

For soil factor, the soil factor of the study area was derived from the FAO standard classification of Ethiopian soil (Mesfine, 1998; Food and Agricultural Organization (FAO), 2006; Assen and Tegene, 2008; Chekol, 2014; Assefa, 2015). The characteristics of each soil group were analyzed based on hydrologic soil grouping system. To this end, the soil group of the study area was grouped into five general classes and converted to raster format. Moreover, the soil raster layer group was reclassified into five groups and new values were reassigned in order of their flood hazard rating. Soil type that has very high capacity to generate very high flood rate is ranked to 5 and the one with very low capacity in generating flood rate is ranked to 1. Accordingly, Pellic and Chromic Vertisols were ranked to the value of 5 as they have very high susceptibility to flooding hazard. Leptosols were ranked to the value of 4 as they have high susceptibility. Orthic and Chromic Luvisols were ranked to the value of 3 as they have moderate susceptibility. Eutric Nitisols were ranked to the value of 2 as they have low susceptibility. Eutric Cambisols were ranked to the value of 1 as they have very low susceptibility to flooding hazard.

6. Rainfall Factor

Many scholars in the field of flooding risk management contend that flooding risk is the most widespread climate change-related disaster risk in the world, and historically floods have been the most prevalent cause of death from natural disasters (Zhiyu et al.,2013; Jha et al., 2012; Santato et al., 2013). Changes in the global climate and individual climatic variables can affect floods in various ways, together with soil moisture and snow storage. Generally, a warmer atmosphere can hold more water vapour, which may increase heavy precipitation and therefore floods (Hall et al., 2014; Ouma and Tateishi, 2014). More extreme rainfall means more likelihood of floods, particularly flash floods (Few et al., 2004; Guo et al., 2014). Moreover, flooding is one of the most widespread of climatic hazards and poses multiple risks to human health (Few et al., 2004; Dang et al., 2011).

For rainfall factor, point rainfall data for 32 years (1984–2015) collected at ten stations (Ambo Plant Protection Research Center, Ginchi, Asgori, Busa, Gedo, Jeldu, Tikur Enchini,Tulu Bolo, WelenKomi, and Woliso) within and around the watershed were received from the Ethiopian Metrology agency. As the data received were monthly total rainfall, total annual rainfall for each year at each station and mean of 32 years (1984–2015) for each station were calculated and then interpolated to Inverse Distance Weight (IDW) in ArcGIS environment. Then it was converted to raster layer to create a continuous raster rainfall data within and around the watershed. This was finally reclassified into five classes using Equal Interval. In this classification, the highest rainfall category was ranked to the value of 5 as it has very high contribution for flooding hazard. On the other hand, the lowest rainfall category is ranked to the value of 1 as it has very low contribution for flooding hazard.

2.3.2. Flooding risk factors

To analyze flooding risk in Ambo town and its watershed, flooding hazard layer, population density, and land use/land cover type were considered as three important factors. These three factors were considered to be equally important in the weighted overlay process.

1. Population Density Factor

Gross population density calculation method is used to calculate the number of person per square kilometers in the watershed. To this end, the human population estimation for the year 2017 at each village in the watershed was considered. Then population shape file was converted to raster layer using Conversion Tools/Feature to Raster. Then, the data layer was reclassified into five sub-factors which are classified using equal interval method and new values re-assigned in order of increasing number of population that is more susceptible to flood hazard. The population density was reclassified in the assumption that the denser the population, the more vulnerable it will be to flood hazard. Accordingly, the highest population density category is ranked to the value of 5 as it is very highly susceptible to flooding risk. On the other hand, the lowest population density category was ranked to the value of 1 as its susceptibility to flooding risk is very low.

2. Land Use Type Factor

The existing land-use classes of the area (water body, built-up, cultivated land, grass land, and forest) were reclassified into five groups in order of their susceptibility to flooding risk. The land use types of the sub-basin were reclassified into a common scale in order of sensitivity for the flood risk analysis. Accordingly, water body was ranked with the value of 5 as it is very highly susceptible to flooding risk. Built-up area land use/land cover type was ranked with the value of 4 as it is highly susceptible to flooding risk. Cultivated land was ranked with the value of 3 as it is moderately susceptible to flooding risk. Grassland land use/land cover type was ranked with the value of 2 as it is low susceptible to flooding risk. Forest land use/land cover type was assigned the value of 1 as it is very low susceptible to flooding risk.

3. Flooding hazard layer

Flooding hazard layer was considered as one of the flooding risk contributing factor in Ambo town's watershed. Very low, low, moderate, high, and very high flooding hazard classes were reclassified based on their susceptibility to flooding risk. Very high flood hazard layer was ranked with the value of 5 as it has the highest susceptibility to flooding risk. On the other hand, very low flooding hazard layer was ranked with the value of 1 as it has the lowest susceptibility to flooding risk.

2.3.3. Integration of analytical hierarchy process (AHP) into Geographic Information Systems (GIS)

This study employed the Geographic Information Systems (GIS)-based multicriateria analysis approach (Wang et al., 2011; Zou et al., 2013; Gigovi´c et al., 2017; Rimba et al., 2017) to analyze flood hazard and risk in Ambo town and its watershed.

Flood risk evaluation is an intrinsically complex multidimensional process including both quantitative and qualitative factors which may be uncertain (Yang et al., 2013). Analytic hierarchy process established by Saaty is a method to solve multiple criteria decision problems by setting their priorities. Analytical hierarchy process (AHP) was adopted for multicriteria decisions in urban flooding hazard and risk analysis (Yahaya et al., 2010; Chowdary et al., 2013; Li et al., 2013; Guo et al., 2014; Rimba et al., 2017). In AHP, multiple pairwise comparisons are based on a standardized comparison scale of nine levels (Saaty, 1977). The nine points are chosen because psychologists conclude that, nine objects are the most that an individual can simultaneously compare and consistently rank (Table 1). Pairwise judgements are made based on the best information available and the decision maker's knowledge

Table 1
Nine-point Pair wise comparison scale.
Source: (Saaty, 1977).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one parameter over another
5	Strong importance	Experience and judgment strongly favor one parameter over another
7	Very strong importance	One parameter is favored very strongly and is considered superior to another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one parameter as superior to another is of the highest possible order of affirmation

Note: 2,4,6,8 can be used to express intermediate values, 1.1, 1.2, etc. for parameters that are very close in importance.

and experience (Chen et al., 2011; Dang et al., 2011; Youssef et al., 2011; Bathrellos et al., 2012; Ouma and Tateishi, 2014; Gigović et al., 2017).

The process of AHP can be summarized in four steps: construct the decision hierarchy; determine the relative importance of attributes and sub-attributes; evaluate each alternative and calculate its overall weight with regard to each attribute, and check the consistency of the subjective evaluations (Bathrellos et al., 2012; Yang et al., 2013; Ouma and Tateishi, 2014).

Let $C = \{C_j \mid j = 1,2,\ldots..,n\}$ be the set of criteria. The result of the pairwise comparison on n criteria can be summarized in an (n_n) evaluation matrix A in which every element a_{ij} $(i, j = 1,2,\ldots..,n)$ is the quotient of weights of the criteria, as given in Eq. (1) (Ouma and Tateishi, 2014):

$$A = \begin{bmatrix} a_{11}\, a_{12}\, . & a_{1n} \\ a_{21}\, a_{22}. & a_{an} \\ . \;. \quad . & . \\ a_{n1}\, a_{n2}. & a_{nn} \end{bmatrix},\ a_{ii} = 1,\ a_{jj} = 1/a_{jj},\ a_{jj} \neq 0 \tag{1}$$

The right eigen value (v) corresponding to the maximum eigen value (λ_{max}) is calculated to normalize and find the relative weight (A_v) of the matrix by following Eq. (2) (Ouma and Tateishi, 2014):

$$A_w = \lambda_{max} w \tag{2}$$

It is highly recommended that the pairwise comparisons in AHP are completely consistent and in this case the matrix A has rank 1 and $\lambda_{max} = n$. In this case, weights can be obtained by normalizing any of the rows or columns of the matrix A**)**. The quality of the output of the AHP is claimed to be strictly related to the consistency of the pairwise comparison judgments. The consistency is normally defined by the relation between the entries of A: $a_{ij} \times a_{jk} = a_{ik}$. The consistency index (*CI)* is given by Eq. (3) (Ouma and Tateishi, 2014):

$$CI = (\lambda_{max} - n)/(n - 1) \tag{3}$$

Where λ_{max} represents the sum of the products between the sum of each column of the comparison matrix and the relative weights and n represents the size of the matrix.

The final calculation is the consistency ratio (*CR*) which is the ratio of the CI and random index (RI) as expressed in Eq. (4):

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{4}$$

Where CI represents the consistency index, RI is the random index representing the consistency of a randomly generated pairwise comparison matrix. It is derived as average random consistency index, computed by Saaty (1980). CR represent consistency ratio.

The values of RI are tabulated in Table 2 and RI value for six parameters is 1.24 (Saaty, 1980). The maximum threshold of CI is $\leq$ 0.1 and CR $\leq$ 10%. The rational value is when the CI and CR have fulfilled the maximum threshold value. The usage of CR lets the user to conclude whether the evaluations are sufficiently consistent Table 3.

The normalized pair-wise comparison matrix is derived by making equal to 1 the sum of the entries on each column. Finally, the objective weight of each factor was built by averaging the entries on each row (Table 4). The basic advantage is that the AHP limits the cognitive demand on the decision maker and provides an approach for checking the consistency of the comparisons. The consistency ratio (CR) is used in order to check inconsistency and limit the possibility of random selection during the construction of the comparison matrix (Bathrellos et al., 2012; Ouma and Tateishi, 2014).

Λmax for Flood contributing factors in the watershed = $2.13 \times 0.42 + 5 \times 0.23 + 7.9 \times 0.15 + 12.5 \times 0.1 + 19 \times 0.06 + 28 \times 0.04 = 6.4$

CR = CI/RI; CI = λ_{max}-n/n-1

RI = Random consistency index and RI = 1.24 for six factors (Table 2).

N = Number of criteria = 6

λ_{max} represents the sum of the products between the sum of each column of the comparison matrix and the relative weights. CR for the flood contributing factors in Ambo town's watershed is 0.06 which is less than the standard 0.1. Hence, the pair-wise matrix ranking is accepted.

To calculate the weight and ranking in each factor, the pair-wise comparison matrix and factor map are employed. The weight value provided the prioritized factor expressed as a percentage value between 0 and 100%. Using a linear weighted combination, the sum of weight was expressed as 100%. A summary of targeted factors, their weights and rankings are listed in Table 5 hereunder. The information provided in the table was applied to generate the flooding hazard map in the study watershed. The ranking of each reclassified factor is based on the literature review, expert interview and local residents' interview. The range of ranking was 1–5; the highest influence factor was rank 5 and the lowest influence factor was 1. The order of normalized weight was land cover (42%),

Table 2
Random index (RI) used to compute consistency ratios (CR).
Source: (Saaty, 1980).

N	1	2	3	4	5	6	7	8	9	10
Random Index(RI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3
Ranking of flood hazard contributing factors in the watershed.
Source: (Based on Experts' and local residents' interview, 2019).

Flood Hazard Factors	Land Cover (LC)	Slope (S)	Soil Type (ST)	Rainfall (RF)	Drainage Density(DD)	Elevation (E)
Land Cover	1	3	3	5	7	8
Slope	0.33	1	3	3	5	6
Soil Type	0.33	0.33	1	3	3	5
Rainfall	0.2	0.33	0.33	1	3	5
Drainage Density	0.14	0.2	0.33	0.33	1	3
Elevation	0.13	0.16	0.2	0.2	0.33	1
Total	**2.13**	**5.02**	**7.86**	**12.53**	**19.33**	**28**

λ_{max} represents the sum of the products between the sum of each column of the comparison matrix and the relative weights.

Table 4
Weighted Comparison table.
Source: (Weighted Comparison Based on Experts' and local residents' interview, 2019)

Flood Hazard Factors	Land Cover (LC)	Slope (S)	Soil Type (ST)	Rainfall (RF)	Drainage Density(DD)	Elevation (E)	Priority Vector X	Percent
Land Cover	0.5	0.6	0.38	0.39	0.36	0.29	0.42	42%
Slope	0.1	0.2	0.38	0.24	0.26	0.21	0.23	23%
Soil Type	0.1	0.07	0.13	0.24	0.16	0.18	0.15	15%
Rainfall	0.1	0.07	0.042	0.08	0.16	0.18	0.1	10%
Drainage Density	0.1	0.04	0.042	*0.03*	0.05	0.11	0.06	6%
Elevation	0.1	0.03	0.03	*0.02*	0.02	0.04	0.04	4%
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**100** %

The natural values were normalized by adding the column values and dividing the value of each cell by the total of column values.

Table 5
Weighted flooding hazard ranking for the watershed.
Source: (Based on Experts' and local residents' interview, 2019 and literature review, 2019)

Parameters	Relative Weight	Reclassified Parameter	Ranking	Hazard
Slope (Degree)	23%	26.04-32.55	1	Very low
		19.53-26.04	2	Low
		13.02–19.53	3	Moderate
		6.51-13.02	4	High
		0-6.51	5	Very high
Elevation (Meters)	4%	2969-3253	1	Very low
		2685-2969	2	Low
		2402-2685	3	Moderate
		2118-2402	4	High
		1834-2118	5	Very high
Rainfall (mm)	10%	1036-1065	1	Very low
		1065-1094	2	Low
		1094-1123	3	Moderate
		1123-1152	4	High
		1152-1181	5	Very high
Drainage Density (km/Km^2)	6%	11.04-13.8	1	Very low
		8.28-11.04	2	Low
		5.52-8.28	3	Moderate
		2.76-5.52	4	High
		0-2.76	5	Very high
Soil Type	15%	Eutric Cambisols	1	Very low
		Eutric Nitisols	2	Low
		Orthic and Chromic Luvisols	3	Moderate
		Leptosols	4	High
		Pellic and Chromic Vertisols	5	Very High
Land use/Land Cover	42%	Forest	1	Very low
		Grassland	2	Low
		Cultivated land	3	Moderate
		Built-up area	4	High
		Water Body	5	Very high

slope (23%), soil type (15%), rainfall (10%), drainage density (6%), and elevation (4%). Looking at the weight of each factor, one can see that land cover has the highest weight. It implies that land cover has more contribution to flooding than other factors.

Once the weight in each factor was determined, the multi-criteria analysis was performed to produce a flooding hazard map by using the GIS approach. In other words, weighted linear combination (WLC) method is used in the process of criteria map aggregation. The underpinning reason for employing WLC is that low scores in one criterion are compensated by high scores in another one in the process of aggregating the criteria flooding hazard maps. In other words, the weighted linear combination (WLC) method multiplies each fuzzy standardized criteria map with criteria weights, obtaining different variations from the AHP method, and then sums the results (Bathrellos et al., 2012; Gigovi´c et al., 2017). Accordingly, flooding hazard map for the watershed was computed as shown in Eq. (5):

$$\text{Flooding hazard Index} = 0.42\text{xlanduse/landcover} + 0.23\text{xslope} + 0.15\text{xsoil type} + 0.1\text{xrainfall} + 0.06\text{xdrainage density} + 0.04\text{xelevation} \quad (5)$$

The result was the flooding hazard area in the watershed. It was categorized into five hazard classes: very low, low, moderate, high, and very high.

To compute the flooding risk map for the watershed, a weight linear combination was applied as shown in Eq. (6):

$$\text{Flooding risk Index} = 0.3333\text{xflooding hazard} + 0.3333\text{xpopulation density (person per square kilometers)} + 0.3333\text{xland use/land cover} \quad (6)$$

Flood risk analysis and mapping for the watershed was done using the flooding hazard layer and the two elements at risk, namely population and land use/land cover (Wondim, 2016). These three factors were considered to be equally important in the weighted linear combination (WLC) process. A summary of targeted factors, their weights and rankings are listed in Table 6 hereunder. The information provided in the table was applied to generate the flooding risk map in Ambo town's watershed. The result was the flooding risk area in the watershed. It was categorized into five risk classes: very low, low, moderate, high, and very high.

3. Results

3.1. Flood hazard analysis and mapping in Ambo Town's watershed

3.1.1. Contributing factors for flood hazard

Land use and land cover was considered as one of the flood hazard contributing factor in Ambo town's watershed. Forest, grass land, cultivated land, built-up area, and water body were rated as very low, low, moderate, high, and very high flooding hazard land use and land cover respectively. Elevation was considered as one of the flooding hazard contributing factor in Ambo town's watershed. The highest elevation of the watershed is 3253 m while the lowest elevation is 1834 m. The lowest elevation category (1834 m–2118 m) was rated as very high flooding hazard elevation category while the highest elevation category (2969 m–3253 m) was rated as very low flooding hazard elevation category. Slope was considered as one of the flood hazard contributing factor in Ambo town's watershed. The highest slope of the watershed is 32 ° while the lowest slope is 0 °. The lowest slope category (0–6.51 degree) was rated as very high flooding hazard slope category while the highest slope category (26.04–32.55 degree) was rated as very low flooding hazard slope category.

Drainage density was considered as one of the flood hazard contributing factor in Ambo town's watershed. The highest drainage density the watershed is 13.8 km/Km^2 while the lowest drainage density is 0 km/Km$^{2.}$ The lowest drainage density category (0–2.76 km/Km^2) was rated as very high flooding hazard drainage density category while the highest drainage density category

Table 6
Weighted flooding risk ranking for the watershed.
Source: Adapted from Wondim, 2016)

Parameters	Relative Weight	Reclassified Parameter	Ranking	Hazard
Flooding hazard Classes	33.33%	Very low	1	Very low
		Low	2	Low
		Moderate	3	Moderate
		High	4	High
		Very high	5	Very high
Population Density(Person/Sq.km)	33.33%	0-58	1	Very low
		58-161	2	Low
		161-209	3	Moderate
		209-1846	4	High
		1846-6596	5	Very high
Land use/Land Cover	33.33%	Forest	1	Very low
		Grassland	2	Low
		Cultivated land	3	Moderate
		Built-up area	4	High
		Water Body	5	Very high

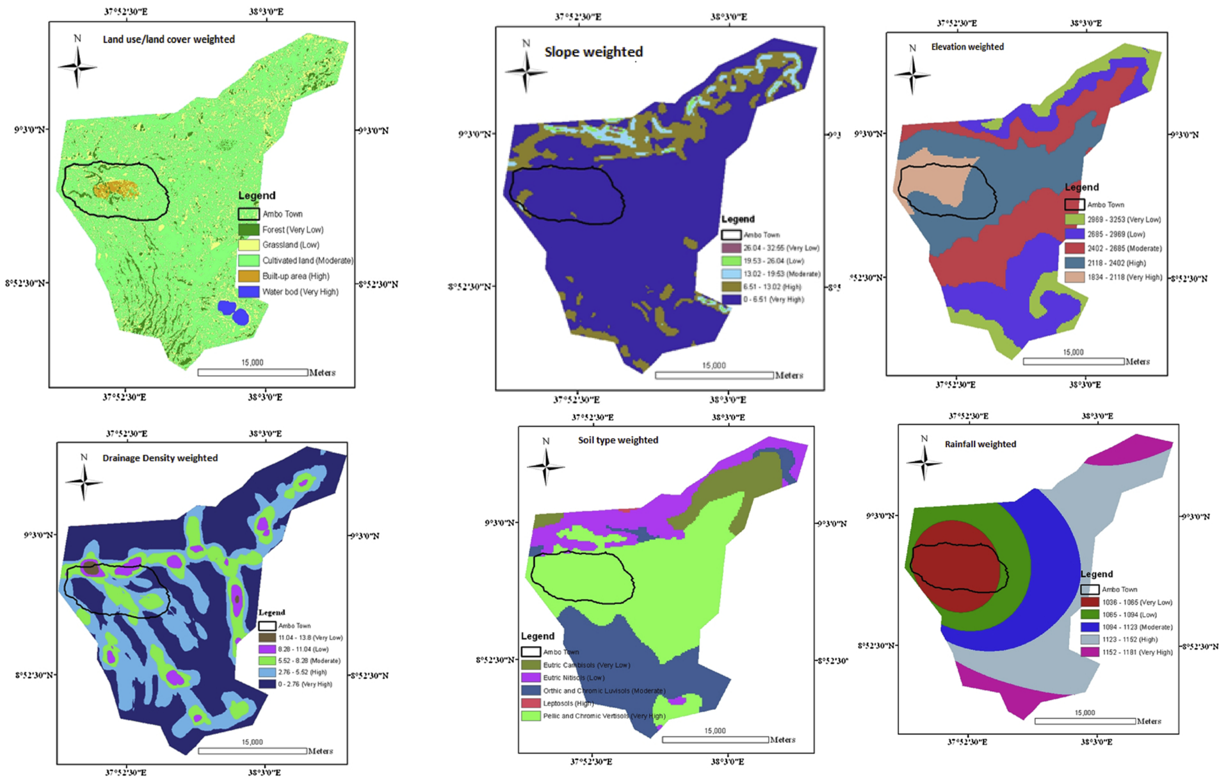

Fig. 3. Land use, slope, elevation, drainage density, soil type, and rainfall as flooding hazard factors.

(11.04–13.8 km/Km^2) was rated as very low flooding hazard category. Soil type was considered as one of the flooding hazard contributing factors in Ambo town's watershed. Eutric Cambisols, Eutric Nitisols, Orthic and Chromic Luvisols, Leptosols, and Pellic and Chromic Vertisols were rated as very low, low, moderate, high, and very high flooding hazard soil type respectively. Rainfall was considered as one of the flood hazard contributing factor in Ambo town's watershed. The highest average annual rainfall of the watershed is 1181 mm while the lowest average rainfall is 1036 mm. The lowest rainfall category (1036 mm–1065 mm) was rated as very low flooding hazard category while the highest rainfall category (1036 mm–1065 mm) was rated as very high flooding hazard rainfall category (Fig. 3).

3.1.2. Flood hazard mapping in the watershed

The result of the flooding hazard in the watershed reveals that 32.24% (260,287,200 m^2), 28.34 % (228753900m^2), 23.95 % (193336190m^2), 11.58 %(93468600m^2), and 3.89 % (31430700m^2) of the watershed is high, very high, moderate, low, and very low flooding hazard area respectively. This implies that more proportion of the watershed is high and very high flooding hazard area (60.58%). Moreover, 34.59% (29348100m^2) and 32.28% (27385200 m^2) of Ambo town is high and very high flooding hazard area respectively (Fig. 4). This implies that more proportion of the town is high and very high flooding hazard area (66.87%).

3.2. Flood risk analysis and mapping in Ambo Town's watershed

3.2.1. Contributing factors for flood risk

Human population density was considered as one of the flooding risk contributing factor in Ambo town's watershed. The highest human population density of the watershed is 6596 persons/Km^2 while the lowest human population density is 0 persons/Km^2. The lowest human population density category (0–58 persons/Km^2) was rated as very low flooding risk human population density category while the highest human population density category (1846–6596 persons /Km^2) was rated as very high flooding risk category. Land use and land cover was considered as one of the flooding risk contributing factor in Ambo town's watershed. Forest, grass land, cultivated land, built-up area, and water body were rated as very low, low, moderate, high, and very high flooding risk land use and land cover respectively. Flooding hazard layer was considered as one of the flooding risk contributing factor in Ambo town's watershed. Very low, low, moderate, high, and very high flooding hazard area was rated as very low, low, moderate, high, and very high flooding risk area respectively.

3.2.2. Flood risk mapping in Ambo Town's watershed

The result of the flooding risk in the watershed reveals that 27.87% (224,951,390 m^2), 27.64 % (223114500m^2), 22.46 %

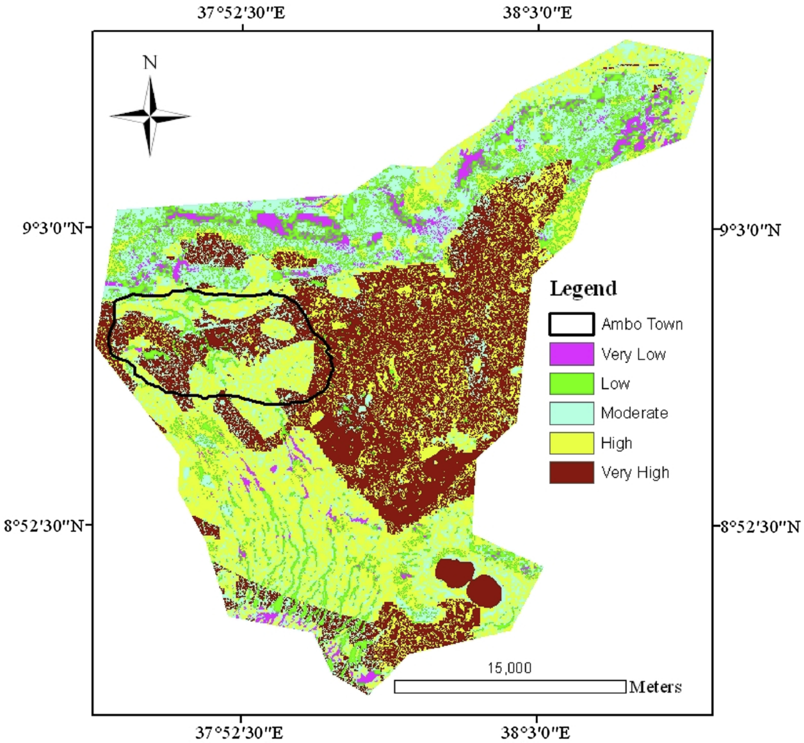

Fig. 4. Flooding hazard Map of the watershed.

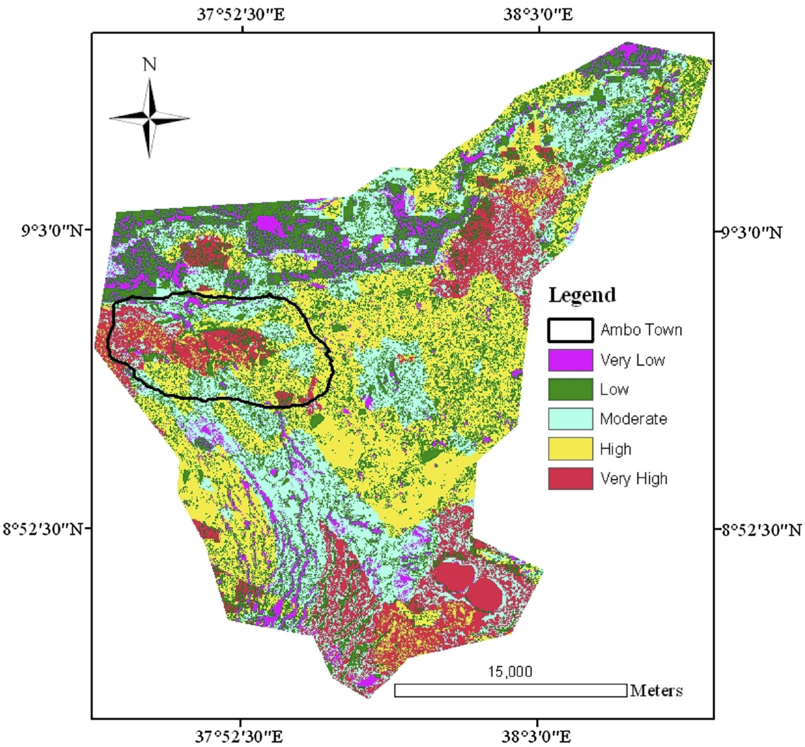

Fig. 5. Flood risk Map for the Watershed.

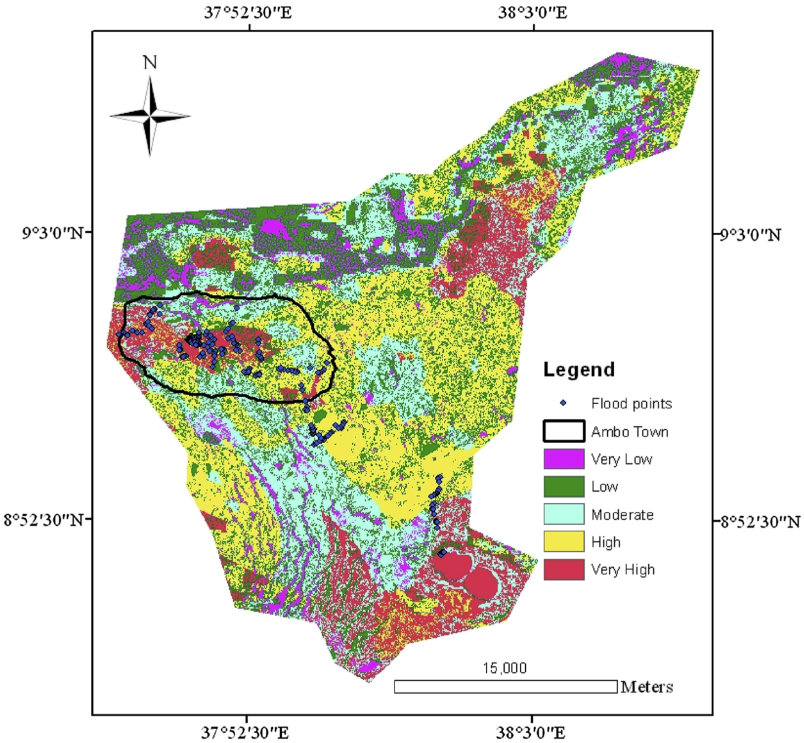

Fig. 6. Distribution of ground truth points of flood risk areas in the watershed.

(181287010m^2), 13.79 %(111294900m^2), and 8.25 % (66628800m^2) of the watershed is high, low, moderate, very high, and very low flooding risk area respectively. This implies that more proportion of the watershed is high and very high flooding risk area (41.76 %). Moreover, 27.70 % (23506200m^2) and 22.39 % (18997200m^2) of Ambo town is high and very high flooding risk area respectively (Fig. 5). This implies that half of the town is high and very high flooding risk area (50.09 %).

3.3. *Verification and observation of flood risk in Ambo Town's watershed*

Verification and observation of flood risk was made during 2017 rainy season (June, July, August, and September) in Ambo town's watershed to compare the final flood risk mapping with the current real field condition in the watershed. To this end, 259 GPS reading ground truth data of flood affected areas across different land use and land cover types were registered and converted to shape file. These point shape files were superimposed with the flood risk map and the flood risk map was verified with the actual field situations (Figs. 6 and 7)

4. Discussion

Flood disasters are among the most frequent and devastating types of disasters over the world. It is necessary to analyze flood risk to ensure healthy and sustainable economic development, and flood risk assessment has become worldwide one of the hot issues in the field of natural science and technology (Yahaya et al., 2010; Zou et al., 2013). Scholars of sustainable urban flooding risk management assert that comprehensive flood risk assessment is a synthetic evaluation and consists of many factors, including the hazard of disaster-inducing factors and disaster-breeding environment, as well as the vulnerability of hazards-bearing bodies (Zerger and Smith, 2003; Sayers et al., 2013; Zou et al., 2013; Guo et al., 2014). For instance, assessing areas vulnerable to flooding disasters is one of the parameters in creating a flood-risk map for disaster mitigation and urban planning (Dang et al., 2011; Wang et al., 2011; Ouma and Tateishi, 2014; Islam et al., 2016; Gigovi´c et al., 2017; Rimba et al., 2017).

This study considered land use/land cover, elevation, slope, drainage density, soil, and rainfall as important flooding hazard factors in Ambo town's watershed. Many scholars in the field of sustainable flooding hazard and risk management attest that land use/land cover change is one of the major contributor of flooding hazard as urban expansion increases, impervious cover increases and forest cover decreases in urban areas contributing to increase in run-off (Tucci, 2007; Jha et al., 2012; Mngutyo and Ogwuche, 2013; Migosi, 2014). For scholars like Gigovi´c et al. (2017) **e**levation has a key role in controlling the movement of the overflow

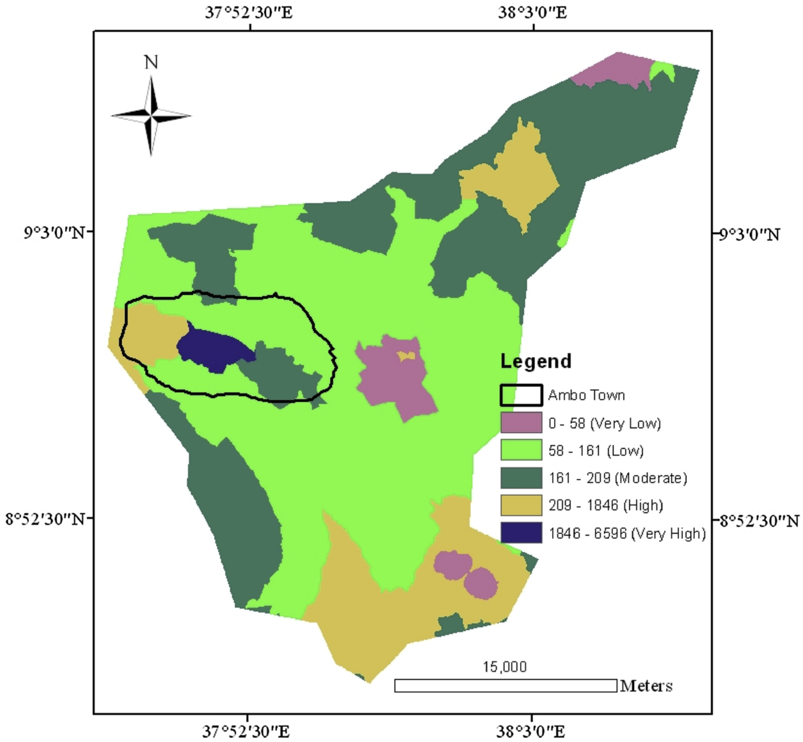

Fig. 7. Human Population Density of Ambo Town's Watershed.

direction and in the depth of the water level. Slope is a major factor in determining the rate and duration of water flow as flatter surface areas are riskier with respect to the occurrence of floods in relation to the steeper surfaces (Gigovi´c et al., 2017; Rimba et al., 2017).

Drainage density is one of the important flooding hazard factors and it is an inverse function of infiltration (Chibssa, 2007; Ouma and Tateishi, 2014; Wondim, 2016). Soil characteristics in a watershed such as soil layer thickness, permeability, infiltration rate and the degree of moisture in the soil before the rain event have a direct effect on the rainfall-runoff process (Zhiyu et al.,2013; Ouma and Tateishi, 2014; Rimba et al., 2017). Observed and projected patterns of climate change can have an amplifying effect on existing flood risk. For example, changing local rainfall patterns may lead to more frequent and higher level of floods from rivers and more intense flash flooding (Andjelkovic, 2001; Few et al., 2004; Jha et al., 2012; Berggren et al., 2013; Hall et al., 2014).

This study considered flooding hazard layer, population density, and land use/land cover type as the three important factors for flooding risk mapping and these three factors were considered to be equally important in the weighted overlay process (Chibssa, 2007; Wondim,2016). Scholars of sustainable urban flooding risk management contend that flooding risk is contributed to by two components, flood hazard and flood vulnerability. The flood hazard component represents physical processes, whereas flood vulnerability represents susceptibility to damage or loss, the risk of human lives, property or human activities (Dang et al., 2011). The flood risk maps thus developed are useful to policy-makers and responsible authorities, as well as to local residents in finding suitable measures for reducing flood risk in the study area (Dang et al., 2011). Without flood risk maps it is not easy to identify the areas at risk, and without a systematic way of making development decisions there will be no consistency in deciding how and where to reduce urban encroachment into at-risk areas. The availability of the land use plan gives readily available guidance to developers, planners and others on which areas may be developed for which uses, and allows the incorporation of flood risk information into their decisions and judgements (Zerger and Smith, 2003; Sayers et al., 2013).

Urbanization, as the defining feature of the world's demographic growth, is implicated in and compounds flood risk (Few et al., 2004; Jha et al., 2012; Santato et al., 2013). Few et al. (2004) contend that human vulnerability to floods is affected by drivers of change like population growth and settlement pattern. In other words, as cities become larger and larger, and as populations become more and more urbanized, urban environmental effects will increase (Andjelkovic, 2001; Few et al., 2004; Santato et al., 2013).

Population growth is asserted to be one of the contributors for urban flooding risk as human population in cities and towns in developing countries is rapidly growing and there is settlement of watersheds and valley bottoms greatly altering drainage patterns and destabilizing slopes and resulting in increasing the risks of flooding and landslides (Dewan et al., 2007; Diagne, 2007; Jha et al., 2012; Wilby and Keenan, 2012; Santato et al., 2013). Dewan et al. (2007) contend that increasing population pressure may force many people to enter the vacant land of cities and towns of least developed countries by filling up of natural channels and floodplains which may result in increased flood risk. In other words, when population growth is faster than the rate at which the municipal authorities or the private sector can provide housing and basic infrastructure, risks can build up quickly. Moreover, settlement of watersheds and valley bottoms has greatly altered drainage patterns and destabilized slopes, increasing the risks of flooding and landslides (Diagne, 2007; Dewan et al., 2007; Few et al., 2004; Santato et al., 2013).

According to Jha et al. (2012), the accelerating urbanization and urban development could also increase significantly the risk of flooding independent of climate change. The impact of future urban growth on flood risk is influenced by the policies and choices of urban dwellers as they may or may not occupy areas at risk of flooding, or adopt suitable urban planning and design (Few et al., 2004; Pottier et al., 2005; Tucci, 2007; Jha et al., 2012). In other words, better planned and managed urban development can mitigate the expected growth in future flood risk (Tucci, 2007; Jha et al., 2012; Kobayashi and Porter, 2012; Mngutyo and Ogwuche, 2013).

5. Conclusions and recommendations

The study focused on analyzing flooding hazard and risk from Geographic Information Systems(GIS)-based multicriteria perspective in Ambo town and its watershed and proposed strategic measures for sustainable flooding disaster risk management in urban watershed. The flooding hazard factors were determined by literature review, personal observation, and discussion with experts and local residents. Accordingly, Land use/land cover, elevation, slope, drainage density, soil, and rainfall were considered as important flooding hazard factors in Ambo town's watershed. Analysis of flooding risk was undertaken for Ambo town's watershed using flooding hazard layer and the two elements at risk, namely human population and land use. Weighted linear combination (WLC) method was used in the process of criteria map aggregation for both flooding hazard and flooding risk.

The result of the flooding hazard in the watershed reveals that 32.24 % (260,287,200 m^2), 28.34 % (228753900m^2), 23.95% (193336190m^2), 11.58%(93468600m^2), and 3.89% (31430700m^2) of the watershed is high, very high, moderate, low, and very low flooding hazard area respectively. This implies that more proportion of the watershed is high and very high flooding hazard area (60.58%). Moreover, 34.59% (29348100m^2) and 32.28% (27385200 m^2) of Ambo town is high and very high flooding hazard area respectively. This implies that more proportion of the town is high and very high flooding hazard area (66.87%). The result of the flooding risk in the watershed reveals that 27.87% (224951390m^2), 27.64% (223114500m^2), 22.46% (181287010m^2), 13.79%(111294900m^2), and 8.25% (66628800m^2) of the watershed is high, low, moderate, very high, and very low flooding risk area respectively. This implies that more proportion of the watershed is high and very high flooding risk area (41.76%). Moreover, 27.70% (23506200m^2) and 22.39 % (18997200m^2) of Ambo town is high and very high flooding risk area respectively. This implies that half of the town is high and very high flooding risk area (50.09%).

As sustainable flooding risk management at urban watershed demand integrated flooding risk management measures (combination of structural and non-structural measures), the following recommendations are forwarded:

- Institutional framework should be strengthened in relation to institutional arrangements, content of urban flood management policies and plans, implementation process, and legislative framework;
- Timely mitigation and preparedness measures should be in place in order to minimize the likely adverse impacts of flooding on lives and livelihoods;
- Participatory planning should be encouraged as it can contribute to public acceptance and support avoiding potential conflicts;
- An integrated basin wide approach to flood management should be practiced as it is essential to address multiple water related issues at watershed level;
- Land use planning and regulation together with building and infrastructure codes and design practices can substantially reduce the vulnerability of the people and other urban activities;
- For sustainable water resources development and integrated flood management the long term and short term planning should be incorporated;
- No matter what approach is employed for effective management it will not work unless the principles of good governance are being practiced;
- Environmental education should be emphasized to build civic responsibility among the citizens;
- Sustainable Drainage Systems (SUDs) should be practiced in urban environment as it helps to minimize the impact of urban development on the flooding and pollution of waterways;
- The watershed management plan comprising afforestation, reforestation, soil and water conservation practices for the upland development should work to regulated discharge of water at downstream.
- Distributed rainwater hydrological circulation repair measures (examples: using water permeable bricks on squares and pavements; constructing concave down greenbelts, infiltration wells, infiltration tubes, infiltration channels and infiltration ponds in front and behind the buildings) should be taken to construct urban rainwater storage and infiltration spaces which are suitable to local circumstance;
- Establishing urban rainwater storage-infiltration system is helpful to reduce flood hazard;
- Constructing reservoirs to cut down the flood into downstream reach and to reduce the intensity of flooding disaster risk;
- Establishing flood-diversion area and flood storage area to change the spatial distribution of floods and consequently to reduce the flood threats on high population and assets density area;
- Constructing two-floor or higher buildings or flat-roof buildings with water-proof materials to facilitate in situ flood escape;
- Constructing flood escape transfer channel and temporary refuge facilities;

- Developing reliable communication and data acquisition network;
- Building flood alarm and emergency response plan;
- It is necessary to pay attention to the coordination between urban development and flood hazard through appropriate spatial planning and land use management; and
- Compiling flood hazard and risk maps and making region divisions on forbidden zone, restricted zone and area for development is necessary for sustainable flood risk management.

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Authors' contributions

Gemechu Shale Ogato actively participated in the project proposal development, data collection, and data analysis under close supervision of Amare Bantider, Davide Geneletti, and Ketema Abebe. Writing had been also substantially contributed by Gemechu Shale Ogato. Amare Bantider, Davide Geneletti, and Ketema Abebe had been involved in critically advising, revising the manuscript and made possible suggestions. All authors read and approved the final manuscript.

Declaration of Competing of Interest

The authors fully declare that they have no any competing interests in publishing the manuscript

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Annexes

Annex 1: Flooding hazard area in Ambo town's watershed

Flooding hazard value	Area (m^2)	Percent
Very Low	31430700	3.89
Low	93468600	11.58
Moderate	193336190	23.95
High	260287200	32.24
Very High	228753900	28.34
Total	**807276590**	**100**

Annex 2: Flooding hazard Area in Ambo town

Flooding hazard value	Area (m^2)	Percent
Very Low	185400	0.22
Low	5502600	6.49
Moderate	22425300	26.43
High	29348100	34.59
Very High	27385200	32.28
Total	**84846600**	**100**

Annex 3: Flooding Risk Area in the watershed

Flooding Risk Value	Area (M^2)	Percent
Very Low	66628800	8.25
Low	223114500	27.64
Moderate	181287010	22.46
High	224951390	27.87
Very High	111294900	13.79
Total	**807276600**	**100**

Annex 4: Flooding Risk Area in Ambo town

Flooding Risk Value	Area (M^2)	Percent
Very Low	2703600	3.19
Low	20907900	24.64
Moderate	18731700	22.08
High	23506200	27.70
Very High	18997200	22.39
Total	**84846600**	**100**

Appendix B. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ejrh.2019.100659.

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