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Prediction of Seawater Flooding Hazard on Settlement Areas in Padang City as a Climate Change Impact using GIS and Remote Sensing Technology

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Abstract. Recently, climate change is becoming the most popular issue in the 20th century. One impact of climate changes is seawater flooding. It occurs in a lowland of coastal area. One of coastal cities that will have impact of sea level rise is Padang City. This is because part of Padang's morphology is a lowland and constrained by the sea. This research aims to analyse and to predict hazard potential of seawater flooding, especially on settlement areas. Statistic model used was GIS and Remote Sensing. DEM classification, representing altitude of Padang City, was used to predict sea level rise. Land change modeler is used to predict settlement areas development, and to calculate impact of flooding on settlement areas. The result showed that there is a sea level rise of 2.8 m, causing seawater flooding in 2500. It also predicts that settlement will cover area of 22,522 ha in 2500. The settlement area impacted by seawater flooding was 1,322 ha. A subdistrict had the highest risk of being drown was Koto Tengah with affected area of 1,026 ha, while the lowest one was Lubuk Begalung with affected area of 6 ha.

Keywords : climate change, flooding, settlement area, GIS and Remote Sensing.

1. Introduction

Climate change is becoming the most popular issue of the 20th century and various conferences in the world are held to discuss climate change, ranging from cause, prevent and impact from climate changes. Increase in fossil fuel burning and land use change have emitted, and continued emitting, increasing pollution of greenhouse gases into the earth's atmosphere. These greenhouse gases include carbon dioxide (CO₂), methane (CH₄), and nitrogen dioxide (N₂O), and rise in these gas concentrations caused a rise in the amount of the heat from the sun withheld in the Earth's atmosphere, heat that would normally be radiated back into space. This increase in heat has led to the greenhouse effect, resulting in climate change. Warming of the climate change system is now unequivocal. It is now clear that global warming is mostly due to man-made emissions of greenhouses gases (mostly CO₂). Over the last century, atmospheric concentrations of carbon dioxide increased from a pre-industrial value of 278 to 379 parts per million (ppm) in 2005, and average global temperature rose by 0.74 °C [1]. At the 21st Century, it shows that the global warming will continue and accelerate. The best estimates indicate that the earth could warm by 3° C by 3100. One of climate change impact is seawater flooding, this can occur in the low altitude of coastal area [2].

Seawater flooding causes hazard to coastal region, because the sea level rise can influence social and demographic in the corresponding area. Seawater flooding in the coastal area can make many problems for activities, especially for cities in coastal zone [3]. Recently, the very large cities in this world are



located in the coastal zone, for example Jakarta in Indonesia, Chongking in China, and many more. Tens million of people in low altitude coastal areas of South and Southeast Asia can be affected by sea level rise [4]. Indonesia has big cities which are mostly located in the coastal area. One of them is the city of Padang, the capital of West Sumatra Province. Padang City has 11 sub-districts namely Padang Utara Subdistrict, Padang Barat Subdistrict, Padang Timur Subdistrict, Padang Selatan Subdistrict, Nanggalo Subdistrict, Kuranji Subdistrict, Pauh Subdistrict, Bungus Teluk Kabung Subdistrict, Koto Tangah Subdistrict, Lubuk Kilangan Subdistrict, and Lubuk Begalung Subdistrict. BPS Padang city stated that The Padang city has a population around 914,968 people in 2016 and is expected to continue increasing every year. The accelerated increase in the sea level will put 6 vulnerable districts along coastline of Padang city in high risk.

2. Method

2.1. Case Study

Case study in this research is Padang City, the capital of Province West Sumatera. $100^{\circ}05'05''$ E - $100^{\circ}34'09''$ E and $00^{\circ}44'00''$ S - $01^{\circ}08'35''$ S. Padang City is a coastal region in Indonesia. This region serves as a center of human activity in the West Sumatera, because Padang is a capital of Province. It has 11 subdistrict, they are Koto Tangah, Lubuk Kilangan, Padang Barat, Padang Timur, Padang Selatan, Bungus Teluk Kabung, Pauh, Kuranji, Nanggalo, Padang Utara and Lubuk Begalung. There was an increase in demand of land for human settlement that caused land use change [5].

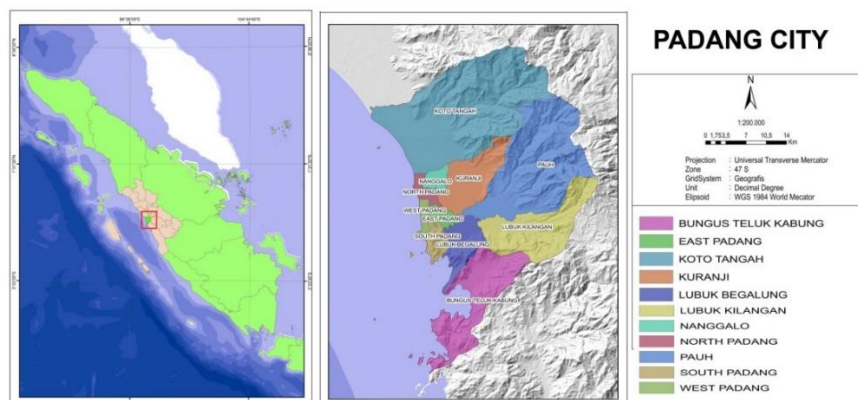


Figure 1. Case study, Padang City, West Sumatera Province, Indonesia

2.2. Material

Spatial data used in this research are taken from various website and governmental sources. Detail of data are listed in table 1.

Table 1. Data for Analysis

Data	Sources	Path and Row
SRTM	USGS EarthExplorer	Path 127 Row 61
Landsat TM5 , 1989	USGS EarthExplorer	Path 127 Row 61
Landsat TM 5, 2001	USGS EarthExplorer	Path 127 Row 61
Landsat OLI 8, 2015	USGS EarthExplorer	Path 127 Row 61
Driving Factor Location	Survey	
Topography	InaGeoportalIndonesia BIG Geospatial Agency	
SPOT 6	LAPAN	
Settlement Sampel Location	Survey	
Administration map	BAPPEDA Padang City	

2.3. Data Analysis

In this research we have three data analysis processes to predict seawater flooding hazard on settlement areas in Padang City as impact of climate changes, such as; increase seawater, land change modeler and seawater flooding on settlement areas. In this research, we predict seawater flooding on settlement areas in Padang City in 2500. We use projection to predict seawater flooding by applying increase value per year as suggested by Intergovernmental Panel on Climate Change (IPCC) [6]. We obtained a high increase in seawater flooding by analysing morphology of Padang City, and to predict settlement areas in Padang City by using Geographical Information System (GIS) and Remote Sensing Technology with Land Change Modeler.

2.3.1. Sea level rise

Sea level rise was predicted using mathematical method and assumption, and digital elevation model (DEM) to get information of altitude and morphology of Padang City. Seawater flooding caused sea level rise. Prediction analysis of sea level rise was carried out by using SRTM imagery to know increase as impact of climate change [7]. The altitude is a basic process as analogic to make spatial data of flooding area. Sea level rise was approximately 0.57 cm/year according to Intergovernment Panel on Climate Change (IPCC). To calculate sea level rise, we used formulae as stated below [8]:

$$Icst = 0,57 \times t \quad (1)$$

where $Icst$ is sea level rise prediction, t is time. The result are calculation of sea level rise and hazard area of seawater flooding predictions. Geography Information System (GIS) was applied to process digital elevation data in order to extract flooding area by altitude. The flooding area was classified as altitude in number of ranges of seawater flooding.

2.3.2. Land Change Modeler

Urban development resembles behaviour of a cellular automaton in many aspects. The space of an urban area can be regarded as a combination of a number of cells, each cell taking a finite set of possible states representing the extent of its urban development. The state of each cell evolves in discrete time steps according to some local rules [9]. All landscape spatial transition models can be expressed in a simple matrix as in equation (2).

$$LU_{t+1} = LU_t \times P \quad (2)$$

with LU_t is the distribution of land uses among the different types at the beginning of the period and LU_{t+1} is showing the distribution of land use types at the end of the projection period, in other words LU_t and LU_{t+1} are vectors composed of the fractions of each landscape type at time t and time $t + 1$, respectively, equation (3) illustrates the P matrix.

$$P = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{bmatrix} \quad (3)$$

A transition areas matrix expresses the total area (in cells) expected to be changed in the next time period. A set of conditional probability images expresses the probability that each pixel will belong to the designated class in the next time period. They are called conditional probability maps since this probability is conditional on their current state [10] as in equation (4).

$$P_m(i, j) = \frac{N(i, j)}{\sum_{k=1}^K n_{ij}} \quad (4)$$

where $N(i, j)$ is the observed data during the transition from state i to j , and n_{ij} is the number of years between time step i and step j , and the total number of years is m ; $P(i, j)$ is the yearly transition probability after normalizing the transition probability in multiyear and K is the number of steps [11]. The illustrates a technique of CA-Markov since a Markov chain analysis is performed in order to estimate the transition matrix between the two past dates and to estimate probabilities of change for the third date to be predicted. Then, CA estimates the spatial distribution of land cover at a later date. Equations below illustrate the evaluation of cells from time t to $t+1$ is determined by a function of state, it neighborhood space and a set of transition rule [12].

$$LU^n = f(LU_{i,j(t)} \cdot S_{i,j(t)} \cdot P_{x,y,i,(t)} \cdot N_{i,j(t)}) \quad (5)$$

$$N_{i,j(t)} = \frac{\sum_t N_{i,j(t)}}{\# \text{ of adjacent cells}} \quad (6)$$

Where,

- $LU_{i,j(t+1)}$: The potential of cell i, j to change at time $t + 1$,
- $LU_{i,j(t)}$: States of cell i, j at time t ,
- $S_{i,j(t)}$: Suitability indexes of cell i, j at time t ,
- $P_{x,y,i,(t)}$: Probability of cell i, j to change from state x to state y at time t (as shown in equation 4) above, and;
- $N_{i,j(t)}$: Neighborhood index of cell i, j .

In this research, to take information of the past and existing land use and land cover change (LULC) from Landsat imagery, we interpreted by using remote sensing technology. Land change modeler was used to predict landuse changes in the future. It was applied especially for settlement area in Padang City by processing with GIS [13, 14]. Land use was classified into 8 classes, i.e: 1) primary forest, 2) secondary forest, 3) settlement, 4) mixed garden, 5) weatland, 6) bush and reeds, 7) bare land, and 8) water body. Prediction of settlement area in Padang City in 2500, was selected because Padang City is always a target of development. Development of settlement areas occurred because many factors, they namely as driving factors. In this research, driving factors are distance from road, distance from cultivated area, distance from settlement area, land elevation, and distance from river [15]. Landuse change Prediction has three processes, the first step is to interpret Landsat imagery, the second is to analyse driving factors in coastal area and distance from the sources [16], and the last process is to predict settlement area change in the future based on cellular automata and markov chain model [17].

2.4. Seawater flooding on Settlement areas

To analysis impact of sea water flooding on settlement area, we used method of overlay map. It is a simple technique to get information on how the subject can give impact one to each other. Where to complete the data, where to take sample of settlement view location, where to locate hazard probability of seawater flooding in the future, that act with ground check location. Figure 2 displays workflow research of seawater flooding on settlement areas from start to finish step.

3. Result and discussion

3.1 Sea level rise in Padang City

Sea level rise as flooding has predicted to cover many districts. The high increase of sea level at surface in 2500 is 2,8m. The sea level rise can fulfil or cover all the depression area, tidal flat, estuary, and lowland around the coastal. In the city, the character of morphology and its altitude caused the large areas are covered by seawater. The flooding increase started from northern subdistrict of Koto Tangah, and ended in Lubuk Begalung subdistrict. The result of spatial analysis represented an image of altitude, surface and prediction of increase in seawater flooding. The settlement areas affected by seawater flooding in Padang City can be obtained by overlaying maps of sea level rise and settlement areas prediction in 2500 as shown in figure 2.

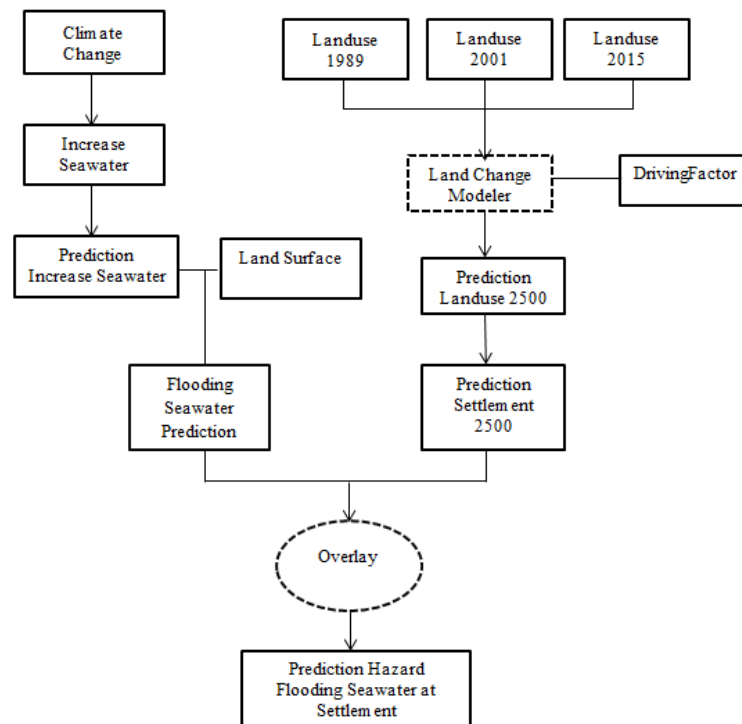


Figure 2. Research Workflow

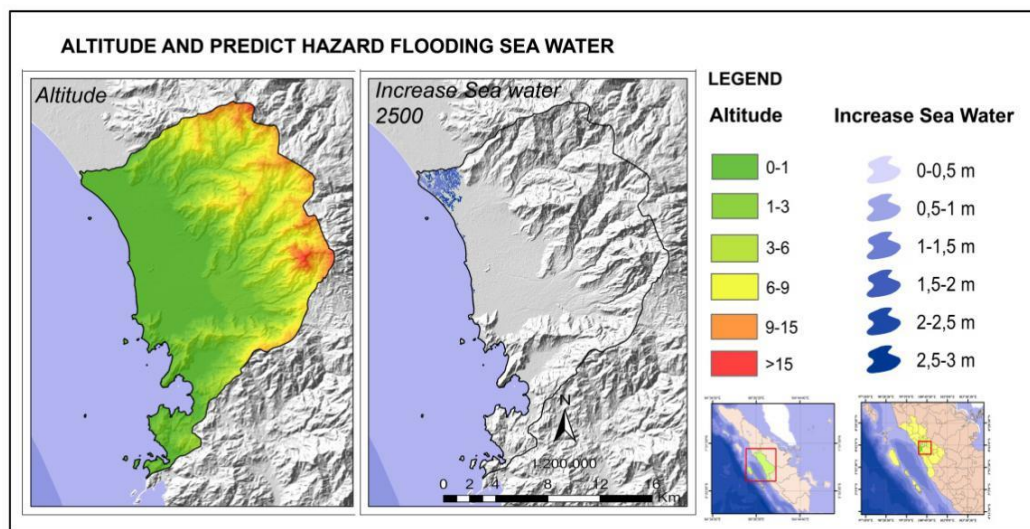


Figure 3. Altitude and prediction of seawater flooding in Padang City

The map shows how sea level rise and flooding in the city. The coastal area is vulnerable to impact of climate changes because of seawater flooding. Overall, in 2500, all of districts located around coastal areas in Padang will experience flooding because of sea level rise. The seawater flooding vulnerable districts were Koto Tengah, Padang Utara, Padang Barat, Padang Selatan, Lubuk Begalung and Bungus Teluk Kabung. The district has the highest vulnerability with the largest area covered by seawater flooding is Koto Tengah. It happens because of the coastal morphology, where land altitude was

relatively not much higher than the sea such as lowland, many swam, estuary and land depression. It was so different from other districts, as shown in the surface map, we can observe when we move to southern area around the sea where the land altitude gradually increases such as Bungus Teluk Kabung that has hilly surface. The region that has a low risk of seawater flooding was Lubuk Begalung subdistrict, because it just has a small area in the coast, and the distance from coast was far enough from coastal line.

3.2 Prediction of Settlement areas and Landuse change

We predict the settlement areas and land use change in the year of 2500. Location and landuse change and settlement areas are categorised by years that are 1989, 2001, 2015, and prediction in 2500. The resulted map of landuse change and settlement areas in Padang City and also their prediction can be seen in figure 4.

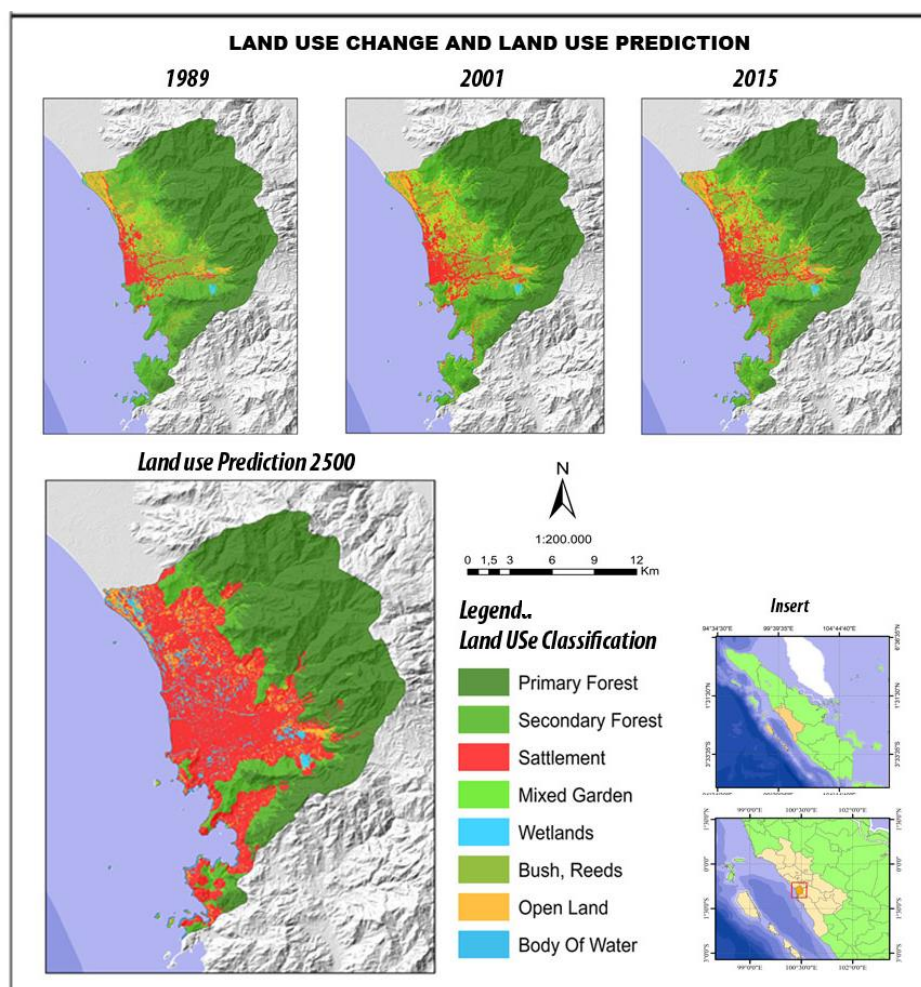


Figure 4. Landuse changes and land change prediction

Landuse change in Padang City resulted from land change modeler value can be seen in figure 4 and figure 5. These figures showed development of settlement areas and landuse change in Padang City from cultivated area, distance from road, distance from river, driver for settlement areas and digital elevation model in Padang City, this prediction use Kappa Index accuracy to get value of prediction.

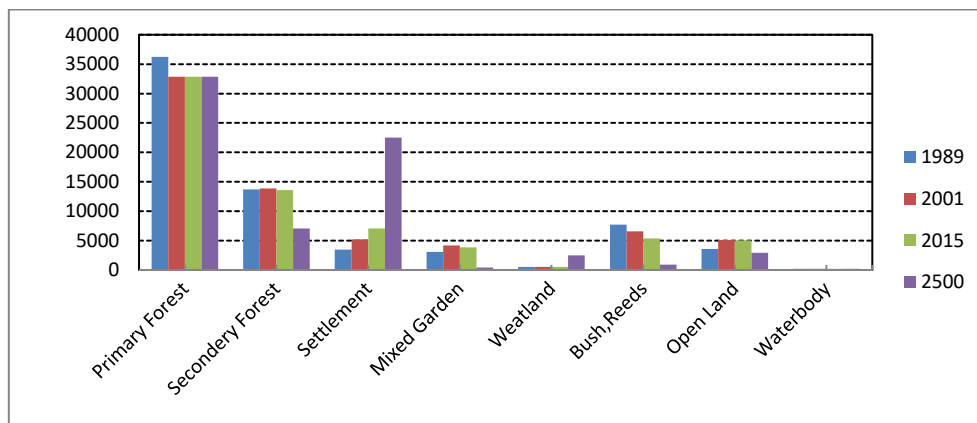


Figure 5. Bar chart of land use changes

The bar chart reveals how the land use changes and land use prediction in 2500. It can be observed that the land use change occurred in the years, some land use type had area increase and some area decreased, but the focus in this case was that the change in settlement area had increased. Generally, land use change, especially settlement areas, was considerably large. In 1989, settlement areas in Padang City was 3,464 ha. There was an area increase in 2001 to 5,230 ha, and in 2015 to 7,070 ha. The prediction of settlement areas in 2500 could reach as high as 22,522 ha.

From this land use map prediction in figure 4, we can observe that generally, all of the lands with fluctuated topography of land cover are forest and natural land cover. The land was protected because of physiography of the land. The high elevation in rough surface acted as barrier to land use change caused by human activity. Most land cover on the lowland is settlement areas, because driving factor is road, land elevation, and support for human activity to develop the urban, in micro aspect as residential or settlement areas. The future prediction map has showed that around the coastal area or near the coastal line has mainly developed as settlement areas. The assumption that the road as driving factor has led to human accessibility to develop the land and to support human activities. Therefore, land use change was the largest in lowland area.

3.3 Prediction of Seawater Flooding at Settlement areas in Padang City

The sea level rise analysis by using digital elevation model classification can predict sea level rise in 2500. The sea level has increased to 2.8 m from existing coastline. The prediction of settlement areas in 2500 represented the future area. The prediction maps of sea level rise and settlement areas in 2500 have been carried out by using overlay method. We can compare where the settlement areas were impacted by seawater flooding or not, and we can make a matrix and then calculate the future affected areas.

Table 2. Seawater flooding at Settlement areas in Padang City in 2500

No	District	Subdistrict Wide (ha)	Hazard Wide (ha)
1	Koto Tengah	23,119	1,062
2	Padang Utara	901	16
3	Padang Barat	624	21
4	Padang Selatan	1,472	62
5	Lubuk Begalung	3,055	6
6	Bungus Teluk Kabung	8,607	154
Total		37,780	1,322

Table 2 reveals the coverage areas of seawater flooding in many districts in 2500. Overall, the highest area effected by flood because of sea level rise was Koto Tengah, while the smallest was Lubuk Begalung. The Koto Tengah has flooding area of 1,062 Ha, while Lubuk Begalung of 6 Hh. The area with the lowest hazard was represented by Lubuk Begalung. If we look at the administration map, it showed that Lubuk Begalung had further distance area from the coastline than Koto Tengah.

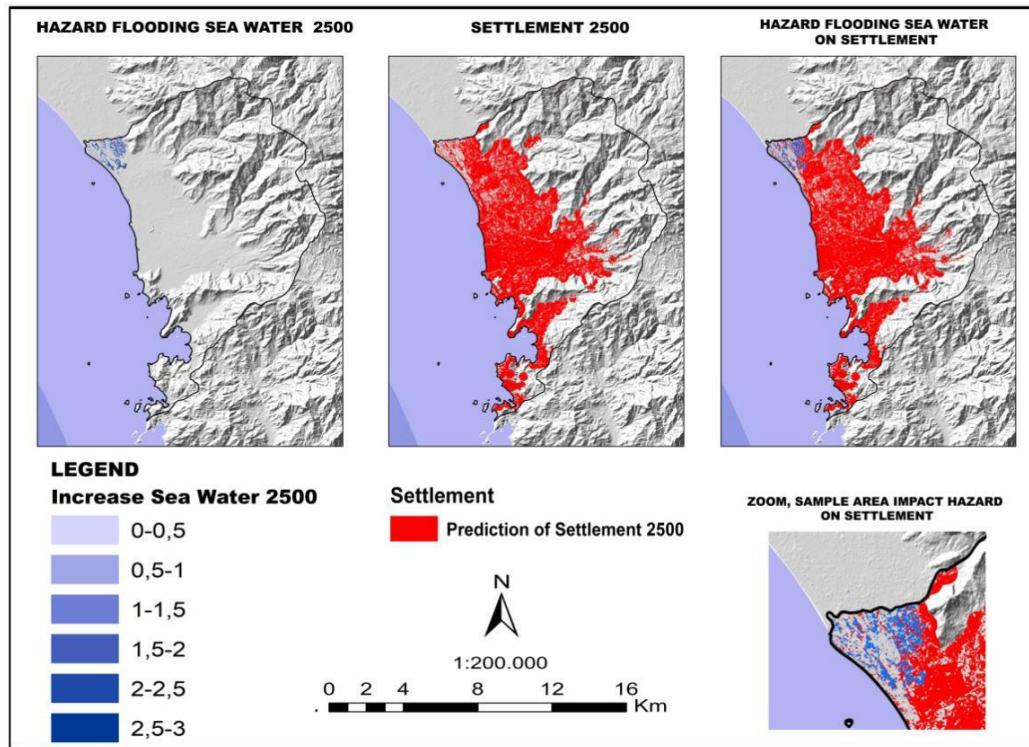


Figure 6. Map of sea level rise and settlement areas predictions in 2500 in Padang City

From figure 6 we can observe how the seawater flooding will affect settlement areas in 2500. It will cause flood in large areas around the coast, and drown many houses. The seawater flooding will also destroy many ecosystem and economic sources, constrain human activities and cause economic loss.

4. Conclusion

Many subdistricts in Padang City have increase in seawater flooding hazard as impact of climate change, especially for settlement areas. The subdistricts near coastline are Koto Tengah, Padang Utara, Padang Barat, Padang Selatan, Lubuk Begalung, and teluk Bayur. It is predicted that sea level rise will cause seawater flooding in 2500 as high as 2.8 m from existing coastline. Development of settlement areas in Padang City is predicted to be as high as 22,522 ha in 2500. Prediction analysis of seawater flooding hazard in Padang City as an impact of climate change showed that 1,322 ha of settlement areas would be affected. The subdistrict has the highest risk was Koto Tengah with predicted affected area of 1,026 ha, while the lowest one was Lubuk Begalung Subdistrict with predicted affected area of 6 ha. It was because Koto Tengah had a long coastline, while Lubuk Begalung has a small area around the coast. This research showed that Remote Sensing and Geography Information System (GIS) can be used to analyse prediction of increase in seawater flooding hazard on settlement areas as an impact of climate change, especially for coastal region, for example Padang City, the capital of West Sumatera Province, Indonesia.

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