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Detecting Flash Flood Hazard Areas Using Geo-Spatial – Based Analytic Hierarchy Process in Weidie Watershed South Western Ethiopia

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Abstract

Torrential rainfall in conjunction with anthropogenic activities and watershed topography in the country particularly in the study area have showed an increasing frequency of flood and becoming a threat and negatively affecting the agricultural production. In this study, Geo-Spatial techniques with Analytic Hierarchy Process method was used in Weidie Watershed; South Western Ethiopia to detecting Flash flood hazard areas. Shuttle Radar Topography Mission Digital Elevation Model, 30 m resolutions were downloaded from United States geological survey and Daily rainfall data of six metrological stations (1987-2015) were collected from National Metrological Agency. The causative factors of flash flood in the watershed are taken into account. Questionnaires were distributed to experts to score each flood contributing factor used as criterion separately in their order of significance. Geo-Spatial method was used to analyse spatial data sets that affect flash flood while the analytical hierarchy process method was used to compute the priority weights of each criterion. The result showed Weidie watershed is resistance permeable surface with less efficient in runoff discharge. The factor weight shows annual rainfall (32.6%) and drainage density (20.3%) were the most flood contributing factors. The flood hazard zone depicted that 106.6 km^2 area where subjected to very highly flash flood hazard zone. Further analysis depicted that up to 31.88 km^2 farm land, 0.1 km^2 built up lands can be under high to Very high risk zone. The result shows that integration of the models can be used to assist decision makers on the threat posed by the disaster.

Keywords: Flash flood; Geographic information system; Multi criteria decision analysis; Analytical hierarchy process

Introduction

Worldwide natural disasters, constituted a major problem. It kills thousands of people and destroys billions of dollars' worth habitat and property each year. Even so its frequency and severity have increased rapidly as a result of rapid growth of the world's population. Floods are one of the most devastating natural hazards, impacting upon human lives and causing severe economic damage throughout the world [1]. It is generally caused by intense precipitation over a short period or normal rain over a long period of time but studies showed that same anthropogenic activities land use land cover changes, channel modification, deforestation and urbanization also influence the occurrence of this hazard [2]. Besides LULC and rainfall flood also topographic factors terrain slope, elevation, drainage density and phedological physical properties of soil causes flood.

In Ethiopia flood area weather-related natural disaster and commonly two type's river flood and flash flood. Flash flood occurs in lowland areas when excessive rains fall in adjacent highland areas, (NDRMC, 2016). Usually, flash floods in the country are caused by heavy rainfall falling on upstream river catchments and gush downstream with huge concentration, speed and force [3]. According to Zewde [4] the frequency and magnitude of flood in the country have increased in the last few decades as a consequence of climate and land-use change which in turn resulting a negative affecting on agricultural production, demonstrating agriculture's sensitivity to climate change. Damot Weidie Woreda is one of a flash flood prone area is SNNPR of the country, frequently affected by sudden flash flood. According to the Ministry of Agriculture and Rural Development Disaster Risk Management and Food Security Sector 2010 report on flood risk frequency in Ethiopia from 1957-2007 the study area is affected nine times by flash flood and resulted in loss of life, destruction of standing crops, infrastructures. Flooding in May 2016 in the area causes significant damages to the crops environment and livelihood. High intensity rainfall events along with the changes in the land use patterns and high population growth terrain characteristics are expected to have implications on the intensity of local flash flooding in the area. So far there were not studies cared out there is therefore the present study will try to consider the causative factors of flooding in the watershed to detect flash food risk area.

Material and Methods

Description of the study area

The study area, located in south west Bilate river catchment, Wolita zone, Southern National Nationality people Region, Ethiopia, is geographically defined 6°51' 0" N to 7°17' 00" N and 37°45' 0" to 38°43' 30"E, an area of 452 km^2 (Figure 1). The watershed area is characterized by dendrite stream pattern and a drainage density of 0.42. The topography of Damot Weidie watershed is steep in upper reaches and abrupt in lower reaches, The altitude ranges from 2,943 to 1,552 M.a.s.l (Figure 1). The climatic condition of the study area referred from Humbo Tebela Metrological station of the long year rainfall (1987-2016), accordingly monthly average temperature of the study area varies between 20.1°C in Marto 16.5°C July.

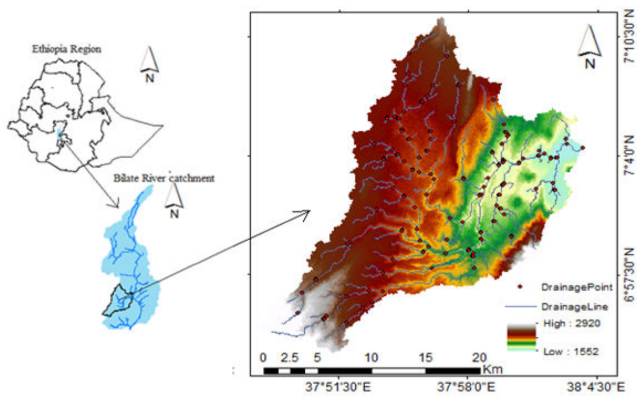

Figure 1: Location map.

The study area is characterized by bimodal rain fall type, short rainy season, which extends between Mar to May and locally known as "Belg" receives 28.5% (340 mm) and the long rainy season and locally known as Kiremt, which extends from June up to October (kerempt) receive 53.6% (639.8 mm). Rainfall patterns in the study area are characterized by high spatial and with slight temporal variability. The annual rainfall distribution ranges between 757.4 to 1931.6 mm with an average value about 1185 mm with standard deviation about 266 mm (Figure 2).

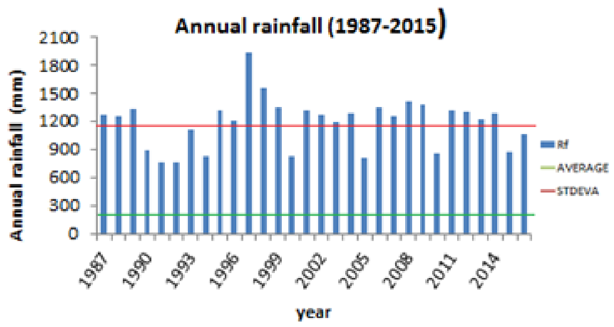

Figure 2: Annual Rainfall.

While the distribution of maximum daily ranges between 12 to 107.4 mm with an average value about 64.8 and standard deviation is about 18.1 mm (Figure 3). The daily maximum rainfall shows that there is an increase in daily maximum rainfall from 1997 to 1998. Return period and probability of the maximum daily rainfall were calculated by Weibull's plotting position formula for the time period from 1966 to 2010 (Figure 4). Figure 5 depicted that maximum daily rainfall increasing with increasing return period though flooding events in the catchment mainly caused by torrential rainfall. The major soil reference groups in Damot Weidie watershed are Lithosols (4%), Dystric Cambisols (16.7%), Eutric Nitosols (25.9%), Pellic Vertisols (28.9%), Chromic Luvisols (3.5%) and Vitric Andosols (21%).

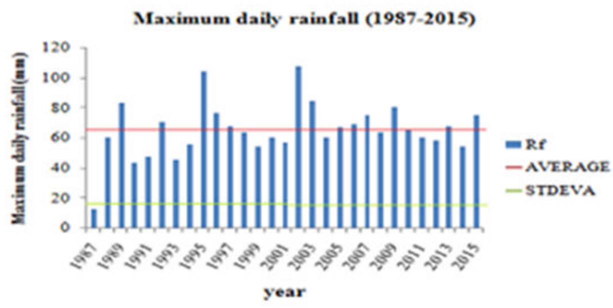

Figure 3: Maximum daily rainfall.

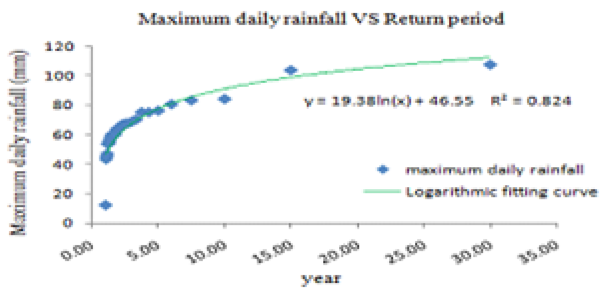

Figure 4: Return period of the maximum daily rainfall.

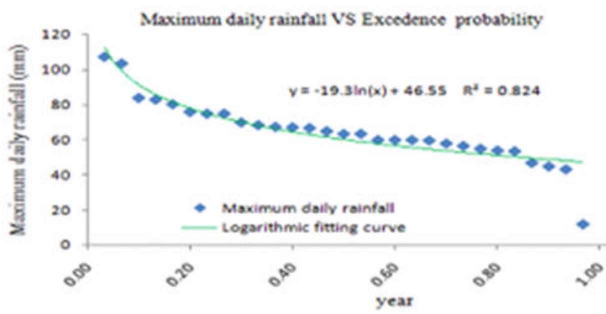

Figure 5: Probability of maximum daily rainfall.

Data used and source

The available data are Land sat imageries of 2016 from USGS, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), 30 m resolutions from USGS, the soil data of FAO [5] at 1:1 000,000 1998 was collected from ministry of agriculture (MoA) and the Daily rain fall for the year 1987-2008 were collected from National Metrological Agency (NMA).

Methodology

The present study used structured interview to identify the relative importance of the causative factors (criteria), GIS to quantify the drainage morphometry and generate terrain criteria maps and remote sensing to map the land use land cover of the area and Analytical Hierarchy Process-(AHP) 1.1 Arc-GIS interface are used for weighting of factor maps. The methods followed in this study are schematically represented in Figure 6.

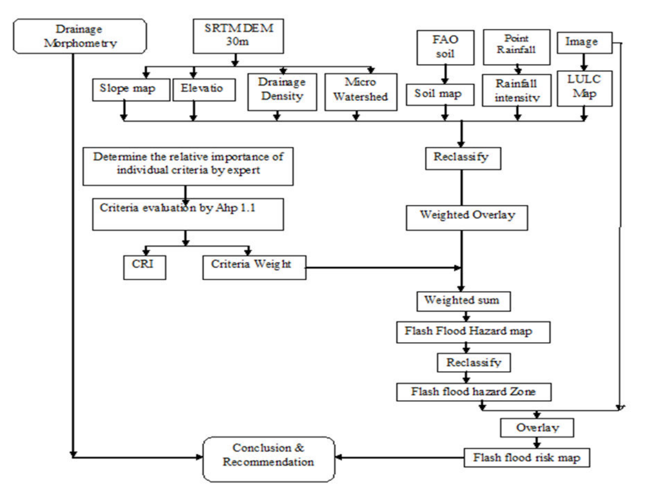

Figure 6: Flow chart for Predicted Flood risk zone map in Micro Watershed.

Selection of experts: The present study defines seven criterion maps (C1=drainage density, C2=basin slope, C3=Elevation, C4=Size of micro Watershed, C5=soil, C6=annual rainfall and C7=Land use) as causative factors. After defining the criteria, the structured interview was undertaken with local experts to identify the relative importance of all the selected criteria. This questionnaire was based on the scale of 1-9 for the experts to assess the relative importance of each individual criterion. The interview was conducted with eight experts that are relevant to the issues. Interviews were conducted face to face. Based on the literature review, the criteria were selected and subjected to a review by the local experts to determine the relative importance of each criterion in resulting flood hazard.

Calculating the drainage morphometry

The present study used Arc GIS 10 to calculate the drainage morphometry of Weidie watershed which is used to quantitatively describe watershed characteristics. Drainage morphometry or variables was extracted from SARTM DEM with a spatial resolution of 30 m.

Weighted overlay

Weighted rainfall distribution: After the rain fall interpolated the rainfall distribution map was generated that show the annual rainfalls of the watershed range from 1112 mm to 1298.5 mm. Then the rainfall distribution map was reclassified in to four classes based on its standard deviation (29.56) and weight was assigned based on their importance in resulting flash flood. Higher weights (8) are assigned to area with Annual Rainfall more than 1230 mm and lower weights (2) were assigned to areas with Annual Rainfall less than 1141 mm. Finally, the weighted rainfall distribution map was created using Arc-GIS weighted Overlay spatial analyst tools. The result showed that 86% of the watershed area receives annual rainfall greater than 1230 mm however only 1% of the watershed area receives annual rainfall of less than 1141 mm.

Land use land cover: The study area has been defined to have five land use land cover categories, which are: Built Up, Mixed Vegetation, Forest, Plantations, and Water Body. The result showed that farm land and bush land covered for 282.5 km^2 (62.6%) and 66 km^2 (14.7%) respectively while built up, woodland, bare land, grazing land and water body accounted to about 1.24 km^2 (0.3%), 34.1 km^2 (7.5%), 45.2 km^2 (10%), 22.1 km^2 (5%) and 0.076 km^2 (0.02%) respectively. An overall accuracy of 90.47% and Overall Kappa Statistics of 0.876 is obtained from the accuracy assessment and accepted. After the image classification weighted land use land cover map of the watershed was generated using Arc-GIS weighted overlay spatial analysis tools by assigning weights to each land use land cover classes i.e., in the order of their importance in resulting flash flood in the area i.e., higher weight (8) are assigned to residential areas and roads, which are mostly made by impervious surfaces and bare lands and areas water bodies whereas lower weight (1) are assigned to vegetated areas have low potential to flooding due to the negative relationship between flooding and vegetation density.

Weighted slope and elevation: After the slope map generated the slope of the watershed classified in to four classes 0%-8%, 8%-15%, 15%-30% and >30% then the weighted slope map was generated using Arc-GIS weighted overlay spatial analysis tool by assigning weights to each class of slope based on their importance in resulting flash flood in the watershed i.e., higher weight (8) were assigned to flat or almost flat 36.8% (166.4 km^2), Whereas moderately steep to steep slope area 13.11 (59.5 km^2) assigned low weight (2). Similarly, the elevation map generated reclassified in to five sub elevation classes using quintile classification method. Then weighted overlay was generated by assigning weights to each classes i.e., higher weight (8) are assigned to areas that lies within the elevation range of 1552-1719 and lower weight (2) are assigned areas that lies within the elevation range of 1951-2920.

Weighted drainage density: The drainage density map of Weidie watershed was reclassified in to five <1-3, 3-5 and >5. Then higher weight (8) was assigned to area that have poor drainage density (Dd of <1 km/km^2) and lower weight (2) to area that have adequate drainage density (Dd of >5 km/km^2).

Weighted soil: Soil map of the watershed was reclassified in to five sub classes (very low, low, moderate, high and very high) infiltration capacity and weight was assigned to each class based on the important of each class in resulting flush flood thus Higher weight 8 were assigned to low infiltration area, and lower weight 2 were assigned to high infiltration potential area.

Criteria weight

The Pair-wise comparison matrix is created by assigning weights by experts. The weights are further evaluated in finding alternatives and estimating associated absolute numbers from 1 to 9 in fundamental scales of the AHP. These weights are computed automatically in ext AHP 1.1 in Arc GIS 10.1. Hence, the results of relative weights of C1=drainage density, C2=basin slope, C3=Elevation, C4=Size of micro Watershed, C5=soil, C6=annual rainfall and C7=Land use. Based on the decision makers' preferences torrential rainfall and Drainage Density were the most floods contributing factors of the study area. The overall result of AHP analysis shows that the consistency ratio (CR) is 0.027, which is much lower than the threshold value of 0.1 and indicates a high level of consistency in the pair wise judgments. Hence, the weights are acceptable. The computed eigenvector is used as a coefficient for the respective factor maps to be combined in the weighted overlay and Using pair wise compression the normalized criterion weights were 20.31%, 12.6%, 6.09%, 4.8%l, 12.99%, 32.62%, 10.59% respectively (Figure 7).

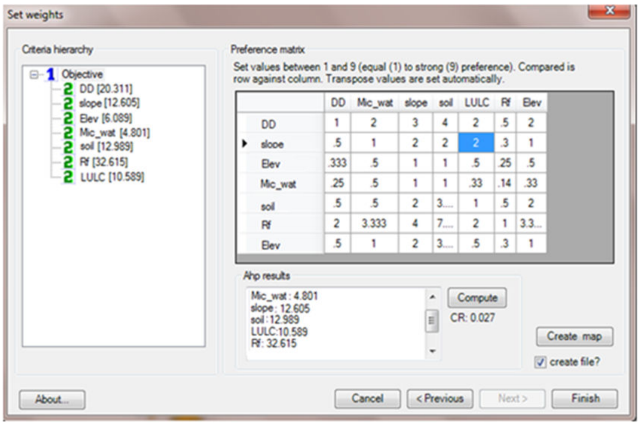

Figure 7: AHP result.

Flash flood analysis

Flash flood analysis was performed in ext AHP 1.1 in Arc GIS 10.1 environment. AHP model perform criteria weighting consistency ratio and flood mapping. After criterion weights are obtained in ext AHP 1.1, Arc GIS 10.1 interface the weights were used for spatial flood risk mapping of the study area. Then the flood risk map where reclassified into five classes as; Very low, Low, Moderate, High and Very high on the output map depicting the flood hazard risk zone of the study and also the flood risk map were overplayed in land use.

Results and Discussion

Drainage morphometry of the watershed

The drainage morphometry of Weidie watershed have been calculated. The total drainage area of Weidie watershed is 452 km^2. The drainage pattern is dendritic in nature and influenced by geology, topography and rainfall condition of the area. The stream analysis shows that the watershed is a 5th order (Figure 8). Thus, there is 1 fifth, 2 fourth, 7 third, 25 second and 101 first orders with a total length of 360.6 km (Figure 9). From the Figure it is observed the total stream length is highest in first order stream order and decrease as the stream order increase [6]. The bifurcation ratio (R^b) values ranging between 1 and 4.02 and the mean bifurcation ratio of the micro-watershed is 3.03. This indicates that the drainage pattern has not been affected by structural disturbances and the observed R^b is not the same throughout stream orders of the micro watershed. Bifurcation ratio values of the sub-watershed ranging between 3 and 4.5 characterize a basin which has experienced minimum structural disturbances. As studies show higher value of R^b indicated strong structural control on the drainage pattern and also streams that have a higher average flood potential due to numerous tributary segments drain into relatively few trunk transporting stream segments.

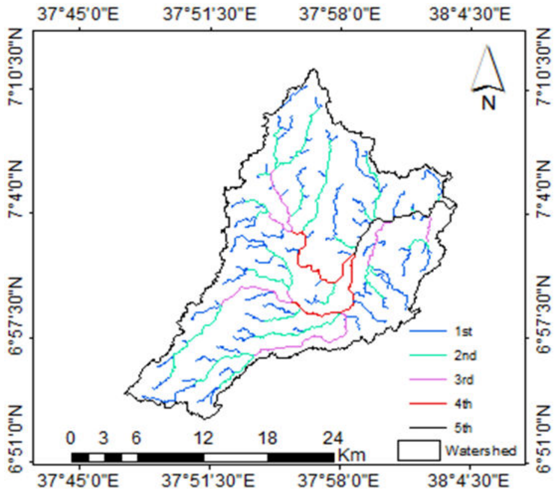

Figure 8: Drainage map with stream orders.

Flood risk zone map

The result of flash flood hazard area depicted that the lower part of the watershed was highly vulnerable to flash flood area as also the result of drainage morphometry of the watershed indicated. Finally, the flash flood hazard area map was reclassified into five classes as; Very low, Low, Moderate, High and Very high on the output map depicting the flood hazard risk zone of the study area (Figure 8).

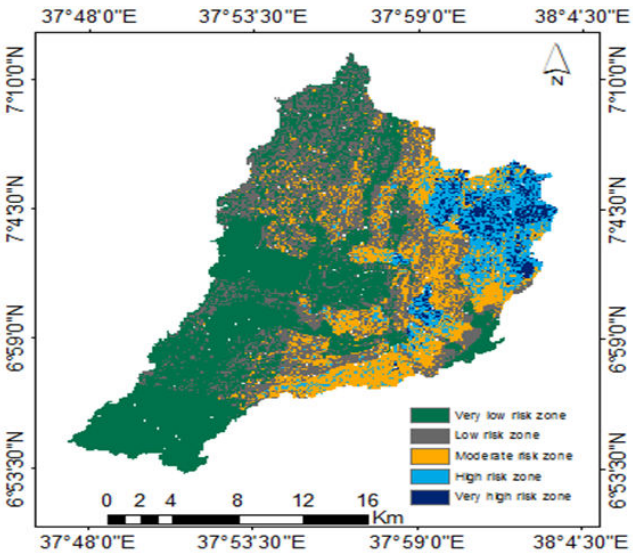

Figure 9: Flood hazard risk zones.

The flood hazard risk zone map below shows that 106.6, 229.5, 62.5, 24.8 and 18.3 square kilometer of Weidie Catchment were subjected flood hazards respectively. Further analysis an overlying between hazard risk zone map and land use revealed that 31.88 km^2 Farm land, 0.1 km^2 built up lands, 6.87 km^2 bare land, 1.88 km^2 shrub lands, and 0.17 grazing land falls under high to very high flood hazard.

Conclusion

Geo-spatial techniques with Analytical Hierarchy Process (AHP) method is valuable tools to detect flash flood hazard are. Weidie watershed is a 5th Order and elongated watershed, resistant permeable surface with low drainage line experienced small structural disturbances and an old dendritic stage nature. Generally the watershed is moderately rugged and covered by low vegetation and receives high rainfall which exposed to high runoff and low intensity erosion. Drainage density was found the most contributing factor for flash flood hazard event next to high rainfall intensity in the watershed. The result of flash flood hazard zone depicted that 106.6 km^2 area of the watershed where subjected to very highly flash flood hazard zone, accordingly the lower part of the watershed was found high flood hazard risk zone. Further analysis depicted that up to 31.88 km^2 Farm land, 0.1 km^2 built up lands can be under high to Very high risk zone. Generally, flood is highly distracting standing crops and resulting in a negative effect in the agricultural production.

Recommendations

Additional meteorological stations should be established with in 30 km distance. The appropriate soil and water conservation measures must be planned and implemented prioritizing the highly flash flood hazard zone. Integrated watershed management works such as constriction of series of funyya-jun, soil bund, Agro-forestry and conservation farming in farm lands, check dams and detention dams in rills and afforestation also Proper grazing management has to be implemented in the upper catchment areas to minimize the speed, magnitude of runoff, whereas in lower catchment area using of diversion canal should be constructed to utilize the damaging runoff for the expansion of spit irrigation. Have a good early warning system in place.

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