Journal of Geomatics Vol 10 No. 1 April 2016

Flood hazard zoning using analytic hierarchy process: A case study for Pampa river basin, Kerala, India

N.A. Mayaja[1] and C.V. Srinivasa[2]
[1]Department of Civil Engineering, Atria Institute of Technology, Anand Nagar, Bangalore, 560098, India
[2]Department of Civil Engineering, Global Academy of Technology, Bangalore, 560024, India
Email: mayaja@hotmail.com, svasa@gat.ac.in

(Received: Jan 06, 2016; in final form: Mar 06, 2016)

Abstract: The river Pampa is the third largest river of Kerala with a catchment area of 2235 km^2. This river almost every year causes substantial damage to human life, properties and the cropland during monsoon. In this study an attempt is made to classify the regions in the river basin in order of risk and severity due to floods. The severity of flood hazard in these locations varies due to various geospatial factors. The hazard due to flood in any particular location and its impact can be assessed in relative terms by using an analytical approach as applied to a set of geospatial factors ranging from qualitative to quantitative type. This paper evolves appropriate risk indices for the entire Pampa river basin and classifies them according to the severity of flood risk using a popular Analytic Hierarchy Process (AHP). The study brought out that two regions in the river basin fall under very high flood risk category whereas four villages come under high risk category. It was revealed that highly populated and urbanized regions located in the downstream of this river basin are more vulnerable to flood hazard.

Key Words: Flood Hazard Index (FHI), Analytic Hierarchy Process (AHP), Pampa river basin, Kerala floods

1. Introduction

The holy river Pampa (also referred as Pamba) in Kerala state is the third largest river (about 176 km) with a catchment area of 2235 km^2. It originates on the Western Ghats and flows through Kuttanadu, the rice bowl of the state and drains into the Vembanadu lake. The severity of floods caused by this river and consequent disasters are increasing annually. Some studies have revealed that the recurring incidents of flood are mainly on account of the human interventions like deforestation, reclamation, sand mining beside indiscriminate developmental activities. It has thereby caused severe damages to the physical and biological environment of this river system. A GIS based study of flood-prone areas of Pampa river basin has been carried out using the ground parameters and satellite imagery (Mayaja and Srinivasa, 2012). In this paper, appropriate flood hazard indices for the river basin have been generated based on the severity due to floods. The study has made use of the well known Analytic Hierarchy Process (AHP) (Saaty and Alexander, 1989).

2. Study area and data used

This study focuses the basin of Pampa river (approximately 2235 km^2) which is shown in Figure 1. The river basin stretches over four districts of Kerala, viz., Idukki, Kottayam, Pathanamthitta and Alappuzha. The area extends over dense tropical monsoon forests, semi-urbanized settlements, one famous pilgrim center – Sabarimala and also a rich agricultural (rice) bowl of Kerala, called Kuttanad. The study area lies between $76^0$20' to $76^0$59' East in longitude and $9^0$19' to $9^0$39' North in latitude. With humid tropical monsoon climate (average annual rainfall 3000 mm with summer rains constituting about 10%), the basin experiences two distinct rainy seasons, South-West monsoon (June to September) contributing about 60% of the rainfall and North-East monsoon (October to December), providing about 30% of the rainfall. With a relative humidity of 70% to 90%, the study area experiences a temperature in the range of 21^0 to 36^0 C. The peak altitude of the basin is about 1677 m (at the origin of the river) and while flowing through a distance of about 176 km the river reaches the sea level and finally joins the Vembanad lake and Arabian sea.

Figure 1: Study area

The population density of the regions (number of persons per km^2) was obtained from the latest National census data. Rainfall data (in mm) was obtained from the India Meteorological Department and Department of Irrigation, Government of Kerala. Land use data and basin slope were availed from the National Remote Sensing Centre of Indian Space Research Organization. Data related to types of soil were taken from the official website of the Department of soil survey and soil conservation, Government of Kerala. The geomorphic data and the details of road networks were collected from the Kerala State Remote Sensing Centre, Thiruvananthapuram. The basin elevation was available in the Survey of India toposheets.

3. Methodology

3.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making statistical technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent and independent variables. It is a statistical tool popularly used in assessing the impact of various conflicting factors and computing risk indices. AHP attempts to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of activities or criteria by 'pair-wise' comparison (Saaty and Alexander, 1989, Saaty 1994, Saaty and Vargas 2002). This technique has been effectively used to identify and rank the factors affecting flood in Kosi river basin (Venkata Bapalu and Sinha, 2014).

In order to perform AHP analysis, a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another, two at a time, with respect to their impact on an element above it in the hierarchy. In making the comparisons, the decision makers can use concrete data on the elements, or they can use their judgments about the element's relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations.

In AHP computation, the decision vectors are constructed at each level of the hierarchy by pair-wise comparison of the elements (decision factors). The eigen vectors so formed are then normalised. The Relative Importance Weights (RIWs) of each decision factor is obtained as the sum of the values in the corresponding row of the normalised eigen vector. Similar computation of RIWs is performed at each level of the hierarchy. The RIWs thus computed are assigned to specific part of the study area. The final solution is evolved by aggregating the product of RIWs at each level. (Saaty and Alexander, 1989).

3.2 Primary decision factors

The first level of the analysis is the generation of the Flood Hazard Index (FHI). In level 2 analysis, this study considered eight primary decision factors viz. population density, rainfall, land use, soil type, basin slope, geomorphic factors, quality of roads and elevation. Once the level 2 decision factors are selected, they are further sub-divided into level 3 sub-factors of smaller class for finer evaluation (Table 1).

The factors considered at level 1, 2 and 3 are illustrated in Appendix 1. The values of the sub-classification at level 3 for level 2 factors is shown in Table 1.

Table 1: Level 3 sub-classifications of decision factors

Level-2 factor	**Level 3 sub-factors**			
Population density (number of persons / km^2)	<1000 (Low)	1000 to 2000 (medium)	2000 to 3000 (high)	>3000 (very high)
Annual average rainfall (mm)	2500 to 3000 (Less)	3000 to 3500 (medium)	3500 to 4000 (high)	>4000 (very high)
Land use-land cover	Agriculture	Forest	Built up	Waste land
Soil type	Hill soil	Clayey loam	Laterite soil	Sandy soil
Slope	3°- 5° (Gentle)	5°-15° (Moderate)	15° - 30° (Steep)	>30° (Very steep)
Geomorphic factors	Denudati-onal Hills	Lower Plateau	Coastal Plain	Alluvial Plain
Road quality	High	Medium	Low	Very low
Elevation (metres)	0 - 10 (Low)	10 to 30 (Medium)	30 to 150 (High)	>150 (very High)

Appendix 1 shows the hierarchy and the relative importance weight of level 2-decision factors (RIWi2) arrived at by pair-wise comparison of the decision factors. This was followed by pair wise comparison within each level 3-decision factor to get the corresponding relative importance weight (RIWi3).

4. Flood Hazard Index (FHI)

4.1 Algorithm

The FHI for each location was determined by aggregating RIWs of decision factors at each level of the hierarchy. FHI was calculated by multiplying the RIWs of level 3-decision factor by the associated RIWs of the level 2 factors at each level and summing the values of all grouped elements. As the problem is defined in three level hierarchies, the simplified generic equation used is as follows:

$$\mathrm{FHI} = \sum_{i=1}^{N2} [(\mathrm{RIW}_i{}^2) * (\mathrm{RIW}_{ij}{}^3)] \qquad (1)$$

where, FHI = Flood Hazard Index; $N2$ = the number of level-2 decision factor; RIW_i^{2} = Relative importance weight of level2 decision factor i; RIW_{ij}^{3} = Relative Importance Weight of level 3 sub-factor j of level-2 decision factor i.

The level 2 normalised relative importance weight matrix computed for various decision factors are given in Table 2.

Table 2: Normalised relative importance weights of level 2

Sl.No	Decision factor	Level–2 Relative Importance Weight
1	Population density	0.35
2	Rainfall	0.091
3	Land Use Land cover	0.076
4	Soil	0.096
5	Slope	0.129
6	Geomorphic	0.04
7	Road quality	0.038
8	Elevation	0.18

The level 3 normalised RIW matrices computed for each of the sub-decision factor are given in Appendix 2. FHI and consistency ratios at levels 2 & 3 are given in appendix 3 and 4, respectively.

4.2 Region specific FHIs

The river basin consists of 52 regions (Panchayaths and Municipalities) as per the local administrative classification of Government of Kerala. All the 52 regions were considered for the purpose of analysis in this study. The FHI in respect of all these regions were computed as per the algorithm given under 4.1. The frequency distribution of FHI is shown in Fig. 2.

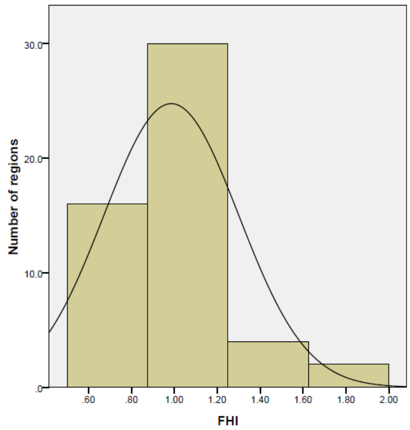


Figure 2: Histogram distribution of FHI

It can be seen that the 52 FHIs so computed are predominantly falling in four frequency bandwidths (Fig. 2). Based on the histogram distribution, the regions of Pampa river basin have been grouped into low, moderate, high and very high flood-risk category. The risk category of these regions along with their respective FHI values are shown in Table 3. A schematically classified risk map of the river basin is shown in Fig. 3.

Table 3: Flood prone regions in Pampa river basin

No.	Zone / region	FHI	Category
1	Thiruvanvandoor	1.87	VERY HIGH
2	Veeyapuram	1.87	VERY HIGH
3	Chengannur	1.32	HIGH
4	Pandanadu	1.32	HIGH
5	Niranam	1.32	HIGH
6	Kuttoor	1.31	HIGH
7	Chenneerkkara	1.20	MEDIUM
8	Omalloor	1.20	MEDIUM
9	Aranmula	1.19	MEDIUM
10	Mulakkuzha	1.19	MEDIUM
11	Mezhuveli	1.19	MEDIUM
12	Kulanada	1.19	MEDIUM
13	Mannar	1.19	MEDIUM
14	Kozhencherry	1.16	MEDIUM
15	Iraviperoor	1.15	MEDIUM
16	Naranganam	1.15	MEDIUM
17	Puliyoor	1.14	MEDIUM
18	Cherukole	1.11	MEDIUM
19	Koipram	1.11	MEDIUM
20	Mylappra	1.09	MEDIUM
21	Mallappuzhassery	1.09	MEDIUM
22	Ilanthoor	1.08	MEDIUM
23	Ala	1.06	MEDIUM
24	Ayiroor	1.05	MEDIUM
25	Ezhamattoor	1.05	MEDIUM
26	Thottapuzhassery	1.05	MEDIUM
27	Manimala	1.04	MEDIUM
28	Naranammoozhi	1.02	MEDIUM
29	Ranni-Perunnadu	1.02	MEDIUM
30	Malayalappuzha	1.02	MEDIUM
31	Kottanadu	1.01	MEDIUM
32	Kottangal	1.01	MEDIUM
33	Ranni-Angadi	1.01	MEDIUM
34	Vadaserikkara	1.00	MEDIUM
35	Ranni	0.99	MEDIUM
36	Ranni-Pazhavangadi	0.99	MEDIUM
37	Kadapra	0.67	LOW
38	Peruvanthanam	0.62	LOW
39	Vechuchira	0.61	LOW
40	Bhudhanoor	0.61	LOW
41	Chennithala-Thripperunth	0.61	LOW
42	Thannithode	0.61	LOW
43	Erumely	0.60	LOW
44	Seethathode	0.60	LOW
45	Elappara	0.59	LOW
46	Aurvappulam	0.59	LOW
47	Konni	0.58	LOW
48	Chittar	0.58	LOW
49	Vandiperiyar	0.57	LOW
50	Peerumade	0.56	LOW
51	Kumily	0.56	LOW
52	Mundakkayam	0.56	LOW

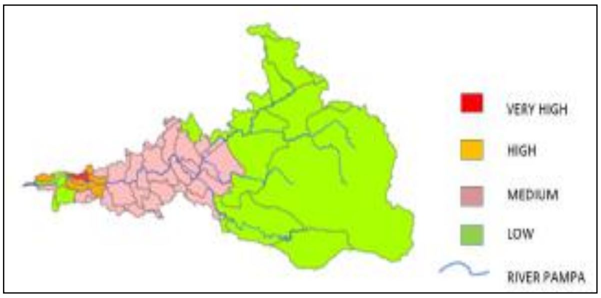


Figure 3: Flood risk map of Pampa river basin

5. Results and discussions

In this study, a set of composite flood hazard indices for the Pampa river basin has been worked out by adopting the AHP methodology. The indices have been derived from primary decision factors viz: population density, annual average rainfall, land use, type of soil, slope, geomorphic features, quality of roads and elevation. The Panchayaths/ municipalities of Pampa river basin have been accordingly classified into low, medium, high and very high risk categories based on histogram distribution of FHI.

The analysis revealed two regions - Thiruvanvandoor, and Veeyapuram - covering about 7.5 km^2 of the basin as areas prone to 'very high' levels of flood risk. Four regions, covering about 35 km^2 come under the 'high risk' category of flood where as another 30 regions (395 km^2) fall under the 'medium risk' category. Remaining portions of the basin are relatively under 'low risk'. It is observed that though the regions falling under very high and high level of flood hazard constitute only 0.3% and 2 % respectively of the basin area, these are densely populated and highly urbanised regions (with density of population more than 3000 persons / km^2), located at the downstream of the river. Further, the land use pattern of these regions reveals high level of built up area and they have good network of paved highways. Thus, it can be inferred that the prime reasons of flood hazard are high rate of urbanization and human interventions in this region. The extensive road networks recently developed in the river basin also testify this finding. Owing to the same reasons the flood occurrence at these regions causes more damages to both humans as well as infrastructure.

Amongst the eight primary decision factors influential in causing flood hazard, the most prominent anthropogenic factor identified is population density. This calls for urgent need of an effective urban planning in the basin and also implementing regulatory mechanisms to check uncontrolled and haphazard rate of urbanisation, which is detrimental to both humans as well as the river itself. The land use and land cover also is identified as an influencing factor. Hence proper environmental and ecological regulations and auditing can reduce the vulnerability of the region to flood. A flood mitigation policy based on the above suggestions can effectively help in reducing the flood risk.

6. Conclusions

Ranking the villages in the flood plain is of utmost importance in flood management planning. In this study, 52 villages in the Pampa river basin are classified according to their Flood Hazard using Analytic Hierarchy Process. The indices have been derived from a variety of parameters (factors) ranging from geospatial data to population density, rainfall, land use, type of soil, slope, geomorphic factors, quality of road and elevation. The flood prone areas of Pampa river basin have been classified into four categories viz. low, medium, high and very high. The analysis reveals that human activities, which result in increased population density, land use land cover changes etc. make the region more vulnerable to flood hazards. Hence a comprehensive basin planning, considering the above factors only will be effective in mitigating flood hazard

References

Mayaja, N.A. and C.V. Srinivasa (2012). A GIS based flood mapping study for Pampa river basin, Kerala. Research dissertation of Visweswaraya Technological University, Karnataka.

Saaty, T.L. and J. Alexander (1989). Conflict resolution: The analytic hierarchy process. Praeger, New York.

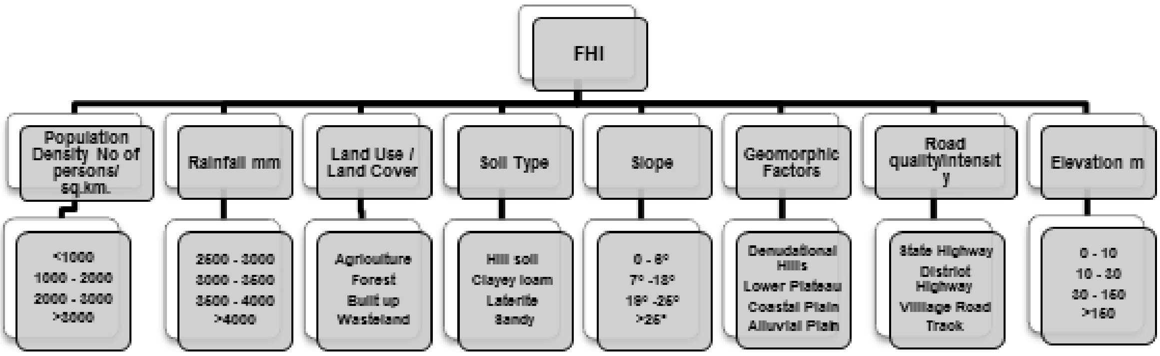
Saaty, T.L. (1994). Fundamentals of decision making and priority theory with the analytic hierarchy process. ISBN 0-9620317-6-3.

Saaty, T.L. and L.G. Vargas (2002). Models, methods, concepts & applications of the analytic hierarchy process. Book. ISBN 0-7923-7267-0, Kluwer Academic.

Venkata Bapalu, G. and R. Sinha (2014). GIS in flood hazard mapping: A case study of Kosi river basin,India. download from internet, http://GISdevelopment.net

Journal of Geomatics Vol 10 No. 1 April 2016

Appendix-1
(FHI computation: Decision Hierarchy at levels 1, 2 and 3)



Appendix 2
(The comparison matrix for level- 2)

Factor	Population Density	Rainfall	LULC	Soil	Slope	Geomor-phic factors	Roads	Elevation
Population Density	**1**	3	4	5	5	7	4	5
Rain-fall	0.333	**1**	0.5	0.333	0.2	4	7	0.25
LULC	0.25	2	**1**	0.333	0.2	3	4	0.2
Soil	0.2	3	3	**1**	0.5	2	2	0.5
Slope	0.2	5	5	0.5	**1**	3	3	0.333
Geomorphic factors	0.143	0.25	0.333	0.5	0.333	**1**	2	0.25
Roads	0.25	0.148	0.25	0.5	0.333	0.5	**1**	0.333
Elevation	0.2	4	5	2	3	4	3	**1**

Appendix 3
(FHI computation)

The FHI for each location was determined by aggregating RIWs at each level of the hierarchy. FHI was calculated by multiplying the RIWs of level 3-decision factor by the associated RIWs of the level 2 factors at each level and summing the values of all grouped elements. The level 2 and level 3 Relative Importance Weight matrices computed are shown below:

Level 2	**Population Density**	RIW = 0.35	**Rainfall**	RIW = 0.091	**LULC**	RIW = 0.076	**Soil**	RIW = 0.096
Level 3	Low	0.048	Very High	0.466	Agriculture	0.238	Hill soil	0.145
	Medium	0.108	High	0.277	Forest	0.116	Clayey loam	0.462
	High	0.259	Medium	0.161	BuiltUp	0.584	Laterite	0.282
	very High	0.586	Less	0.096	WasteLand	0.062	Sandy	0.111

Level 2	**Slope**	RIW = 0.129	**Geomorphic factors**	RIW = 0.04	**Road quality**	RIW = 0.038	**Elevation**	RIW = 0.18
Level 3	Gentle	0.586	Denudational Hills	0.222	very Low	0.468	Low	0.554
	Moderate	0.259	Lower Plateau	0.237	Low	0.279	Medium	0.219
	Steep	0.108	Coastal Plain	0.122	Medium	0.149	High	0.133
	Very steep	0.048	Alluvial Plain	0.419	High	0.103	very High	0.094

Journal of Geomatics Vol 10 No. 1 April 2016

Appendix 4
(The consistency ratios at levels 2 and 3)

Consistency Ratio CR	**Level 2**	**Level 3**								Overall CR
		Population Density	Rainfall	LULC	Soil	Slope	Geomorphic factors	Roads	Elevation	
	0.176	0.048	0.014	0.071	0.129	0.048	0.027	0.008	0.029	3.106