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Mapping Flood Prone Areas of Bilate Watershed Using Integration of Multicriteria Analysis and GIS Techniques

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Abstract— Flood disaster from all other natural disasters has got wider attention because of its big impact made still now on the loss of life, property damage and economic loss. Flood prone areas mapping has been taken as a device to minimize the impact of flooding events. Peoples developed an integration of Geospatial Techniques and Multicriteria analysis for this purpose. In this study flood prone area of Bilate watershed is mapped using Multicriteria and Geospatial techniques. Five parameters were selected as criterion namely Rainfall, Slope, drainage density, Landuse/landcover and soil of the watershed ranked and given weights of 41.9%, 26.3%, 16.0%, 9.7% and 6.2%, respectively using Analytical Hierarchy Process. The final result produced using Weighted overlay function of the five criterions developed identified three flood prone areas in the watershed as high, moderate and low flood prone areas covering 28.5% (1603.16 Km²), 61.4% (3453.82 Km²) and 10.1% (568.14 Km²) area from the watershed, respectively.

Index Terms— Flood prone area, Analytical Hierarchy Process, Vulnerability, Bilate watershed, Multicriteria Analysis, GIS, Weight Value

INTRODUCTION

Natural disasters throughout the world are causing death of peoples, spreading disease, damaging property, harming economically and affecting the people socially and psychologically. Amongst the natural disasters occurring throughout the world flooding events take the lion share in terms of economical damage and loss of life (Akyurek and Yalcin, 2016). To save the life of people, property damage and economic loss related to flood hazards it is required to prepare planning and management strategies. To have so it is needed to map flood prone areas so that planners and decision makers can easily address areas where flood hazard is pronounced and they will prepare and take mitigation measures as soon as possible (Ajin et al., 2013). The importance of flood prone area map is very crucial. Flood Prone area map can be produced by applying Multicriteria analysis, remote sensing and GIS Techniques as used in (Ajin et al., 2013) (Akyurek and Yalcin, 2016). The integration of multicriteria approach, remote sensing and GIS techniques will enable us to present the flood prone areas mathematically and pictorially. The advantage of using this approach is its easiness and less data consuming making it time and cost efficient approach.

The objective of this particular study is to identify flood prone areas in Bilate watershed so that planners and decision makers will prepare themselves starting from landuse palnning to mitigation measures to be taken to protect the people and their property from flood hazards.

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STUDY AREA

Bilate Watershed is one of the watersheds located in the rift valley lake basin of Ethiopia as part of the great rift valley of Africa. The watershed is geographically bounded in 365483W to 426838E and 726037S to 896469N as shown in Figure 1. The elevation of the watershed ranges from 1174 to 3334 masl indicating undulating nature of the ground. The mean annual rainfall in the basin ranges from 669 mm to 1353 mm showing very high spatial variation in rainfall pattern. The watershed covers a total area of 5625.12 Km² in Oromia and South Nations, Nationalities and People Regional states in Ethiopia.

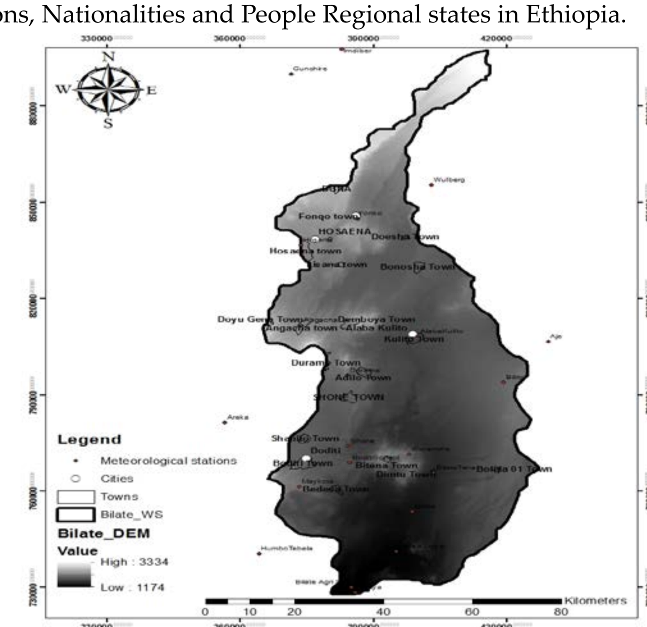

Figure 1: Study Area Map of Bilate Watershed

METHODOLOGY

Multicriteria analysis together with Geospatial techniques has got wider application in different areas of mapping. For this particular study, the same method is used as described below.

The first step done in this part is collecting pertinent data. Data which are identified as pertinent in this area are 30 years of daily rainfall data from 23 meteorological stations, soil shape file from FAO website, Landsat ETM+ image file and DEM of the watershed from ASTER site.

After once all the necessary data are collected, they are processed to come up with necessary class and format to be used in the Overlay function. Using the 30 years daily rainfall data collected from 23 meteorological stations, the mean annual rainfall of each stations are calculated in Excel. Afterwards these data has been fed to ArcGIS Geostastical Analyst tool and mean annual areal rainfall of the watershed is generated using inverse square distance weighting technique and reclassified to the required classes and saved as raster file.

The DEM data downloaded from ASTER site has been used to generate slope map and drainage density map of the watershed in ArcGIS spatial analyst tool using surface and density functions, respectively. These maps are reclassified to the required classes using Reclass function in ArcGIS Spatial Analyst tool and then saved as raster file since the overlay function finally works with raster file.

From soil shape file data downloaded for Ethiopia from FAO site, the soil map is clipped for the watershed, reclassified as per the requirement and saved as raster file. The final step in data preparation is reclassifying the landuse/landcover of the watershed from Landsat ETM+ image using supervised image classification method in IDRISI 17.02 software and saved it as raster file.

After all the necessary data have been prepared, defined and formatted well, the next step is ranking and giving weight to each criterion (data) using pair wise comparison matrix approach in Analytical Hierarchy Process (AHP) as developed by (Saaty, 1980). Using this technique the criterions (data prepared) are ranked according to their importance and given weight using IDRISI 17.02 software keeping the consistency ration less than 10% (0.1).

The final stage in mapping of flood prone area map of the watershed done is inputting all the criterions with their respective weight value in ArcGIS Spatial Analyst extension tool Weighted overlay function. At last the composite map representing areas with their respective flood prone area classes produced and reclassified as per the requirement.

RESULT AND DISCUSSION

Rainfall

One of the critical factor which affect the occurrence and magnitude of flood is rainfall as discussed in (Ajin et al., 2013) (Dano et al., 2012) (Yahaya, 2008). The depth of rainfall and its frequency of occurence plays the great role in this regard.

If heavy rainfall falls in a given area for longer period of time, evenif the soil has high infiltration capacity, all the pore spaces of the soil will be held by water. The soil afterwards has no room to accept any water, so that the water becomes runoff depending on the nature of the ground. Therefore, heavy rainfall indicates high flooding event resulting the area as highly flood prone area (Ajin et al., 2013). This shows magnitude of rainfall and flooding events have direct relationship.

30 years daily rainfall data is collected from around 23 meteorological stations which are found inside and outside the watershed boundary selected based on the availability of long period data and similarity in their hydrometeorological characteristics. Using the data, 30 years mean annual rainfall is calculated for ecah stations. This all rainfall data are point data. Because of its lack of representativeness, the point rainfall data is converted to mean areal rainfall value within the watershed in ArcGIS Geostastical Analyst extension using Inverse square distance technique. The result is then reclassified in to four classes as shown in Figure 2.

The rainfall result shows that about 18.4% (1035.02 Km^2) area from the watershed gets low rainfall (669 mm to 920 mm) indicating low flood prone level. Over 50% of the watershed area is categorized in very high rainfall class and high flood prone probability. All the results regarding rainfall of the basin are calculated and summarized in Table 1.

Table 1: Mean annual rainfall class identified with its respective flood vulnerability level

Rainfall Class (mm)	Flood Vulnerability level	Area coverage in %	Area coverage in Km^2
669 - 920	Low prone area	18.4	**1035.02**
921 - 1011	Moderate prone area	16.5	**928.14**
1012 - 1102	High prone area	11.2	**630.01**
1103 - 1353	Very high prone area	53.9	**3031.93**
	Total Area	100%	**5625.12**

Slope

Slope is a term used to indicate elevation difference between two points with respect to horizontal distance (Nag SK, Kundu A, 2016).

For a given rainfall to become runoff, slope is one of the critical factor. Slope affects the infiltration capacity of the soil. The steeper the slope, the higher will be the runoff since the soil will not get time to infiltrate the water through its pore spaces.

The relationship between slope and flood vulnerability is inverse in such a way that steeper slope results high runoff and low flood vulnerabiltiy level in that area. Whereas, in flat areas the runoff rate is low resulting high residence time of water on the ground and results high flood vulnerability level.

For the study area, the slope is calculated using DEM downloaded from ASTER site in ArcGIS spatial analyst extension tool. The slope calculated is reclassified in to four groups using scales used in (Fekadu, 2018) and shown in Figure 3.

The result shows that over 50% of the watershed area has a slope in class of 8 - 16 degrees and categorized in high flood vulnerability level. 1.4% (78.75 Km^2) area has a very steep slope and low vulnerability to flood as shown in Table 2.

Table 2: Slope classes in Bilate watershed identified with their respective flood vulnerability level

Slope Class (Degrees)	Flood Vulnerabilty level	Area coverage in %	Area coverage in Km^2
0 - 8	Very high prone area	31.6	**1777.54**
9 - 16	High prone area	52.8	**2970.06**
17 - 30	Moderate prone area	14.2	**798.77**
31 - 70	Low prone area	1.4	**78.75**
	Total Area	100%	**5625.12**

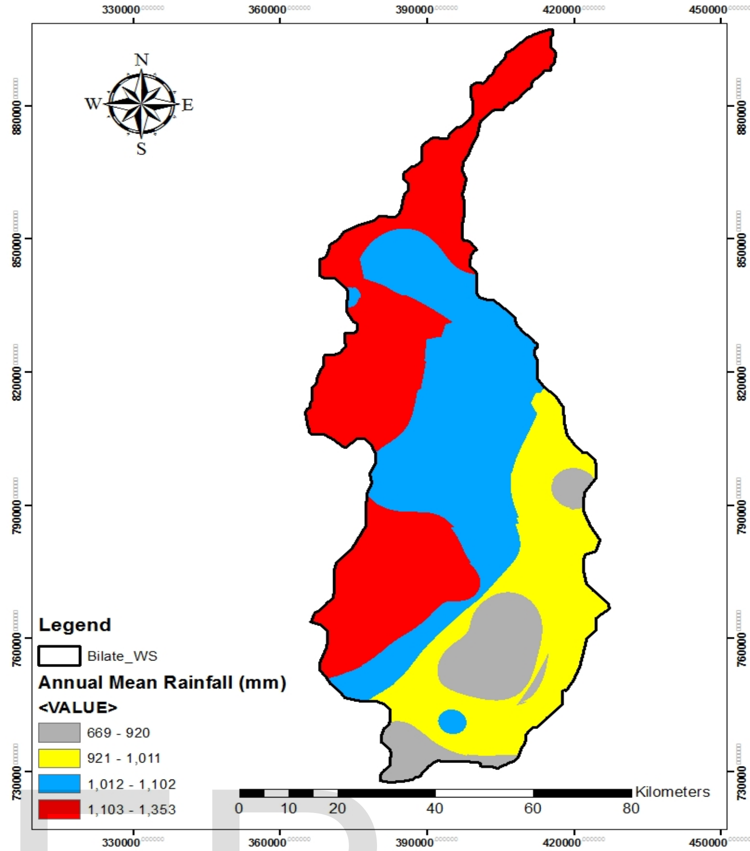

Figure 2: Mean annual areal rainfall of Bilate Watershed

Drainage Density

Drainage density of a given watershed tells about the degree of runoff. High drainage density category indicates low infiltration capacity and steep slope in that particular area. This means the runoff is very high, so that the probability or flooding in that area is minimum. This shows infiltration and flooding events have inverse relationship (Ajin et al, 2013).

The drainage density of the watershed is generated using Spatial Analyst tool in ArcGIS software from DEM data downloaded for the watershed. For this study, the drainage density is divided in to four categories as shown in Figure 4.

From the total area of the watershed 24.4% (1372.53 Km^2) is categorized as low drainage density class and it is highly flood prone area. Only 1.9% (106.88 Km^2) of the watershed area has very high drainage density and indicates low flood prone area in the vicinity. The overall flood vulnerability level and the area covered by each class is summarized in Table 3.

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Table 3: Drainage density calculated with their respective flood vulnerability level

Drainage density value (Km/Km²)	Flood Vulnerability level	Area coverage in %	Area coverage in Km²
0 - 0.18	Very high prone area	24.4	1372.53
0.19 - 2.35	High Prone area	53.8	3026.31
2.36 - 3.53	Moderately prone area	19.9	1119.40
3.54 - 4.704	Low prone area	1.90	106.88
	Total Area	**100%**	**5625.12**

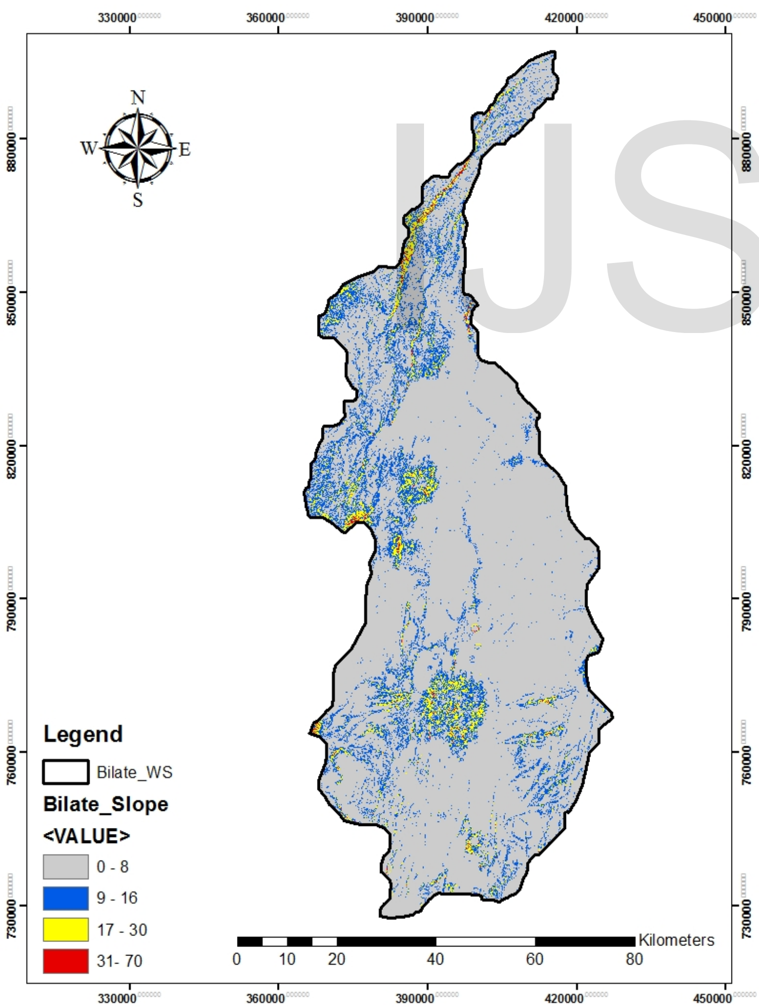

Figure 3: Slope map of Bilate watershed

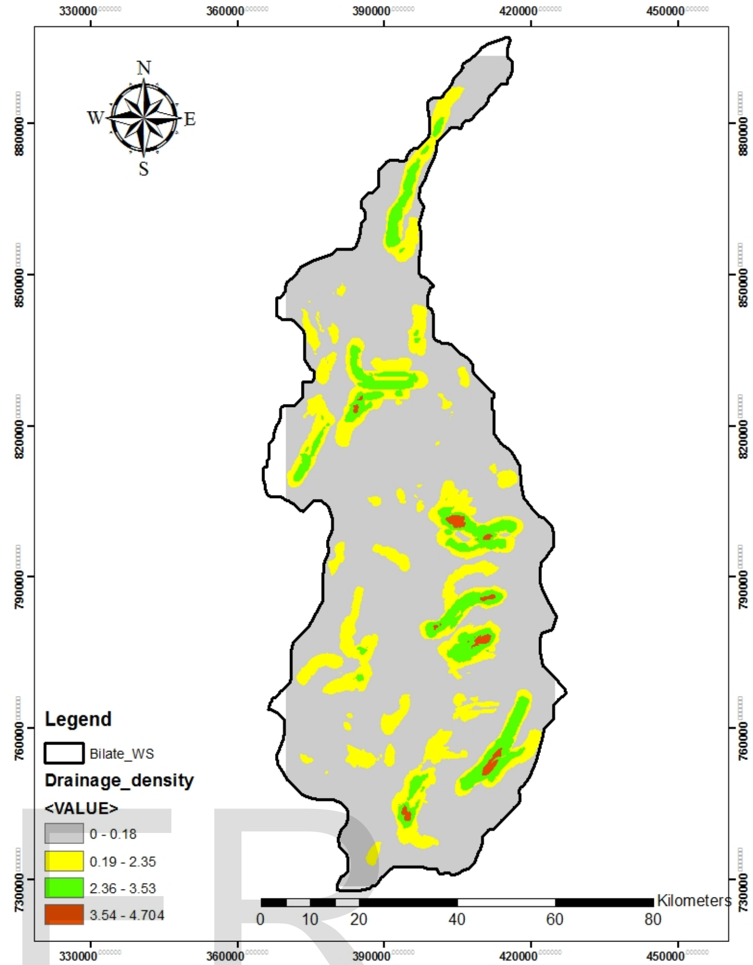

Figure 4: Drainage Density map of Bilate watershed

Landuse/Landcover

Landuse/Landcover is used to indicate for what purpose the surface is used. Landuse/Landcover in the world is changing with increasing trend of population and urbanization. The space occupied by construction works is increasing. This increases the level of imperviousness of the surface contributing to flooding events.

Landuse/Landcover map for the study area is prepared from Landsat ETM+ image extracted by the method called Supervised classification using IDRISI 17.02 software. Then it is reclassified to four groups as shown in Figure 5.

Referring (Ajin et al., 2013) and (Fekadu, 2018), the Watershed's Landuse/Landcover group vulnerability to flood is done as shown in Table 4.

It is noted from the result that large area of the watershed is covered by forest and woodland group (48.4%). This class is given low flood vulnerability level. Shrubland and Grassland together cover 1.2% (67.50 Km²) area of the watershed and categorized in high flood vulnerability level.

Table 4: Landuse/Landcover category of Bilate watershed with their respective flood vulnerability level

Landuse/Landcover type	Flood Vulnerabilty level	Area coverage in %	Area coverage in Km^2
Waterbodies	Very high prone area	22.2	
Shrubland and Grassland	High Prone area	1.2	
Cultivation	Moderately prone area	28.2	
Forest & Woodland	Low prone area	48.4	
	Total Area	100%	**5625.12**

Soil

Soil type is important in flood study since it affects the infiltration rate directly and the runoff indirectly (Nicholls and Wong., 1990). The higher the infiltartion capacity of the soil, the lower will be the vulnerability to flood. In soil types which have low infiltration rate, the rainfall fall will accummulate on the top surafce and icrease vulnerability to flood.

For this study, soil shape file from FAO site (FAO 97) is downloaded and the soil type of the watershed is identified as shown in Figure 6.

The result shows that 26.9% (1513.16 Km^2) area of the watershed is covered by fine sandy loam soil texture and it high infiltration capacity. This soil texture is categorized in low flood vulnerability level. The high flood vulnearability level is given to soil texture class identified as Clayey since it has low infiltration capacity. This covers 2.1% (118.13 Km^2) area from the watershed. All the results related to soil are summarized and presented in Table 5.

Table 5: Soil texture identified in Bilate watershed with their respective flood vulnerability level

Soil Texture Class	Flood Vulnerabilty level	Area coverage in %	Area in Km^2
Fine Sandy Loam	Low prone area	26.9	**1513.16**
Silt Loam	Moderate Prone area	32.4	**1822.53**
Clayey Loam	High prone area	38.6	**2171.30**
Clayey	Very High prone area	2.1	**118.13**
	Total Area	**100%**	**5625.12**

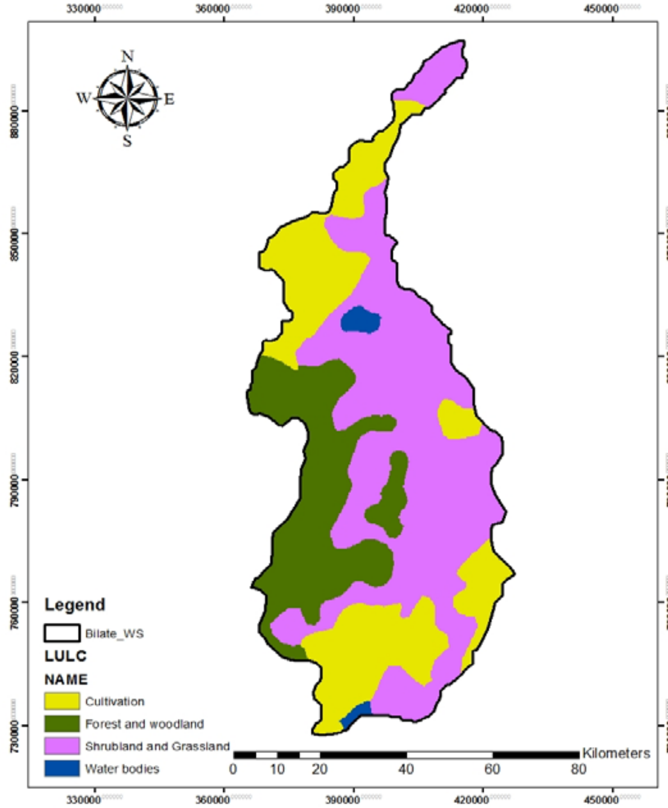

Figure 5: Landuse/Landcover map of Bilate Watershed

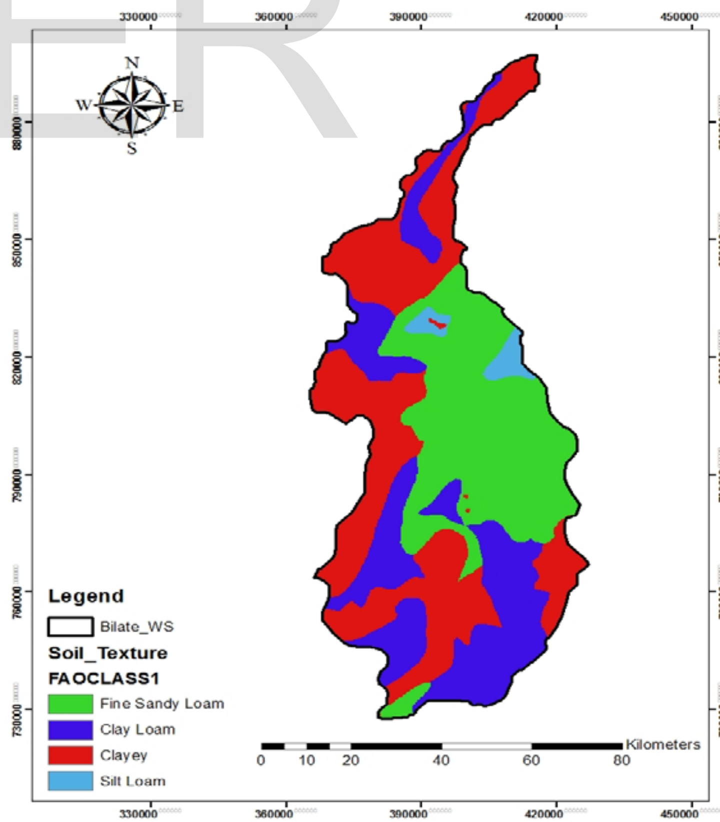

Figure 6: Soil Texture Map of Bilate Watershed

Flood Prone Areas

The flood vulnerable area is the composite map obtained by weighted overlay technique in ArcGIS software. To develop the map, it is required first to rank the criterions selected and then calculating the weight value of each criterions using pair wise comparison technique which is called Analytical Hierarchy Process as developed by (Saaty, 1980). Studies of (Ajin et al., 2013), (Yahaya, 2008), (Akyurek and Yalcin, 2016), (Dano et al., 2012), (Monika et al., 2016), (Elsheikh et al., 2015)and (Fekadu, 2018) reviewed and the rank of the five selected criterions were developed as Shown in Table 6.

Using IDRISI 17.02 software, the weight value of each criterion is calculated and shown in Table 6. The check of the result whether it is acceptable or not is done by looking for the consistency ratio. According to (Saaty, 1980), the consistency ration calculated should be less than 10% (0.1). The consistency ratio calculated from the pair wise comparison matrix is equal to 1.5% (0.015), which is less than the limit value set by (Saaty, 1980) showing that the result of weight value obtained for each criterion in Table 6 is acceptable.

Table 6: Weight value calculated and rank given to each criterion used in flood prone area mapping

	Category	Weight Value	Rank
1	**Rainfall**	41.9%	1
2	**Slope**	26.3%	2
3	**Drainage Density**	16.0%	3
4	**LULC**	9.7%	4
5	**Soil**	6.2%	5

In weighted overlay function of ArcGIS software, all the criterions set were inserted with their respective weight value and the composite map showing flood prone area is produced and reclassified in to three classes as Shown in Figure 7.

The final result shows that from the total area of the watershed 28.5% (1603.16 Km2) is delineated as highly flood prone area. This area is mostly inclined to the Northern, North Eastern and South Eastern Part of the watershed. The central, North Western and South Western portion of the watershed is categorized as moderately flood prone area covering almost 61.4% (3453.82 Km2). The south tip and South Central part of the watershed is characterized with its low flood prone class and covers around 10.1% (568.14 Km2) area of the watershed.

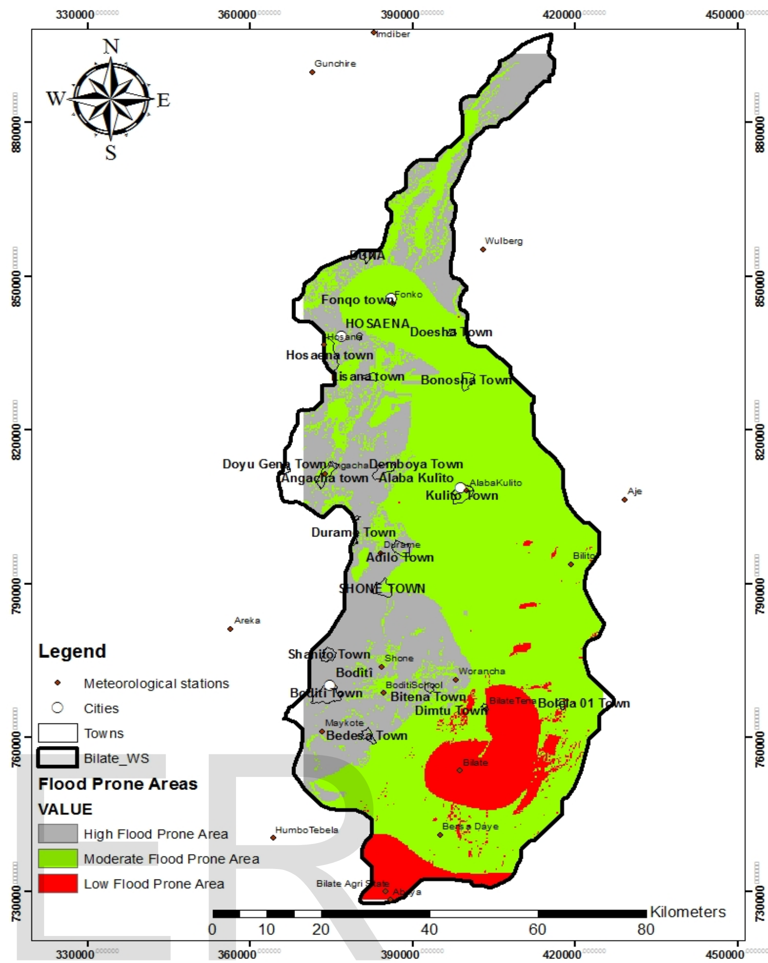

Figure 7: Flood Prone Areas map of Bilate watershed

CONCLUSION

The most widely used methodology for mapping flood prone area is Integration of multicriteria analysis with that of GIS Techniques because of its less data requirement and cost efficiency. In this study the same methodology has been found effcient approach to map flood prone areas in Bilate Watershed using Rainfall, Slope, Drainage density, Landuse/Landcover and soil parametrs.

With the abrupt increase in population and rapid urbanization trend, it is expected that the flooding events even aggravate from what is existing now. To cope up with the flood, this prepared map can act as an input for policy makers and planners to prioritize and come up with flood protection and mitigations measures.

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