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Integrated Hydrological Modelling Over Upstream Catchments of Himalayan Rivers and Assessment of Extreme Hydrological Events†

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Abstract: Flash floods in the Himalayan Rivers result in hundreds of death causing a sudden hazard in a minimum period of time. The Hydrological Events of most happened cloud burst incidents in the Indian Himalayas with an unexpected heavy overwhelm of precipitation in a short interval over a small region. These Extreme Hydrological events are assessed through the Analytical Hierarchy Process for the upper stream catchments of Tehri Dam and Srinagar. The morphometry characteristics of these catchments are collaboratively integrated with the SAC Hydro Simulated discharge and rainfall data to bring out the flash flood vulnerable hazard region over surrounding catchment regions.

Keywords: Flash floods, Cloud burst, Hydrological events, AHP

1. Introduction

The eventuality of natural disasters accompanying with the water particularly flash floods is common phenomena in the hilly part of Indian Himalayas. The overwhelm of water in these hilly mountains are more than the usual level, with some specific reasons of cloud burst in the catchment zone, vigorous and lengthened rainfall, causing the obstruction of river channels which induce the sudden breakage of artificial/natural lakes [1]. The cloudburst incidents are associated with the unusual steep slopes and bad inclines of the Himalayan orography, making the ultimate platform for the flash flood activities. Even though the advance techniques have arisen but the prediction of this catastrophic occurrences remain dare [2]. The morphometry characteristics of the catchments enact the hydrological processes, in addition to observed parameters of discharge and intense rainfall data over the flash flood liable zones. The morphometric estimation of the drainage network helps to learn the behavioral characters of the drainage network and its impact on the flood-prone areas [3, 4]. Drainage basins are delineated with Digital Elevation Model, and Stream number and Stream orders are computed by Strahler theory in order to access flash flood vulnerability [5]. To understand the catchment response to hydrological events, various flood deriving parameters in morphometry analysis are rainfall, slope, drainage density, land use, etc, are predominantly assessed for flood hazards. But the difficulty in getting spatial predicting data from various sources are inappropriate in handling. The research on GIS tools reveals that flow direction, flow accumulation, precipitation, drainage are some parameters for flooding events. These parameters are weighted among the priority based on saaty's nine-point scale and analyzed with the model of Analytical Hierarchy Process-AHP [6, 7]. The paper concentrate on the mapping of flood-vulnerable prone areas which are highly correlated in the Indian Himalayan rivers where the flash floods and cloudburst are common happening incidents. The decision-making techniques are used to puzzle out the complex issue via Analytical Hierarchy Process. The main objectives of this paper are to produce flood vulnerable areas by the following steps

1. Analysis of morphometry parameters using SRTM DEM integrated with discharge and rainfall data from SAC Hydro Model.
2. Normalized these parametric classified values via Analytical Hierarchy Process by assigning priority weight to each parameter.

2. Materials and methods

2.1. Study area

The study area of Tehri Dam catchment at the deep of Garhwal hills of Uttrakhand across the river of Bhagirathi and Bhilangana at the extent of 30.3781° N latitude and 78.4804°E longitude Srinagar catchment extended at the latitude of 30.2247° N and longitude of 78.7986° E which having the major tributary of the Ganga river basin flowing in the name of river Alaknanda.

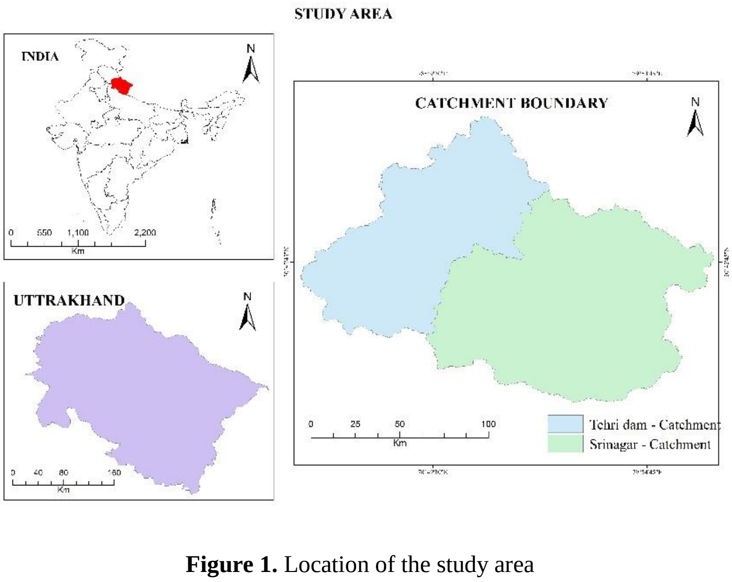

Figure 1. Location of the study area

2.2. Datasets

The goals of this research paper are achieved by data gathered from different sources. Different GIS layers were created in this study area catchments. Shuttle Radar Topography Mission (SRTM) DEM at the spatial resolution of 30m used for the determination of morphometric characteristics of the catchments namely drainage density, slope, relief ratio and stream frequency by delineate the catchment boundary regions. The SRTM DEM used for the generation of slope map and to produce hillshade regions along the catchment boundary. To study the catchment surface forms and its importance, these quantitative approaches of slope evaluation is used [8]. SAC hydro model developed by Space Application Centre, Ahmedabad are providing daily day average and accumulated discharge and rainfall data for India at 5Km resolution. These datasets were gathered and put into this study and study area data are extracted using ArcGIS 10.5. The National Resource Database (NRDB) are used to acquire geological layer at the scale of 1:250000.

2.3. Methodology

The methodology involves in determining the causative parameters for flood occurring in the study region catchments and finally, these causative criterions are put into the Analytical Hierarchy Process to evaluate flood susceptible zonation in the catchments are illustrated by the following figure.

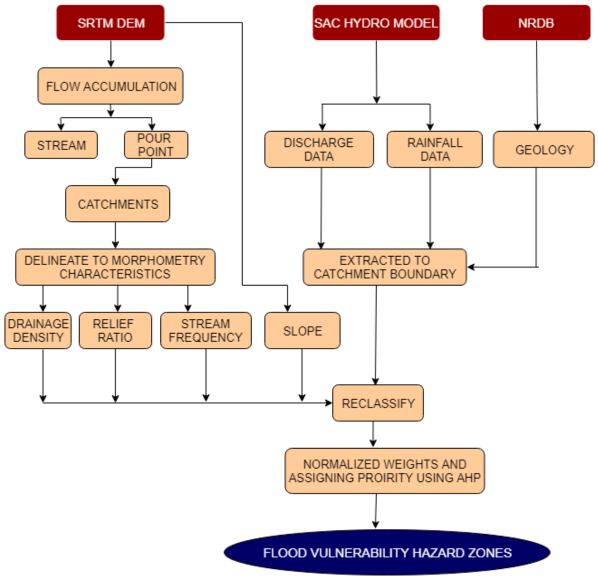

Figure 2. Flowchart for flood hazard zones

2.3.1. Development of catchment morphometry

The two catchment morphometric parameters were inferred by using the linear, areal and relief characteristics. In this study, drainage density, relief ratio, and stream frequency are assessed to achieve the vulnerability assessment of two catchments [9]. The following table 1 is used to calculate the catchment morphometry response.

Category	**Parameter**	**Derivation Procedure**
Areal	Drainage Density	DD= ∑L/A; where DD=Drainage Density, ∑L=sum of all stream lengths and A=Catchment area (Horton 1932)
Areal	Stream Frequency	F_s=N_u=/A; F_s =Sream Frequency, N_u=total length of stream, A= catchment area (Horton,1945)
Relief	Relief Ratio	Rh=H/L; where Rh=relief ratio, H=Horizontal distance along the longest dimension in parallel to drainage line and L=Length of the catchment (Schumm,1956)

Table 1: Catchment Morphometry Parameters

2.3.2 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) provides a systematic approach for assessing and merging various factors to support the decision-making technique for various assessment both in qualitative and quantitative level. This AHP technique helps to achieve the assessment of various factors and solving the complex problems of overlapping and combined issues between multiple criteria factors. [10]. This framework was proposed and developed by Saaty's nine-point scale in 1980 for the decision-making process. The degree of consistency solved by the consistency ratio (CR) and this CR should be less than or equal to 0.10 implies the pairwise matrix is acceptable.

3. Results and Discussion

3.1. Pair-wise comparison matrix for multi-criteria and its consistency

The pair-wise comparison matrix weighted the various parameters and finding alternatives using absolute numbers of 1 to 9 in scale value of AHP. The weights are estimated by Microsoft excel and priority index value are assigned to each parameter. Hence, the results contain relative weights of C1=Discharge, C2=Rainfall, C3=slope, C4=Drainage Density, C5=Geology, C6=Relief ratio, and C7=Stream frequency are shown in table 2. Therefore, the results are incorporated into the ArcGIS 10.5 software to identify the flood-vulnerable hazard zones over the catchment region [11].

Parameters	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**mean**	**Weight in (%)**
C1	0.53	0.72	0.64	0.42	0.48	0.36	0.33	0.50	50
C2	0.07	0.09	0.16	0.17	0.14	0.18	0.17	0.14	14
C3	0.07	0.05	0.08	0.17	0.14	0.18	0.21	0.13	13
C4	0.11	0.05	0.04	0.08	0.10	0.09	0.08	0.08	8
C5	0.08	0.05	0.04	0.06	0.07	0.09	0.08	0.07	7
C6	0.09	0.03	0.03	0.06	0.05	0.06	0.08	0.06	6
C7	0.07	0.02	0.02	0.04	0.03	0.03	0.04	0.04	4

Table 2: Pair-wise Comparison Matrix and its Relative weight

3.2. Consistency Check

The consistency of the pair-wise matrix is evaluated by the following index:

CR= CI / RI

Where CR = Consistency Ratio

CI = Consistency Index

RI= Random Index (the value are assigned using the following table 3).

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table3: Random Index Value

AHP theory indicates, the thumb-rule set of Consistency ratio (CR) must be less than or equal to 0.1. For this, foremost the Consistency Index is to be calculated using the following equation,

$CI = (\lambda max - n) / (n- 1)$

From the table 1, $\lambda max = 7.36$

n = 7 (No. of parameters we used)

then, CI= (7.36 -7) / (7-1) = 0.061 which is less than 0.1

Since CR's value is lower than the threshold (0.1) the weights' consistency is affirmed.

Factor	**Tehri dam catchment**		**Srinagar catchment**		**Weight**
	Criteria	Index	Criteria	Index	
	0.01-50	0.05	0.25-50	0.05	
	50-100	0.09	50-100	0.10	
Discharge (m3/S)	100-500	0.16	100-500	0.13	50%
	500-1000	0.26	500-1000	0.28	
	1000-1749.02	0.45	1000-1736.81	0.44	
	62-189	0.04	140.3-275.15	0.05	
	189-316	0.09	275.15-410	0.11	
Rainfall (mm/day)	316-443	0.15	410-544.85	0.16	14%
	443-570	0.31	544.85-679.7	0.29	
	570-697	0.40	679.7-814.5	0.40	
	0-2	0.43	0-2	0.45	
	2-7	0.28	2-7	0.27	
Slope (%)	7-10	0.15	7-10	0.15	13%
	10-15	0.09	10-15	0.09	
	15-81.76	0.05	15-87.56	0.05	
	0.36-0.39	0.05	0.34-0.38	0.05	
	0.39-0.41	0.10	0.38-0.43	0.12	
Drainage Density	0.41-0.43	0.18	0.43-0.47	0.15	8%
	0.43-0.45	0.24	0.47-0.52	0.26	
	0.45-0.48	0.43	0.52-0.56	0.42	
	Sandy Loam	0.66	Sandy	0.66	
Geology	Sandy	0.22	Sandy Loam	0.22	7%
	Snow/ others	0.12	Snow/ others	0.12	
	0.05-0.12	0.43	0.04-0.09	0.43	
	0.12-0.18	0.29	0.09-0.13	0.28	
Relief Ratio	0.18-0.24	0.15	0.13-0.17	0.16	6%
	0.24-0.30	0.08	0.17-0.21	0.08	
	0.30-0.36	0.05	0.21-0.26	0.05	
	0.18-0.20	0.05	0.16-0.19	0.05	
	0.20-0.22	0.10	0.19-0.22	0.10	
Stream Frequency	0.22-0.24	0.19	0.22-0.25	0.19	4%
	0.24-0.25	0.26	0.25-0.27	0.25	
	0.25-0.27	0.41	0.27-0.30	0.40	

Table 4: Multi-criteria Decision Analysis for Tehri dam and Srinagar Catchment

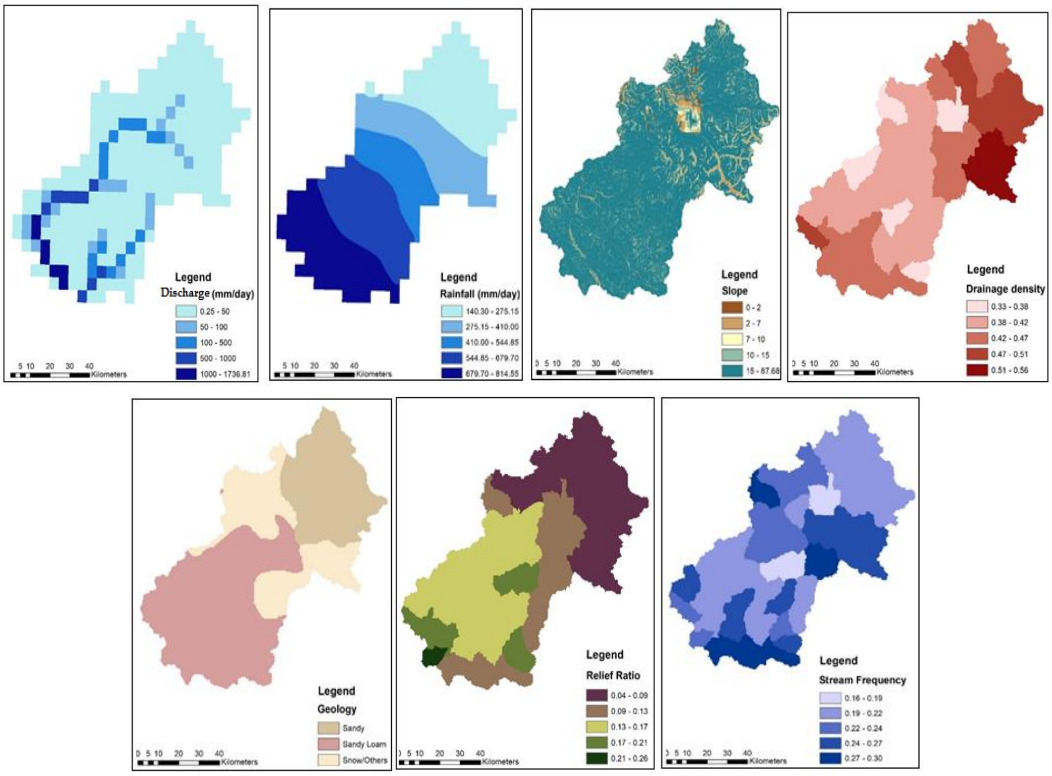

Figure 3. Multi-Criteria Parameters Map of Tehri Dam Catchment

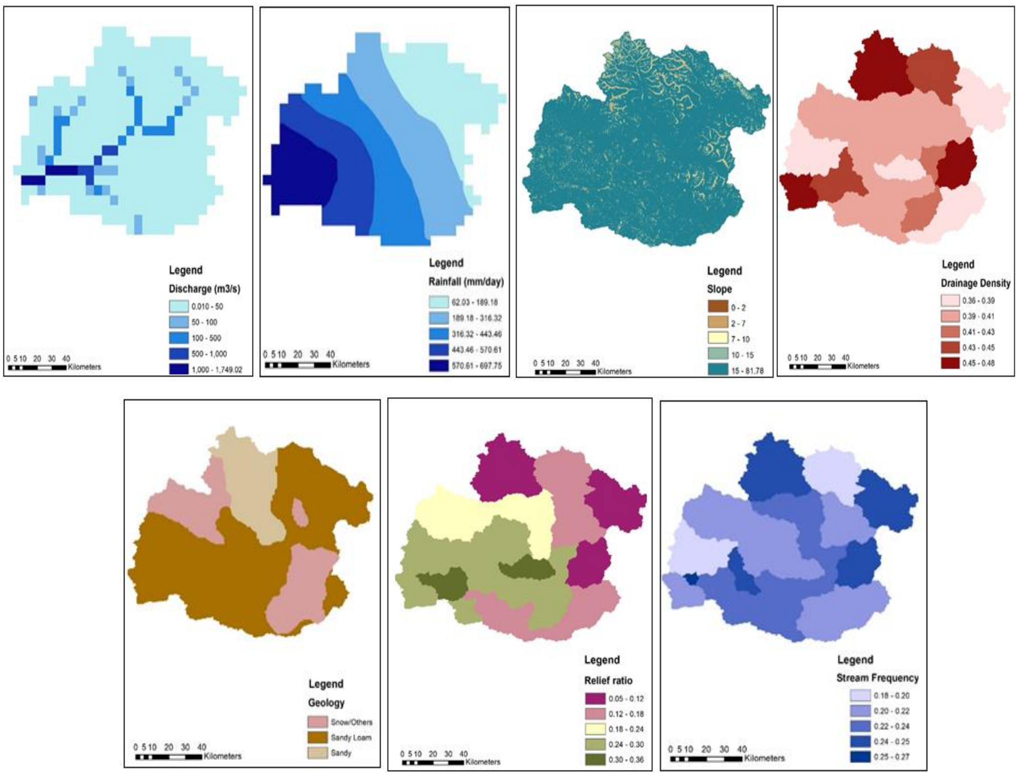

Figure 4. Multi-Criteria Parameters Map of Srinagar Catchment

For every parameter, the ranges are classified and the index value is assigned based on the vulnerability characters. Every layer is Reclassified with their range value and multiplied their index value with range value and again layers were get Reclassified with the index value. Once the weight in each factor was determined, the multi-criteria analysis was performed to produce a flood-vulnerable area by using the GIS approach. To compute the vulnerable area, a weight linear combination was applied as shown in equation: Z = (50 x Discharge) + (14 x Rainfall) + (13 x Slope) + (8 x Drainage density) + (7 x Geology) + (6 x Relief ratio) + (4 x Stream Frequency)

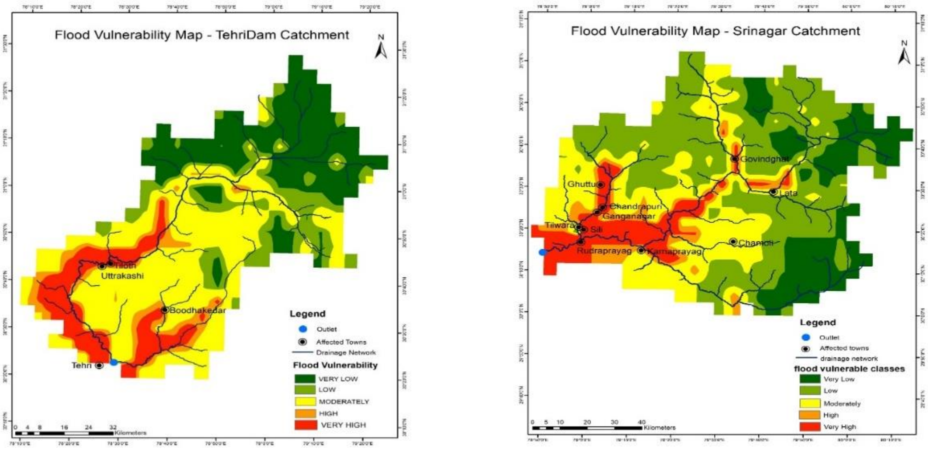

Figure 5. Flood Vulnerability Hazard Zone Map

The final vulnerable map output has been represented in the above figure 5. with a graduated scale of a color map indicating the flood vulnerability. The vulnerability of flood areas is categorized into 5 (five) criteria, namely "Very high vulnerable", "High vulnerable", "Moderate vulnerable", “Low vulnerable”, and “Very low vulnerable”.

3.3. Area Estimation of Flood Hazard

The above flood vulnerability hazard map figure 5 shows the range of vulnerable and area which are very highly prone to the flash floods are assessed under the red zone. Mostly, it is seen clearly that, very high to highly prone areas are very close to the river Bhagirathi and the river Bhilanganga. The sudden flash flood causes a dramatic increase in river water level and creating a hazard to the people belonging to the river line liable livelihood. The vulnerability area is calculated and showed in the following table 5.

Vulnerable Class	**Tehri Dam Catchment**		**Srinagar Catchment**	
	Area (in sq.km) Total area=7294.78	**Area (in %)**	**Area (in sq.km) Total area=10554**	**Area (in %)**
Very Low	2000.24	30%	1775.52	18%
Low	800.1	12%	3875.47	40%
Moderate	2775.34	41%	2450.30	25%
High	425.05	6%	525.06	5%
Very High	750.09	11%	1050.13	11%

Table 5. Area Calculation for the study area Catchments

4. Conclusion

The assessment of flash flood hazard zone map is necessary for very high prone areas where the extreme weather events often happening. The final priority assessing map shows the clear cut decision on where the flash flood can make a vigorous effect at the sudden cause of time. The systematic approach of AHP helps to determine various Criteria analysis made at one time to produce the output results. In addition, Consistency Ratio of the pair-wise comparison matrix is 0.06, acceptable at the thumb-rule set. Although very high prone area shows less percentage calculation, the place where they are estimated is very close to the river line level. These catchments show very high vulnerable in the downstream region where the floods are accumulated and discharged. The future work will be carried out to determine the flash flood hazard zones in the whole Himalayan catchments.

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References

1. D. Sharma, D. (2006). Floods and Flash Floods in Himachal Pradesh: A Geographical Analysis.
2. A.P. Dimri; A. Chevuturi; D. Niyogi; R.J. Thayyen; K. Ray; S.N. Tripathi; A.K. Pandey; U.C. Mohanty; Cloudbursts in Indian Himalayas: A review Earth-Science Reviews DOI:10.1016/j.earscirev.2017.03.006 YEAR:2017
3. Diakakis, Michalis. (2010). A Method for Flood Hazard Mapping Based on Basin Morphometry: Application in Two Catchments in Greece. Natural Hazards. 56. 803-814. 10.1007/s11069-010-9592-8.
4. I. A. Jesuleye1, U. H. Okeke1, A. O. Atijosan1, R. A. Badru1, J. E. Adewoyin1, and A. T. Alaga1 Morphometry Assessment of Oba River Basin and Its Implications for Flood 2016 DOI: 10.9734/JGEESI/2016/30266
5. Omran, Adel & Schroeder, Dietrich & El-Rayes, Ahmed & Geriesh / Griesh, Mohamed Helmi. (2011). Flood hazard assessment in Wadi Dahab, Egypt based on basin morphometry using GIS techniques.. 10.13140/RG.2.1.2502.1520.
6. Abd Nasir Matori, Dano Umar Lawal, Khamaruzaman Wan Yusof, Mustafa Ahmad Hashim, Abdul-Lateef Balogun Spatial Analytic Hierarchy Process Model for Flood Forecasting: An Integrated Approach IOP Conf. Series: Earth and Environmental Science 20 (2014) 012029 doi:10.1088/1755-1315/20/1/012029
7. Saba Zehra, Sheeba Afsar Flood Hazard Mapping of Lower Indus BasinUsing Multi-Criteria Analysis Journal of Geoscience and Environment Protection, 2016, 4, 54-62 Published Online April 2016 in SciRes. http://www.scirp.org/journal/gep .doi.org/10.4236/gep.2016.44008
8. Samson, Samuel & Eludoyin, Adebayo & Ogbole, John & Alaga, A & Oloko-oba, Mustapha & Okeke, U & Popoola, Oladimeji. (2016). Drainage Basin Morphometric Analysis for Flood Potential Mapping in Owu Using Geospatial Techniques. Journal of Geography, Environment and Earth Science International. 4. 1-8. 10.9734/JGEESI/2016/22223.
9. Oyatayo, Kehinde & Iguisi, E.O. &, Sawa &, Iorkua & Ndabula, Christopher & Jidauna, Godwill. (2018). Assessment of Parametric Flood Vulnerability Pattern of Makurdi Town, Benue State, Nigeria. 12. 11-28.
10. Stefanidis, S. & Stathis, D. Assessment of flood hazard based on natural and anthropogenic factors using the analytic hierarchy process(AHP)Nat Hazards (2013) 68: 569. https://doi.org/10.1007/s11069-013-0639-5
11. Dano Umar Lawal; Abdul-Nasir Matori; Ahmad Mustafa Hashim; Khamaruzaman Wan Yusof; Imtiaz Ahmed Chandio Detectingflood-susceptible areas using GIS-based analytic hierarchy process International Proceedings of Chemical, Biological and Environmental Engineering (IPCBEE) 2012 Vol.28 pp.1-5 ref.12