1. Introduction

The flood occurs when the capacity of the channel fills and the water flows out of the channel (Huang et al., 2008; Veerbeek and Zevenbergen 2009; Merz et al., 2010; Markantonis et al., 2013; Hudson et al., 2014; Perera et al., 2015; Yang et al., 2015; Aris M., 2003; Doswell III, 2003). Flood harms both urban and rural areas. Urban hurt contains direct harm to residential and non-residential buildings (Jha et al., 2012). Rural smash up contains injure towards farming merchandises, farmhouses, and near agricultural land infrastructures. Farming hurt was commonly lower than metropolitan injury; thus, farming harm assessment was made lower from time to time or merely accounted very few with easy methods and uneven estimates (Forster et al., 2008). Topographically, in Ethiopia, there are mountains and lowland areas (IBC, 2005). Ethiopia has nine main river basins; the drainage schemes start from the centrally located upland and formulate their manner downwards to the outlying lowland. Mainly for the duration of the training period (June–September), foremost permanent rivers, and their frequent tributaries form the country's drainage systems bring their peak discharge (Gashaw and Legesse, 2011).

Flood has been a permanent nature as well as frequent occasions within floodplains of downpour rainwater areas, anywhere in Ethiopia where more than 80% of annual rainfall cascades within the four moist months (Sanyal and Lu, 2005). The main problems in Ethiopia concerning floods are inundation and bank erosion. Moreover, the flash flood which occurred before a few years in the countryside washed away houses, infrastructures, killed a lot of people, and damaged agriculture. The problem depends on the river system's topography of the plain, flow phenomena and land cover (Lin, 1999; Ologunorisa and Adejumo, 2005; Agbola et al., 2012). The flooding in the river was caused by the spilling of the main river as well as its tributaries (Abedella, 2007).

A nation practices two types of floods, river and flash floods. For the maximum part floods within the nation take place as a consequence of river spread out following extended rainwater causing inundation of area beside riverbanks within the flat plain. The main river inundation prone areas were components of middle and downstream plains of the Awash River; Afar and Oromia regions lie beside the higher parts of the Somali Region along the Wabi Shabelle; Gilo and Akobo rivers flow lowland areas of Gambella along the Baro; the widespread floodplains adjacent Lake Tana and the banks of Rib, Gumara and Megech rivers located in

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Amhara, and downstream areas along the Omo River in Southern Nations, Nationalities and Peoples of Ethiopia (DPPA, 2013).

The cause of river inundating is an effect of surplus rainwater within a short period as well as the subsequent high river discharge enormously disquieted in the Fetam River, Ethiopia. As a major raining period (Jun, July, August, and September); the floodplain of the Fetam River prolongs to fastidious areas that were not usually enclosed through the water. The flash or river flooding often occurs inside the lowland and the smooth topographic areas of the Fetam River. The extreme rainwater within the highlands of the area causes inundating at its downstream and harms farmlands, and built-up areas close to any part of the river (Bishaw, 2012).

The flood threat valuation was used to know the possibility of incidence of a definite exposure in a definite prospect period for its strength and area of the collision. Hazard was a possibly damaging physical occurrence; the visible is a fact that might cause the loss of living, property damage, economic and social trouble as well as environmental failure (Silver, 2016).

Information regarding the flooding characteristics and its effects were essential for flood management bodies for decision making in flood management strategies such as the construction of flood protection structures, to grow flood crisis plans and human settlement planning. Therefore, the major aim of this research was to assess flood vulnerability areas and factors contributing for flood vulnerability of Fetam River with GIS and the Hydraulic Engineering Centre-River Analysis System (HEC-RAS) model.

2. Materials and methods

2.1. Description of the study area

The study was conducted at Banja, Sekela, Bure, Guagusa Shikudad, and Womberma Districts which are located in the Awi and West Gojam zone of the Amhara region. The districts are located at a latitude of 10° 40’ to 11° 03’ North and a longitude of 36° 39’ to 36° 48’ East as shown in Figure 1 below. The average elevation of the districts is 2069 m above mean sea level and the mean annual rainfall is 1750 mm.

The watershed was marked with different topographic variations. The main slope coverage was 0–8% (52.29% of the total area), 8–19% (29.41% area coverage). Flat and more or less gently sloping accounts for 10.16% and 5.74% correspondingly, steep slopes envelop 2.39% of the whole area. The driest period of the year in the study area is from November to January. Generally, the Fetam watershed lies in the wet dega, moist weina-dega, wet weina-dega, moist upper kola, and moist lower kola agro-climate zones. The watershed has been covered by eight soil types. Among them, Dystric Nitosols and Pellic Vertisols are the main ones; Chromic Vertisols, as well as Eutric Cabisols follow. Moreover, precipitation of the watershed is a bi-modal, the stature precipitation period being from June to September as well as the minor is from February to May with unpredictable temporal and spatial inconsistency.

The soil types of the study area are characterized with shallow, moderate to deep, and very deep in-depth and sandy clay to clay in textural classes.

2.2. Data collection and methodology

For this study, secondary data collected from books, journals, manuals, conference proceedings and streamflow and precipitation were used.

The Digital Elevation Model (DEM) and other important Parameters for flood vulnerability plotting were investigated with ArcGIS. Flood producing aspects such as drainage density, digital elevation model, land use/land cover, soil type, rainfall, and slope were also designed for flood vulnerability valuation with ArcGIS.

For the development of a map of flood plains, rainfall data from rain gauge stations and 30m by 30m high resolution of DEM of a watershed in raster format have been collected from the Ethiopian map agency and used for this study. Four selected meteorological stations: Tilili, Shindi,
Sebadar, and Gundil, which have better quality and well-distributed long period daily records over the study area, were selected and used for analysis. These daily records of the mean annual precipitation from the period 1999–2012 were used to find historical floods.

2.2.1. Flood vulnerability assessment

The selected flood distribution features; soil map, slope, rainfall, elevation, drainage density, and land use/land cover have been rasterized and categorized within raster format and weighted-overlaid with ArcGIS to make a critical flood vulnerability map. A digital elevation model of a 3-D illustration for the terrain surface was made from terrain elevation data. DEM was used in symbolizing as a raster or as a vector-based triangular irregular network (Brunner et al., 2015). The overall methodology of this research is presented in Figure 2.

3. Results and discussion

3.1. Flood vulnerability factors analysis

The main flood causing factors such as slope, elevation, average rainfall, drainage density, land use/land cover, and soil type were used for inundation of vulnerability valuation. The raster layers were classified based on their inundating ability of the watershed besides previous revision (Abebe, 2007).

3.1.1. Slope factor

The slope of the study area resulted from a 20-meter contour interval characteristic rank which was digitized from the Digital Elevation Model scale with additional modification within the GIS environment. The characteristics were changed to a 3-D shapefile using 3D Predictor Tools. The slope characteristic rank was changed more to raster using the conversion tool into raster. The slope raster layers were further re-categorized into five subgroups with regular grouping systems (equal interval) as shown in Figure 3.

As presented in Figure 4, the re-categorized slopes have been given significance one to five through the upper value, five showing high effect in resulting very high inundation rate, while the lower value, one, indicating very low influence showing very low flood rate. Consequently, an area with a very low slope was ranked as one, and an area with a very high slope was ranked as five. This categorization method segregates a variety of feature worth to the same sized sub-ranges which allow specifying the number of intervals, while Arc Map computes anywhere don’t do so.

The smaller slope value was flatter topography and, likewise, the upper slope values were the steeper topography. Depending on their vulnerability to inundating, slopes were characterized into five ranks. According to these classifications, areas with the smallest slope are ranked to class five (<8%) and are extremely affected by the flood. Similarly a high vulnerability ranked to class four (8–19%), moderate
Figure 3. Raster map of slope layer.

Figure 4. Reclassified map of Raster slope layer.
ranked class three (19–36%), low ranked to class two (36–57%) and very low ranked to class one (>57%). Unlike breaking, the values were checked depending on the local information, expert knowledge, as well as the achievable comprehensions for slope hazard map.

3.1.2. Elevation factor

DEM were changed to elevation raster layers with the ArcGIS conversion tool. The elevation raster layer was computed from the created TIN. The elevation raster layers were more re-categorized into five sub-groups using a normal classification system (Equal Interval). Thus, the categorization method split a variety of feature values into the same-sized sub-ranges, allowing them to identify numeral intervals. The latest value was re-categorized to flood vulnerability rating. Hence, the categorization procedure to the smallest elevation was extremely affected by the flood. Thus, class five upper elevations have been affected by the flood more than class one as shown in Figure 5.

The lesser elevation worth mentioning was the flatter topography and the upper elevation was the steeper topography. Depending on their vulnerability to flooding, it has been categorized into five classes (Figure 6). An area at the lowest elevation was extremely pretentious with flood ranked to class five (<1201.8m). Subsequent high vulnerability is ranked to class four (1201.8–1635.6 m), moderate ranked to class three (1635.6–2069.4 m), low ranked to class two (2069.4–2503.2 m) and very low ranked to class one (>2503.2 m).

3.1.3. Rainfall factor

This was a point from the data collected at four stations within the study area. From this data, annual average rainfall was calculated for each station using Inverse Distance Weight (IDW) method and was converted to the raster layer which is ultimately re-categorized into five ranks using an equal interval. The re-categorized precipitations were provided with one to five through the upper value, five indicating high influence in ensuing extremely high flood rate, whereas the smallest value, one, viewing incredibly low impact inconsequential extremely low flood rate. As a result, an area with very high rainfall is ranked to class five and an area with very low rainfall is ranked to class one as shown in Figure 7.

During the categorization system (as presented in Figure 8), the higher rainfall value, is extremely affected with extreme exposure to overflow and was categorized as class five (>2198 mm/year), high ranked to class four (2031–2198 mm/year), moderate ranked to class three (1861–2031 mm/year), low ranked to class two (1696–1861 mm/year) and very low ranked to class one (<1529 mm/year).

3.1.4. Drainage density factor

The drainage density was the whole length of all the streams and rivers in drainage divided by the whole area of the drainage. Drainage of the study areas was derived from digitized river systems of the Fetam watershed and more rectified within the GIS setting, presented in Figure 9. Moreover, the spatial analyst extension line density modules were accustomed to calculate the drainage density of the study area. Line density computes the amount per unit area from polyline characteristic to descend inside a radius around each cell.

The Fetam watershed was used to estimate the drainage density with the spatial analyst extension. According to the classification method shown in Figure 10, an area with the higher value is very highly affected by flood and ranked to class five (>0.00293 km/km2), high ranked to class four (0.00285–0.00293 km/km2), moderate ranked to class three (0.0025–0.00285 km/km2), low ranked to class two (0.00097–0.0025km/km2) and very low ranked to class one (<0.00097 km/km2).

3.1.5. Land use/land cover factor

Land use/Land cover of the watershed area was reassigned with classified land use/land cover form in five common grades and was improved into the raster layer. Further, the land use/land cover type was re-categorized into five classes, depending on their capacity to raise or
Figure 6. Reclassified map of elevation layer.

Figure 7. Raster map of rainfall layer.
reduce the rate of inundating. Hence, cultivated land use type can increase flood degree in the area and it is ranked to class five, bare land is ranked to class four, grassland is ranked to the class three, shrub and bushland are ranked to class two and forest land is very low capability to create flood and is ranked to class one, as presented in Figures 11 and 12 below.

3.1.6. Soil factor

There are a variety of soil types, among these five major soil classification are recognized depending on the hydrologic soil grouping scheme of the Ministry of Water, Irrigation and Energy of Ethiopia. These are Euthric Nitosols, Chromic Vertisols, Lithosols, Pellic Vertisols, Rock surface, and Chromic Luvisols (Getahun and Gebre, 2015).
Figure 10. Reclassified drainage density layer.

Figure 11. Raster map of land use/land cover layer.
Consequently, factors of the watershed were derived as of the FAO measure categorization of Ethiopian soil. The characteristic of every soil class is examined depending on the hydrologic soil grouping scheme. Hence, it is classified into five mutual clusters and was renewed into a raster format. Further, raster layer classes were re-categorized into five classes, and a new value change was made based on their flood danger rating. The class that has extremely high capability to produce incredibly high flood rate is class five and incredibly low capacity to produce flood rate is ranked to class one; therefore, Pellic Vertisols are ranked to class five, Lithosols are ranked to class four, Eutric Cabisols are ranked to class

Figure 12. Reclassified land use/land cover layer.

Figure 13. Soil raster layer.
three, Dystric Nitosols are ranked to class two, and Rock Surface are ranked to class one, as presented in Figures 13 and 14.

3.2. Pairwise comparisons of the factors

It was frequently supposed to Multi-Criteria Decision Analysis (MCDA) happening at earlier times. The excellence of experts on MCDA considered to their restraint stem mostly as of the premature work on objective indoctrination (De Brito, M. and Evers, M. 2016; Matori et al., 2014; Drobne and Lisec, 2009). According to Matori et al. (2014), suggestion a structure that investigates human beings’ decision-making processes by distinguishing among the design, brainpower, with the option phase, MCDA methods are numerical algorithms. Numerical algorithms explain the suitability of meticulous effect on the origin of contribution criteria and this influence mutually through various mathematical or logical means of deciding disagreement. Using this procedure, the influence value range from 1 to 9 was allocated to every factor with professionals to replicate their relation consequence. By the weighted linear

| Slop | Elevation | Rainfall | Land use/cover | Drainage density | Soil type |
|------|-----------|----------|----------------|------------------|-----------|
| 1    | 3         | 3        | 3              | 5                | 7         |
| 1/3  | 1         | 3        | 3              | 5                | 5         |
| 1/3  | 1/3       | 1        | 3              | 3                | 3         |
| 1/3  | 1/3       | 1/3      | 1              | 3                | 3         |
| 1/5  | 1/5       | 1/3      | 1/3            | 1                | 3         |
| 1/7  | 1/5       | 1/5      | 1/5            | 1/3              | 1         |

Table 1. Pairwise comparison of six criterion matrix.

| Slop | Elevation | Rainfall | Land use/cover | Drainage density | Soil type |
|------|-----------|----------|----------------|------------------|-----------|
| 1/3  | 0.33      | 0.33     | 0.33           | 0.33             | 0.33      |
| 1/5  | 0.2       | 0.33     | 0.33           | 0.33             | 0.33      |
| 0.14 | 0.2       | 0.2      | 0.2            | 0.33             | 0.33      |
| sum  | 2.33      | 5.06     | 7.86           | 10.53            | 17.33     |

Table 2. Pair-wise comparison decimal matrixes.

| Slope | Elevation | Rainfall | Land use/cover | Drainage density | Soil type |
|-------|-----------|----------|----------------|------------------|-----------|
| 1     | 0.33      | 0.33     | 0.33           | 0.33             | 0.33      |
| 0.33  | 1         | 3        | 3              | 5                | 5         |
| 0.33  | 0.33      | 1        | 3              | 3                | 3         |
| 0.33  | 0.33      | 0.33     | 1              | 3                | 3         |
| 0.2   | 0.2       | 0.33     | 0.33           | 1                | 3         |
| 0.14  | 0.2       | 0.2      | 0.2            | 0.33             | 0.33      |
| sum   | 2.33      | 5.06     | 7.86           | 10.53            | 17.33     |

Figure 14. Reclassified soil layer.
combination technique, every map layer was overlaid in ultimate GIS spatial examination for flood vulnerable zone imitation. A primary step in the AHP was a calculation of a pair-wise comparison matrix, where all entry symbolizes the qualified importance of one factor to the other. The relative significance between the two factors was calculated along with a numerical scale from 1 to 1/9. The relationship between a mathematical value and intensity of less importance was as follows: 1 = equal importance, 1/3 = moderate, 1/5 = strong, 1/7 = very strong, 1/9 = extremely at the contrary, high significant variables were rated between 1 and 9 (Lappas I. and Kallioras A., 2019; Getahun Y, and Gebre S., 2015; Papaioannou et al., 2015; Kandilioti et al., 2012; Saaty, 2004). By the weighted linear combination technique, every map layer was overlaid in ultimate GIS spatial examination for flood vulnerable zone imitation.

The weighted linear combination system that was accepted with any of the GIS schemes has been superimposed. Therefore, the yield of the weighted linear combination technique provides a map replicated for the most part for prospective flood vulnerable parts of the Fetam watershed, presented in Tables 1, 2, 3, 4, 5, and 6.

The Consistency Index (CI), which is calculating of departure from consistency, is estimated with procedure:

\[ CI = \frac{\lambda - n}{n - 1} \]  

Where \( n \) is the number of factors (6) and \( \lambda \) is the average value of the consistency vector estimated in Table 7.

\( \lambda = (6.70 + 6.84 + 6.57 + 6.19 + 6.14 + 6.32)/6 = 6.46 \)

Based on the above equation, \( CI = 6.46 - 6/6 - 1 = 0.09 \).

To measure the heftiness of the professional sight the Consistency Ratio (CR) was computed with Eq. (2). The effect was presented in Table 7.

\[ CR = \frac{CI}{RI} \]

Where, \( RI \) is the random inconsistency index which was standard using Saaty (1980) and whose value depends on the number (\( n \)) of aspects being associated; for \( n = 6, RI = 1.24 \).

CR can also be further simplified using Eq. (3).

\[ CR = \frac{0.09}{1.24} = 0.073 \]

Table 3. Normalized pairwise matrix calculated.

|       | Slope | Elevation | Rainfall | Land use/cover | Drainage density | Soil type |
|-------|-------|-----------|----------|----------------|------------------|-----------|
| Slope | 0.43  | 0.59      | 0.38     | 0.28           | 0.29             | 0.27      |
| Elevation | 0.14  | 0.20      | 0.38     | 0.28           | 0.29             | 0.19      |
| Rainfall | 0.14  | 0.07      | 0.13     | 0.28           | 0.17             | 0.19      |
| Land use/cover | 0.14  | 0.07      | 0.04     | 0.09           | 0.17             | 0.19      |
| Drainage density | 0.09  | 0.04      | 0.04     | 0.03           | 0.06             | 0.12      |
| Soil type | 0.06  | 0.04      | 0.03     | 0.02           | 0.02             | 0.04      |

Table 4. Determined relative criterion weights.

|       | Slope | Elevation | Rainfall | Land use/cover | Drainage density | Soil type | criteria weight |
|-------|-------|-----------|----------|----------------|------------------|-----------|-----------------|
| Slope | 0.43  | 0.59      | 0.38     | 0.28           | 0.29             | 0.27      | 0.37            |
| Elevation | 0.14  | 0.20      | 0.38     | 0.28           | 0.29             | 0.19      | 0.25            |
| Rainfall | 0.14  | 0.07      | 0.13     | 0.28           | 0.17             | 0.19      | 0.16            |
| Land use/cover | 0.14  | 0.07      | 0.04     | 0.09           | 0.17             | 0.19      | 0.12            |
| Drainage density | 0.09  | 0.04      | 0.04     | 0.03           | 0.06             | 0.12      | 0.06            |
| Soil type | 0.06  | 0.04      | 0.03     | 0.02           | 0.02             | 0.04      | 0.04            |

Table 5. The Eigen Vector weights of each flood factor obtained after the pair-wise comparison.

| Flood Factor | Normalized weighted | Influence (%) |
|--------------|---------------------|---------------|
| Slope        | 0.37                | 37            |
| Elevation    | 0.25                | 25            |
| Rainfall     | 0.16                | 16            |
| Land use/cover| 0.12               | 12            |
| Drainage density | 0.06               | 6             |
| Soil type    | 0.04                | 4             |

Table 6. Determined consistency ratios (CR).

|       | Slope | Elevation | Rainfall | Land use/cover | Drainage density | Soil type | Weighted Sum Value | criteria weight | Weighted Sum/weight criteria |
|-------|-------|-----------|----------|----------------|------------------|-----------|--------------------|-----------------|-----------------------------|
| Slope | 0.37  | 0.74      | 0.49     | 0.35           | 0.31             | 0.51      | 2.51               | 0.37            | 6.70                        |
| Elevation | 0.12  | 0.25      | 0.49     | 0.35           | 0.31             | 0.51      | 1.70               | 0.25            | 6.84                        |
| Rainfall | 0.12  | 0.08      | 0.16     | 0.35           | 0.19             | 0.51      | 1.08               | 0.16            | 6.57                        |
| Land use/cover | 0.12  | 0.08      | 0.05     | 0.12           | 0.19             | 0.51      | 0.73               | 0.12            | 6.19                        |
| Drainage density | 0.07  | 0.05      | 0.05     | 0.04           | 0.06             | 0.51      | 0.38               | 0.06            | 6.14                        |
| Soil type | 0.05  | 0.05      | 0.03     | 0.02           | 0.02             | 0.51      | 0.21               | 0.04            | 6.32                        |

Table 7. Random inconsistency indices.

| n   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----|----|----|----|----|----|----|----|----|----|----|
| RI  | 0.00| 0.00| 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45| 1.49|
As a result, $0.073 < 0.1$ shows that there was a pragmatic degree of consistency in a pair-wise comparison and, thus, the weights $0.37, 0.25, 0.16, 0.12, 0.06,$ and $0.04$ values were allocated with slope, elevation, rainfall, land use/cover, drainage density, and soil types, respectively.

### 3.3. Analytic Hierarchy Process (AHP) Spatial Flood Forecasting

The rasterized and classified flood generating factors have been weighted. Research Saaty’s methods were used depending on the Analytic Hierarchy Process; whereas, a pair-wise comparison was organized for each map through a 9-point significance scale. According to Saaty (1980), AHP was a multi-criteria decision-making technique that offers a logical way of measuring and incorporating the effects of different issues connecting different level-dependent, qualitative, and quantitative information. It was a methodology to thoroughly estimate the qualified significance of a set of performance with pairwise comparison (Ahmad A., 2018; Fekadu A., 2018; Bapalu and Sinha, 2005).

Weighting techniques were used to prioritize the comparative significance of each factor qualified to a different factor. The greater burden, the more important was the factor in weighted overlay relative to different factors. The consistency ratio that values $<0.1$ was acceptable. The computed consistency ratio of 0.073 to illustrate a given pairwise weight was accepted. The pairwise assessment states a high weight for the slope followed by elevation; average precipitation, land use/land cover, drainage density, and soil group.

| Flood vulnerability Level | Area (km²) | Percent of Area Coverage |
|---------------------------|------------|--------------------------|
| Very Low                  | 2.81       | 0.25%                    |
| Low                       | 121.28     | 10.96%                   |
| Moderate                  | 280.89     | 25.38%                   |
| High                      | 634.11     | 57.30%                   |
| Very High                 | 67.54      | 6.10%                    |

Calculated Eigen Vector values have used a coefficient of the particular flood factors that was used for land use/land cover, slope, elevation, drainage density, rainfall, and soil group layers to be united within weighted overlay in ArcGIS to produce the ultimate flood hazards map of Fetam River by using an equation developed by Saaty (1980).

Flood hazards = $0.37 \times \text{[Slope]} + 0.25 \times \text{[Elevation]} + 0.16 \times \text{[Rainfall]} + 0.12 \times \text{[Land use/cover]} + 0.06 \times \text{[Drainage density]} + 0.04 \times \text{[Soil type]}

### 3.4. Flood Vulnerability Map

The slope, elevation, rainfall, land use/land cover, drainage density, and soil types have been used to develop a flood vulnerability map by using GIS and AHP or multi-criteria decision-making techniques (Fernández and Lutz, 2010; Karaman and Erden, 2014; Rozos et al., 2011; Peng et al., 2012; Karaman, 2015; Bathrellos et al., 2012). The flood vulnerability caused by the excessive discharges of the main rivers is predictable to increase due to climate change (Knoop BA. and Joost, 2013). Based on a flood vulnerability study in the Fetam watershed, the flood generating factors were developed in a Geographic Information System environment along with multi-criteria decision-making techniques. The study indicated that land use/land cover change, which involved an intensification of agricultural activities, increased the over-flow magnitude that caused high flood vulnerability zone in the downstream part of the river basins (Bishaw K., 2012). According to this study, the flooded areas in the Fetam watershed for the return periods, 5, 10, 25, 50, and 100 years were $13.78$ km², $17.34$ km², $20.47$ km², $24.85$ km², and $27.31$ km², respectively. This is based on streamflow respective values of $35.82$ m³/s, $39.4$ m³/s, $43.93$ m³/s, $47.28$ m³/s, and $50.62$ m³/s for return periods of 5, 10, 25, 50, and 100 years and other factors.

The over-flow threat valuation map was made by using inundation generating factors, such as slope, elevation, rainfall, drainage density, land use/land cover, and soil types of Fetam watershed using GIS besides multi-criteria Analytic Hierarchy Process method and weighting overlays.

It showed that $2.81$ km², $121.28$ km², $280.89$ km², $634.11$ km², and $67.54$ km² were corresponded to very low, low, moderate, high, and very...
high flood vulnerability, correspondingly (Table 8). This finding is similar to a flood vulnerability study at Dire Dawa Town by Alemayehu (2007).

The vulnerability map shows high to extremely high flood vulnerability intimidations within the upstream and downstream parts of the river, which was lowland flat area of the Fetam watershed (Figure 15). High flood threat envelops the highest area that is 57.30%. There was low to incredibly low flood vulnerability prospects in the middle and downstream parts of the watershed.

4. Conclusions

Particularly inundation producing issues were computed to demarcate overflow threat regions through multi-criteria calculation methods within the GIS environment. An allowance of inundation produced factor was calculated using a pairwise technique for ultimate weighting overlay analysis to compute the flood vulnerability map. The influences to extremely high, high, moderate, low, and very low vulnerability regions were formulated depending on various probable recognitions in addition to the knowledge of the earlier study.

The overflow vulnerabilities showed that the lowland area close to the Fetam River, predominantly from the upstream, middle, and downstream sides, were within high to extremely high flood vulnerability regions. The inundation vulnerability intimidation from the downstream side of the Fetam River was from low to incredibly low flood vulnerability treated region.

The specific farming terrain from the low-lying part which was in high or extremely high inundation risk threats was pretentious with floods in the major raining period. A lowland farming and grassland beside Fetam River at Abaya Kalo and Denbun kebele showed persistent large flooded areas.

As can be comprehended from the model outcome discussed in the results, almost a large fraction of the lower reach of the river was flooded with high inundation depth and was found decreasing from upstream to downstream.

5. Recommendations

❖ The responsible person of the districts and the Region must cooperate to protect flood vulnerable areas and must plan flood threats evaluation plan on their growth plan
❖ Development of flood protection structures and soil conservation practices should be carried out in the upstream and downstream part of the site to reduce the magnitude of the flood.
❖ Adoption of appropriate land use planning practices in a flood-prone area ought to be made to reduce the adverse effects.
❖ Sufficient drainage conditions from the Fetam watershed mainly high to extremely high flood vulnerability risk regions has to be enhanced, and land use has to be appropriately administered to minimize floods vulnerability through the foremost raining period.

Declarations

Author contribution statement

Arega Mulu, Hunegnaw Desalele: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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