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Modelling Coastal Flood Hazard Using ArcGIS Spatial Analysis tools and Satellite Image

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Abstract: ***The objectives of the study are flood hazard mapping and infrastructure and settlement/population vulnerability assessment in a low laying coastal flood prone area of Lae coast for different flood magnitudes. Different variables like coastlines data, High resolution LiDAR satellite image (20cm) and Digital Elevation Model (1 m resolution), historic tidal gauge sea levels, future projections of global mean sea level rise, Infrastructure elements and demographic information along the Lea coastal track are used to modelled and develop the coastal flood hazard data base. Maximum of hourly peak sea level is 1.96 m in Lae coast according to historic tidal gauge sea levels. Frequency analysis is carried out to estimate extreme sea levels for coastal flood hazard mapping for the basis of specified flood frequencies or return periods. of 3 m and 4.5 m is considered (1:50 and 1:100 years). Hazards maps are developed to determine the water level and inundated area for 50-years (3 m) and 100-year (4.5 m) return periods flood. Vulnerability functions of risk elements and flood hazard maps are analyzed in ArcGIS environment to develop maps for vulnerable area, population and infrastructural elements. The result shows that an area of 38.19 sq km area is under the risk of inundation in the middle of this century (50 years return period) and 48.08 sq km in the end of this century (100 years return period). A majority of urban populations in the region live in coastal areas, inundation would also likely cause large costs for infrastructure relocation. These hazard maps can be developed for any other coastal areas of Papua New Guinea to manage coastal hazards in the context of regional and local knowledge, using data gathered by site-specific tide-gauges and other relevant technology.***

Keywords: Remote Sensing; GIS, Frequency analysis, Inundation, Risk element, Return period

1. Introduction

A natural disaster is a major adverse event resulting from natural processes of the Earth; examples include floods, volcanic eruptions, earthquakes, tsunamis, and other geologic processes. A natural disaster can cause loss of life or property damage, and typically leaves some economic damage in its wake, the severity of which depends on the affected population's resilience, or ability to recover (Bangkoff et al., 2004). An adverse event will not rise to the level of a disaster if it occurs in an area without vulnerable population (Alexander 2002).

Hydrological Disaster (Flood) is a powerful, sudden and destructive change either in quality of earth's water or in distribution or movement of water on land below the surface. A flood is an overflow of an expanse of water that submerges land. In the sense of "flowing water", the word may also be applied to the inflow of the tide. Flooding may result from the volume of water within a body of water, such as a river or lake, which overflows or breaks levees, with the result that some of the water escapes its usual boundaries. While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, it is not a significant flood unless the water covers land used by man like a village, city or other inhabited area, roads, expanses of farmland, etc. Papau New Guinea lies on the lies on the Pacific Rim of Fire and experiences the geotectonic movements quite often. The graphic illustration below shows the movement of the plates. East and West Sepik, Southern Highlands, Oro and Milne Bay Provinces are prone to Earthquake. Landslides in Papua New Guinea are generally associated with large shallow earthquakes and rainfall. Many landslides occur during the wet season as the rainwater infiltrate the soil and weaken the restraining properties of the soil or rock causing it to move. Landslides denude the soil and vegetation from steep slopes, destroy food gardens, bury people, dam rivers and destroy infrastructure. Landslide dams can be damaging from back flooding or flooding downstream when breached. In PNG the Government only investigates and reports the landslides that have caused damage to infrastructures, mine sites and loss of life. In Papua New Guinea there are three different types of floods, flash floods, rapid onset floods and slow onset floods. Flash floods occur with a few hours of torrential rain with little or no warning and dissipate rapidly. This type of flood is most common in most parts of Papua New Guinea. Rapid Onset Floods occur with several hours of heavy rainfall which can last for several days and are very much specific to medium sized river catchments. Slow Onset Floods occur gradually over a fairly long period of time and are only characteristic of large river systems such as Sepik and Fly Rivers.

Coastal flood is another type of flood which mainly occurs when storm surges, waves and/or extremely high tidal waves inundate low-laying coastal areas. Floods can have both positive and negative impacts. They can bring welcome relief for people and ecosystems suffering from prolonged drought, but also are estimated to be the most costly natural disaster in Papua New Guinea. Every year in Papau New Guinea, floods cause millions of kina damage to buildings and critical infrastructure, such as roads and bridges as well as to agricultural land and crops. They also disrupt business aand can affect health and school of communities (Table 1 and Figure 1).

Table 1: Disasters that have occurred between 1980 -and 2010

No of events:	55
No of people killed:	3,456
Average killed per year:	111
No of people affected:	1,346,645
Average affected per year:	43,440
Economic Damage (US$ X 1,000):	178,253
Economic Damage per year (US$ X 1,000):	5,750

Source: EM-DAT, 2010

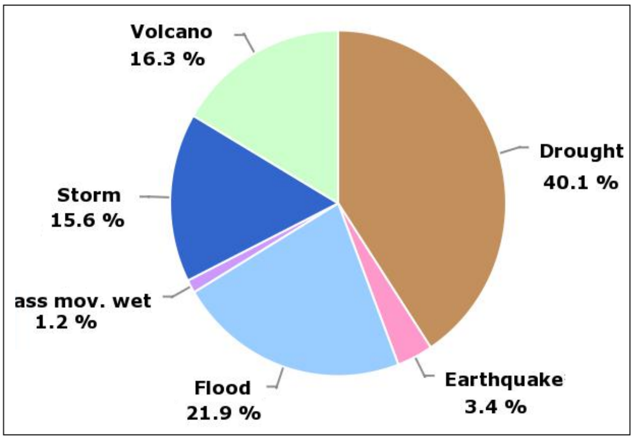

Figure 1: Percentage of people affected by disaster type as reported between 1980 and 2010

2. Literature and Problem Statement

Morobe is prone to numerous natural hazards such as earthquakes, volcanic eruptions, tsunamis, drought, frost, floods, tropical cyclones, landslides, the impact of climate change including climate variability and sea level rise. Flooding is common on low-lying flood plains. Inundation occurs due to prolonged rainfall during the wet season often causes severe impacts to low lying areas, crops, road crossings, culverts, bridges and urban drainage infrastructure. Country has experienced about 15 inland flood events from 1990 to 2009 and almost in all principal rivers in Papua New Guinea, namely Fly, the Sepik, the Markham, the Purari and the Kikori river. Some of the notable events occurred in year 1992,1993, 1998, 1999, 2003, 2004, 2005, 2006, and 2007.

Flooding in the coastal areas is one of the most important climate change related hazards in the North Coast and the Islands Region as settlements are usually located in the coasts. There are a scattering of islands off shore, and coastal ranges dominate the landscape just inland of the coast. Coral reefs protect much of the province’s coastline, and the wave environment is in general a low energy one. Late December through January are the months for spring or “king” tides, which is one of the causes of coastal flooding in PNG.

Historically notable coastal flood event due to king tides is December 2008 leading to flooding in the study area. King tides, stronger wave actions and sea level rise resulting in expansion of inundation in the coastal areas of study area.

Over the past several decades, the Pacific region as a whole has experienced increases in annual mean temperature, in variability of rainfall pattern, and in intensity of rainfall events. Tropical cyclones hit PNG at the rate of about one cyclone per year. Weather extremes induced by climate change could exacerbate flooding intensity and frequency in flood prone inland and coastal regions in the future. Climate change is also likely to exacerbate the risk of coastal hazards by sea level rise to magnify the impact of storm surges and waves on coastal areas. During the 20th century, the average mean relative sea level around the Pacific region had increased at the rate of 0.77 mm annually, although the rate of rise had been variable across locations due to local meteorological-oceanographic factors and vertical land movement. By the end of 21st century, sea level is projected to more than double in all Pacific small island countries with a similar distribution of changes among countries.

Many GCMs project estimates of over 1 m for most Pacific countries including Papua New Guinea by the end of 21st century. Given that the most important effect of sea level rise is to increase the inundation of coastal areas, an area of about 15,000 square kilometers (3.45% of the total land area) could possibly be inundated. Global average sea level in 2012 was 1.4 inches (35.56 mm) above the 1993-2010 average (Merrifield, 2012), which was the highest yearly average in the satellite record (1993-present). On a yearly basis, differences in sea level from place to place are largely due to shifts in the position or strength of major currents or else due to natural climate patterns that cause regional cooling or warming.

The sea-level rise near Papua New Guinea measured by satellite altimeters since 1993 is about 7 mm per year, and above 8 mm per year near Solomon Islands (PCCSP).

In areas near PNG, sea level has reportedly increased by as much as 30 mm per year, with the highest rate of increase observed during **El Niño** and the **Southern Oscillation** (ENSO) events.

Remote sensing and geographic information systems (GIS) proven their usefulness in disaster management. Remote sensing and GIS provides a database from which the historical disasters that have occurred before can be interpreted, and combined with other information to derive hazard maps, indicating which areas are potentially vulnerable. In the disaster rehabilitation phase GIS is used to organise the damage information and the post -disaster census information, and in the evaluation of sites for reconstruction. Remote sensing is used to map the new situation and update the databases used for the reconstruction of an area, and can help to prevent that such a disaster occurs again.

This study has been envisaged with a view to determine coastal hazard and the vulnerability of the coastal assets along the Lae coastal tract using remote sensing and GIS approach. This research provides information at local level that could be used by planner. As a majority of urban populations in the region live in coastal areas, inundation would also likely cause large costs for infrastructure relocation.

3. Study Methodology

The need to study the coastal processes is due to its involvement of the release of the energy carried in the wave which then performs work, in terms of the erosion of cliffs, and the movement or transport of beach material. Therefore it is important to know if any of the three breakers exist in the coastline. The following data are obtained by the sources mentioned in the table above and are used in the calculations, namely deep sea wave period, deep sea wave height, density of salt water and beach slope. Levelling is performed along two locations in the coastline Aigris Market and Vocopoint to get the slope for breaker type calculations. Breaker type is calculated using the following equation-

$$\textit{Breaker type} = m / (Ho / Lo)^{1/2}$$

Where- m is the beach slope, Ho is the deep sea wave height (0.97 m), Lo is the deep sea wave length (74.49 m)

According to above equation output value, the breaker type can be classified as follow-

spilling breaker = < 0.5, plunging breaker = 0.5 – 3.3 and surging breaker = > 3.3.

Coastal flood hazard maps are important tools for understanding the hazard situation, planning development activities in an area and can be used as supplementary decision making tools. Flood hazard maps are characterized by type of flooding, depth, velocity and extent of water flow, and direction of flooding. Flood hazard maps can be prepared based on specified flood frequencies or return periods, for example 1:50 and 1:100 years. These Scenario (1:50 years) explains linear combination of extreme sea level and projected global mean sea level rise for the middle and end of this century.

Different data sets are used to generate coastal flood hazard maps and to identify Vulnerable Major Infrastructure for the basis of specified flood frequencies or return periods (1:50 and 1:100 years). They are i. Coastlines data for study area (Lae coast of Morobe province), ii. High resolution LiDAR satellite image (20cm) and Digital Elevation Model (1 m resolution) data, iv. Topography data (30m SRTM data), v. Historic tidal gauge sea levels recorded on hourly/daily basis from 1984 to 1998 (NTF, 2000), vi. Future projections of global mean sea level rise for middle and end of 21st century vii. Infrastructure elements of along the lea coastal track (PNGRIS, 2008), and demographic information of the study area (Geobook, 2009).

Table 2: Estimated extreme sea levels for middle and end of 21st century

Vintage of Sea Level	Maximum of Hourly Peak sea level (m)	return periods flood mapping (depth in m)	
		50 years	100 years
1984 - 1998 (14 years)	1.96	3.00	4.5

Maximum of hourly peak sea level is 1.96 m in Lae coast after analyzing above available data for coastal flood hazard analysis. Estimated extreme sea levels of 3 m and 4.5 m (Table 2) is considered for (OCCD, 2014) coastal flood mapping for the basis of specified flood frequencies or return periods (1:50 and 1:100 years). Vulnerability functions of risk elements and flood hazard maps are analyzed in ArcGIS 10 environment to develop maps for vulnerable area, population and infrastructural elements (Figure 2). Few approaches are followed to develop hazard maps for the study area are as following.

I. Identification, acquisition, compilation and review of tidal amplitude information available at Lae tidal station.
II. Based on high tidal amplitudes for a particular coastal stretch, identify the particular timeframe when the maximum tide occurs.
III. Integration of maximum extreme sea levels (Tidal amplitude+ peak sea wave+ projected global mean sea level rise) with coastal onshore topography data to demarcate the inland extent of inundation using GIS techniques.
IV. Future projections of global mean sea level rise for two time slices (middle and at the end of 21st century) for the study area
V. Finally spatial analysis tools of ArcGIS v-10 are used to calculate inundated area, villages, total population affected, numbers and type of infrastructure affected in two different return period, 1:50 years and 1:100 Years.

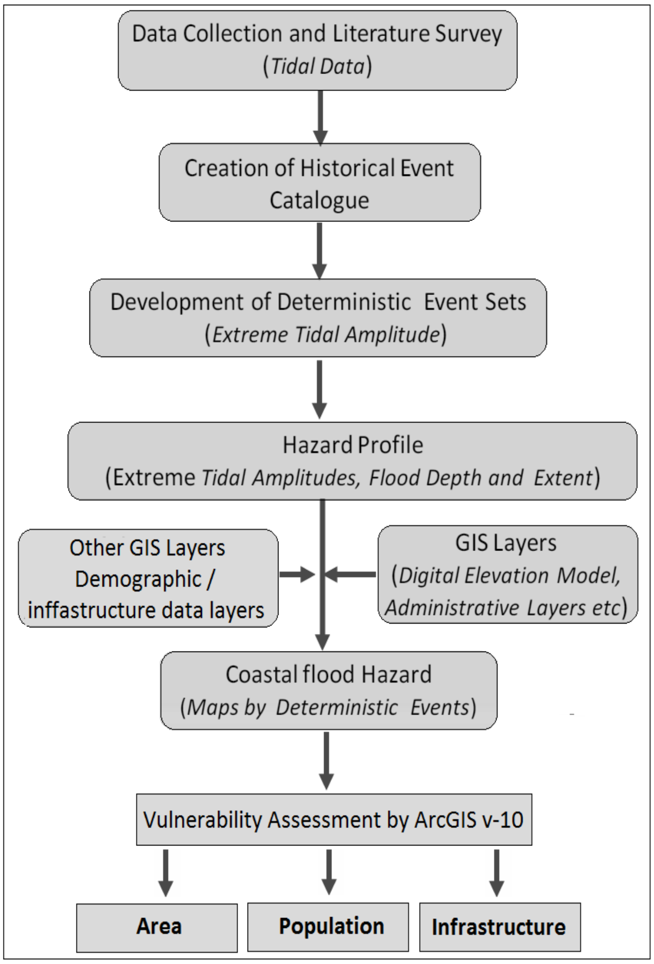

Figure 2: Methodological flow chat for coastal flood Hazard

4. Results and Discussion

Two sections along Lae coast Voco point /Lae Yatch Club and Aigris Market were studied where slope of the beach was calculated. Slope calculated =1.353 m for vocopint, which was less than 3.3 therefore recording as a Surging breaker. Slope calculated= 0.776 for Aigris Market which was found to be between 0.5 and 3.3 therefore recording as a plunging breaker (Figure 3). In addition to that plunging breaker found at Aigris market beach has a low slope, low energy causing less damage to the beach front, but less energy to distribute sediments. Satellite image shows sediment filled beach front while beach front at vocopoint has lesser sediment distribution. This is due to a higher slope calculated, thus showing the presence of surging breaker with high energy that is damaging to the shores and good in sediment distribution.

The output of coastal hazard model shows an area of 38.19 sq km area is under the risk of inundation in the middle of this century (50 years return period) and 48.08 sq km in the end of this century (100 years return period). A total population of 13278 of 26 villages are demarked as vulnerable along the Lae coastal tract. In spatial reference to Lababutu village which is located (Left side of Markhan River mouth) 4 km away from the Lae city along the coast is in a vulnerable condition, could totally washed away with by the effect of a extreme king tide (Table 3 & Figure 4).

Table 3: Vulnerable condition of Lababutu village for estimated flood depth

Location X: 495695.91Meters (146.960701) Y: 9254037.47 Meters (-6.752271)	Return periods flood mapping 50 years
Households	251
Population	1276 (2008)
Primary school	1 (Labu Butu Elementary)

Figure 3: Coastal effect at Aigris market and Vocopoint

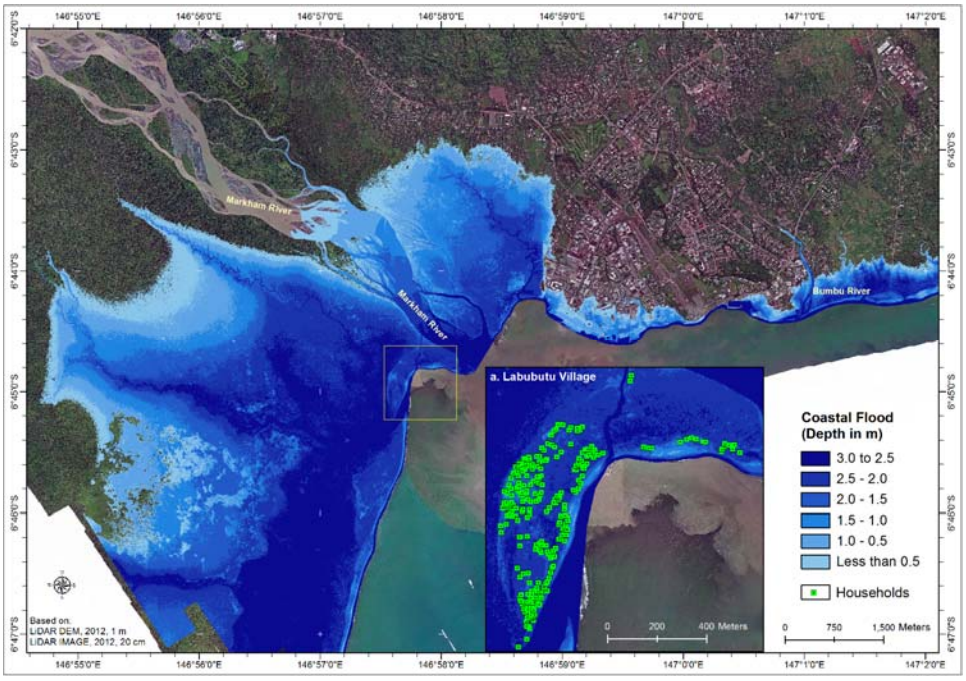

Figure 4: Projected coastal flood in 1:50 year return period overlayed on LiDAR image

Numbers of existing infrastructures along the coast, like three (3) community primary schools, one (health centre), 17.29 km of road also under the thread of coastal flood hazard as derived from 1:50 years return period (Table 4 &

Figure 5). On top of it two (2) bridges and another 10 km road (total 27.05 km) are under vulnerable condition according to 1:100 years return period hazard map (Table 4 & Figure 6). A majority of rural and urban populations in the region live in coastal areas. A total population of 10407 of 18 villages (1:50 years) and 13278 of 26 (1:100 years) villages are demarked as vulnerable along the Lae coastal tract (Table 5).

Table 4: Vulnerable Area and Infrastructural Elements for estimated flood depth

Sl. No.	Vulnerable Major Infrastructure	1:50 Years		1:100 Years	
		Area	Number/Length	Area	Number/Length
1	Community Primary School	38.19 Sq km	3	48.08 Sq km	3
2	Higher Secondary School		0		0
3	Vocational School		0		0
4	University		0		0
5	Health Centre		1		1
6	Aid Post		0		0
7	Airstrip		0		0
8	Bridge		0		2
9	Major Road (Length)		17.29 km		27.05 km

Table 5. Vulnerable Villages and population for estimated flood depth in different return periods

Sl. No.	CU Name	CU Number	Ward Name	Total Population (2008)	
				1:50 Years	1:100 Years
1	Ibis Street	001	LAE CITY	-	247
2	Seagull Street	002	LAE CITY	38	38
3	Labubutu	009	LABUBUTU	1276	1276
4	Labumiti	010	LABUMITI	817	817
5	Fleetbank Street	019	LAE CITY	158	158
6	Simbang Street	020	LAE CITY	-	457
7	Sp Brewery Street	023	LAE CITY	237	237
8	Spreybank Street	024	LAE CITY	436	436
9	Macdhui Street	026	LAE CITY	-	120
10	Sumiho Street	065	LAE CITY	1153	1153
11	Sletfjord Street	072	LAE CITY	139	139
12	Lae Main Wharf	080	LAE CITY	119	119
13	Mumbu Street	086	LAE CITY	-	297
14	Vitias Street	087	LAE CITY	-	591
15	Unkai Street	091	LAE CITY	-	584
16	Papuan Compound	200	LAE CITY	960	960
17	Biwat/Kabriman/Keker	201	LAE CITY	1653	1653
18	Tufi Settlement	206	LAE CITY	992	992
19	Popondetta Settlement	652	LAE CITY	1269	1269
20	Bumbu Settlement 1	653	LAE CITY	217	217
21	Bumbu Settlement	660	LAE CITY	-	134
22	Bumbu Settlement (Drumwara)	661	LAE CITY	-	441
23	Bumbu Settlement (Sepik)	663	LAE CITY	479	479
24	Korogu Settlement	664	LAE CITY	111	111
25	Bumbu Settlement 2	665	LAE CITY	218	218
26	Bumbu Settlement 3	666	LAE CITY	135	135
	Total			10407	13278

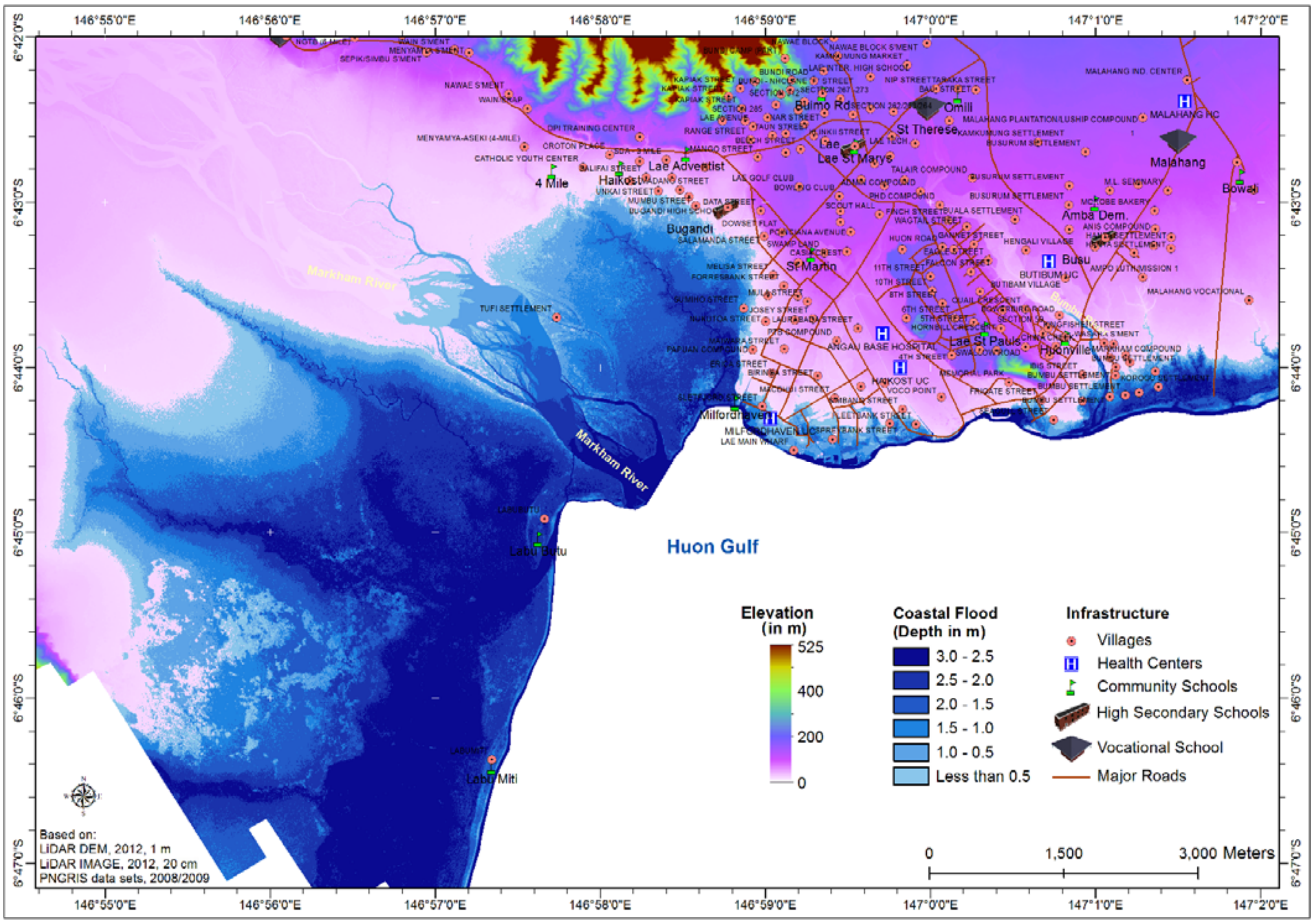

Figure 5: Vulnerable infrastructure and projected coastal flood in 1:50 year return period

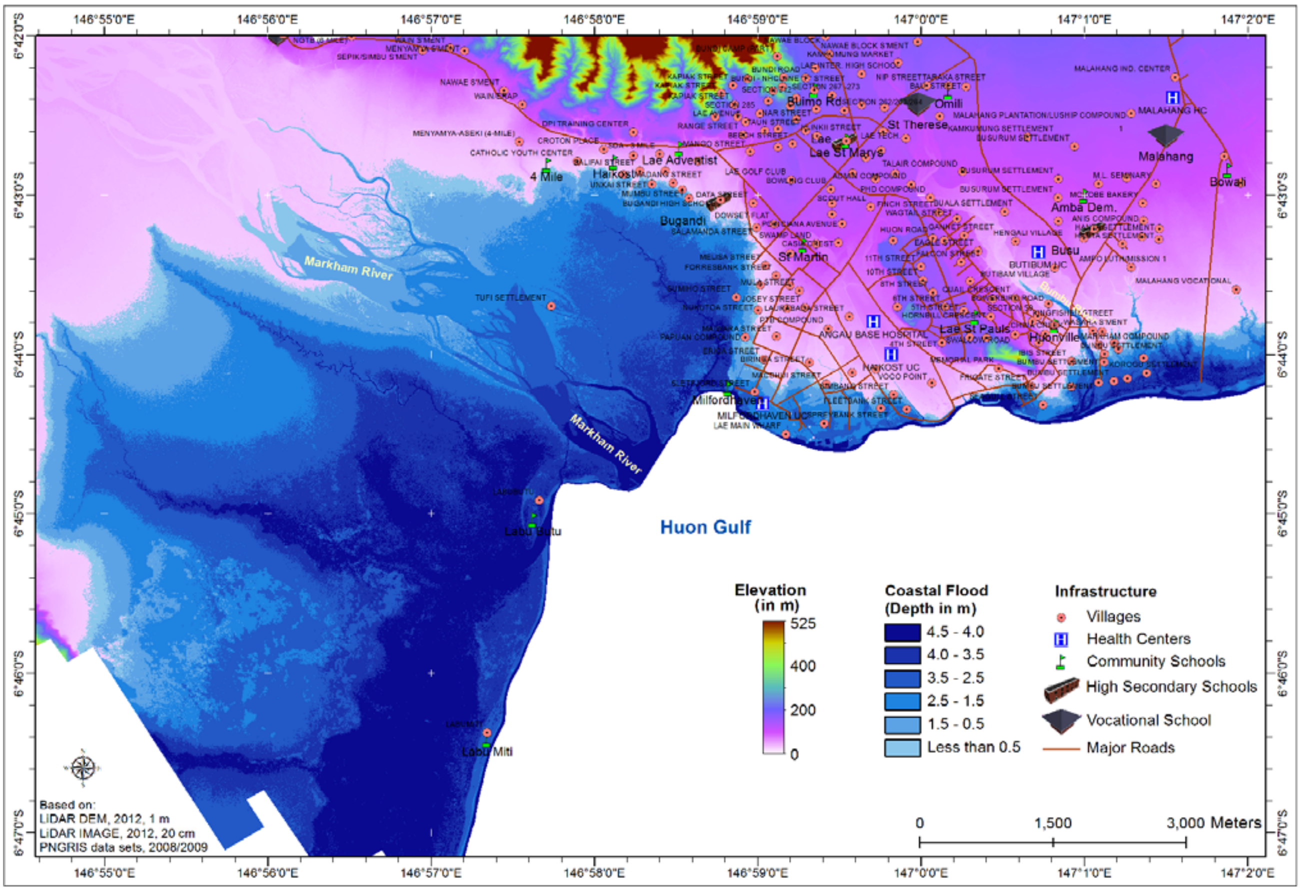

Figure 6: Vulnerable infrastructure and projected coastal flood in 1:100 year return period

5. Conclusion

Local sea level rise could lead to a decline in the availability of water supply, increase in coastal erosion, and contribute to the loss of productive agricultural lands. As a majority of urban populations in the region live in coastal areas, inundation would also likely cause large costs for infrastructure relocation. Most coastal hazards are intrinsically local in nature as the regular and repetitive local processes of wind, waves, tides and sediment supply that fashion the location and shape of the shorelines, other than the periodic tsunami and exceptional storms. Therefore, coastal hazards in the study area shall need to be managed in the context of regional and local knowledge, using data gathered by site-specific tide-gauges and other relevant technology. Shorelines naturally move around over time in response to changing environmental conditions. Many planning regulations already recognize this, for example by applying minimum building setback distances or heights from the tide mark. In addition, engineering solutions (groynes, breakwaters, sea-defence walls) may be used to stabilize a shoreline, if required.

6. Recommendations for future studies

Indeed, the present work makes an initial attempt for disaster mapping, particularly flood hazard modeling over a coastal tract, but it also evokes lot of scopes for further studies. Some of the ideas are presented here. Of course there is every scope for further improvements in land use/ land cover characterization as well as using coastal topography and bathymetric data built from higher resolution satellite data for entire coastal tract of Papua New Guinea. Emphasis might be placed in constructing the model selection for different independent variables. Variables such as ‘run off and soil loss’, ‘coastal land use’, 'El-nino', prevailing global and local wind patterns etc might be considered for further improvements.

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