Kodagu disaster (Floods - Emphasis on Catchment Fragmentation Index and unscientific land usage) analysis using GIS.

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Abstract. India is a densely populated country, natural hazards like floods and landslides cause a great impact on peoples’ life and property as well. The floods and landslides in Kodagu, Karnataka was not only because of unexpected heavy rain but has various man-made causes like unscientific land-usage modifications. This unscientific land usage and linear constructions like roads railways, etc. have caused catchment fragmentation, hindered or blocked the natural streamflow, and resulted in localized water stagnation, resulting in floods and landslides. This paper defines an index-catchment fragmentation index to generalize the causes of both unscientific land usage and linear constructions (mainly roads). Catchment fragmentation causes variations in soil moisture content, flow path, flow velocity, flow connectivity, as well as on concentration time. This paper uses the Multi-Criteria Decision Making-Analytical hierarchy process (MCDM-AHP) to create a flood hazard zonation map and also aims at predicting the hazard and vulnerability zones and hence tries to guide on correcting the unscientific land usages.

Keywords: MCDM-AHP, Catchment fragmentation index, Unscientific land usage.

1. Introduction

A natural hazard is a damaging phenomenon within a specified period and region due to a set of existing or predicted conditions that can cause loss of life as well as property [1]. Floods are the overflow of water beyond its natural limits, mainly due to heavy rainfall or snowmelt and sometimes because of collapsing of the dam. Apart from these reasons it is also caused by deforestation, climate change, etc.

The study deals with interpreting and analyzing the reasons behind devastating floods and landslides of Kodagu district in Karnataka of the year 2018 and 2019. Though the floods were mainly due to heavy rain but were also greatly influenced by anthropogenic activities which tend to disturb the equilibrium of the catchment. So, a zonation map is required considering the combined effect of all the influencing factors of the potential hazard. According to National Research Council, 2005; Rao, predicting the intensity and duration of the short burst intense rainfall is difficult, which often also

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triggers floods as well as landslides in slopy terrain. Kodagu faced around 130633.88 hectares of cropland. INR 50,672 lakh of worth crops was destroyed, the main economic source of Coorg people. An estimated INR 415 crore loss due to damage to the roads, bridges, and infrastructure [2,3].

A zonation map is required before any disaster management or mitigation studies. As the regions of high probability zones can be concentrated upon, thus increasing the focus and reducing the time as well as investment in disaster management. The zonation maps can be generated by various techniques like -inventory-based probability studies or deterministic or heuristic or statistical techniques [4]. The Multi-criteria decision analysis method- analytic hierarchy process (AHP) is used in this study considering the heterogeneity of the attributes of all the criteria, belongs to heuristic analysis. One of the main advantages is that this method avoids the generalization of data and considers the uniqueness of the particular event, its region [6], and causative factors. This study mainly deals with the effect of anthropogenic activities which have increased the probability of such events and a flood hazard zonation map is prepared using ArcGIS and M algorithm as proposed by Satty [5].

2. Study area
Kodagu is considered one of the ecologically sensitive areas of Western Ghats of Karnataka (Figure 2), with rare and rich fauna and flora. Kodagu extends from 11.56˚N-12.52˚N and 75.22˚E-76.12˚E. The toposheet numbers of the region used are 48P/10, 48P/7, 48P/11, 48P/15, and 48P/12. During the monsoons of 2018, Kodagu has experienced very heavy rainfall. Madikeri and Somwarpet taluk had received cumulative rainfalls of 4692 mm and 2701 mm respectively, breaking the 87-year-old record of the year[7]. Though it was concluded that heavy rain was the cause but it is also debatable that anthropogenic pressure was the main reason for the floods. There is a lot of lessons that this disaster teaches us and help in future planning of our urban infrastructures which should not disturb the natural ecosystem and its processes.

The study area experienced heavy rainfall (Monsoon) which resulted in floods and landslides in August. The daily rainfall trends of the month August 2018 and August 2019 (collected from Karnataka State Natural Disaster Monitoring centre) is plotted to show the variation of such an event against a normal scenario. There was around a 400% increase in rainfall against the normal rainfall, for the days from 13th to 18th August 2018 [12], (Figure 1).

![Figure 1. Rainfall in the month of August 2018 of the 2 catchments against the normal rainfall](image-url)

The Kodagu district (Figure 3) is delineated and the 2 catchments (Figure 4) are considered for the study. Catchment 1 was the most affected by floods in the year 2018 and 2019, hence this catchment is chosen to study the floods in this paper. The landslide of catchment 2 was analysed in the previous part of this work [8].
Land-use-Land-cover (LULC) determines how the rainfall is portioned into the runoff, or whether it is infiltrated or evaporated [10]. The catchment area showed that urbanized areas and the area under the plantations increased to about 20%, while the Forest area decreased to about 40% [9, 11]. (Figure 4), which is especially alarming for an ecologically sensitive area like Kodagu. If the catchment is not having the capacity to retain rainwater, there would be no percolation into the ground, most water would flow into oceans, causing floods in the monsoon followed by droughts because of unreplenished groundwater. Along with flash floods, the district also witnessed landslides.

Figure 2. Karnataka state map

Figure 3. Kodagu district map

Figure 4. Delineated catchments

LULC of the year 2016 is considered, just before the floods and landslides, to prevent erroneous results due to changes in the landscape after the disaster.

Figure 5. LULC trends of Kodagu for the years, 1973 and 2016

2.1. Data used
1). DEM data from Google earth pro.
2). LANDSAT 8 images from earth explorer-USGS.
3). Shapefiles of the district and taluk boundary from Karnataka GIS portal.
4). Digital Soil Map of the World prepared by the Food and Agricultural Organisation (FAO) has been used for the identification of the Hydrological Soil Groups (HSG) present in the study area.
5). Annual rainfall data from the IMD website and daily rainfall from Karnataka State Natural Disaster Monitoring Centre (KSNDM) [9].
6). Geomorphology, geology, road network, lineament shapefiles from Bhukosh website. ArcGIS software is used in delineating the watershed, finding the catchment area as well as analyzing the AHP results using the tools of the software.

3. Analysis of disaster trends for the year 2018-19
By comparing the Land-use land cover trends of Kodagu district with previous disasters f 2018-19 (flood and landslide), a general conclusion can be drawn about the landslide and flood-affected areas.

- The urban settlements of the entire district are clustered about the state highway of Madikeri taluk. The map (released by the Government of Karnataka) shown above shows the landslide in the year 2018 and 2019 were clustered around the state highway of Madikeri taluk (Figure 5, Figure 7) and near plantations of Harangi basin of Somwarpet taluk [13,14]. The slopes created due to road construction if left unsupported can lead to slope instability causing landslides which are enhanced during rain. The stream network is hampered, thus leading to waterstagnation which causes more infiltration, decreasing the angle of friction leading to landslides
- The floods of the year 2019 and 2018 (Figure 6) also show a general trend as they are concentrated around urban settlements and plantations of Virajpete and Gonikoppa (Figure 7), even though they are away from the banks of the river north of them. This can infer that localized blocking of drainage and localized water stagnation due to slope modifications, unscientific land usages like plantations, construction of roads [11], clustering of settlements disturbed the catchment and no alternative methods were used to restore the blocked drainage. The terrace farming at the plantations is believed that have caused localized water stagnation.

Catchment 1 is considered for analysis, as it was most prone to floods.

4. Methodology
The Multi-Criteria Decision Making (MCDM)-Analytical Hierarchy Process (AHP) is used for generating the probable flood hazard zones [15] of Catchment 1. Considering the wide range as well as the heterogeneity of the attributes and multiple criteria, the MCDM-AHP method is chosen to predict the most probable zones of the hazard with the theoretical background as well as inventory studies of the different criteria considered for the Kodagu region.
- This method compares two criteria at a time through a pairwise comparison matrix as per users’ decision based on theoretical background and the location-specific inventory studies; in
which the user compares the two criteria based on the relative contribution to floods ranging from one to nine, where one means both criteria in pairwise comparison are equally contributing, whereas nine means one of the criteria is extremely dominating the other (1. equally contributing; 3. slightly more contribution; 5. Quite more contribution; 7. more contribution; 9. Extremely dominant in contribution; 2, 4, 6 and 8 are intermediate values) [5, 15, 16, 17]. After solving, we get relative priority weightage and ranking of the different criteria considered. The AHP method was used to conclude the contribution of each criterion to a particular hazard.

Figure 8. flow chart representing the methodology

- The thematic maps are in raster format and they are Resample to UTM zone 42 coordinate system and pixel resolution of 10m. The relative rank of different attributes of a particular attribute has been assigned using Reclassify tool of ArcGIS, based on its probability of occurrence of floods, using scale 1-9, (1- low probability of floods, 9- highest probability of floods).
- The advantages of the AHP method are, it allows identifying inconsistency of the ranks given to the pairwise comparisons using CR (consistency ratio) as an indicator. If CR <10%, it indicates a good level of consistency [5,18,19], but these ranks are assigned based on users’ decisions.
(CR-consistency ratio, CI-consistency Index, RI-random index)

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

Table 1. Values of Random Index (RI) concerning

| n  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----|----|----|----|----|----|----|----|----|----|----|
| RI | 0  | 0  | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]

Where \( \lambda_{\text{max}} \) is the principal eigenvalue and \( n \) is the number of criteria. Random consistency index (RI) (Table 1) average of randomly generated reciprocal matrices (Saaty 1980).

- Based on priority obtained from the matrix calculations, the attribute Reclassified thematic maps are multiplied with their respective priority percentage (Equation 4) to obtain flood hazard zonation maps (Figure 8).

4.1. The criteria considered for the study of the zonation map of the flood are:

4.1.1. Catchment Fragmentation Index (CFI)

This index depicts the macro-level effects of unscientific land usage and practices. These changes in LULC have led to catchment fragmentation which causes variations in soil moisture content, flow path, flow velocity, flow connectivity, water stagnation as well as concentration time. The deforestation and conversion of forests to plantations, agricultural lands, or grasslands has led to intensified and sudden flood peaks. The flow connectivity is getting disturbed due to roads and urban infrastructures. The stream networks have been hampered by unscientific land usages like plantations, and linear constructions like the transport network or the power lines which led to fragmentation of catchment thus blocking the stream networks and natural drainage systems.

This can infer that localized blocking of drainage and water stagnation due to slope modifications, unscientific land usages like plantations, construction of roads [11], clustering of settlements disturbed the catchment and no alternative methods were used to restore the blocked drainage.

Catchment Fragmentation index (CFI) (Equation 3, Figure 16) has been defined to depict the extent of catchment fragmentation. The index has considered the blockage and hindrance of the stream network due to terrace farming, urban area, and linear constructions mainly roads (Figure 10). The main river network intersection is not considered since it’s not hindered due to the presence of bridges and culverts. Thus the 15000<flow<20000 (Figure 11, Figure 12, Figure 13) is considered to study the hindrance (Figure 14, Figure 15).

\[ CFI = \text{BLOCKAGE DUE TO LINEAR CONSTRUCTIONS} + \text{BLOCKAGE DUE TO UNSCIENTIFIC LULC(TERRACE FRAMING AND URBAN AREA)} \]

![Flow chart showing Catchment fragmentation index methodology](image-url)
If the road network increment and LULC changes can be predicted, the susceptibility of the catchment to flood and landslides in the future thus can also be predicted.

4.1.2. Slope

The slope is a topographic feature (Figure 17) that represents the steepness i.e rate of change of elevation, generally, the steepness increases the probability of the flood also decreasing at that particular region. The slope was classified into 5 classes-Very steep(>45°), steep(35°-45°), moderately steep(25°-35°), rolling(10°-25°), undulating(2°-10°) and flat(0-2°). At steep slopes, there are low chances of water stagnation, lower infiltration, and higher velocity of water, and regions downstream can face higher flood peaks due to steep slopes [20,26].

4.1.3. Slope curvature

Curvature is the second derivative of the surface. The PLAN CURVATURE is perpendicular to the direction of maximum slope. If it is positive surface is laterally convex, if negative the surface is laterally concave and a zero indicates the surface is linear. PROFILE CURVATURE (Figure 18) is parallel to the slope. If it is positive the surface is upwardly concave (flow is accelerated), if the negative surface is upwardly convex (flow is deaccelerated) and a zero indicates the surface is linear (ESRI). Profile curvature is considered for the study of floods [20,26].

4.1.4. Soil

Soil data is collected from the Hydrologic soil group (Figure 19) [23]. The soils present are 3,4,13,13.
- 3- moderately high runoff potential (<50% sand and 20-40% clay)
- 4- high runoff potential (<50% sand and >40%clay)
- 13- high runoff potential, unless drained (<50% sand and 20%-40%clay)
- 14- high runoff potential unless drained (<50% sand and >40%-clay)

4.1.5. Topographic wetness index (TWI)

TWI (Figure 20) represents the tendency of water accumulation in an area with elevation difference and hence the soil moisture. It is a function of slope and upstream contributing area per unit width orthogonal to flow direction.

\[
TWI = \ln \left( \frac{SCA}{\tan \phi} \right)
\]

SCA is a specific catchment area, assuming properties of soil and rock mass are the same SCA represents a tendency to receive water while slope represents the tendency to drain water. Higher the TWI, the higher the probability of floods and landslides [20,26].

4.1.6. Topographic roughness index (TRI)

The topographic roughness index (Figure 21) indicates the amount of elevation difference between the pixels of DEM(Digital Elevation Model). Thus if TRI increases, the probability of occurrence of flood decreases [20,26].

4.1.7. Stream power index (SPI)

The SPI (Figure 22) is related to the geomorphology along a stream, which influences the loss of potential energy of the river along with its flow. It also depicts the erodibility capacity of the river. The higher the value of SPI, the more probable to floods [24].

4.1.8. LULC
The runoff in a catchment mainly depends on the amount of precipitation and land use land cover (LULC) (Figure 23) trends of that catchment [9]. Changes in LCLU are majorly influenced by anthropogenic activities more than natural changes. This greatly influences how rainfall partitions into infiltration to groundwater recharge or runoff or evapotranspiration. The thick evergreen vegetation has deep root systems increasing slope stability. But most of the forests are transformed into plantations and urban settlements. The plantations in the study area followed the contour farming method which can be because of localized water stagnation [21]. LULC of the year 2030 (from CA Markov chain principle) is used for zonation map prediction.

4.1.9. Rainfall
The rainfall trends are shown in Figure 1 which shows the rare event of rain in the Kodagu region for August 2018 and this rare event is considered for the study (Figure 24).

4.1.10. Distance from stream
The distance from a stream (Figure 25) is calculated using the Euclidean distance tool of ArcGIS, the places closest to the river stream are most susceptible to floods [20,26].

4.1.11. Geology
The region consists of Charnockite, Sargur, Peninsular Gneissic complex, and Khondalite as its geological features (Figure 26). From the reports of previous floods, Khondalite, Peninsular Gneissic complex are most susceptible to floods followed by Charnockite and Sargur [22,25].

4.1.12. Elevation
Elevation of the region is shown (Figure 27). Relatively low-lying regions are most susceptible to floods [26].

4.1.13. Topographic position index (TPI)
TPI (Figure 28) compares the elevation of each pixel of DEM with the mean elevation of neighboring pixels. The extreme negative values indicate valleys, moderate negative values indicate lower slopes, zero indicates flat ground and a moderately positive value indicates upper slope, and extreme positive values indicate cliff edges or ridges [26].

![Figure 10. Road network map](image1)

![Figure 11. Stream network with flow>15000](image2)
As no railways are present, main roads are considered as the linear construction causing an obstruction. 2000<flow<15000 is generated using overlay tools. Hindrance points of a stream (2000<flow<15000) and roads network is generated using intersect tool.

**Figure 12.** flow>2000  
**Figure 13.** stream network with 2000<flow<15000

**Figure 14.** blockage points of stream

**Figure 15.** blockage density due to roads  
**Figure 16.** Catchment fragmentation index
Figure 17. Slope variation map

Figure 18. Profile curvature map

Figure 19. Soil map

Figure 20. TWI variation map

Figure 21. TRI variation map

Figure 22. SPI variation map

Figure 23. LULC 2030

Figure 24. Rainfall variation map
5. Results and discussions

The pairwise comparison matrix of the AHP process is obtained (Figure 29). There are 78 pairwise comparisons, the Principal Eigen Value is 14.543, and the Consistency ratio is 0.083 (<0.1). Hence the AHP comparison results are consistent and reliable.
| ATTRIBUTE       | RANK | PRIORITY |
|----------------|------|----------|
| CFI            | 3    | 13.8%    |
| Slope          | 9    | 2.9%     |
| Profile curvature | 11  | 1.9%     |
| Soil           | 10   | 2.2%     |
| TWI            | 4    | 10.2%    |
| TRI            | 8    | 3.9%     |
| SPI            | 2    | 14.6%    |
| LULC           | 5    | 9.1%     |
| Rainfall       | 6    | 6.5%     |
| DS             | 1    | 26.1%    |
| Geology        | 13   | 1.4%     |
| Elevation      | 12   | 1.7%     |
| TPI            | 7    | 5.7%     |

Using the Raster calculator tool of ArcGIS, the flood hazard zonation map is prepared using the expression given below: the priority percentage is multiplied with the Reclassified thematic layers (all thematic layers used are with 10m resolution)

**Flood hazard zonation map** = 0.138 × (Reclassified CFI thematic map) + 0.029 × (Reclassified slope thematic map) + 0.019 × (Reclassified profile curvature thematic map) + 0.022 × (Reclassified soil thematic map) + 0.102 × (Reclassified TWI thematic map) + 0.039 × (Reclassified TRI thematic map) + 0.146 × (Reclassified SPI thematic map) + 0.091 × (Reclassified LULC thematic map) + 0.065 × (Reclassified rainfall thematic map) + 0.261 × (Reclassified DS thematic map) + 0.014 × (Reclassified geology thematic map) + 0.017 × (Reclassified elevation thematic map) + 0.057 × (Reclassified TPI thematic map)

The flood hazard zonation (Figure 30) so generated is also validated with the previous events of 2018 and 2019 of catchment 1.
Considering the consequences after floods, the region is divided into risk zones—socio-economic risk zones are urban areas and most vulnerable to floods as they cause loss of life and property (Figure 31). The next most vulnerable region is the agriculture and plantation regions as they cause great economic losses and Kodagu being the ecologically most sensitive region, the forest region is considered vulnerable as well as there could be a threat to rich and rare fauna and flora. The least risk zones are barren land.

Using Overlay-tools, the risk and hazard zones are combined to get FLOOD VULNERABILITY ZONES (Figure 32).

The flood vulnerability zonation map divides the area into five different zones of different susceptibility and vulnerability classes—very low, low, moderate, high, and very high-risk. From the priority obtained from MCDM-AHP, we can also conclude that the man-made causes like LULC—urban settlements and plantations, road network density also contributed to triggering the floods and landslides, and these areas (the urban settlements and agriculture lands) are more vulnerable as it can cause loss of life and property.

6. Conclusions

Catchment 1 of the Kodagu region was most susceptible to frequent flooding and the most common triggering factors are heavy rainfall, terrain, and mainly the anthropogenic pressure which disturbed the equilibrium of the catchment fragmentation as depicted by the catchment fragmentation index. In the present study, flood hazard zonation mapping for the year 2030 has been carried out using multi-
criteria analysis (AHP-weighted) and CA-Markov chain principle with the help of remote sensing and GIS and ArcGIS software. The result was further validated by comparison with past events of 2018 and 2019. Future expansion of road networks, railways, plantations, or urban settlements should be done scientifically and no future increase in catchment fragmentation should be allowed, in unavoidable cases necessary steps to be taken to assure the equilibrium in the catchment and its hydrological processes.

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