Flood Hazard Micro Zonation from a Geomatic Perspective on Vitilevu Island, Fiji

Varo, J., Sekac, T. and Jana, S. K.*
Department of Surveying and Land Studies, Papua New Guinea University of Technology, Lae 411, Morobe Province, Papua New Guinea, E-mail: joelivaro@gmail.com, tingneyucsekac@gmail.com, sujoy2007@gmail.com
**Correspondence Author*

Abstract
Flash floods in the rural and urban areas led to high level of water in the roads, houses and agricultural land which create numerous problems such as traffic problems, water-borne diseases, and damages of roads and collapse of buildings. It is impossible to reduce the occurrence of floods but it is possible to identify the risks zone and employ measures to reduce its disastrous effect. The aim of this paper is to demarcate the flood risk zone of Vitilevu Island into 'low', 'moderate', and 'high' classes. In order to fulfil this, we use hydrology, site-soil-geology, and geomorphology and SRTM DEM data. The method used is called Analytical Hierarchical Process (AHP) to ascertain the relative impact weight of flood causative parameters to get the flood hazard index (FHI). The outcome was the flood hazard Zone of Vitilevu Island showing selected infrastructures vulnerable to different zone of flood. Thus, this present study contributes conceptually, contextually and temporally towards the use of GIS and urban planning disciplines.

1. Introduction

According to Miles et al., (1999) practitioners and researchers in flood engineering have recognized geographic information system (GIS) to be a significant and vital tool in modelling spatial phenomenon related to risk and hazard. GIS, as an engineering tool has been primarily used for its spatial data storing and presentation features. Degiorgis et al., (2012) revealed that flood risk management needs to overcome national borders, geographic location and socio-economic limitations. This present study endeavoured into identifying potential areas of flood hazards in VitiLevu Island. In lieu, rainfall, distance to river drainage, topography, flow accumulation, land use, slope, soil texture, soil drainage and geology were integrated with ease using the GIS to achieve the desirable output. There were numerous similar approaches undertaken around the world on this specific discipline which highlight the essential role of GIS in Disaster Risk Reduction (DRR) and Disaster Risk Management (DRM).

The main aim of this research is to identify flood hazard zones on VitiLevu Island. Hence, the following three (3) objectives were thoroughly considered in order to fulfill this aim; (1) Identify bio-environmental factors that causes flood, (2) Analyse and synthesize the collected data through Analytical Hierarchical Process (AHP), Multi – Criteria Analysis (MCA) and advanced GIS environment, and (3) Demarcate flood hazard zones and highlight the socio-economic, physical and environmental measures to reduce hazards risks. Hence, provide substantial evidence for sound and well-informed decision making.GIS based approach is widely used to identify natural related hazards such as flood hazard zonation, liquefaction, landslide, fire and tsunami. Pal et al., (2007), Varo et al., (2019(a) and 2019(b)) and Sekac et al., (2016(a),(b),(c) and 2019) used AHP to demarcate earthquake hazard zones. According to Fernández et al., (2010) five parameters were incorporated to produce an urban flood hazard zoning in Tucumán Province, Argentina which were: distance to the drainage channels (D), topography (heights and slopes) (H & S), ground water table depths (GWD), and urban land use (LU).

So far, numerous studies have been done to identify flood hazard zones in different countries such as the United States (Mastin, 2009), Papua New Guinea (Samanta et al., 2018, Sekac et al., 2015), China (Liang et al.,2011), Egypt (El Bastawesy et al., 2009, Ghoneim et al., 2002, Youssef et al., 2011), Saudi Arabia (Saud, 2010 and Dawod et al., 2011), India (Bhatt et al., 2010) and Ghana (Forkuo, 2011). Seejata et al., (2018) and Pal et al., (2018) also used Analytical Hierarchical Process to assess the flood hazard zones or areas of susceptibilities. The authors employed 6 parameters namely rainfall intensity, river density, slope, elevation, soil permeability and land use. The final product was a flood hazard zonation map of Sukhothai province in Thailand.

2. Background of Study Area

According to World Bank (2015), Fiji is expected to incur average annual losses over the long term of F$158 million (US$84 million) due to flood, earthquakes and tropical cyclones. Fiji Islands is located 178^0 East and 17^0 South on global coordinate system, have a total of 322 islands, atolls and islets but only 50% of those are inhabitable by human beings. The Fiji Bureau of Statistics (2017) revealed that 76.6 % or 678,153 out of 884,887 of Fiji's total population lives within the case study area alone, VitiLevu Island. According to Varo et al., (2019) and Rahiman and Pettinga (2008), VitiLevu, the main island of Fiji with a total land mass of approximately 10,344 Square Kilometre, is located in a seismically active area within the Fiji Platform, a remnant island arc that lies in a diffuse plate boundary zone between the Pacific and Australian tectonic plates in the South West Pacific. VitiLevu is the largest in the Fiji Islands and is the site of the Capital city, Suva. It is the location of the two cities and 10 towns. According to Burke et al., (2011) and Lata and Nunn (2012) all these urban centres were coastally located within 30-meters from mean sea level and highly vulnerable to flood, tsunami and earthquake.

Fiji has an amazing geological setting. Experts' such as Rodda (1967)and Parson et al., (1990)suggested that Fiji Islands represent a portion of the old Vityaz Arc which was split up and rotated clockwise to its present position. The opposing plate movements have resulted in the formation of transform faults such as the Fiji Fracture Zone to the north and the Hunter Fracture Zone to the south. Seafloor spreading resulted in divergence and opening up of the North Fiji Basin and the Lau Basin (Fiji Mineral Resources Department, 2015, Rahiman and Pettinga, 2008, Bartholomew, 1959,Shackleton, 1936 and Hirst, 1965). According to Yeo et al., (2010) at least 225 people in the Fiji Islands died as a result of the 1931 hurricane and flood, representing the largest loss of life from a natural disaster in Fiji's recent history. The frequency of these major floods appears to have changed around 1931 (Figure 3). Before that time (1892-1931), a major flood occurred with an average frequency of 6.7 years, whereas after that time (1932–2002) a major flood occurred with an average frequency of 3.2 years.In April 2018, Cyclone Josie and Cyclone Keni interspersed with heavy rain have left towns inundated, roads impassable with power and water disconnected in less than two weeks.According to the World Bank (2017), Fiji loses more than F$500m (US$240m) in assets per year on average because of tropical cyclones and floods. Therefore, Fiji has experienced an increase in frequency and intensity of cyclones and flash floods.

3. Data Collection and Pre-Processing

The data collected undergone some pre-processing stages before incorporating into the ArcGIS 10.5 software for analysis. The nine (9) parameters used for this present study are Flow Accumulation (FA), River Distance (RD), Elevation (E), Land use (L), Rainfall (R), Slope (S), Soil Texture (ST), Soil Drainage (SD) and Geology (G). Vector layers were converted to raster layers for reclassification, ranking and assigning of weightage. Data were acquired through government ministries/departments, academic institutions and organisations as presented in Table 1 below.

This present study establishes a foundation for further flood hazard analysis for Fiji Islands in the future. Nine (9) thematic layers were analysed outside ArcGIS environment using the Analytical Hierarchical Process (AHP) also known as Saaty's model gleaned from Saaty (1977, 1980, 1992 and 2008). According to Varo et al., (2019) and Sekac et al., (2016), Multi Criteria Analysis (MCA) techniques happen to be a significant decision support tools for dealing with complex decision constellations where technological, economical, ecological and social aspects are included.

3.1 Methodology

This present study adopted a multi-criteria analysis (MCA) incorporating a Flood Hazard Index (FHI) associated with GIS environment. The three main reasons of using AHP method were availability of data, limited time frame of research and its application to earlier studies on this hazard around the world. The AHP matrixes were designed according to literature research, expert opinions and stakeholder survey & consultations. As shown in Figure 1 the spatial analyst tool in ArcGIS 10.5 has been used to manipulate and integrate nine (9) physical parameters in the production and delineating of the flood hazard zones as shown in Figure 2 below. Figure 2. Nine parameters assessed under each; **a** Rainfall Intensity (mm),**b** River distance (Km), **c** Elevation (m), **d** Flow Accumulation, **e** Land use, **f** Slope (degrees), **g** Soil texture, **h** Soil drainage, **I** Geology

The pairwise comparison matrix is shown in Table 2 using 9 x 9 matrix, where diagonal elements are equal to 1. The values of each row are compared with each column to define the relative importance to obtain rating score.For example, rainfall intensity is significantly more important from geology and therefore assigned the value 9. Row describes the importance of geology. Therefore, the row has the inverse value of the pair-wise comparison (e.g. 1/9 for rainfall). The consistency check was carried out to ascertain the values of correlation between variables. In this case, the canonical correlation formula used is described in Equation 1.

$$CR = \frac{CI}{RI}$$

Equation 1

Where CR = consistency ratio
Where CI = consistency index
Where RI = random index

Thus, in this study the RI = 1.46. The acceptable CR must be < 0.1. CI is calculated using Equation 2 below where calculated λmax = 9.53. RI values are given in specific tables.

$$CI = \frac{lamda\max - n}{n-1}$$

Equation 2

Table 1: Data source

Data	Description	Source
Rivers	Derived from Department of Town and Country Planning. Data source year: 2018.	Fiji Town and Country Planning
Soil factors & Soil Attributes	Derived from Fiji Land Use Planning Guidelines. Data source year: 2015	Fiji Ministry of Agriculture
Rainfall factors	Derived from Fiji Meteorology Department Data source year: 2019	Fiji Meteorological Department
Land Use/Zoning/Built infrastructures	Derived from Fiji Department of Town & Country Planning. Data source year: 2018	Fiji Department of Town and Country Planning
Slope	Derived from the Secretariat of South Pacific Community. Data source year: 2018	Fiji Mineral Department
Landsat 8 ETM & satellite image (30m spatial resolution – 2017)	Downloaded from https://libra.developmentseed.org/ for verification purposes. Data source year 2019.	PNG University of Technology
Geology (rock type classification)	Derived from Fiji Geology map. Data source year: 1936, 1959, 1990, 1994 & 2015.	Fiji Mineral Resources Department & PNG University of Technology

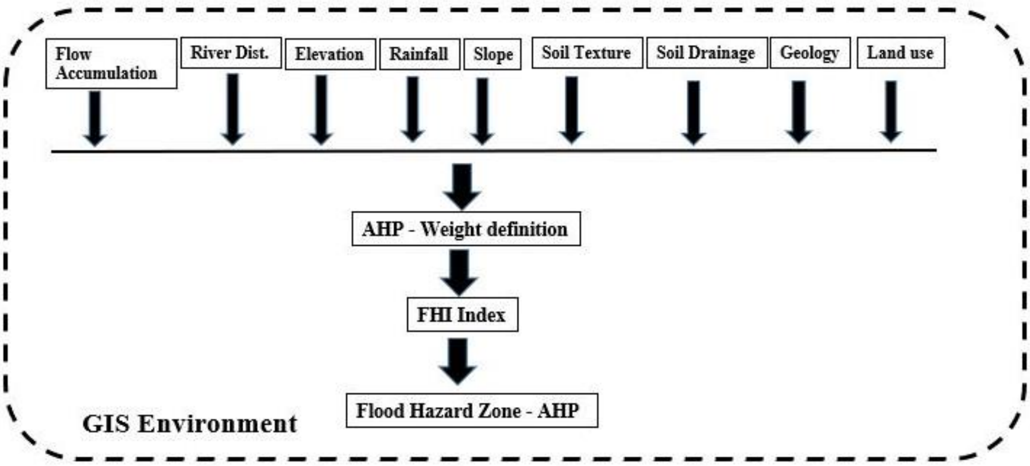

Figure 1: Methodological flow chart

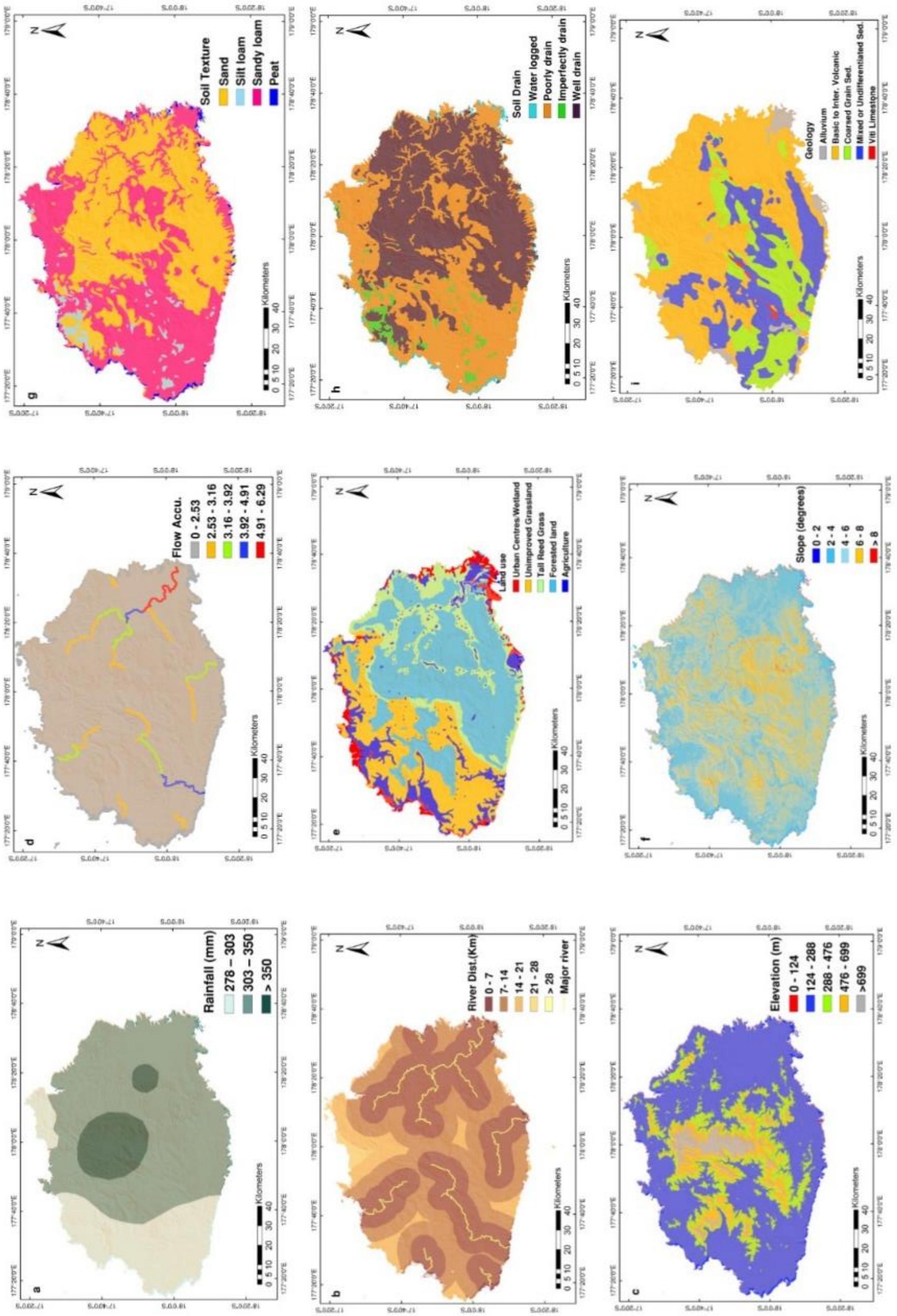

Figure 2: Nine parameters assessed under each; **a** Rainfall Intensity (mm),**b** River distance (Km), **c** Elevation (m), **d** Flow Accumulation, **e** Land use, **f** Slope (degrees), **g** Soil texture, **h** Soil drainage, **I** Geology

Table 2: Pair wise comparison of Parameters

Focus	Theme								
	Rainfall	**River Dist.**	**Elevation**	**Flow Acc.**	**Land use**	**Slope**	**Soil Texture**	**Soil Drain**	**Geology**
Rainfall	1	2	3	4	3	6	7	8	9
Dist. Drain Net	1/2	1	2	3	4	5	6	7	8
Elevation	1/3	1/2	1	2	3	4	5	6	7
Flow Acc.	1/4	1/3	1/2	1	2	3	4	5	6
Land Use	1/5	1/4	1/3	1/2	1	2	3	4	5
Slope	1/6	1/5	1/4	1/3	1/2	1	2	3	4
Soil Texture	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3
Soil Drainage	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2
Geology	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1

Table 3: Nine parameters with weight, area, normalized rate and percentage area

Parameters	**Weight**	**Classes**	**Ratings**	**Normalize rate**	**Area (KM. Sq.)**	**Area (%)**
Rainfall Intensity (mm)	0.296	278 – 303	1	0.161	30743.42	73.19
		303 – 350	2	0.262	7973.956	18.97
		> 350	4	0.416	3304.11	7.86
Dist. Drain Network (Km)	0.222	0-7	5	0.416	170.31	11.24
		7-14	4	0.262	250.45	16.54
		14-21	3	0.161	321.95	21.26
		21- 28	2	0.098	388.53	25.66
		>28	1	0.062	382.78	25.28
Elevation (m)	0.157	0 - 124	5	0.416	298.09	0.28
		124 - 288	4	0.262	69928.57	67.42
		288 - 476	3	0.161	17806.55	17.16
		476 - 699	2	0.098	10273.7	9.9
		>699	1	0.062	5404.7	5.21
Flow Accumulation	0.11	0 - 2.53	1	0.062	104192.1	98.36
		2.53 - 3.16	2	0.098	825.756	0.77
		3.16 - 3.92	3	0.161	511.988	0.48
		3.92 - 4.91	4	0.262	210.084	0.19
		4.91 - 6.29	5	0.416	188.324	0.17
Land use	0.077	Mixed Forest	1	0.062	4644.1	43.67
		Sparsely vegetated	2	0.098	1622.54	15.25
		Agricultural	3	0.161	1145.58	10.77
		Pastures	4	0.262	2733.35	25.7
		Urban - wetland	5	0.416	487.41	4.58

Slope (degrees)	0.053	0 - 2	5	0.416	1366.5	13.17
		4-Feb	4	0.262	3288.4	31.7
		6-Apr	3	0.161	5686.14	54.82
		8-Jun	2	0.099	29.81	0.28
		> 8	1	0.062	0.31	0.002
Soil Texture	0.037	Sand	1	0.096	8880.41	48.08
		Silt Loam/Loamy soil	2	0.161	771.354	4.17
		Sandy Clay Loam	3	0.277	8208.64	44.44
		Peat	4	0.466	608.57	3.29
Soil Drainage	0.026	Well drain	1	0.096	8880.41	48.08
		Imperfectly drain	2	0.161	771.35	4.17
		Poorly drain	3	0.277	8208.64	44.44
		Water logged	4	0.466	608.57	3.29
Geology	0.019	Alluvium	1	0.416	394.13	3.84
		Basic to Intermediate volcanic	2	0.262	5564.8	54.29
		Coarse grain sedimentary	3	0.161	1803.37	17.59
		Mixed or Undifferentiated Sedimentary	4	0.099	2448.35	23.88
		Viti Limestone	5	0.062	37.9937	0.37

Finally, calculated consistency ratio is 0.045 that is lower than the threshold 0.1, the weights' consistency is assured. All the nine (9) parameters were assessed, assigned with weightage and area calculated as presented in the Table 3 below. Rainfall intensity assigned with 0.296 weightage which is the highest whereby of all other parameters were assigned according to their relative contributions to flood hazards. The principle is that the higher the rainfall intensity the high chances of flood. Geology was assigned with the weightage of 0.019 due to its trivial contribution to flood. However, each parameter's rating was applied according to the knowledge of significant contribution towards flood. For example, for rainfall intensity classes 278 – 303 millimetres of rainfall was assigned with the rating of 1 compare to >350 millimetres with the rating of 4. Hence, 1 means equal of no significant contribution to flood while 4 means very high significant contribution to flood.

3. Results and Discussion

Finally, all the nine (9) parameters were consolidated using the Multi Criteria Analysis (MCA) in ArcGIS 10.5 to project the Flood Hazard Index (FHI). The below Equation 3 was used to calculate the Flood Hazard Index (FHI) for this present study accordingly.

$$FHZ = [(Rw*Rs)+(RDw*RDr)+(Ew*Er)+(FAw*FAr)+(Lw*Lr)+(Sw*Sr)+(STw*STr)+(SDw*SDr)+(Gw*Gr)]/\sum w$$

Equation 3

Where '**R**' is Rainfall, '**RD**' is river distance, '**E**' is elevation, '**FA**' is Flow Accumulation, '**L**' is Land use, '**S**' is Slope, '**ST**' is Soil Texture, '**SD**' is Soil Drainage and '**G**' is Geology.

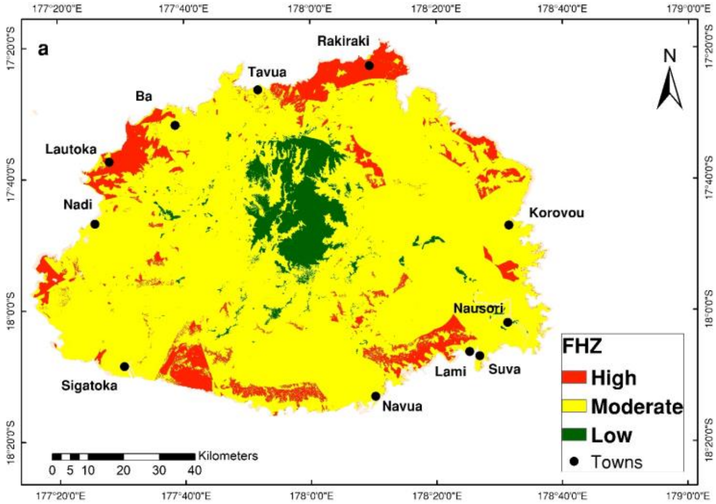

Figure 3a: Flood hazard zonation of Vitilevu Island

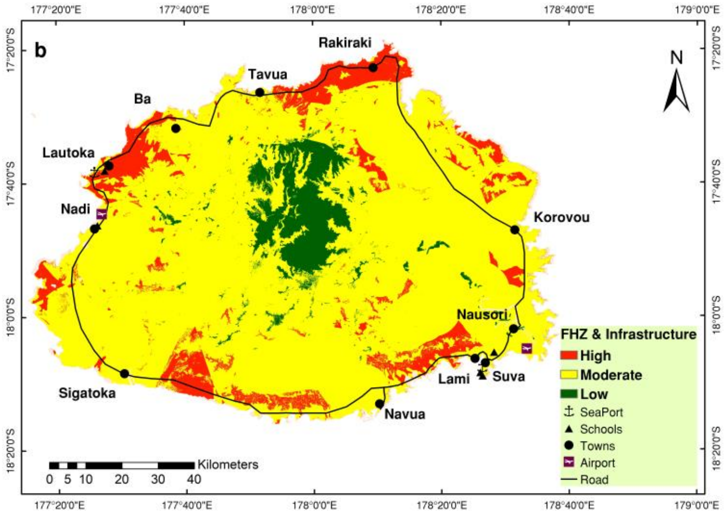

Figure 3b: Built features assessed under flood hazard zonation of Vitilevu Island

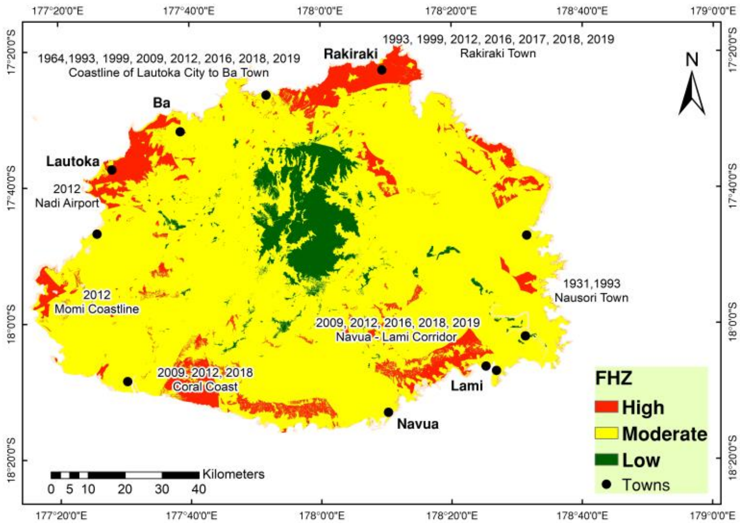

Figure 4: Flood validation map of Vitilevu Island

Table 4: Results of flood hazard zonation and percentage area

Flood Hazard Index (FHI)	Flood Hazard Zones (EHZ)	Area (Sq. km)	Area %
1.55 – 2.40	Low	749.8	7.46
2.40 – 3.26	Moderate	8275.7	82.3
3.26 – 4.12	High	1024.4	10.1

Table 5: Built features assessed under each zone

VITILEVU ISLAND	FLOOD HAZAR ZONES		
	HIGH	MODERATE	LOW
TOWNS/CITIES	Rakiraki Lautoka	Suva Nausori Tavua Ba Lami Navua Nadi Korovou Sigatoka	-
Airports	-	Nadi international airport Nausori	-
Universities & vocational Schools	-	FNU Suva (Nasese) USP (Laucala) FNU (Samabula) FNU (Nadi)	-
Seaports	Lautoka	Moderate	-
Main road (Km)	116.0	245.0	3.39

Interestingly, the Table 4 below illustrated that 7.46% area under low zone, 82.3% of the total land area is under moderate flooding zone and 10.1% area under high zones. Pluvial flooding appears in places associated with poor drainage and low-lying topography which mostly seen on coastal areas of towns and cities during flash torrential rainfall. Fluvial flooding is exacerbating by prolong rainfall hours. Even though many of the towns are in moderate zone, the possibility of land-borne flooding is no exception to them such as Navua town. Different zones were demarcated through FHI which revealed three categories or classes from 1.55 – 2.40, 2.40 – 3.26 and 3.26 – 4.12.

The study reveals that the high zone areas are seen near the river banks where water flows. This means that structural and non- structural measures need to be developed and implemented in order to avoid losses for businesses, residences and agricultures closer to these areas. Table 5below illustrates the features assessed under each flood hazard zone.Figure 3breveals the selected built features on the three flood hazard zones.

The study reveals that the western side also known as the leeward side of the Vitilevu Island is highly vulnerable to flooding during torrential rainfall. For example, a rainfall > 350 mm has more impact with associated risk on high zone area as shown on Figure 3babove. Even though the leeward side is associated with dry weather, it contains other parameters that are highly causative to flooding whilst lessen the infiltration rate of surface water run-off such as poor soil drainage and infiltration, low lying elevation and pastures. Contemplating on the built features, it is ascertained that the high zone includes 2 towns, 1 sea port and 116 kilometres of main road, moderate zone comprised of 9 towns, 1 sea port, 2 airports, 4 universities and vocational schools and 245 kilometres road coverage while low zone comprised of 3.39 kilometres road coverage. Therefore, this present study highlighted the need for preventative and forward disaster risks planning for the Fiji Islands.

Figure 4 revealed the flood verification map of the study area which truly reflects the spatial analysis and validates the methodology used for this present study. Therefore, the result is accurate and reliable for urban planners to ascertain safe places for future developments.

4. Conclusion

Urban and regional planners, engineers, sociologist and economist need to elevate their collaboration techniques in order to curb flood hazards. Flood hazard zonation and assessment for Fiji Islands is highly paramount in this current age in order to protect the lives of some 884,887 population, reducing the risks of disaster and implementing dynamic planning policy to ameliorate the country's disaster resiliency and management. The historic flood data retrieved for this study revealed that Fiji Islands has experienced a norm of increasing frequency, severity and magnitude of cyclone and flood hazards. GIS based decision making is widely used and proven tool to provide visual and readable solution for disaster risks reduction and proper preparedness. Future work will be investigation on inclusions of other physical factors. In addition, the weighting of relative importance factors must be revised flexibly due to changes of relevant factors and also the level of spatial resolution or pixel sizes.

This present study contributes towards this discipline of knowledge conceptually, contextually and temporally. Conceptually amalgamating urban planning and disaster risk reduction concepts, contextually herald the first ever research and provide baseline information in this field for Fiji islands and temporally presenting flood zonation in a 2 dimensional model for priority planning. Urban planners, who are at the forefront and first line of defence in combating and reducing disaster risks should be enlightened of the implementation of GIS environment in assisting and supporting decision making. This present study revealed the urgency to disseminate and share knowledge across the government sectors, non – government sectors and the general public about the potential disastrous impact of flood hazards on major areas in VitiLevu Island. Therefore, it is recommended that government responsible office shall spearhead the following; 1) incorporation of flood hazard considerations early in the process of integrated development planning and investment project formulation, 2) put a higher value on flood risk reduction in evaluating investment projects, and 3) increase the proportion of expenditures for prevention activities relative to rehabilitation and reconstruction

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