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Multi-criteria decision approach to identify flood vulnerability zones using geospatial technology in the Kemp-Welch Catchment, Central Province, Papua New Guinea

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Abstract

Flood is a natural part of the hydrologic cycle, a natural phenomenon known for its catastrophic impacts on the environment, livelihoods, and properties, both economically and socially. It is the leading natural disaster in the world today affecting so many people, especially in the Asia region. Papua New Guinea has an abundance of rich resources and still possesses most of its natural geographic habitats and environments, but is also familiar with natural disasters like floods, earthquakes, landslides, volcanic eruptions, and droughts. Floods bring about tremendous destructions to anything that lies in its path, but it restores the health of the waterways/channels and redistributes the fertile sediments onto the floodplain. This research paper is focused on flood risk analysis using GIS and remote sensing, multi-criteria decision approach (MCDA), analytical hierarchy process (AHP), and the weighted linear combination (WLC). GIS-based spatial analysis techniques are useful for flood risk and hazard mapping with remote sensing technologies which provides an alternative to the conventional/traditional survey techniques. GIS coupled with remote sensing provides a basic framework/platform that helps in all stages of disaster assessment and management from preparedness, to response and recovery. Multi-criteria decision analysis (MCDA) is a collection of techniques that aid decision-makers in properly structuring multi-faceted decisions and evaluating the alternatives. AHP is a tool under MCDA that is used for dealing with complex decision-making and helps decision-makers set priorities and draw better decisions. Altogether, GIS-based MCDA-AHP became an efficient technique in flood risk mapping where multiple flood influential factors/criteria are incorporated into the GIS analysis process to producing better flood risk maps. In the present study, nine independent variables, namely elevation, slope, soil texture, soil drainage, landform, rainfall, distance from the main river, land use/land cover, and surface runoff, are used for flood vulnerability analysis. The resulted output demonstrated a span of value ranging from 1.13 (least vulnerable) to 4.15 (most vulnerable). The final map with 5 distinct classes is developed based on the natural junk classification method. The result indicated that about 4.57% of land area as "very high" and 12.49% as "high" flood vulnerable class and a total of 6700 people are living in those vulnerable zones. Past flood events are compared with the flood vulnerable database to validate the modeled output in the present study. This type of study will be very useful to the local government for future planning and decision on flood mitigation plans.

Keywords Flood · Remote sensing · Geographical information system · Papua New Guinea · Mapping · MCDA · AHP · WLC

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Introduction

Flood is an inundation of water over dry land, especially for riverine floods; it is an outcome of river waters overflowing its banks as a result of heavy intensive rainfall over a period of time (Merz et al. 2010). It is the leading natural disaster across the world today that affects so many people and poses the most destructive consequences on properties, infrastructures, facilities, businesses, and lives (Youssef et al. 2011; Du et al. 2013).

Floods are a natural part of the hydrological cycle on Earth, varying in size, duration, seasons, and locations around the globe, which is how they are given their type descriptions. There are different types of flood as described by researchers. Redd (2017) described four types of floods, namely overbank flooding, flash flooding, coastal flooding, and ice-jam flooding. Emergency Essential (2015) described five flood types to be river floods, coastal floods, storm-surge floods, inland floods, and flash floods, and others who have described only two or more than five flood types in their work. These descriptions are either a general or specific type of floods; however, according to Maddox (2014), the most common types would be the coastal (surge), riverine (fluvial), and urban (pluvial) floods.

Coastal/surge floods are a result of extreme tidal conditions, like storm surges and hurricanes that cause the water to rise and move towards the shore. Areas near the coast or shores of open waters (sea and ocean) experience this type of flooding when the pushed-off seawater overwhelms those low-lying areas. Riverine/fluvial flooding is a result of excessive water overflowing the banks of rivers due to its incapacity to hold excessive water. Overbank river flooding occurs at any size river channel where the water exceeds the river's capacity and flows over the river banks and floods the area, while flash floods occur at the low-lying river channels where there is an intense, high torrent of excessive water and the force is much greater than that of the overbank river flood. Urban/pluvial floods are a result of intense heavy rainfall (precipitation), independent of an overflowing water body, due to the impervious surfaces, drainage blockages, and other constructional (dams, levees, water pipes) failures caused by storms.

Hundecha et al. (2017) stressed on the different characteristics of flooding and the importance of understanding the types of flood when comprehending other details of the flood like their spatial extent, the processes that led to it, and the main drivers/factors that caused it. This is also the key to proper flood risk management since important flood control factors vary depending on local conditions. With that, information on the various flood control/influential factors can be incorporated in analyses to enhance the estimation and assessment of floods.

A report (IFRC 2018) has indicated statistics of the increased number of people approximating to 730 million that are affected by a total of 1522 floods worldwide over the last 10 years (2008–2017). Asia is the world's most densely populated region that had encountered the largest proportion (40.6%) of the 3751 disasters recorded by EM-DAT (2018) over the last 10 years, followed by the regions of Americas, Europe, Africa, and Oceania. Papua New Guinea (PNG) is part of Oceania region, ranked as the second-largest island country in the region and that has an abundance of rich resources and still possesses most of its natural geographic habitats and environments, but is also familiar with natural disasters like floods, earthquakes, landslides, volcanic eruptions,

and droughts. Particularly for riverine flooding, villages and communities in the vicinity of catchment areas are highly vulnerable to floods, mostly the ones located near/along the riverbanks and at lower areas of the land, where flash floods are most likely to occur at the downstream areas of rivers and poses the most destructive impacts.

This natural disaster also affects the environment as well as the social and economic states of those affected regions. Environmental impacts include the destruction of properties, developments and the land itself, and water as an essential human resource, also a natural part of the environment becomes polluted, contaminated and is unsafe for human consumption. Socio-economic impacts are those that affect businesses, activities, services, and other resources people are unable to engage with due to road blockages, communication barriers, damaged bridges, and submerged properties/facilities. The fact that the daily social and economic activities are halted already affects people and their lives.

Based on a report from EM-DAT (2010), about 55 major disasters took place between 1980 and 2010 which killed 3456 people (111/year) and huge economic damages ($5,750,000/year). About 21.9% events that happened are caused by flood. Recent news headlines reported several flood cases that have occurred in the Central Province in PNG. The National news paper (2017) reported that Central Province is highly prone to natural hazards including floods; UNDP (2017) identified communities in the Central Province vulnerable to floods; Post Courier (2019) reported two children found dead from the flood events in Central Province; EMTV News (2019) announced nine people confirmed dead and one reported missing after the heavy floods in the Central Province and houses in the IduIdu village in Agevairu went underwater after the Aroa River burst its banks flooding into the village in Central Province. Most people, especially those that reside in rural areas lack the knowledge of preparedness and mitigation procedures. All natural disasters including floods are inevitable and unstoppable which means that humans cannot stop it from occurring. However, addressing these issues by means of mapping the identified risk zones can help them to take preparatory, prevention, and risk reduction measures or plans that need to be taken. However, flood vulnerability mapping is an essential step for an early warning system and mitigation of the future flood management strategies (Tehrany et al. 2015). Remote sensing and GIS techniques can analyze all associated information in order to easily demarcate suitable vulnerable zone (Saha et al. 2005; Wang et al. 2013; Pourghasemi et al. 2014). This research study is to help understand the importance of flood influential factors and how they impact flooding. These factors are incorporated into the GIS analysis processes as flood risk parameters or thematic data layers and the analysis of their relationship; how they affect or contribute to the flood becomes a key part of the study. More emphasis is made on the effort to recognize which

factors are more influential to the flood phenomenon and which are not. Delineating flood risk zones is important; however, understanding the reasons why which zones are risky or not prone to floods becomes an even helpful and useful knowledge to better plan solutions for preparations, preparedness, and mitigation for people occupying land in the vicinity of those zones. The aim is to identify zones or areas that are susceptible to floods based on the analysis of several flood influential factors through the use of MCDA-AHP technique and GIS integration in modeling a flood vulnerability map.

Study area

Central Province is located on the southern coast of PNG at coordinates 9° 30′ S, 147° 40′ E, covering an area of 29,998 km^2. The catchment called Kemp-Welch is located within the province, between Kairuku-Hiri and Rigo districts and covers an area of about 3082.34 km^2 (Fig. 1).

Research methodology

It is essential to identify different influential factors of flood, their relationship to one another, and their level of influence on the phenomenon studied, i.e., flood. To achieve that, the needed datasets, the preferred specific methodologies, and processes that will be used to process and analyze these datasets are outlined and explained. There are many flood assessment techniques for flood risk mapping different researchers have utilized in their work; however, a major factor in choosing the right technique/method to use is the availability of datasets, software capability, and location of study. On that note, the MCDA-AHP technique (Zou et al. 2013; Samanta et al. 2016) was selected for this flood risk mapping project.

Influential factors of floods are more or less interchangeably related or influenced by one or the other in the event of flood occurrence. The risk of flood occurrence is not solely dependent on or caused by just one or two factors. For example, a heavy rainfall and river waters outflowing their banks
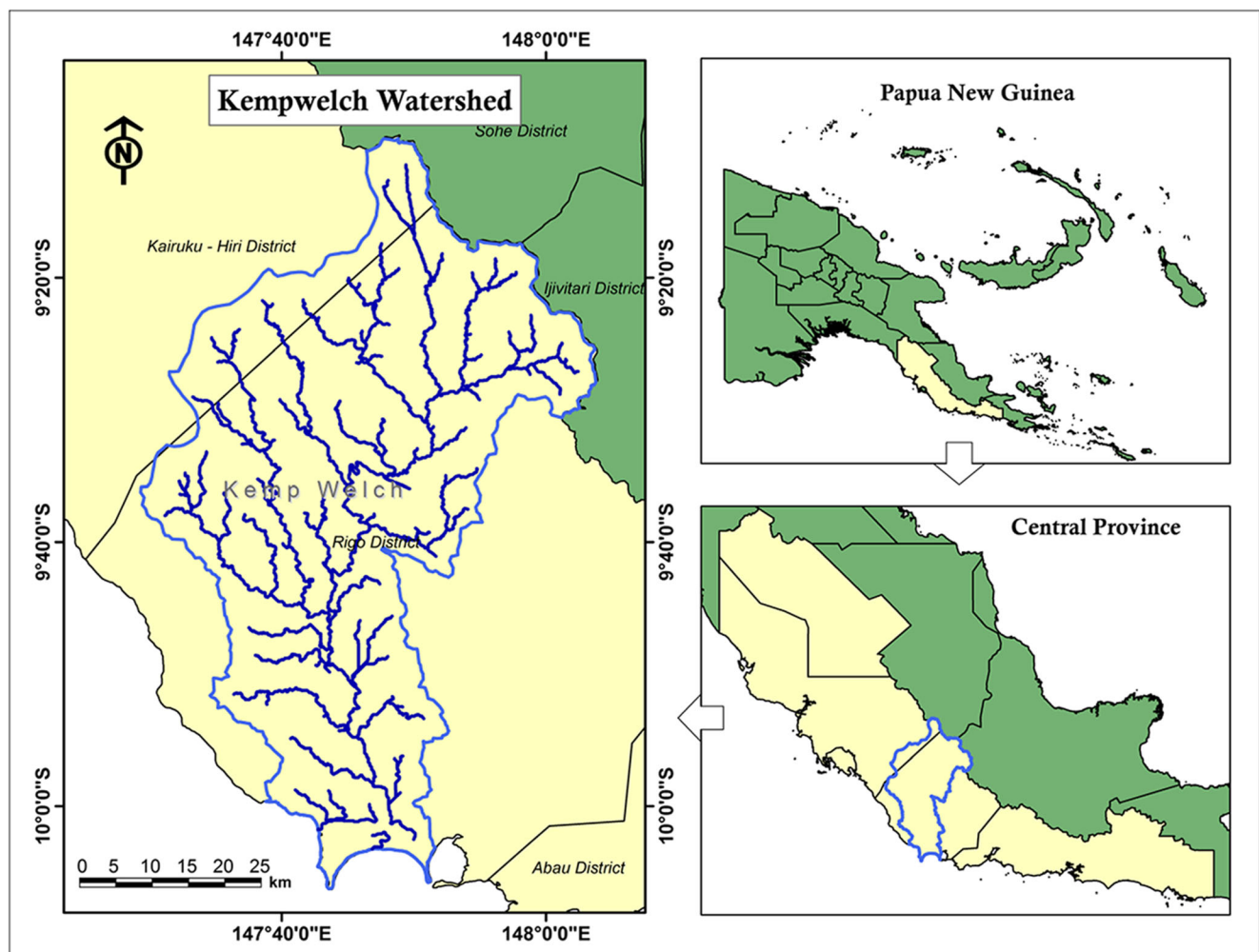

Fig. 1 Location map of the study area

are not enough to cause a flood although they are considered in some literatures major factors to the phenomenon. It is rather the influence of several factors that lacks something in their natural structure that contributes to the flood event, whether it is a natural or human influential factor.

Natural factors are considered to be meteorological, geomorphological, and topographical elements. The meteorological elements consist of rainfall, wind, and temperature of the location which is relative to the climatic conditions of the region. Heavy rainfall over a period of time in an area results in floods; however, rainfall/precipitation is influenced by the amount of atmospheric temperature and wind. Geomorphological refers to the geological structure of the earth, mainly the formation and structure of rocks. The relevance of this factor as one of the natural influential factors is the relationship between the characteristics of the configuration of the earth and how water behaves with it, based on its infiltration, drainage, and runoff. Landform is another important factor that contributes to flood risks; the rock formation, sizes, and orientation attributes influence the behavior of the flow of water over and through land. Soil's physical properties affect the nature of water infiltration and drainage. The rate of infiltration depends on the type and property of soil content; it also determines the amount of infiltration it can take. According to Morgan (2005), soil is an important factor that controls the amount of water that will be available for surface runoff after a rainstorm event. Soil physical properties include soil types, soil structure, soil texture, and soil porosity and they vary from place to place (Daniel et al. 2017). These variations in soil properties contribute to the variations in water retention, availability, transport, and storage. The topographical factors refer to the shape of the natural land surface as well as the artificial physical features of an area. Terrain features like elevation and slope are significant factors that also influence the occurrence of flooding. Variations of elevations have a definitive impact on climate characteristics. As such, different rainfall and temperature regimes engendered varied vegetation and soil forms (Harley and Samanta 2018). Areas at a higher altitude have a lesser risk to floods than those of the low-lying areas with a gradual slope than those areas having steep slopes. Slope has great influence on the vertical percolation of water and the velocity of surface runoff (Samanta et al. 2016). Water flows

to the river as runoff on slopes with steep angles where infiltration is less likely to happen, and the more the surface runoff, and the quicker the rate of the runoff, it can cause a flood.

Human beings contribute to the risks of flood occurrence in relation to the types of activities that are being implemented; this factor is generally referred to as land use. These activities range with their purpose, duration, and size, for example, deforestation, land-degradation, agriculture, industrialization, and farming. Apparently, too much of such activities have a consequence on the alteration of the natural and physical configuration of the geography as a whole. Urbanization and population growth are important influential factors on flood risk or any disaster risk, mainly because of the fact that the larger population demands greater use of the land, thus increasing the risk of disaster (Duaibe 2008). Asian countries are heavily populated, and, consequently, as a result have experienced more natural disasters than any other country, a case of 236 severe flooding, 650 million impacts, and 33,000 lives lost (Wood 2018). Deforestation is an action taken to cater to other activities like agriculture, logging, and other plantation purposes. In relation to that, the loss or absence of vegetation is the key aspect of deforestation that increases the risk of flooding in an area. Vegetation, especially natural forests and trees help reduce major flood risks. This is due to the permeation ability of tree and plant roots that help the soil infiltrate the water and lessen the amount of floodwater resulting in surface runoffs.

Primary data are scarce in this region (PNG) and data acquisition is constrained by time and finance. The Department of Surveying and Land Studies provides secondary data like satellite images, aerial photographs, and other metadata resources they have acquired themselves and from other reliable sources. With that, for this study particularly the data that were used are those that are available in the department and from those other reliable sources like the PNG Resource Information System (PNGRIS 2009) and the Remote Sensing Department in UPNG (Geobook 2009) (Table 1).

A total of nine parameters were selected to conduct this research, namely land use/land cover, elevation, slope, surface runoff, distance from river, rainfall, soil texture, soil drainage, and landform (Table 2). These thematic layers/parameters were derived from initial data sets which were collected

Table 1 Description of datasets used for the research

Dataset type	Resolution	Year	Spatial references	Source
Landsat 8 OLI	30 m	2013	WGS 1984 UTM, Zone 55	USGS Earth Explorer
DEM	30 m	2009		Department of Surveying and Land Studies
Soil data	90 m	2009		PNGRIS; GEOBOOK
Rainfall data		2009		
Landform data		2009		
Validation data	Point location	2009		

Table 2 Description of thematic layer derivation from raw datasets

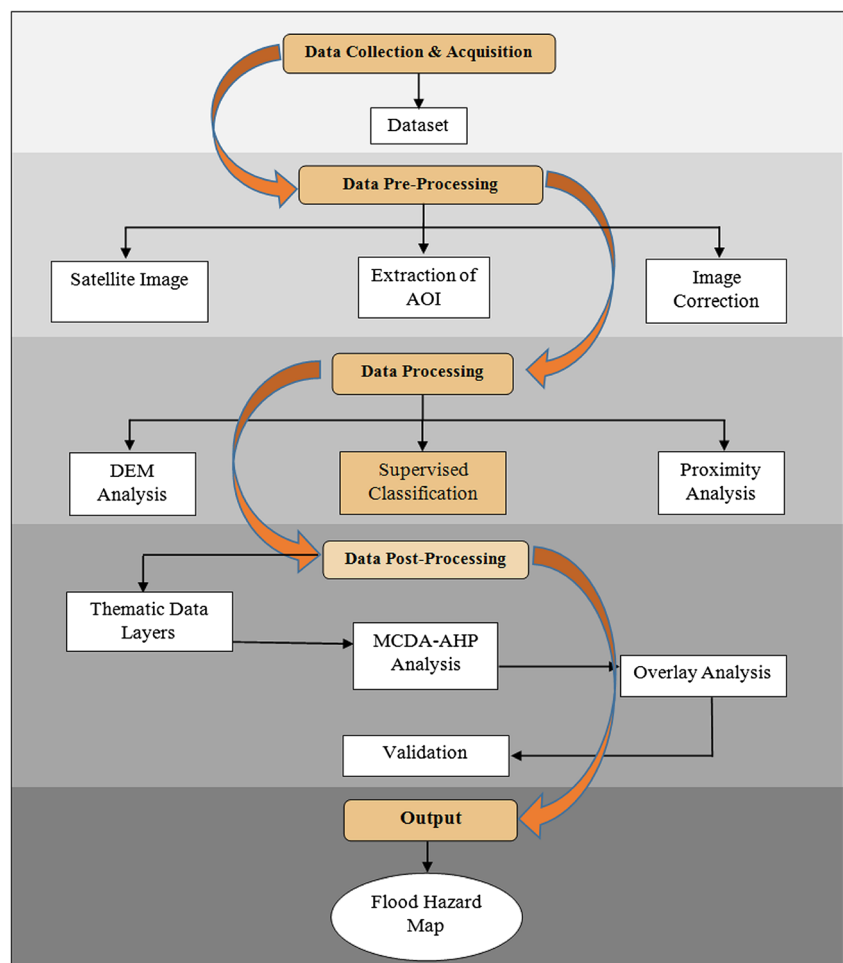| Thematic layers (parameter)	Dataset
1. LU/LC	Landsat 7 ETM+ (30 m)
2. Elevation	Central DEM—30 m
3. Slope	Central DEM—30 m
4. Surface runoff	PNGRIS and Landsat 7 ETM+ (30 m)
5. Distance from river	Central DEM—30 m
6. Rainfall	PNGRIS
7. Soil texture	PNGRIS
8. Soil drainage	PNGRIS
9. Landform	PNGRIS

through analysis, classification, reclassification, proximity analysis.

Image correction and enhancement is a necessary and important pre-processing task that accounts for geometric and radiometric errors in the image data before it goes through information-extraction process, i.e., data processing. The Landsat 8 OLI satellite image was enhanced to improve its interpretability and data quality. In most raw data, the pixel values fall within a narrow range and makes interpretability and information-extraction difficult; thus, one way to improve this is to utilize the full range of gray level values. The linear contrast enhancement technique, i.e., Min-Max stretching was used to enhance the image quality before data processing. Clipping analysis tool was used to clip out the area of interest from the datasets, preserving the content of information from the original source data. Clipping was done in ArcMap where a shape file of the study area was created and used to extract only the relevant information for the study area. Data processing was the next stage of the methodology that takes care of the processes of the preparation of the different thematic layers that were used as inputs into the analyses of generating the flood vulnerable maps (Fig. 2).

Elevation (meter) and slope (degree) maps were generated from the DEM data using the spatial analyst tools in ArcGIS version 10. Soil, landform, and rainfall layers were extracted from the PNGRIS database using the information from their metadata document. Soil texture was classified into the four fundamental groups known as the Hydrologic Soil Group (HSG). Soil texture affects the infiltration capacity and rate of water into the soil. Finer grains have a higher infiltration rate than the bulky/intact grains of soil. HSG has groups A, B, C, and D with the type of soil texture and their infiltration rates

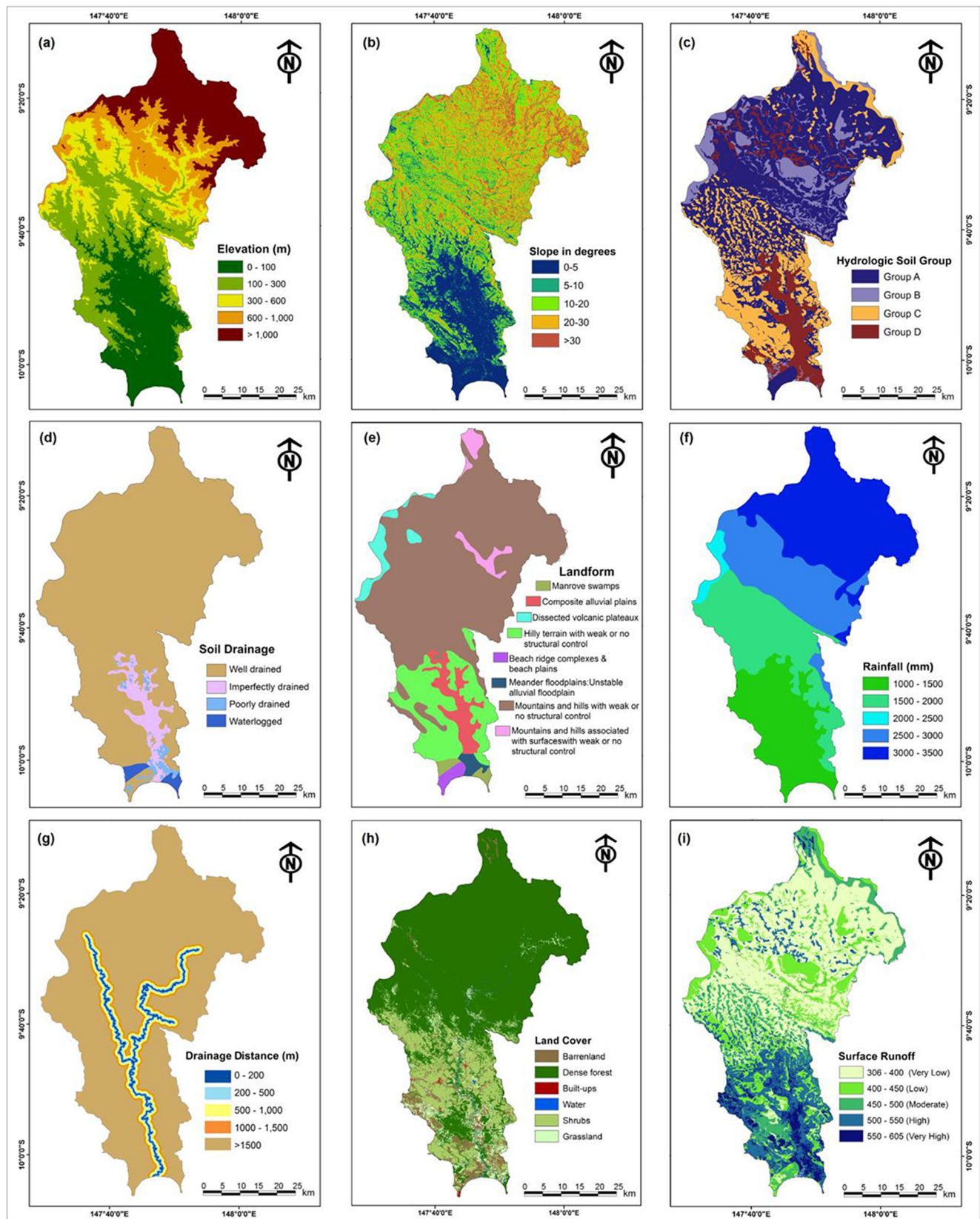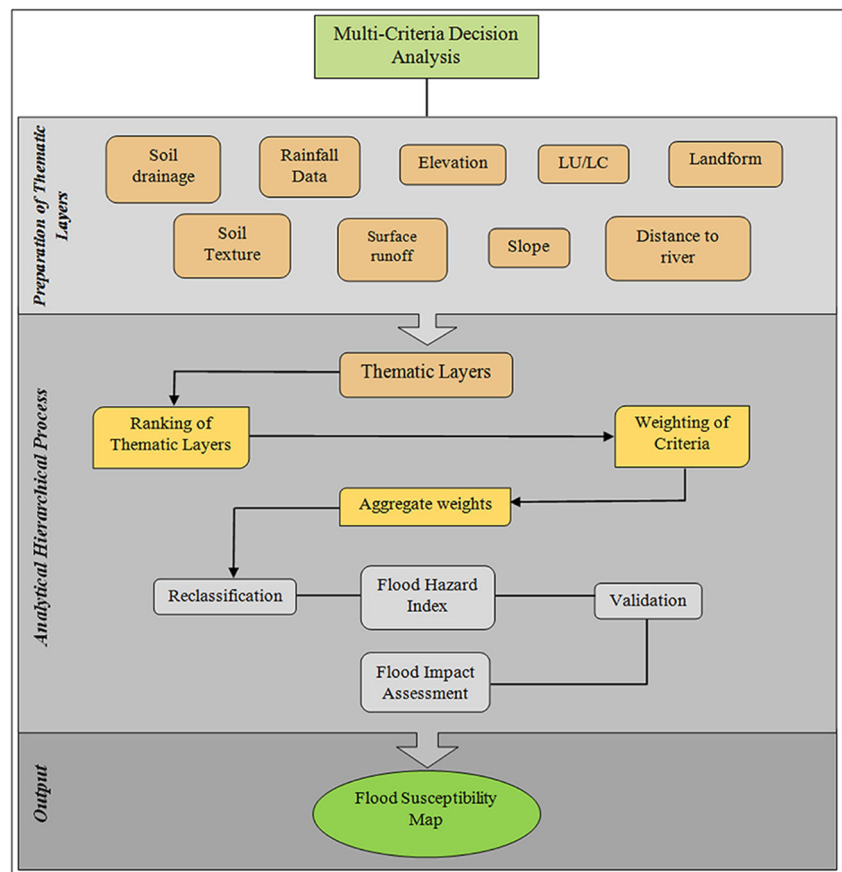**Fig. 2** Overall methodological flowchart of the research

Fig. 3 Thematic layers of parameters used for flood vulnerability analysis: **a** elevation in m, **b** slope in degree, **c** hydrologic soil group, **d** soil drainage, **e** landform, **f** rainfall in mm, **g** distance from drainage, **h** land use/land cover, **i** surface runoff

Fig. 4 MCDA-AHP methodological flowchart

that determine how well they respond to the water on soil and how they affect surface runoff. Buffer analysis technique was used to calculate the distance from the main drainage using the river linear shapefile. Landsat8 OLI satellite image was used for generating the land use/land cover (thematic) layer through supervised classification using Erdas Imagine 8.5. Classification scheme is given below, adopted from the USGS classification system, but only 6 classes out of 9 were used in this study. After the classification, an accuracy assessment report (overall accuracy of 95.45 and Kappa of 0.8892) was generated to examine the level of accuracy of the classified map. Surface runoff database was generated on the basis of soil conservation service model (Pal and Samanta 2011). $Q = (P -$

$Ia)^2/(P - Ia + S)$, where Q is the actual surface runoff in millimeters, P is the storm rainfall (mm), S is the potential maximum retention (mm), and Ia is 0.4S (Initial abstraction [mm]). To calculate the value of potential maximum retention (S), another simple was used; $S = (25,400/CN) - 254$, where CN is curve number of hydrologic soil cover complex, which happens to be a function of soil type, land cover, and antecedent moisture condition. Figure 3 a–i represent all parameters that were used for flood vulnerability analysis with their subclasses.

The AHP technique was used to develop, calibrate, and evaluate each of the parameters/thematic layers (Fig. 4). Each thematic layer, i.e., elevation, slope, LU/LC, rainfall, landform, soil texture, soil drainage, surface runoff, and

Table 3 The weight description scale

Value	Weight	Weights description
1	Equal	Two parameters have equal importance/contribution to the phenomenon.
2	Moderate	Expertise/experience strongly favor one parameter over another.
3	Essential/strong	Expertise/experience strongly favor one parameter over another.
4	Very strong	A parameter is very strongly favored and shows dominance over another.
5	Extreme	The evidence favoring one parameter over another is of the highest possible order of affirmation.

Table 4 Parameters with their corresponding classes and their ranks, areas, and overall parameter weight

Parameters	Classes	Rank	Area (km²)	%	Weight
1 Elevation [E]	100	5	671.57	21.78	2
	300	4	735.19	23.84	
	600	3	540.06	17.51	
	1000	2	447.65	14.51	
	>1000	1	689.66	22.36	
2 Slope [S]	0–7	5	224.34	7.27	3
	8–15	4	840.56	27.26	
	16–23	3	982.59	31.86	
	24–30	2	394.22	12.78	
	>30	1	642.26	20.83	
3 Soil texture/HSG	A	1	1682.19	54.58	3
	B	2	366.16	11.88	
	C	3	690.52	22.40	
	D	4	343.46	11.14	
4 Soil drainage [SD]	Perfectly drained	1	2843.71	92.26	3
	Poorly drained	2	159.05	5.16	
	Imperfectly drained	3	44.64	1.45	
	Waterlogged	4	34.97	1.13	
5 Landform [L]	Mangrove swamps	3	34.04	1.10	2
	Beach ridge complexes and beach plains	3	32.11	1.04	
	Composite alluvial plains	4	164.02	5.32	
	Meander floodplains: unstable alluvial floodplain	5	30.72	1.00	
	Dissected volcanic plateau	2	87.76	2.85	
	Hilly terrain with weak or no structural control	1	469.72	15.24	
	Mountains and hills with weak or no structural control	1	2179.53	70.71	
	Mountains and hills associated with relict surfaces with weak or no structural control	1	84.47	2.74	
6 Rainfall [R] (mm)	1000–1500	1	617.28	20.03	2
	1500–2000	2	699.27	22.69	
	2000–2500	3	56.45	1.83	
	2500–3000	4	652.31	21.16	
	3000–3500	5	1057.02	34.29	
7 Drainage buffer [DB]	200	5	85.87	2.78	4
	500	4	104.22	3.38	
	1000	3	150.80	4.89	
	1500	2	141.75	4.60	
	>1500	1	2601.61	84.35	
8 LULC	Water	5	16.02	0.52	1
	Dense forest	1	2239.06	72.60	
	Shrubland	3	495.62	16.07	
	Barrenland	4	160.79	5.21	
	Grassland	4	159.79	5.18	
	Urban built-up	2	12.85	0.42	
9 Surface runoff [SR]	306–400	1	1582.21	51.34	5
	400–450	2	43.28	1.40	
	450–500	3	369.27	11.98	
	500–550	4	905.34	29.38	
	>550	5	181.45	5.89	

Table 5 Pairwise comparison matrix for all parameters

	SR	DB	SD	HSG	S	L	E	R	LULC	Weight
SR	1	2	3	3	3	4	4	4	5	29
DB	0.5	1	2	2	2	3	3	3	4	20.5
SD	0.33	0.5	1	1	1	2	2	2	3	12.83
HSG	0.33	0.5	1	1	1	2	2	2	3	12.83
S	0.33	0.5	1	1	1	2	2	2	3	12.83
L	0.25	0.33	0.5	0.5	0.5	1	1	1	2	7.08
E	0.25	0.33	0.5	0.5	0.5	1	1	1	2	7.08
R	0.25	0.33	0.5	0.5	0.5	1	1	1	2	7.08
LULC	0.2	0.25	0.33	0.33	0.33	0.5	0.5	0.5	1	3.94
∑	3.44	5.74	9.83	9.83	9.83	16.5	16.5	16.5	25	113.17

SR surface runoff, *DB* drainage buffer, *SD* soil drainage, *HSG* soil texture/hydrological soil group, *S* slope, *L* landform, *E* elevation, *R* rainfall, *LULC* land use/land cover

distance from river were considered a criterion. For each criterion, its classes were ranked based on its influence on the flood, from the worst to best using the values from 1 to *n*, n being the most influential and 1 being the least influential. Each ranking was weighted according to their relative importance based on the expert's knowledge and results from research and finally all the weightings of the parameters/criteria were combined or aggregated and given an overall score (ranked) to generate a flood vulnerable index map. The weighting criterion in Table 3 is adopted from Saaty (1987), where the fundamental scale 1 to 5 was considered instead of 1, 3, 5, 7, 9, and intermediate values. Table 4 summarized all weight and ranks which were given to each parameter and their subclasses. Pairwise comparison is a fundamental element in AHP, particularly in assigning weights to criteria. Basically, the purpose is to identify which criterion has more influence (importance) on the phenomenon and which has less. A matrix was established between sets of criteria and comparisons were made among all parameters selected for the study. Additionally, weights were calculated by

comparisons between alternatives for each criterion (Table 5). The normalized weight (NW) for each criterion was calculated in the next step (Table 6) and aggregated or synthesized by multiplying the ranks of each class by their corresponding criteria.

The past flood event database was prepared to validate the result. The important information about the past flood events was collected with their dates (year), spatial locations (x-y coordinates), and location names (village/area). Inundation data from PNGRIS was used to validate the flood hazard map. Twenty-five flood event points from the inundation data were superimposed on the flood vulnerability map.

Finally, an impact assessment was dome using village points and road infrastructure layer. A total of 98 villages are located within the boundaries of the catchment area and are spatially distributed throughout the area. The main purpose was to find out villages and road infrastructure that are at risk of floods and specifically at what vulnerable zones, like more vulnerable zone, less or least vulnerable zones.

Table 6 Normalized weights for all parameters

	SR	DB	SD	HSG	S	L	E	R	LULC	∑	Normalized weight
SR	0.29	0.35	0.31	0.31	0.31	0.24	0.24	0.24	0.2	2.49	0.28
DB	0.15	0.17	0.2	0.2	0.2	0.18	0.18	0.18	0.16	1.62	0.18
SD	0.1	0.09	0.1	0.1	0.1	0.12	0.12	0.12	0.12	0.97	0.11
HSG	0.1	0.09	0.1	0.1	0.1	0.12	0.12	0.12	0.12	0.97	0.11
S	0.1	0.09	0.1	0.1	0.1	0.12	0.12	0.12	0.12	0.97	0.11
L	0.07	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.08	0.54	0.06
E	0.07	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.08	0.54	0.06
R	0.07	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.08	0.54	0.06
LULC	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.32	0.04
∑	1.01	1.01	0.99	0.99	0.99	0.99	0.99	0.99	1	8.96	1.01

SR surface runoff, *DB* drainage buffer, *SD* soil drainage, *HSG* soil texture/hydrological soil group, *S* slope, *L* landform, *E* elevation, *R* rainfall, *LULC* land use/land cover

Results and discussions

The weighted linear combination analysis in ArcGIS was used to process this information and generate the values for the flood vulnerability index (Fig. 5a). This final output will be a 30-m resolution flood vulnerable map showing the areas within the catchment that are susceptible or vulnerable to floods. The resulted output demonstrated a span of flood index value ranging from 1.13 (least vulnerable) to 4.15 (most vulnerable). The final flood vulnerability map was classified into 5 distinct classes that show the specific flood potential zones based on natural junk classification method, namely very low (less than 1.85), low (1.86–2.34), moderate (2.35–2.67), high (2.68–3.12), and very high (more than 3.13) vulnerability (Fig. 5b). These different potential zones are results from the influence of the nine parameters that have been integrated into the analysis. The very high and high flood potential zones are mostly due to the hydrological soil group of group D and C influence with their infiltration capacity of about 0–0.15 in./h. Infiltration is slow at within these zones and therefore, the rate of inundation is faster than that of the infiltration rate, especially during heavy intensive rainfalls. Due to low infiltration rate, high flood-prone zones

are within the poorly and imperfectly drained areas. Again, surface runoff is the result of land cover features and soil characteristics, where very high surface runoff is located within the highly flood-prone zones. Both the drainage and runoff contribute a great deal to the amount of flood that is proposed to occur in the high flood-prone zones. Mangrove swamps, meander floodplain, and composite alluvial plain landscapes are mostly situated in the high flood-prone area. The highly analyzed to be affected areas are at the lowlands (low altitudes at about 0–100; 100–300 m) and mostly flat-lands between 0 and 5°. These areas will mostly be affected as a result of the high surface runoff within those areas. There is very high rainfall at high altitudes than at the low-lands, but because of elevation and slope, the surface runoff flows down slopes and accumulates at lowlands-flatlands, thus causing floods to occur at these low-flat lands than at high altitudes and much steeper sloped areas. The most potential flood zones are found within 0–200 m and moderate between 200 and about 500 m from the river. When the main river has exceeded its water holding capacity, the rest of the water flows over the river's banks and those areas and population near these zones are more affected as the effect of flood is much more there than farther from the river. The
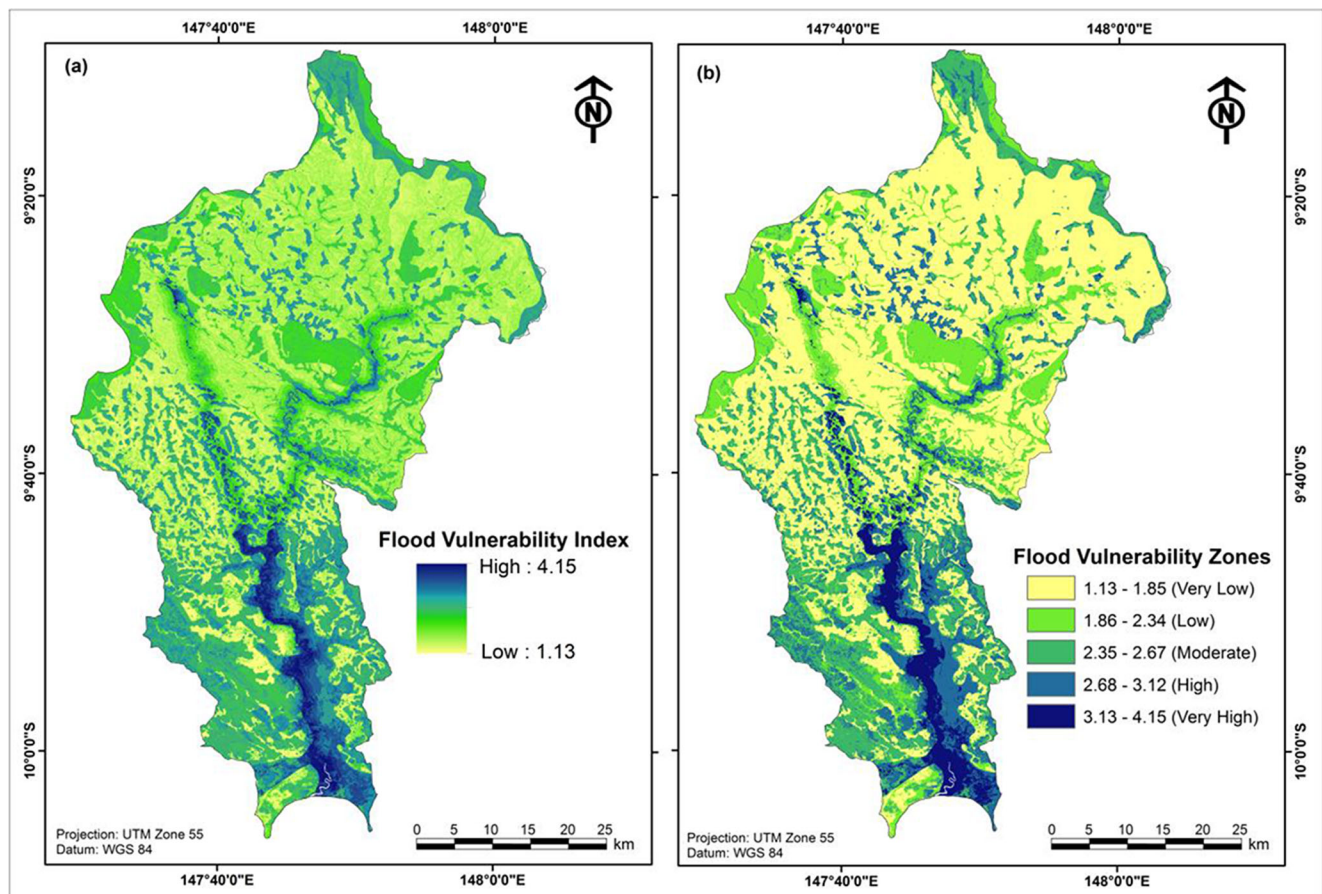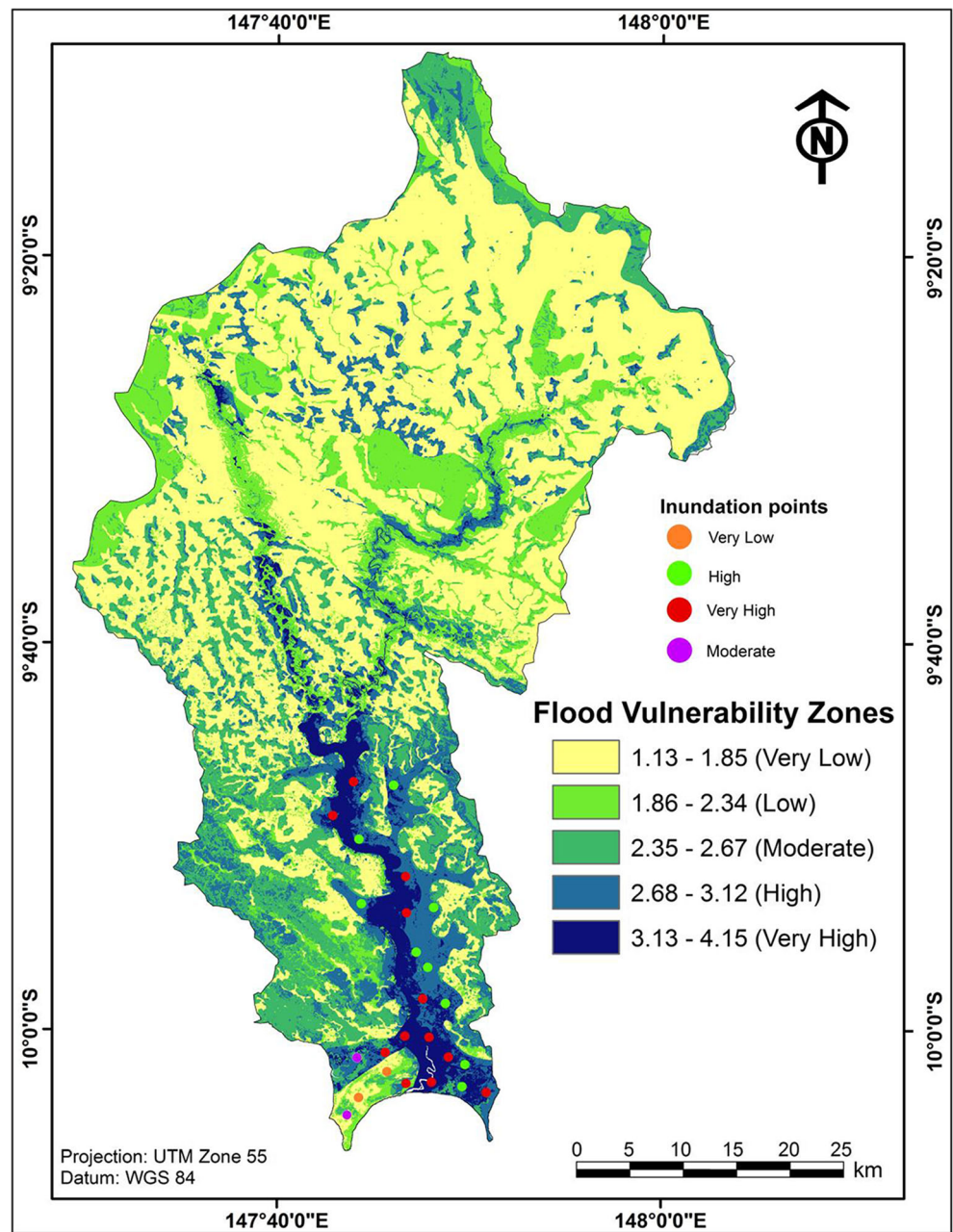

Fig. 5 Flood vulnerability map: **a** vulnerability index map, **b** classified vulnerability zones map

Fig. 6 Superimpose of past flood events and flood vulnerable zones

spatial distribution of land cover features displays those areas covered with what type of feature. The type of land cover feature depicts the potential of any flood occurrence based on the features' characteristic towards water. In this case, as shown on the flood map, those zones that are demarcated as high to very high are those areas that have shrubland, grassland, and water (river) land covers. These areas are prone to be inundated due to the soil's exposure to the atmosphere

Table 7 Validation points and flood zone description

	Inundation description	No. of inundation points	Flood vulnerability zones
2	Periodic brief flooding	12	Very high
3	Long-term inundation	9	High
7	Tidal flooding	2	Moderate
8	Tidal flooding with freshwater inundation	2	Very low

and less vegetation where surface water has little or no soil infiltration and overtime accumulates and inundates the land as flood.

Past flood events that have occurred in the study area were compared with the final output of the flood vulnerability map. This is particularly to validate the accuracy of the MCDA-AHP technique that was used to carry out the analysis for generating the flood map showing the susceptible zones within the catchment. All 25 past flood points were overlaid on the resulted flood vulnerable database (Fig. 6). These points represent different types of inundation and their relationship with the flood vulnerability zones (Table 7). Figure 7 and Table 7 show 21 past flood points out of 25 are situated on high to very

high flood vulnerable class based on the resulted vulnerability database. Based on validation, the output accuracy is calculated as 84.00%.

Point on polygon overlay operation was carried out to identify number of villages under each vulnerable zone of modeled flood vulnerability map. The results of overlay operation shows 30 (30.6%) out of 98 villages are located under high to very high flood vulnerable zone. About 6700 (25.6%) living in this village out of a total of 26,213 population in the catchment area are living in the vulnerable zone (Fig. 7 and Table 8). Finally, the line on polygon overlay operation was carried out to identify the total length of road under each vulnerable zone of modeled flood vulnerability map. About

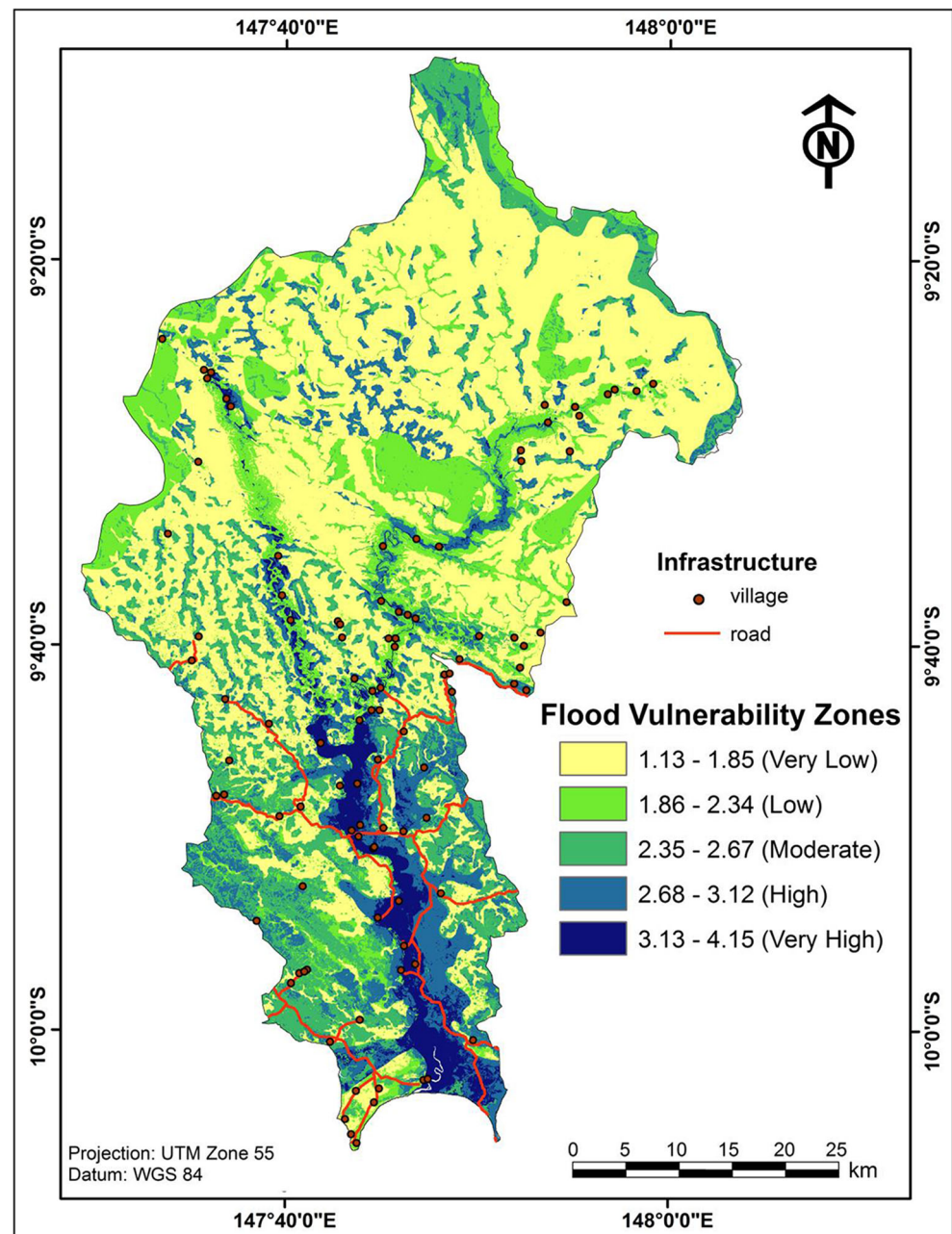Fig. 7 Overlay of villages and major roads on the flood vulnerable zones

Table 8 Infrastructure impact assessment

Flood vulnerability zones	Description	Area (km^2)	Area (%)	No. of villages
5	Very high	140.71	4.57	18
4	High	384.49	12.49	12
3	Moderate	596.88	19.40	19
2	Low	483.78	15.72	26
1	Very low	1471.29	47.81	23

64.06 km existing major roads are under high to very high flood vulnerability zone (Fig. 7).

Conclusions

Flood being a natural cause in the water cycle is inevitable; it cannot be ruled out or stopped completely, at least not by people. Developed nations have built structural defenses like dams and levees against flood and yet its force still breaks through the barriers and cause massive destructions to anything that is lying in its course. Non-structural solutions like preparations, preparedness, awareness, mitigation, response, and recovery plans prior to flood events become very efficient tools to save more lives and damages during flood events. Thus, GIS and remote sensing technologies are utilized to assess flood risk zones in areas that have been flooded before to analyze important elements involved in the flood event to help planners and decision-makers to better plan both structural and non-structural solutions. In addition to that, Papua New Guinea still being a developing country in terms of economical strategizing may not be the best fit for structural solutions. However, on the contrary, non-structural solutions especially awareness, preparations, and preparedness measures can be effectively implemented to prevent major losses of lives and damages to properties. These strategic plans and measures can be taken on the basis of the vulnerability of the area, its properties, population, and the environment. The aim was "to identify zones or areas that are susceptible/vulnerable to floods" in order to obtain a clear visual perspective and a better understanding of the exact locations where a flood is likely to occur. More emphasis and careful planning should be focused on the very high, high, and the moderate vulnerable flood zones than those of the low and very low zones. Again, sometimes in the worst-case situations, a natural phenomenon like flood can wipe so many lives and cause massive destruction to both properties and the environment. Even so, such analysis and research can be tools to help planners, engineers, governments, and those in the community to plan, strategize, and build their livelihoods in secured areas where the impacts become lesser than it would without those measures. In this way, more lives can be spared and collateral damage is minimized.

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