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Flood hazard modelling and risk assessment in the Nadi River Basin, Fiji, using GIS and MCDA

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Abstract

This paper presents a simple and affordable approach to flood hazard assessment in a region where primary data are scarce. Using a multicriteria decision analysis (MCDA) approach coupled with GIS layers for elevation, catchments, land-use, slope, distance from channel, and soil types, we model the spatial extent of flood hazard in the Nadi River basin in western Fiji. Based on the flood hazard model results we assess risk to flood hazards in the greater Nadi area. This is carried out using 2007 census data and building location data obtained from aerial photography. The flood model reveals that the highest hazard areas in Nadi are the Narewa, Sikituru and Yavusania villages followed by the Nadi central business district (Nadi CBD). Closer examination of the data suggests that the Nadi River is not the only flood vector in the area. Several poorly designed storm drains also present a hazard since they get clogged by rubbish and cannot properly evacuate runoff thus creating water build-up. We conclude that the MCDA approach provides a simple and effective means to model flood hazard using basic GIS data. This type of model can help decision makers focus their flood risk awareness efforts, and gives important insights to disaster management authorities.
Keywords: *Geographic Information Systems (GIS), Multi-critera decision analysis (MCDA), flood modelling*

1. Introduction

The January 2009 floods in Fiji were reported to be amongst the worst in the history of the country. Nationwide, 11,458 individuals were evacuated, 11 people died, and economic losses exceeded FJD$ 113 million (Holland, 2009) (Figure 1). The Nadi River basin, a small and very reactive watershed, was one of the worst hit with flood heights up to 3.5 metres. Little is known about the hydrology of the basin therefore inhabitants living in the area have been caught off guard by several floods in the past decades. Flood hazard modelling using geographic information system (GIS) requires a variety of spatial input data layers, such as slope, elevation and land use. A fundamental problem with this type of model is how to compare and evaluate the relative importance of the input data layers. Multicriteria decision analysis (MCDA) methodologies and techniques provide a robust analytical framework for dealing with these types of complex decision making problems (Köksalan, 2011). A MCDA technique that has been successfully applied in the spatial modelling context is the analytic hierarchy process (AHP). As an MCDA technique AHP has been used to assign weight and rank values to GIS data input layers. Combined MCDA-GIS approaches have proved successful in several natural hazards studies (Rashed and Weeks, 2003; Gamper *et al.*, 2006) and other geo-environmental studies (Dai *et al.*, 2001; Kolat *et al.*, 2006). Studies using this approach aimed specifically at urban flood hazard modelling include Ozcan and Musaoglu (2010) and Fernández and Lutz (2010).

The objectives of this study were twofold: First, to determine the spatial extent of flood hazard in the greater Nadi town area, and second, to identify populations and buildings at greatest risk to flooding. We used a coupled GIS-MCDA modelling approach to meet the first objective, and conventional GIS overlay techniques to meet the second objective.

2. Study Area

The Nadi River basin is located on the west side of Viti Levu, Fiji's main island. The Nadi River is the largest river in western Fiji with an estimated length of 62 km, a drainage area of approximately 520 km^2, and is made up of 45 sub-catchments which vary in size. It flows east to west from the Naloto Range, through the Nausori Highlands, down the Nadi Valley and into the South Pacific Ocean (Figure 2). Its head is located at Vaturu Lake, an artificial basin created by a dam. Its mouth is situated in the inter-tidal zone of the west coast, dominated by mangroves. The upper part of the basin is steep with many rocky outcrops, whereas the lower basin is covered by small hills and dominated by a flat alluvial terrace at the valley bottom. The highlands are covered by natural vegetation and pine plantations while the coastal hinterlands have commercial sugarcane fields and human settlements (JICA, 1998).

The western portion of Fiji experiences a distinct seasonality in precipitation and temperature: a hot and wet summer season (from December to May) and a cooler and drier winter season (from June to November) (Terry and Kostaschuk, 2004). According to the Fiji Meteorological Services (FMS 2009) 2009 was the fifth wettest year over the last two decades; the mean annual rainfall was 359.7 mm above the

Figure 1. Aerial view of Nadi Town during the 2009 floods (source: SOPAC 2009).

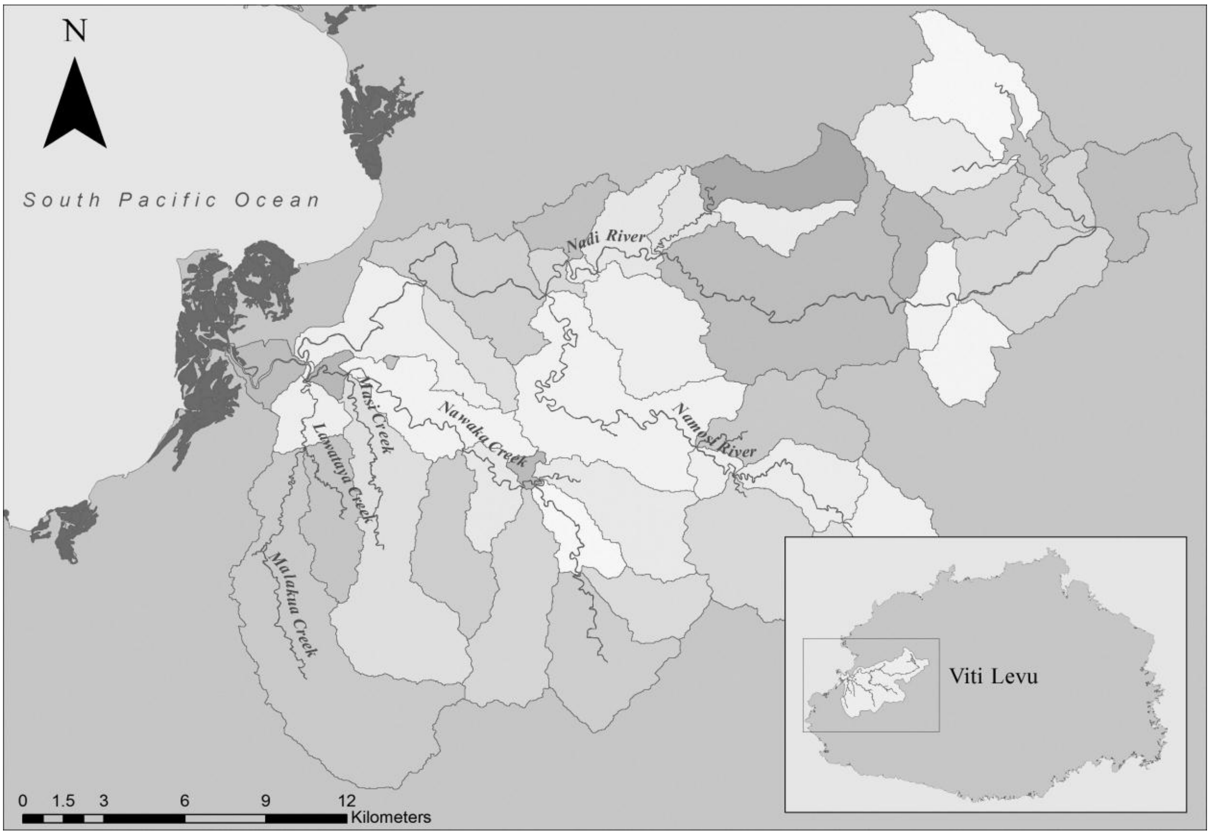


Figure 2. Nadi River basin and its catchments.

1971-2000 long term average (2379.1mm) with significant variation across the country and the wettest January in 52 years (Figure 3).

Nadi is Fiji's third largest urban area with a total population of 42,284 inhabitants, approximately one quarter of which live in Nadi town with the remainder living in the peri-urban area (FIBS, 2007). The Nadi River plays an important part in the lives of the local community. Based on a survey conducted in February 2009, 63% of the households stated that they relied on the Nadi River for various purposes (Holland, 2009). The most common use was fishing, although people also rely on the river for irrigation and for washing during water stoppages. Water quality was reported to have deteriorated significantly during the 2009 flood. Of the households sampled, 70% stated the water in their taps and/or in the river was not safe to drink following the floods, or was extremely dirty. Many health impacts are common either directly from the flooding (injuries) or as a result of the subsequent poor environmental conditions (sickness) (Holland, 2009).

3. Methodology

Figure 4 presents the basic steps followed in this study. The first step was to acquire and evaluate existing GIS datasets to build a database of required inputs for the GIS model and to prepare an efficient survey of the study area. Datasets obtained include satellite imagery, topographical, hydrological, pedological and census data. Based on the evaluation of existing GIS data it was determined that a more accurate digital elevation model (topography) would be needed to generate inputs such as slope and elevation. The second step was to create a more detailed and accurate digital elevation dataset through an extensive field survey covering low-lying areas (under 10 metres AMSL). Over 40,000 elevation data points were taken throughout the study area using Differential GPS (DGPS). An additional 200 points were taken on foot in the villages and near the river bed, 4,000 points were taken on the Nadi River from a boat and 40 points were taken in the centre of the channel and the depth of the channel was measured using a weighted line.

With the required GIS data inputs available and properly prepared, it was possible to carry forward with developing, calibrating, and running the GIS model. The fourth step of the process involved creating the analytical hierarchy process (AHP) matrices and the GIS model. Creating the AHP matrices involved assigning a value of relative importance to each input data layer relative to every other input data layer in the GIS model. Procedural details on creating AHP matrices are available from online tutorials (Teknomo, 2006). Analytical hierarchy process (AHP) values are unique to each environmental setting thus priority vectors (i.e. AHP values) needed to be determined for Nadi Basin. This was done by running the model and calibrating the AHP values to produce output that matched the 2009 flood extents and flood marks (Step 5). The sixth step—an evaluation of results—was done when the flood hazard model was properly calibrated. Results were assessed by analytical means offered by the AHP process, and through field verification. The seventh and final step was to assess populations and buildings at risk to flood hazard by overlaying these data with the flood hazard map within the GIS. Populations and buildings within seven hazard zones, ranging from "very low hazard" to "extreme hazard" were identified and mapped.

3.1 The Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is an analytical technique falling under the general rubric of multi-criteria decision analysis (MCDA) and was developed by Thomas Saaty (Saaty, 1980) in the 1970s. The objective of AHP is to identify the relative importance, or "usefulness", of multiple paired criteria to achieve a stated goal (Carr and Zwick, 2007). This is carried out through a structured comparison of all possible paired combinations of criteria using a cross-tabulation matrix. For each pairing, the modeller selects a value from -9 to +9 reflecting the relative importance of one criterion compared to the other. Values close to 1 indicate that two criteria being compared are "equally important" whereas values close to 9 suggest one criterion is "extremely more important" compared with its pair. Negative values follow the same logic but reflect "less importance" as opposed to "more importance". Numeric values from the matrix are used by an AHP transformation equation to produce a scale of the relative importance of each criterion based on the pair-wise comparison. Thus the outcome of AHP is to produce a standardized interval scale from an ordinal ranking of relative importance while taking into consideration interactions among the criteria.

In our study the major goal of AHP was to identify the relative importance of several spatial inputs in defining the spatial extent of flood hazard in the Nadi River basin, and this required one AHP matrix at the global level. In addition to the overall model, AHP matrices were used to compare the relative importance of criteria within data layers. For example an AHP matrix and runoff charts were used to assign "importance" values to different soil type categories. Table 1 presents the "weighting" values for each data input layer, and the "ranking" values for within-layer categories.

A useful characteristic of AHP is the ability to test for inconsistencies in judgement when paired criteria are compared in the AHP matrix. For example, if criterion A is considered more important than B (A > B), and B more important than C (B > C), then it would be inconsistent to consider C more important than A (C > A). Inconsistencies in the AHP matrix can be calculated mathematically as a consistency ratio (CR) which measures the coherence of the pair

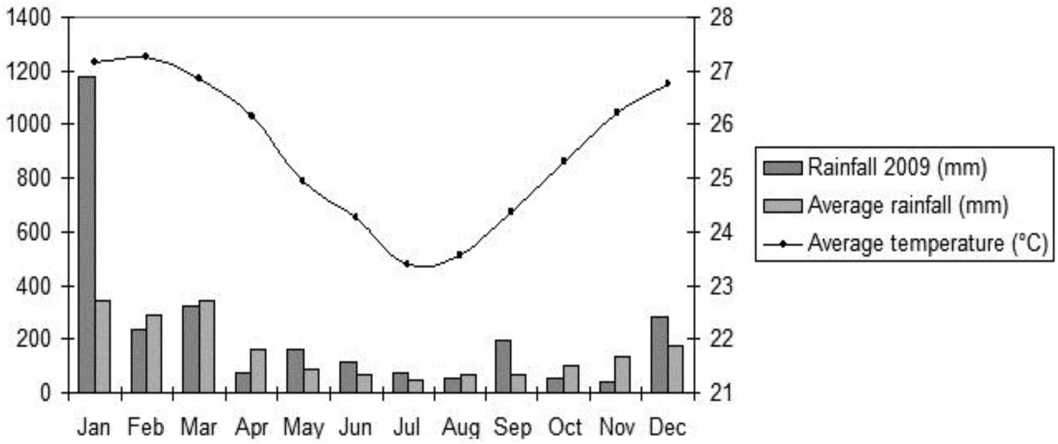


Figure 3. Total monthly rainfall in 2009 compared with typical (average) monthly values of rainfall and temperature at Nadi Airport (source: FMS 2010).

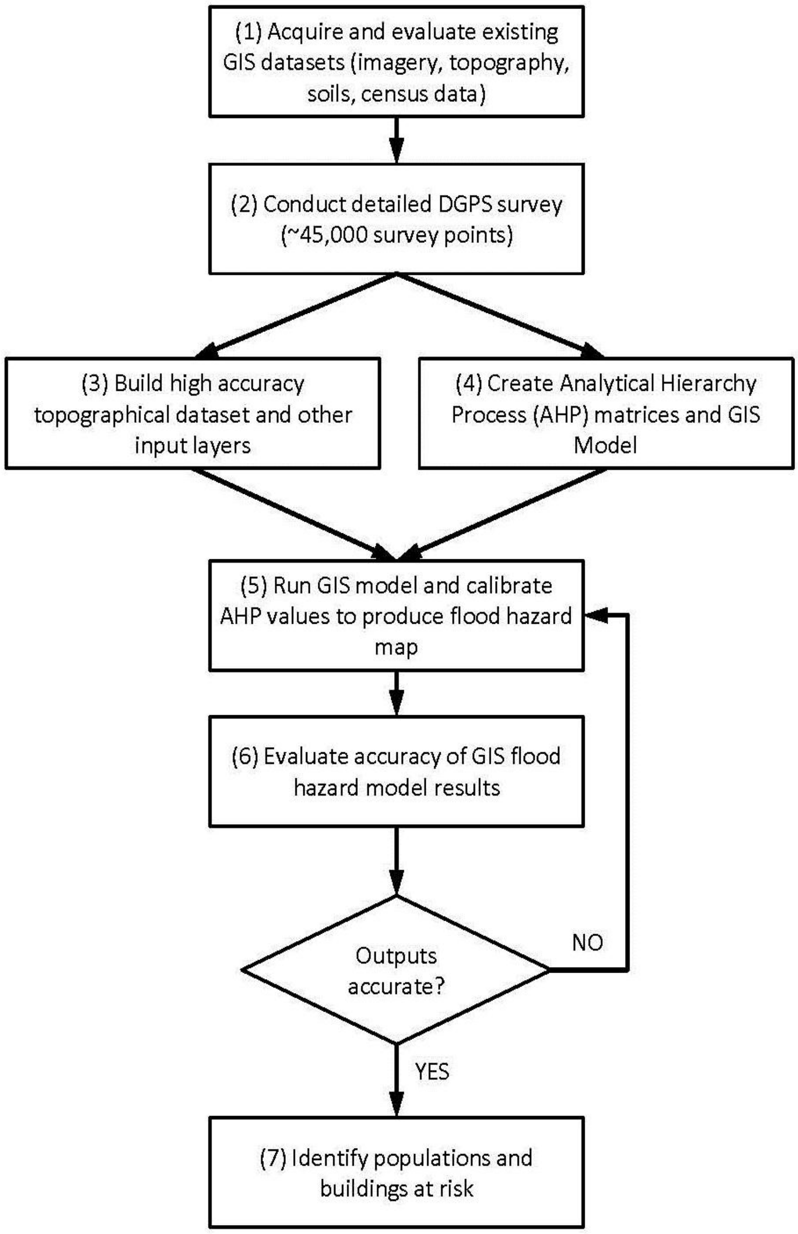


Figure 4. Flowchart of flood hazard study.

Table 1. Assigned weight and rank values for the layer/classes of the study area.

Layers	Weighting	Classification	Ranking
Elevation	0.4810	10 and +	0.2905
		8 to 10	0.2499
		6 to 8	0.1632
		4 to 6	0.1158
		2 to 4	0.0812
		1 to 2	0.0587
		1 and -	0.0408
		Consistency Ratio:	**0.0155**
Catchment	0.2080	Other	0.6667
		Nadi	0.3333
		Consistency Ratio:	**N/A**
Land-use	0.1365	Forest	0.3426
		Mix crops/Open areas	0.2263
		R	0.1532
		Cane	0.1049
		Dense R/Dirt Road	0.0700
		C/I	0.0476
		Roads/Dense C	0.0326
		Wet areas	0.0228
		Consistency Ratio:	**0.0377**
Slopes	0.0839	1 and +	0.8571
		0 to 1	0.1429
		Consistency Ratio:	**N/A**
Distance	0.0543	> 1000	0.4396
		200 to 1000	0.3718
		100 to 200	0.1401
		< 100	0.0485
		Consistency Ratio:	**0.0346**
Soil types	0.0364	Class A	0.6030
		Class B	0.2232
		Class C	0.1116
		Class D	0.0622
		Consistency Ratio:	**0.0124**

(R= residential / C= commercial / I= industrial)

wise comparisons. A consistency ratio of 0.10 or less suggests a reasonable level of consistency, while a consistency ratio above 0.10 suggests unreasonable inconsistency, requiring the modeller to revise judgements of comparison in the AHP matrix (CCI, 2005).

Generating the final flood hazard map was carried out by summing the six input GIS data layers with their respective weights and derived ranks using AHP. Expressed formally, each pixel *i* in the output map (H_i) was calculated using the following summation:

$$H_i = \sum_{j=1}^{n} W_j * X_{ij}$$

where, X_{ij} is the rank value for each category in layer *j*, W_j is the weight of layer *j* and *n* is the number of layers in the model.

3.2 Data Layers

Six GIS data layers were used in the GIS flood hazard model, and two GIS data layers were used to assess the human and infrastructure vulnerability to flood hazard. The six inputs for the flood hazard model were: elevation, catchments, land use (surface imperviousness), slope, distance from channel, and soil type. Each input was used in raster format with a five metre pixel resolution. Human and infrastructure layers were population data from the 2007 Fiji Census and building locations. A brief description of these data layers and their importance is given below.

3.2.1 Elevation layer

Historically, low-lying areas were known to be the worst hit in Nadi and many residents mentioned that these areas were also the first to be inundated. Furthermore, floods are also governed by gravity which pulls the water towards low-lying areas and eventually the ocean. Therefore, elevation was selected as the most important input for the GIS-MCDA model. Seven classes were created from the digital elevation model: < 1 m, 1 to 2 m, 2 to 4 m, 4 to 6 m, 6 to 8 m, 8 to 10 m and > 10m. These classes were selected because flooding in Nadi occurs in areas below 10 metres. This layer has a weight of 48.10% on the total model and has a consistency ratio of 0.0155 (Table 1).

3.2.2 Catchments layer

Logically, to be flooded by the Nadi River, areas need to be part of the Nadi catchments. Consequently, the catchments extent was selected as the second most important input for the flood hazard model. This input was added because early iterations of the model erroneously suggested flooding outside the Nadi catchments. The catchments input layer was generated from the digital elevation model using a special extension (HEC-GeoHMS (USACE, 2010)) within the GIS. Two classes were identified: Nadi catchments and other catchments. This layer has a weight of 20.80% on the total model and has a consistency ratio of 0.0000 since only 2 classes were used.

3.2.3 Land use layer

Because land use is expected to influence runoff and significantly influence flooding, it was considered the third most important input for the model. Land use is an important layer because runoff and overland flow occur where soils in rural areas become saturated, a process that can be exacerbated where agricultural soils are exposed to splash erosion and surface crusting (Bradford *et al.*, 1987); in addition urbanized land uses contain large impervious areas such as roads, sidewalks, parking areas and roofs. Not only do these land uses produce higher discharges but lag times are also reduced (Bell, 1999). Sixteen land use classes were digitised from satellite imagery: commercial, dense commercial, residential, dense residential, industrial, main roads, paved roads, dirt roads, sand, sugarcane, mixed crops, forest, mangrove, marsh, open spaces and water. Afterwards, these were aggregated into 8 more general land use classes based on similar surface runoff characteristics according to the U.S. Department of Agriculture's (USDA) Urban Hydrology for Small Watersheds Report (USDA, 1986). This layer represents 13.65% of total model and has a consistency ratio of 0.0377.

3.2.4 Slope layer

The slope layer was the most difficult factor to evaluate in the AHP because no authoritative documentation could be found proposing a good way to categorize slope angles in relation to flood hazard. Many articles agreed that steeper slopes would be beneficial since they would prevent the accumulation of runoff stored in depressions thus creating ponding (USDA, 1986; Fernández and Lutz, 2010; Ramlal and Baban, 2008). Many iterations of the model were made with different values and a different number of classes. Optimal results were achieved with two classes: areas that are equal to or less than one degree, and areas with more than one degree slope. With these two classes, the results concurred with observations made after the 2009 floods. The degree slope input was derived from the digital elevation model. This layer has a weight of 8.39% on the total model and has a consistency ratio of 0.0000 since only 2 classes were used.

3.2.5 Distance from channel layer

To classify the distance to channel layer into categories influencing flood hazard, we applied the parameters used by Fernández and Lutz (2010) with adjustments. The values were adjusted with data from flood marks provided by SOPAC. Thus, the selected distances were: < 100 m, between 100 and 200 m, between 200 and 1000 m, and > 1000 m. However, in the Fernández and Lutz model "distance from channel" (Fernández and Lutz, 2010) is actually "distance from storm drains" and not distance from "rivers, streams, irrigation drains and storm drains". Because our Nadi model used distance to the river we determined a lower weighting was appropriate. Consequently, this layer has a smaller weight of 5.43% on the total model and has a consistency ratio of 0.0346.

3.2.6 Soil types layer

Pedology and geology have a noticeable influence on drainage capacity. The original soils dataset was reclassified into four USDA soil types based on different drainage capacity (USDA, 1986). Since there was some uncertainty about this reclassification (Fijian soils are different from soils in the U.S.) and on the accuracy of the soil polygons (no metadata was provided in the original file) this layer has the lowest weight. Its weight is 3.64% and it has a consistency ratio of 0.0124.

3.2.7 Building footprint layer

Satellite imagery was used to identify building footprints in the study area. Since many roofs in Nadi are very reflective (most of them are made of tin) a reclassification was made to isolate the roof's spectral signatures. The resultant output was a bi-colour raster file with one colour representing very reflective materials (mostly roofs) and the other colour representing all other objects. This image was then converted to polygon form to refine the accuracy of the classification. The polygon's areas were calculated so that objects smaller than 30 m^2 and larger than 13,795 m^2 could be deleted since they would be either too small or too big to be buildings/rooftops. This eliminated most of the objects that were not roofs such as cars, water and clouds, also having a very reflective signature. Land use values (from the land use layer) were used to attribute each of the polygons. Polygons that were not identified as a residential, commercial, industrial or sugarcane were deleted since buildings are rarely constructed in the other available land uses (ocean, rivers, mangroves, roads, etc.). In all, 6,416 shapes were automatically identified by this procedure. Some buildings needed to be added manually (since they were not identified by the process) and some errors (other objects that were not buildings) needed to be removed. After these additional steps, 778 features were added for a total of 7,194 structures.

3.2.8 Census data layer

Tabular and vector data from the 2007 census was added to the GIS to provide additional information for risk assessment to human population in times of floods. The basic aggregated unit was the enumeration area (EA), a polygon delineated by the Fiji Bureau of Statistics that contains approximately 150 households. Number of individuals, age, sex, education levels, number of households per enumeration area (EA), house condition, house wall type, and building materials were available through the census layer. There were 86 EAs in the study area. Additional data such as average number of people per household, and population density were calculated from the raw census data using the GIS.

4. Results and Analysis

The model produced a flood hazard layer combining all six inputs discussed in the previous section. Six hazard levels, ranging from "very low hazard" to "extreme hazard" identified flood hazard in the greater Nadi Area. According to the model, less than a third of the Nadi area is under severe flood hazard.

Having identified flood hazard areas, the second part of the study was to assess human and property vulnerability and risk to flood hazard. This was done through GIS overlay analysis using the building locations data and data from the 2007 census. Output from the model showing flood hazard zones and at risk populations and buildings are presented for the Nadi CBD area (Figure 5) and the Narewa, Sikituru, and Yavusania villages (Figure 6).

The assessment of properties revealed that 2% of the buildings are in extreme hazard, 10% are in very high hazard, 11% are in high hazard, 23% are in moderate hazard, 40% are in low hazard and 14% are in very low hazard. Even though flood hazard can be high in some areas, this does not necessarily mean these are areas with high risk. Risk is a function of flood hazard and human vulnerability combined (Wisner *et al.* 2004). Individuals living in high hazard areas may be more resilient (or less vulnerable) to the hazard. For example, people with low income, no bank savings and a poorly built housing would be less resilient (or more vulnerable) than people with higher incomes, bank savings and a well-built house.

Overall, the highest flood marks are in the Nadi CBD, but most of the structures there are tall commercial building made of concrete that will survive the floods. Furthermore, people living in Nadi Town have greater incomes (more tertiary diplomas suggest this) and better built houses (better building quality and materials) than the people living in the Narewa, Sikituru and Yavusania villages. Finally, the average number of houses in the upper part of the top 3 hazard levels is higher than in the Nadi CBD (80% vs. 60%).

5. Discussion

In developing countries such as Fiji, it is common for large, important river basins to be found lacking in data and information on past flooding events, and in particular spatial information on flood hazards. Though a somewhat simplistic approach to measure flood hazard in the lower Nadi Basin the MCDA-GIS model described in this study and the accompanying risk assessment make important contributions, in both methods and data, to a better understanding of flooding in the Nadi area. In the discussion below we briefly comment on the contributions and validity of the MCDA-GIS model approach, attempts to validate model results through field recognizance, and limitations of the modelling effort.

5.1 MCDA-GIS Model Using AHP

A key advantage to using AHP for multi-criteria decision analysis is the ability to account for interactions, or multiple comparisons, among the criteria being considered (Carr and Zwick, 2007). Non-pairwise weighting methods, which have been common in GIS modelling over the past couple of decades focus on a sequential process to assign weights and ranks to input criteria (Chang, 2010; Carr and Zwick, 2007). With AHP the process of assigning weights considers multiple pairwise comparisons and measures inconsistencies in those comparisons with the consistency ratio. This assures a logical assignment of criteria weights that is sometimes not considered in non-pairwise methods because a linear relationship between criteria and weights is assumed.

A disadvantage to the MCDA-GIS modelling approach using AHP is that while AHP assures consistency in comparative importance among the criteria, the assignment of ranked importance (e.g. “strongly more important” vs. “very strongly more important”) is still subjectively determined by the modeller and/or the judgement of experts. To investigate error propagation due to criteria weights in a MCDA-GIS model using AHP, Fernández and Lutz (2010) conducted a sensitivity analysis on criteria weights using Monte Carlo simulation. They found that an important source of model uncertainty was caused by variation in the two model inputs with the highest weight value, or measure of relative importance. This is not surprising since the inputs with the highest weights account for the greatest influence on the resulting model because they are deemed relatively more important. What this suggests however, is that the reliability of the raw data for the most important inputs (i.e. those that get assigned the highest weights) is critical for optimal model results. In our case the top two inputs were the elevation layer and the catchment layer, which combined account for nearly 70% of the final value in each output cell in the resulting flood hazard map (see Table 1, weighting for elevation (0.481) + weighting for catchment (0.208) = 0.689). The critical nature of these layers underscores the need for accurate input data, particularly for the most important model inputs, and justifies the care and effort taken early in the project to acquire 40,000+ elevation points with which we created a highly detailed and accurate elevation dataset for the lower Nadi basin.

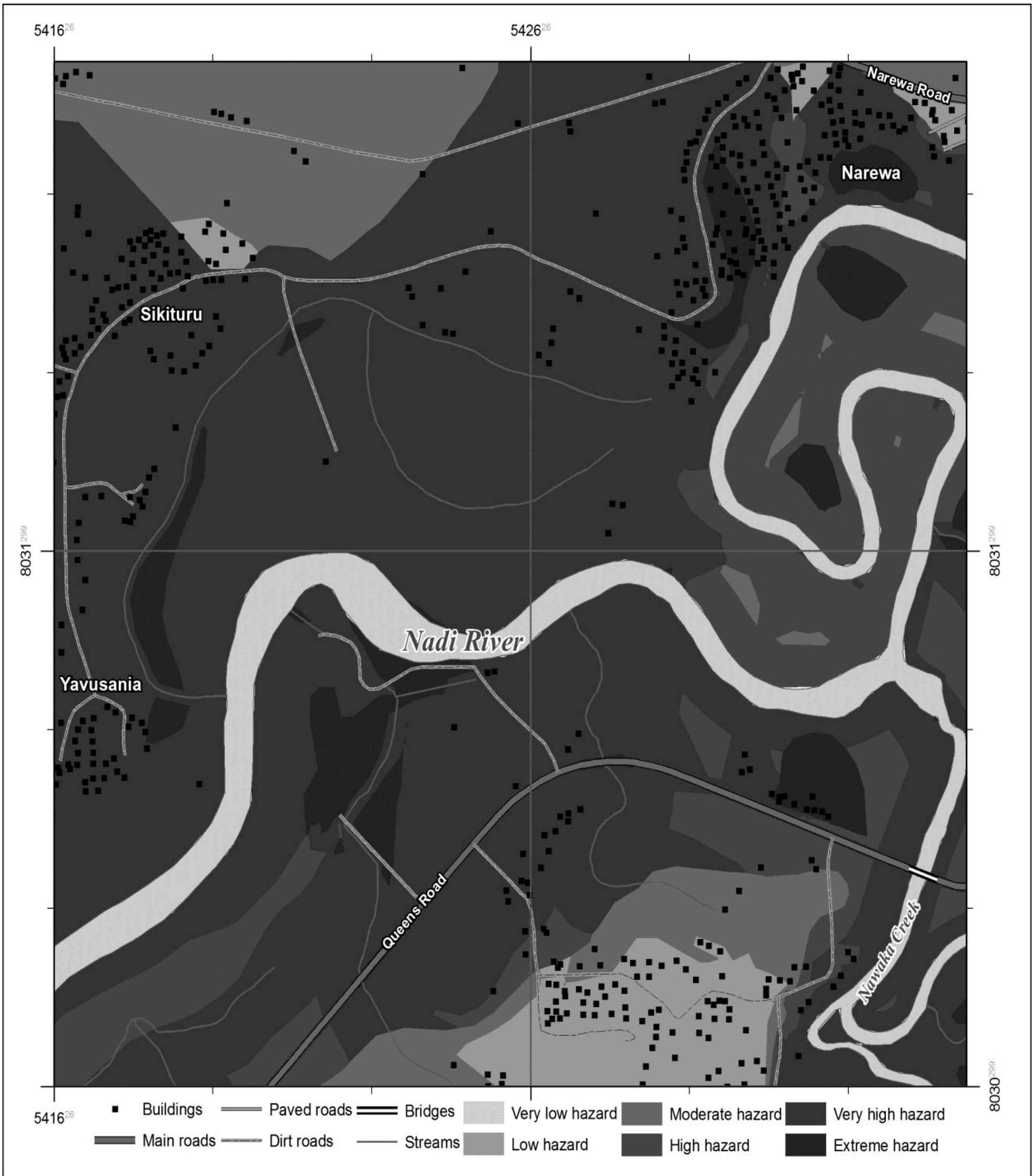
5.2 Model Validation Through Field Observation

Previous flood modelling studies (Duan *et al.*, 2009) have successfully used field observation as an effective means to validate flood hazard model results. To evaluate the validity of our flood hazard model output, several key individuals from the Nadi Town Council, the Nadi Basin Catchment Committee (NBCC) and the local Fiji Disaster Management Council (DIMAC) office, were asked to evaluate and comment on the model results. Local merchants and village chiefs were also consulted to have a more complete perspective. In all, ten interviews were conducted to verify the accuracy of the model. A blank map was presented to the participants and they were asked to identify areas that were flooded in 2009 based on their knowledge. Afterwards, the flood

Census data	
Enumeration areas in the zone	15
Total population (2007)	6,441
Total number of house holds	1,394
Education level	
No formal education / primary diploma	1,343
Secondary / specialist diploma	4,353
Tertiary diploma	745
House condition	
Good condition	812
Average condition	503
Poor condition	79
House wall building materials	
Concrete	816
Tin / iron	418
Wood	153
Bure materials	3
Makeshift materials	3

Satellite data	
Buildings in the zone	1,307
Difference census / satellite	87
Building types	
Dense commercial (dark blue)	247
Commercial (light blue)	93
Dense residential (dark orange)	247
Residential (light orange)	680
Industrial (yellow).	94
# of buildings in each hazard zones	
Extreme vulnerability	92
Very high vulnerability	226
High vulnerability	472
Moderate vulnerability	298
Low vulnerability	161
Very low vulnerability	58

Figure 5. Nadi CBD flood model results.



Census data	
Enumeration areas in the zone	3
Total population (2007)	2,575
Total number of house holds	451
Education level	
No formal education / primary diploma	589
Secondary / specialist diploma	1,835
Tertiary diploma	151
House condition	
Good condition	268
Average condition	150
Poor condition	33
House wall building materials	
Concrete	287
Tin / iron	90
Wood	66
Bure materials	6
Makeshift materials	1

Satellite data	
Buildings in the zone	518
Difference census / satellite	67
Building types	
Dense commercial (dark blue)	0
Commercial (light blue)	0
Dense residential (dark orange)	0
Residential (light orange)	514
Industrial (yellow).	4
# of buildings in each hazard zones	
Extreme vulnerability	40
Very high vulnerability	330
High vulnerability	48
Moderate vulnerability	86
Low vulnerability	14
Very low vulnerability	0

Figure 6. Narewa, Sikituru and Yavusania villages flood.

hazard map created with the model was presented and they were asked to comment and compare the results. Their observations were collated to assess the limitations of the model.

5.3 Model Limitations

For the most part, the flood hazard model results were consistent with the observed spatial extent of flooding based on eye-witness accounts of the 2009 Nadi floods. There were however some areas where flood hazard was overestimated, and others where flood hazard was underestimated. These errors can be accounted for by limitations of the model which are briefly discussed below.

5.3.1 Missing input layers

In Nadi, many poorly designed storm drains pose a serious threat to surrounding buildings. They have a tendency to get clogged with rubbish and debris and cannot properly evacuate runoff thus flooding areas around them. Some of the highest flood marks in 2009 (up to 2.4 metres) were found on houses just a few metres away from these storm drains. Due to the scale of analysis the Nadi MCDA-GIS model did not model the location of storm drains in the study area. Improvements to the model might include an input of distance to storm drains.

5.3.2 Accurate input layers

It was impossible to survey the entire study area with the DGPS. The topographic model created for the elevation layer is very complex but could not identify some of the micro topography features in the study area. Consequently, some depressions and low areas were not identified and therefore could not be correctly evaluated by the model. LiDAR data would have not missed these features, but LiDAR data was not available during the development of the model. When available, LiDAR data should be incorporated in the topographic model to remedy this problem.

5.3.3 Limitations of a static modelling technique

The model did not measure channel flow or stream order. As a result, hazards presented by small streams in the model are exaggerated and hazards from bigger streams are underestimated. For example, Nadi-Malakua confluence is a critical point since these large rivers meet in an area were the Nadi River goes through a tight set of meanders slowing the water flow. This is very hard to model with the MCDA-GIS technique since the complex physical dynamics regulating channel flow could not be integrated. However stream order can be calculated and could be added to enhance the accuracy of the model.

6. Conclusion

The model presented in this study presents a valuable first-stage analysis of flood hazard in the lower part of the Nadi River basin and presents an opportunity to further assess the flood risk to human populations and properties in the Nadi town area. Prior to this study, little spatial data existed for this area of Fiji. The digital elevation model generated by this study provides the most accurate detailed GIS elevation dataset for this urban area currently available. The combination of the analytic hierarchy process (AHP) with GIS proved to be an effective method to deal with the question of relative importance of different inputs in a structured manner. Improvements could be made by including inputs that were not available at the time of the study. Furthermore, based on eye-witness accounts, the hazard map generated by the model is consistent with observed 2009 flood extents in the Nadi area. The knowledge and data gained from this study will be useful to city planners and disaster management authorities concerned with flooding in the Nadi lower river basin.

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