

Probabilities of Sea Level Rise and Adaptive Planning  
Strategies in Indramayu Regency, Indonesia

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# Probabilities of Sea Level Rise and Adaptive Planning Strategies in Indramayu Regency, Indonesia

by

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## Abstract

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Sea level rise is a significant and growing threat to the coastal region of Indramayu Regency, Indonesia. This area as one of cities in Northern Coast Java has important role in supporting economic activities. Increasing rates of sea level rise are expected to lead to permanent inundation, and saline intrusion in low-lying coastal areas.

This research presents an assessment of the expected impacts with cumulative effect and cumulative probabilities. It projects future sea level rise based on local measurement with normalized projection and applies it to digital elevation models to illustrate the extent to which the Indramayu coast is vulnerable. Then suggest adaptation options opportunities for managing coastal areas in response to sea level rise.

The method applied in this research can be divided into 3 main steps, following the 3 research objectives: mapping inundated areas based on determined scenario, calculating land loss as a sea level rise impact, and recommending adaptation options including visualization to minimize the impacts.

It is estimated that around 30% of Indramayu's land area will be affected by inundation from various scenarios. The result recommends that there are 3 adaptation option such as accommodation, protection, and retreat that can be applied in this area.

**Keywords: sea level rise, inundation, adaptation option**

*I dedicated this work for:  
My mom, you are the sunshine of my life*

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Enschede, November 2010

**Indri Koesindriyani**



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## 1. INTRODUCTION

### 1.1. Background

Climate is one of key factors in every natural resource management issue and its changes will have impacts on many ecological, hydrological and resource-degrading processes. The climate changes such as increasing temperature, changing of precipitation patterns, and rising sea level have always been a fundamental driver of ecological processes and land use systems.

The International Panel on Climate Change (IPCC) estimates that the global average sea level will rise between 0.18 to 0.59 meters in the next century (IPCC, 2007). Furthermore in FAO (1998), the worst scenario projects a sea level rise of 95 cm by the year 2100, with large local differences (tides, wind and atmospheric pressure patterns, changes in ocean circulation, and vertical movements of continents) in the relative sea level rises. It means the impacts of global sea level rise will effect locally very different, hence need for local scenario rather than global (Warwick et al, 1996).

Coastal areas are particularly vulnerable to rising sea level especially with flat topography. Coastal area will be exposed to increasing risks, including increased inundation, accelerated beach erosion, land subsidence, and seawater intrusion into fresh and groundwater sources (salinisation). The impacts will affect the coastal development and activities such as agriculture, aquaculture, etc. and loss can not be avoided. Coastal areas have important socio-economic and environmental functions. The former is as traditional resources based activities such as coastal fisheries, aquaculture, forestry, and agriculture, in line with other activities, for instance industry, shipping and tourism. It is strategic importance for development. The economic growth rates in the coastal areas are higher than average in many parts of the world. About 60% of the world population lives within 60 km of the coastline (UNEP, 1991). The socioeconomic developments in the coastal areas are faster than elsewhere (Bijlsma et al, in Jelgersma, 1993) and last but not least coastal areas are important ecologically, they provide a high number of biodiversity.

To estimate the impacts of sea level rise in the coastal area, Geographic Information System (GIS) can be used as a tool (Shataee and Malek, 2008). The GIS based model allows the user to perform a variety of scenarios based on changes in parameter values (e.g. the rate of sea level rise) (Hennecke et al, 2004). Moreover, if the potential impacts on society ca be identified and quantified (UNEP, 1991; van Dam in Jelgersma et al, 1987), it will avoid costly planning and investment mistakes (Rivas and Cendrero in Finkl et al, 1994). Remote sensing (RS) analysis, help in extracting information of

existing land use from satellite imagery. With spatial analysis in GIS, land loss that caused by inundation as sea level rise impact can be calculated.

The GIS and RS analysis result are expected become an input in planning and adapting to sea level rise effect. Planning includes understand and forecast, assessment and management of risks (Frasseto, 1989). Adapting is one way to diminish the vulnerability. Adaptation can be autonomous or planned (Maciver and Dallmeier, 2000). Planned adaptation requires intervention from decision makers and needs strategic actions. Adaptation to sea level rise is no longer a question of “if” but rather of “how”, “where” and “how fast”. Adaptation options include managed retreat, accommodation, and protection. UNEP (1991) defines 3 different coastal protection strategies as adaptation options such as preservation, retreat, and selective preservation. Adaptation options are needed to minimize the impacts and assure the activities still continue for coastal resources sustainability. One element of effective coastal resources management requires the ability to project the response of coastal areas to short and long term climate variations (Daniels, 1996), since any change in climatic processes will finally affect the coastal area in some way (Gornitz et al, in Finkl et al, 1994).

## **1.2. Research Problem**

Indramayu Regency as one of cities in Northern Coast Java has important role in supporting economic activities such as agriculture, oil and gas, aquaculture, plantation, forest, tourism, and so on. Indramayu becomes one of agriculture centers in West Java Province, because more than 50% of existing land use is dominated by paddy field and it supports 13.37% of GDRP ([www.indramayukab.go.id](http://www.indramayukab.go.id)).

On the other hand, based on previous research this area has sea level rise rate until 8 mm/year (MMAF, 2009). It means the risks faced will be higher, because almost 98,70% of this area has a flat topography (0-3 m). Permanent inundation will occur significantly where the coastal profile is flat or gently sloping (Pernetta in Fraserio, 1989).

Inundation will be extremely important economically, since most fertile agricultural in this area is at or close to present sea level. Loss of coastal agricultural area will result in increasing agricultural activities inland and lead to the erosion and soil fertility problems. The inundation of paddy field will change directly to productivity levels and diminish the community income. Moreover the social and economic losses cannot be avoided.

Unfortunately, local government still considers that sea level rise is not serious threat. Meanwhile, the impacts that have already happen, are solved partially by each agency independently and the possibilities of integrated adaptation options have not examined systematically.

With proposing appropriate adaptation options to face sea level rise impacts, it is expected to reduce social and economic losses, and to conserve sustainably coastal resources as community livelihood.

### **1.3. Research Objectives**

The main objective of this research focuses on how to model local sea level rise in Indramayu Regency, anticipate on the impact of sea level rise in this area. This leads to the following sub objectives:

1. To predict future inundated areas associated with sea level rise over the next 25, and 50 years scenario respectively;
2. To identify how much land cover/land use loss if there is no applied adaptation options;
3. To recommend adaptation options as response in facing sea level rise.

### **1.4. Research Questions**

Regarding the sub objectives above, the research questions are:

- a. *What is the probability of occurrence in various scenarios 25 and 50 years of the cumulative effect of MSLR, tidal range, and wave height?*
- b. *How much area will be inundated by cumulative effect over the next 25, and 50 years respectively?*
- c. *What is the current land cover/land use in this area?*
- d. *How much land per land cover/land use type will be inundated due to the cumulative effect over the next 25 and 50 years respectively?*
- e. *What kinds of adaptation options are feasible?*

### 1.5. Conceptual Framework

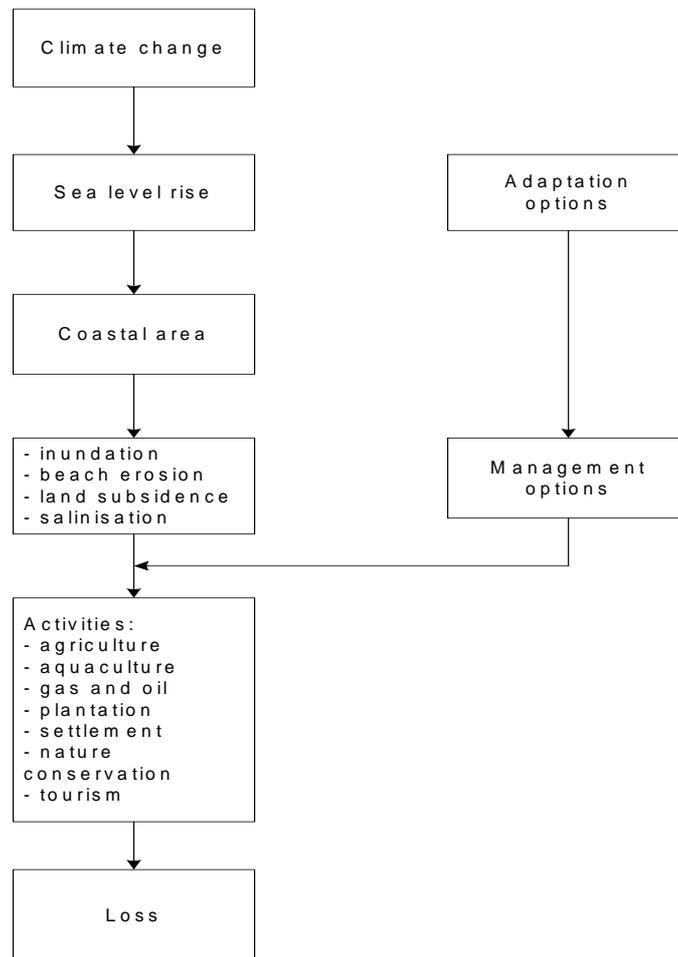


Figure 1.1 Conceptual framework

### 1.6. Overall Methodology

The general workflow of this research is illustrated by the flowchart in figure 1.2. This research is divided into 3 parts. First part is mapping inundated areas that derived from predicting sea level rise and generating digital elevation model (DEM). In calculating future sea level rise, it includes trend, deviations, probabilities, and extremes values.

The second part is generating land use map. The purpose is to define existing land cover/land use. If it is overlaid with inundated areas map, the amount of land loss will be identified. After classifying existing land use and considering the sea level rise scenario, it can be characterized what kind of adaptation option needed. The adaptation type selection is based on result from TOWS (Threats, Opportunities, Weaknesses, and Strengths) analysis to develop strategies by analyzing the external

environment (threats and opportunities), and internal environment (weaknesses and strengths). It becomes input in choosing appropriate adaptation option in the last part.



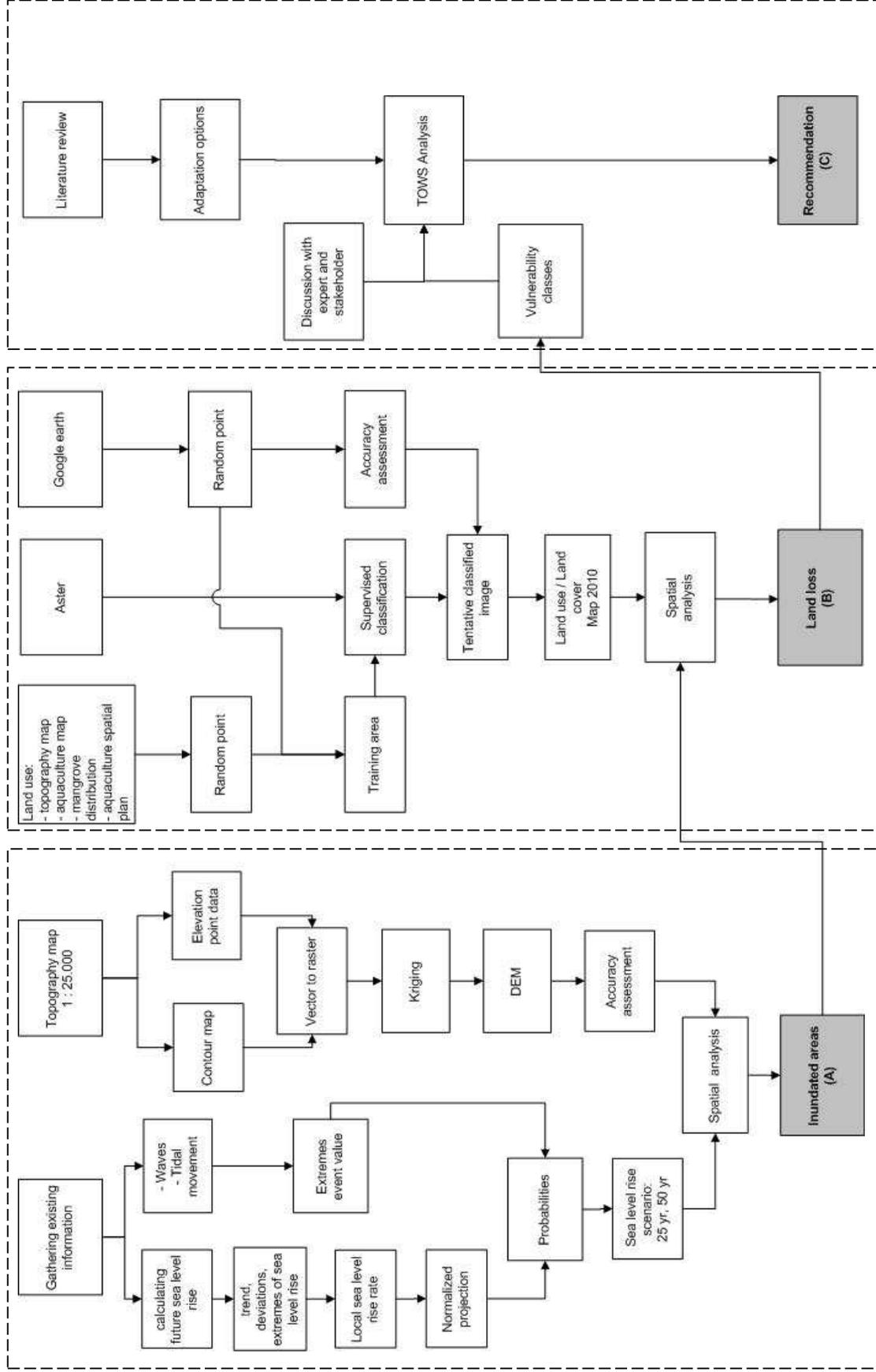


Figure 1.2 Overall Methodology

## 2. CONCEPT AND DEFINITION

This chapter explains the general overview of sea level rise which it outlines the factors that control sea level and the impacts of sea level rise on coastal area. It finishes with explanation of planning options, and role of remote sensing and geographic information system (GIS).

### 2.1. Sea Level Rise

Sea-level rise can be a product of global warming through two main processes: expansion of sea water as the oceans warms up, and melting of polar ice caps. Global warming is predicted to cause significant rises in sea level over the course of the twenty-first century. Multiple complex factors may influence this change.

Local mean sea level (LMSL) is defined as the height of the sea with respect to a land benchmark, averaged over a period of time (such as a month or a year) long enough to correct for fluctuations caused by waves and tides. Eustatic change (as opposed to local change) results in an alteration of the global sea levels, such as changes in the volume of water in the world ocean's or changes in the volume of an ocean basin.

The changes of sea level are divided into two categories, short term and periodic changes, and longer term changes. There are many factors which can produce short-term (a few minutes to 14 months) changes in sea level.

**Table 2.1 Contributed actors to short term and periodic changes**

	Time scale (P = period)	Vertical effect
Periodic sea level changes		
Diurnal and semidiurnal astronomical tides	12–24 h P	0.2–10+ m
Rotational variations	14 month P	
Meteorological and oceanographic fluctuations		
Atmospheric pressure	Hours to months	–0.7 to 1.3 m
Winds (storm surges)	1–5 days	Up to 5 m
Evaporation and precipitation (may also follow long-term pattern)	Days to weeks	
Ocean surface topography (changes in water density and currents)	Days to weeks	Up to 1 m
El Niño/southern oscillation	6 mo every 5–10 yr	Up to 0.6 m
Seasonal variations		
Seasonal water balance among oceans (Atlantic, Pacific, Indian)		
Seasonal variations in slope of water surface		
River runoff/floods	2 months	1 m

	Time scale (P = period)	Vertical effect
Seasonal water density changes (temperature and salinity)	6 months	0.2 m
Seiches		
Seiches (standing waves)	Minutes to hours	Up to 2 m
Earthquakes		
Tsunamis (generate catastrophic long-period waves)	Hours	Up to 10 m
Abrupt change in land level	Minutes	Up to 10 m

Source: [http://www.statemaster.com/encyclopedia/Sea-level-rise#Overview\\_of\\_sea-level\\_rise](http://www.statemaster.com/encyclopedia/Sea-level-rise#Overview_of_sea-level_rise)

Various factors influence the volume or mass of the ocean, afterward those will lead to long-term changes in eustatic sea level. The two primary influences are temperature (because the volume of water depends on temperature), and the mass of water caged on land and sea as fresh water in rivers, lakes, glaciers, polar ice caps, and sea ice. The changes in the shape of the oceanic basins and in land/sea distribution will affect sea level.

In 2001, the Intergovernmental Panel on Climate Change's Third Assessment Report predicted that by 2100, global warming will lead to a sea level rise of 9 to 88 cm. Future sea level rise is not expected to be globally uniform. Some regions show a sea-level rise substantially more than the global average (in many cases of more than twice the average), and others a sea level fall.

## 2.2 Inundation

Sea level rise will have four major impacts that are relevant to comprehensive planning in general: inundation and shoreline recession, increased flooding from severe weather events, saltwater contamination of ground water and surface water supplies, and elevated water tables (Deyle et al, 2007). The most obvious impact of sea level rise is simple inundation of previously dry land.

Coastal plains in general would be less vulnerable than atolls, deltas, and barrier islands. These areas are becoming more developed every year. Sea level rise will claim more private and public structures each year. The greatest danger to coastal communities is extreme events, when for example maximum scenario of sea level rise is combined with maximum high wave. Furthermore, the high tide can add several meters to the inundation. It can be devastating to any coastal community. Vertically, the water can reach heights of more than 1 meter. In general, the more height of water level input, the larger the area that will be flooded.

Since sea level rises, the elevation of the mean high tide line will move to landward at a rate determined by the slope of the local topography. Land use that locates in the path of shoreline recession due to elevated sea level rise and erosion may be adversely affected in several ways. As the mean high tide line moves landward, above-ground structures such as wastewater treatment and reclamation facilities, water supply

treatment facilities, and sewer lift stations may initially be subject to intermittent flooding from spring high tides (NRC, 1987).

### **2.3 Adaptive Planning Strategies to Sea Level Rise**

Adaptation is defined as “*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderates harm or exploits beneficial opportunities*”, (UNFCCC, 2006) after (IPCC).

Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation. Planned adaptation options to sea level rise are usually presented as one of three generic options as follows (IPCC CZMS, 1990; Biljlsma et al., 1996; Klein et al, 2001):

- a. (Planned) retreat: the impacts of sea level rise are allowed to occur and human impacts are minimized by pulling back from the coast by land use planning and development control.
- b. Accommodation: the impacts of sea level rise are allowed to occur and human impacts are minimized by adjusting human use of the coastal zone to the hazard with increasing flood resilience (e.g. raising homes on pilings), warning systems and insurance. New development can be directed away from areas that are anticipated to be affected by inundation, shoreline recession, and advancing coastal flood boundaries. Setbacks can be employed to require that new structures be built back from the shore by some multiple of the annual average erosion rate.
- c. Protection: the impacts of sea level rise are controlled by soft or hard engineering, reducing human impacts in the zone that would be impacted without protection. The physical structures that can be used to protect developed areas from erosion and inundation include: offshore breakwaters, perched beaches, revetments, dikes, floodwalls, seawalls, bulkheads, dams, beach nourishment, dune building, and marsh building (Sorensen, Wesiman & Lennon, 1984). This will be a challenge to coastal management, since seawalls and breakwaters are generally expensive to construct, and the costs to build protection in the face of sea-level rise would be enormous.

Titus (1991) suggests that choices among these options will be based on an evaluation of the value of the land and the built environment to be protected compared to the costs of protection. Titus predicts that highly developed coastlines will be protected from sea level rise with a combination of hard and soft engineering measures. In areas that are considered too expensive to adequately protect, Titus suggests that the sea may be allowed to advance and accommodation strategies such as raising the land or structures will be implemented. Areas that are not heavily developed but that have other natural value (such as barrier islands for their aesthetic value) may be protected. Retreat strategies are likely to be limited to less developed areas, without significant investments in infrastructure, and natural areas such as

coastal wetlands that are capable of naturally adapting to sea level rise if not constrained by topography or the built environment.

Throughout human history, improving technology has increased the range of adaptation options in the face of coastal hazards, and there has been a move from retreat and accommodation to hard protection and active seaward advance, as illustrated by the changing approaches to managing flooding in the Netherlands (van Koningsveld et al., 2008).

Adaptation analyses at the global scale normally consider one of two distinct approaches such as protection of all developed areas, and an optimization approach where 'economically worthwhile areas' are defended. In addition, it can be expected that climate change risks do not affect all members of the society equally. Instead, various societal groups as well as various sectors of the economy are affected differently. A decisive factor to determine the degree to which a person, a societal group or an economic sector is affected is its vulnerability. Blaikie et al (1994) vulnerability is the characteristics of a person or a group in terms of their capability to anticipate, to cope with, resist, and recover from the impact of a natural hazard. Instead of emphasizing solely characteristics of the natural or technological hazard itself or the exposure (structure, building etc) to the hazards, this definition focuses on the question on how communities and social groups are able to deal with the impact of a natural hazard.

Changes on sea level have a direct adaptive response from beaches and coastal systems, as it can see in the succession of a lowering sea level. When the sea level rises, coastal sediments are in part pushed up by wave and tide energy, so sea-level rise processes have a component of sediment transport landwards. This results in a dynamic model of rise effects with a continuous sediment displacement that is not compatible with static models where coastline change is only based on topographic data.

As a consequence of sea level rise, central and local governments face additional challenges in decision-making, particularly in coastal areas. Management plans implemented to deal with sea level rise must be flexible enough to deal with coastal locations and land use types, because they respond differently to changes in sea level. Before implementing planning and response programs, as a first step this research will provide a clearer picture and input of the impact of inundation on land use.

#### **2.4 Role of Remote Sensing and Geographic Information System (GIS)**

Inundation presents as a coastal problem. Moreover to predict its areas and to assess the land loss, it is needed to have the latest information on the predicted inundation, and expected loss over large areas. Remote sensing and GIS are indispensable tools for predicting inundation and its impact on coastal through spatial modeling, mapping, and visualizing.

To achieve that, this research using remotely sensed data like medium resolution satellite sensor that can provide the required information such as existing land use in a timely and reliable way. Due to assessing the

vulnerability of an area to inundation, the maximum expected height of water must be compared with the elevation of the area to predict whether the area will be flooded during a certain scenarios.

### 3. METHODS

#### 3.1. Study Area

Indramayu Regency is located in 107°52' – 108°36' E and 6°15' – 6°40' S. Flat topography dominates this area with slope 0-2%. The total area is 204.011 ha. Situated along northern Java Coast, its coastline has length 141.1 km. This location makes the temperature is relatively high around 18-28°C. It is suitable for agriculture. This regency is divided into 31 sub districts with 313 villages, and almost 30% of administrative area borders directly with the sea (10 sub districts and 35 villages).

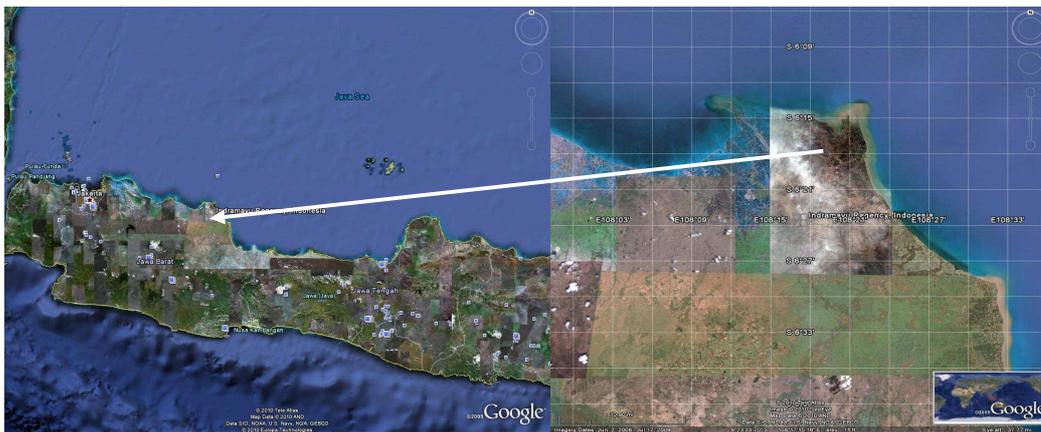


Figure 3.1 Study Area

#### 3.2 Research Methods

The method applied in this research can be divided into 3 main steps, following the 3 research objectives: mapping inundated areas based on determined scenario, calculating land loss as a sea level rise impact, and recommending adaptation options.

##### 3.2.1 Inundation Mapping

The main factors for defining inundated areas are elevation and water levels expressed in probabilities of occurrence. Inundation mapping is divided into 3 steps: generating a Digital Elevation Model, preparing sea water level scenarios and their corresponding probability, and determining inundated areas.

##### 3.2.1.1 Generating Digital Elevation Model

Relating to expected scenario, impact analysis would be much easier if finer-resolution topographic maps were available in coastal areas (Titus and Narayanan, 1995). To analyze the distribution of inundated areas, a digital elevation model (DEM) is required. Maune (1991) defined a DEM as “the digital cartographic

representation of the elevation of the land at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum". To achieve the expected result of inundated areas distribution, minimum vertical accuracy level ( $\Delta h$ ) of DEM has to be considered with local sea level rise rate ( $\Delta SL$ ).

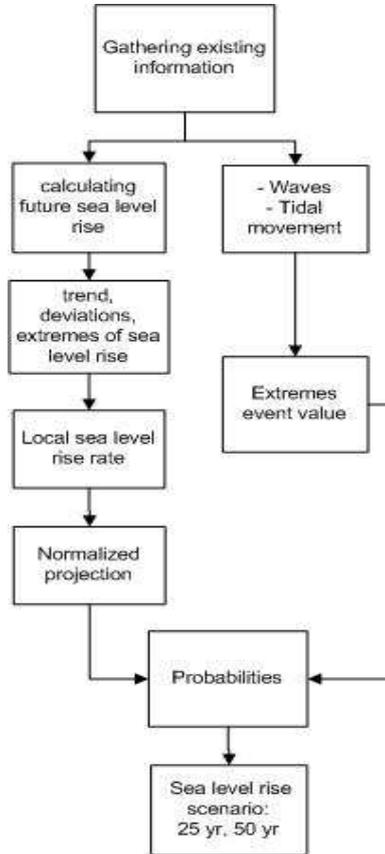
### **Accuracy Assessment**

This accuracy assessment is done in order to assess the result of DEM generation. Since, there is no field data availability, to calculate the accuracy of DEM, it is used holdout method (Baraldi et al, 2005 after Kohavi, 1995). He described that dataset is divided into two groups, training set and test set. In which training set is used to train the classifier, and test set is used to estimate the error rate of the trained classifier. It typically 2/3 of the available data set should be used for training and the remaining 1/3 of data should be employed for testing. Usually, test samples are taken from available data set by simple random sampling. Between training and test sample should be independent each other.

#### **3.2.1.2 Preparing Water Level Input**

For the determination of sea water level height, the probabilities of sea level rise rate are the main input. However for planning (adaptive strategies) and coastal protection purposes, tidal movements, wave height and the probability of extreme event have to be considered as well. Figure 3.5 shows the flowchart of the adopted method.

**Detailed Flowchart**



**Figure 3.2 Detailed Sea Level Rise Flowchart**

**A. Sea level rise probabilities**

Sea level rise probabilities for the study area are based on the Normalized Sea Level Projection (see table 3.4), and transformed into Local Sea Level Estimates (see equation 1) (Titus and Narayanan, 1995).

$$\text{local}(t) = \text{normalized}(t) + ((t - 1990) \times \text{trend}) \tag{Eq. 1}$$

Where :

local (t) = the rise in sea level by year t at a particular location (in cm)

normalized (t) = the rate from the normalized table by year t (see table below)

1990 = reference year of sea level

trend = the current rate of relative sea level rise at the particular location

**Table 3.1**  
**Estimating Sea Level Rise at A Specific Location**  
**Normalized Sea Level Projections, Compared with 1990 Levels (cm)**  
**Sea Level Projection by Year**

Cumulative Probability	2025	2050	2075	2100	2150	2200
1	-10	-16	-21	-24	-32	-40
5	-3	-4	-5	-6	-7	-8
10	-1	-1	0	1	3	5
20	1	3	6	10	16	23
30	3	6	10	16	26	37
40	4	8	14	20	35	51
50	5	10	17	25	43	64
60	6	13	21	30	53	78
70	8	15	24	36	65	98
80	9	18	29	44	80	125
90	12	23	37	55	106	174
95	14	27	43	66	134	231
97.5	17	31	50	78	167	296
99	19	35	57	92	210	402
Mean	5	11	18	27	51	81
$\sigma$	6	10	15	23	47	81

Source: (Titus and Narayanan, 1995)

E.g. for the estimation of the local sea level rise with the normalized projection, for the year 2025 with 1 and 50% probability the calculation is as follows. N.b. the current rate of sea level rise in Indramayu Regency is 8 mm/year.

For 50% chance:

$$\begin{aligned} \text{local (2025)} &= 5 + (2025-1990)*0.8 \\ &= 33 \text{ cm} \end{aligned}$$

For 1% chance:

$$\begin{aligned} \text{local (2025)} &= 19 + (2025-1990)*0.8 \\ &= 47 \text{ cm} \end{aligned}$$

## B. Tidal Movement

Tidal movement is influenced by the position of the moon, the sun, and gravity. Due to these factors, tidal movements have periodic pattern. Tides are caused by the gravitational influences of the moon and the sun, which create tidal waves. These waves have periods of about 12 and 24 hours. The water movements are affected by the Earth's rotation and the land masses and are therefore different for each location.

One reason for monitoring tidal behavior is to establish vertical datums from which heights and depths for both hydrographic and land surveys are measured. It also facilitates accurate tidal predictions to allow safe navigation in harbors and shallow areas, and assists in planning coastal zone management.

The values of tidal movement are derived from field measurements in Indramayu Regency which was done for 15 days observation from 25 June – 9 July 2009, (Ministry of Public Works, 2009). With using Least Square Analysis, the result is shown the table 3.5 below. Those values can be used for 18.6 years prediction (Ministry of Public Works, 2009).

**Table 3.2 Water Level Position**

Water Level Position	Elevation (cm)
Highest High Water Level (HHWL)	198.823
Mean High Water Spring (MHWS)	124.171
Mean High Water Level (MHWL)	116.289
Mean Sea Level (MSL)	85.946
Mean Low Water Level (MLWL)	60.336
Mean Low Water Spring (MLWS)	48.288
Lowest Low Water Level (LLWS)	0.000

Source: Ministry of Public Works, 2009

Water level input only use Highest High Water Level (HHWL) as extreme value ie. 198.823 cm. For identifying inundated areas where started from coastline (0 m), this value still has to be adjusted with MSL = 0. It means the HHWL value is  $198.823 - 85.946 = 112,877$  cm.

**C. Wave height**

Wave as one of extreme event factors is induced by wind. From MMAF report (2009), wave height maximum and their return period is presented in the table 3.6.

**Table 3.3 Wave Height Maximum in Indramayu Regency**

Return Period (in years)	Hmax (m)
2	0.16
5	0.32
10	0.47
25	0.70
50	0.88
100	1.08

Source: Ministry of Marine Affairs and Fisheries, 2009

#### D. Calculation of the cumulative effect of water level input

The cumulative effect of the parameters in the previous sections is used as water level input for determining inundated areas. It is divided into 3 scenarios: minimum, middle and maximum. This figure tries to illustrate the water level input for maximum scenario.

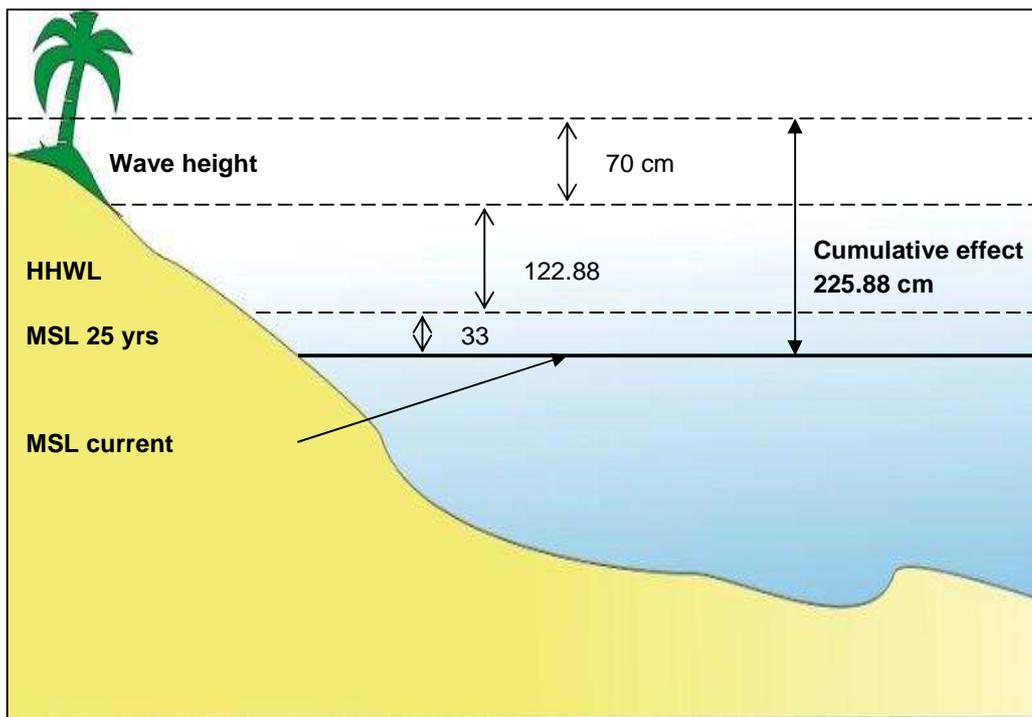


Figure 3.3 Water level inputs for cumulative effect

#### E. Computing vertical reference shift

To represent the horizontal spreading of inundation, the water level input will be mapped relatively to a tidal reference level (NOAA, 2009). Since in Indonesia there is difference in defining the vertical reference and coastline between data sources, the input water levels need to be adjusted (Syafi'i, 2010) with:

- Topographic map which uses Mean Sea Level (MSL) as common reference level for elevation;
- Chart datum (usually uses lowest water tide level) is a common reference level for depth information as well as a baseline recommended by the International Hydrographic Organization (IHO);
- Satellite image which has certain land and sea boundary at time of exposure.

### 3.2.1.3 Defining Inundated Areas

This stage uses spatial analysis which deals with neighbourhood operation and iteration (Marfai, 2008). A flowchart of the activities in this stage is presented in figure 3.7. Neighbourhood operation has been applied on DEM data in order to calculate the horizontal extend of the inundation on the coastal and lowland area, given a certain sea water level height.

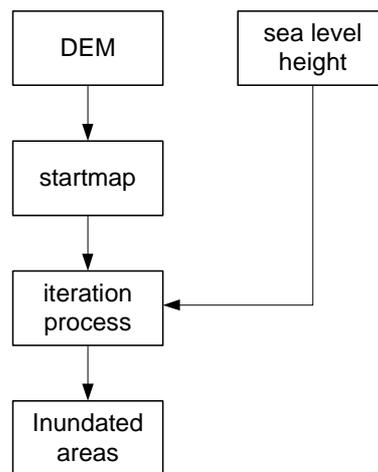


Figure 3.4 Inundation Detailed Flowchart

#### Inundation Modeling Using Iteration Process

Neighbourhood operation, as a spatial analysis tool on the GIS-ILWIS system, has been applied on DEM data in order to calculate the spreading of coastal inundation (Marfai, 2007). This operation makes use of a small computation window (e.g., 3\*3 cells) that repeats a specified calculation on every pixel in the map, taking into consideration the values of its neighbours (ILWIS, 2001). The neighbourhood function for *tidal encroachment computation* is an iterative procedure. Iteration is a consecutive repetition of a mathematical operation, using the result of one calculation as input for the next. The calculation stops when the difference of the output compared to the input is insignificant, or if the number of iterations as defined before is reached. Iterative calculations are performed line by line, pixel by pixel and take place in all directions on the digital map.

The input map for iteration is called a start map and contains pixels, which act as the starting point of the calculation. The iteration expression defines a certain condition or defines a calculation to be performed. Once the start map has been created, the iteration process can be done.

In ILWIS format the iteration formula can be seen in equation (Marfai, 2006):

$$\mathbf{Iteration\ result = MapIterProp(startmap, iterexpr, nr\ of\ iteration)} \quad (\text{Eq. 2})$$

Where:

<b>Iteration result</b>	the name of the output raster map that will contain the result of the iteration
<b>MapIterProp</b>	The iteration expression which defines the calculation to be performed
<b>startmap</b>	The name of the input map which contains one or more pixels acting as the starting point for the calculation
<b>iterexpr</b>	The iteration expression which defines the calculation to be performed
<b>nr of iteration</b>	The number of iterations to be performed

$$\mathbf{Inundation\ map = MapIterProp(start.mpr, iff(dem > 2.26, start, nbmax(start\#)))} \quad (\text{Eq. 3})$$

Where:

<b>Inundation map</b>	Result map
<b>MapIterProp</b>	Iteration operation with propagation
<b>start.mpr</b>	The start map for start the iteration
<b>dem</b>	DEM data
<b>2.26</b>	Number 2.26 is the water level input (m)
<b>nbmax</b>	Returns the largest value of the values found by a neighborhood matrix

### 3.3.2 Impact of Inundation to Land Use

Land use loss will be calculated based on overlaying inundated areas with the existing land use map. To get existing land use map, ASTER (August 2010) is used for extracting information. A flow chart of the steps in the production of the land cover map is presented in figure 3.8.

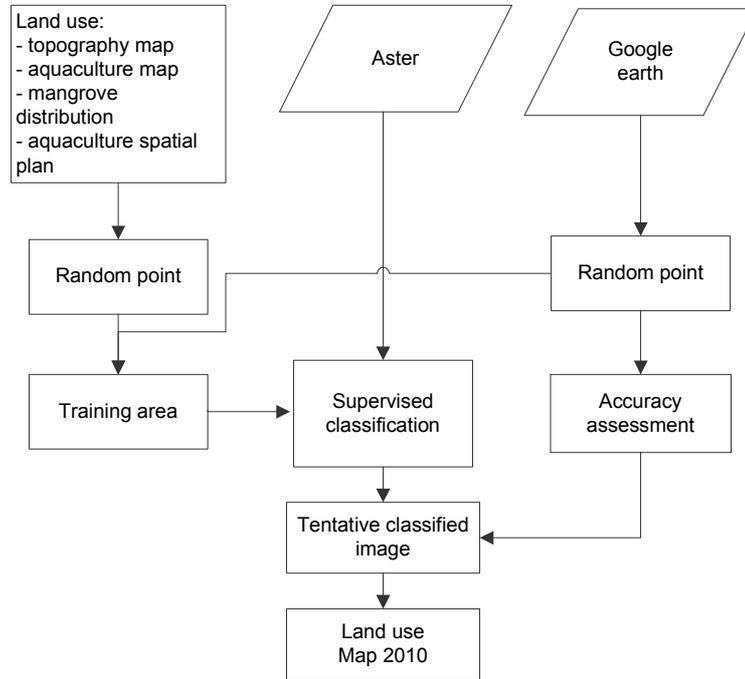


Figure 3.5 Land Use Classification Detailed Flowchart

### 3.3.2.1 Land Use Classification

- Geo referencing and geo-coding

ITC (2009) describes that geo-referencing and geo-coding the image is the process of giving coordinate and determining image or map into certain coordinate system. The purpose is to make the map can be combined with other spatial data.

- Supervised Classification

Image classification is done in order to convert imageries into thematic map. Maximum likelihood method is chosen in this research. The training areas become input information for computer to assign the pixels to classes. Google Earth image and existing data such as topography map, aquaculture map, and mangrove distribution are used for sources in selection of training areas. Table 3.8 shows the different appearance of each land use/land cover from Aster image and Google Earth.

**Table 3.4 Training Sample for Each Land cover/Land use**

Aster	Google Earth	Description
		Paddy field
		Aquaculture
		Forest
		Mix vegetation
		Dry agriculture
		Water body
		Settlement

### 3.3.3.2 Accuracy assessment

Accuracy assessment is done in order to assess the result of classification. It is important to make the classification result reliable. The purpose of quantitative accuracy assessment of maps generated from remote sensing image is the identification and spatial distribution assessment of map errors. Quantitative accuracy assessment of maps involves the comparison of a site on a map against reference information for the same site (Baraldi et al, 2005 after Congalton and Green, 1999).

An error matrix was used to evaluate the accuracy. How often the classification suited with the training set and how often it unsuited, it will shown by errors of commission and errors of omission. The error

matrix as a whole can give the user's and producer's accuracies for each category as well as the overall accuracy for each scene (Lillesand, 2000).

### 3.3.3 Proposed Adaptation Options

In this research, proposed adaptation options have to consider land use loss (vulnerability classes), result discussion with the expert and stakeholder, as an input for appraisal of adaptation options based on TOWS (Threats, Opportunities, Weaknesses, and Strengths) analysis. The purpose is to find suitable adaptation options.

Initially, selecting adaptation options is begun with literature review through evaluation of existing policy and adaptation options, and result discussion with expert and stakeholder. Evaluation and literature review are useful for determining what objective of adaptation options.

#### 3.3.3.1 Vulnerability Classes

Vulnerability assessment from direct effects of sea-level rise such because of inundation has been developed by Nichols and Nimura (1998), as an alternative approach to measure the impact. As a result, they divide vulnerability into 4 classes based on land loss calculation that shown in table 3.9.

**Table 3.5 Vulnerability Classes**

Impact Categories	Vulnerability Classes			
	Low	Medium	High	Critical
Land loss (area loss / total area) x 100%.	<3%	3–10%	10–30%	>30%

Land loss itself is produced from spatial analysis result between inundated area map and land use/land cover classification. Considering this table, it can be calculated land loss for each land cover/land use and converted into vulnerability class.

#### 3.3.3.2 Proposed Adaptation Options

Proposed adaptation options are generated from TOWS method. TOWS is acronyms for arrangements of the words Threats, Opportunities, Weaknesses, and Strengths. The only difference between TOWS and SWOT (Strength, Weaknesses, etc) is that TOWS emphasizes the external environment like SWOT emphasizes the internal environment. TOWS uses a SWOT analysis to develop strategies by analyzing the external environment (threats and opportunities), and internal environment (weaknesses and strengths).



## 4. RESULT

The chapter on results is divided into four sub-chapters. The first sub-chapter (4.1) is about inundation mapping, including DEM generation and its accuracy assessment, probability of sea level rise and extreme events and visualization of inundated areas based on certain scenarios. The second sub-chapter (4.2) explains the result of land cover/land use mapping based on and ASTER-image of 2010, including the accuracy assessment, and land cover/land use loss caused by inundation, following the scenarios presented in section 4.1. Proposed adaptation options with TOWS matrix analysis is described in the third sub-chapter (4.3). Sub-chapter for (4.4) presents a visualization of adaptation options.

### 4.1 Inundation Mapping

The inundation model was generated using DEM and different scenarios of cumulative effect. This model was projected for the next 25 and 50 years.

#### 4.1.1 Digital Elevation Model (DEM)

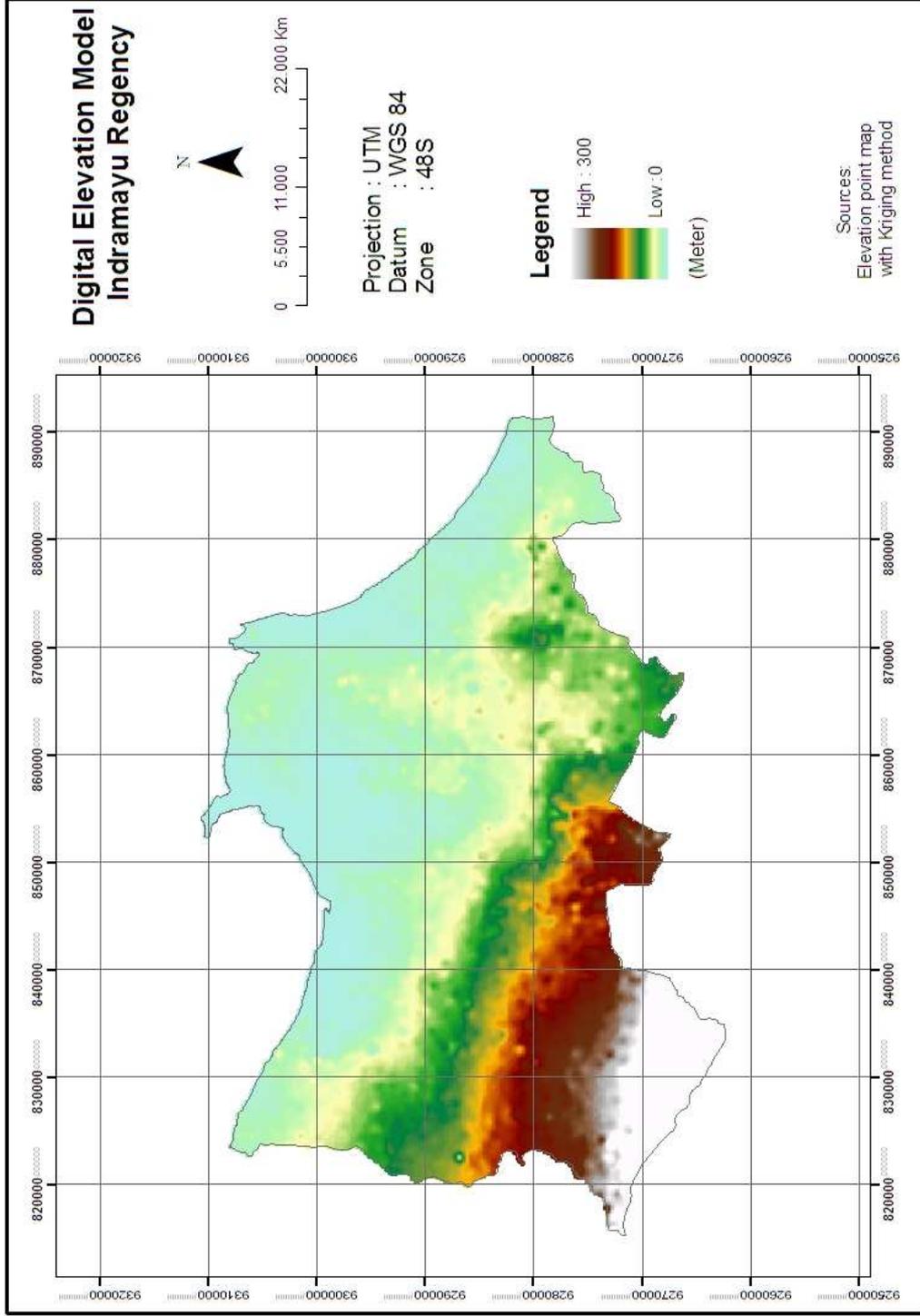
Derived from some 2612 elevation points, a Digital Elevation Model (DEM) of Indramayu Regency (figure 4.1) was generated using ILWIS. The DEM was interpolated based on Kriging method of a point elevation map (see 3. xxx) to a pixel size 15 x 15 m. The obtained minimal height difference is 1 cm.

#### Accuracy Assessment

To perform an accuracy assessment of the DEM, test samples were collected from elevation point data. Based on hold out method (Baraldi et al, 2005 after Kohavi, 1995), which typically 2/3 of the available elevation points data should be used for training and the remaining 1/3 of the elevation points data should be used as test samples. Due to the relative small point elevation data set, only 10% was used for the accuracy assessment. Based on the RMSE calculation, the result (table 4.1) shows that in general the accuracy is 1.23 m.

**Table 4.1 Accuracy Assessment of DEM**

	Height (m)			Total
	0 - 3	3 - 10	>10	
<b>RMSE</b>	0,84	1,15	1,40	1,23



**Figure 4.1 Digital Elevation Model of Indramayu Regency**

#### 4.1.2 Sea Level Rise Probabilities

In table 4.2 and figure 4.2 the estimated local sea level rise at Indramayu Regency and the probability of occurrence is presented. Basically, the formula is to multiply the historical sea level rise (8 mm/yr) in Indramayu Regency by the future number of years from 1990 plus the Normalized Sea Level Projections (see section 3.2.1.3).

**Table 4.2**  
**Estimated Local Sea Level Rise at Indramayu Regency with**  
**Normalized Sea Level Projections**

Cumulative Probabilities	Years					
	2025	2050	2075	2100	2150	2200
<b>1</b>	18	32	47	64	96	128
<b>5</b>	25	44	63	82	121	160
<b>10</b>	27	47	68	89	131	173
<b>20</b>	29	51	74	98	144	191
<b>30</b>	31	54	78	104	154	205
<b>40</b>	32	56	82	108	163	219
<b>50</b>	<b>33</b>	58	85	113	171	232
<b>60</b>	34	61	89	118	181	246
<b>70</b>	36	63	92	124	193	266
<b>80</b>	37	66	97	132	208	293
<b>90</b>	40	71	105	143	234	342
<b>95</b>	42	75	111	154	262	399
<b>97.5</b>	45	79	118	166	295	464
<b>99</b>	<b>47</b>	83	125	180	338	570
<b>Mean</b>	33	59	86	115	179	249

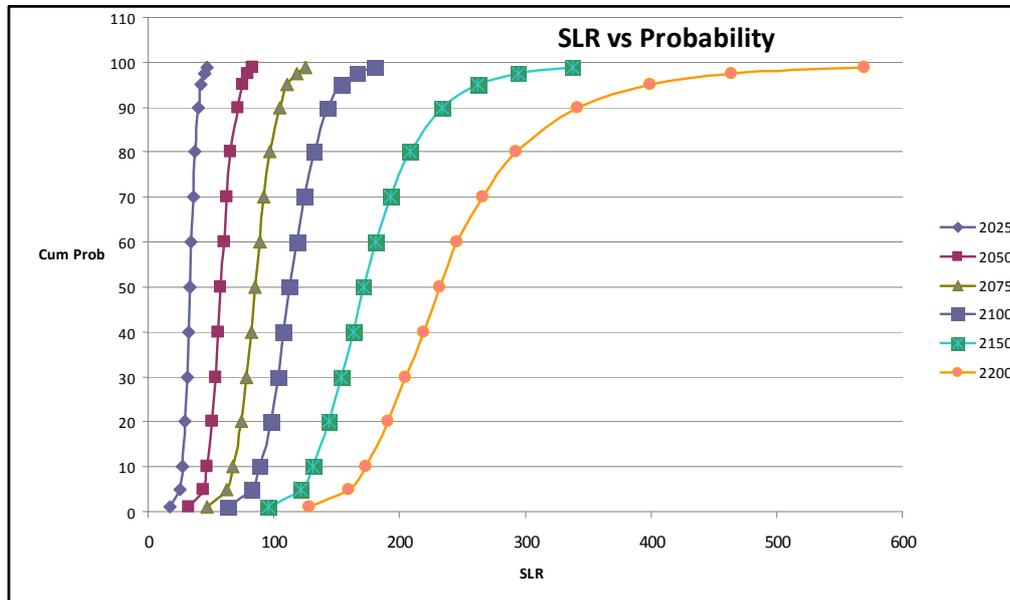


Figure 4.2 Sea Level Rise Probability Graph

#### 4.1.3 Cumulative Effect of Water Level Input and Probabilities Calculation

For local/regional planning purposes, the sea level rise alone is not sufficient and has to be adapted for tidal effects (highest high water level) and probabilities of wave heights (see section 3.1.2.3.D). In table 4.3 till 4.6 the cumulative effect for the three scenarios is presented. The selection of the scenarios is discussed in section 3.2.1.3. The cumulative effect for the different scenarios was input for the visualization (based on the DEM) of the areas which subsequently are inundated (see section 4.2.2 and figure 4.6 till 4.12).

Since MSLR are given as probabilities, it was decided to depict 3 scenarios for a MSLR with a probability 1% and 50%, expressed as cumulative probabilities that would be MSLR 1% and MSLR 50% cumulative probability.

**Table 4.3 Cumulative Effect of Water Level Input Calculation for 25 years Scenario**

	Scenario								
	MSLR 1% prob			MSLR 50% prob			MSLR 1% prob		
MSLR (cm)	27	27	27	42	42	42	60	60	60
HHWL (cm)	113	113	113	113	113	113	113	113	113
Wave Height (cm)	70	88	108	70	88	108	70	88	108
<b>Cumulative Effect (cm)</b>	<b>210</b>	<b>228</b>	<b>248</b>	<b>225</b>	<b>243</b>	<b>263</b>	<b>243</b>	<b>261</b>	<b>281</b>
		<b>25 Low</b>			<b>25 Mid</b>			<b>25 High</b>	

**Table 4.4 Cumulative Probabilities Calculation for 25 years Scenario**

	MSLR 1% prob			MSLR 50% prob			MSLR 1% prob		
	MSLR	0,01	0,01	0,01	0,5	0,5	0,5	0,01	0,01
HHWL	1	1	1	1	1	1	1	1	1
Wave Height	1	0,5	0,25	1	0,5	0,25	1	0,5	0,25
<b>Cum. Probabilities</b>	<b>0,01</b>	<b>0,005</b>	<b>0,0025</b>	<b>0,5</b>	<b>0,25</b>	<b>0,125</b>	<b>0,01</b>	<b>0,005</b>	<b>0,0025</b>
		<b>25 Low</b>			<b>25 Mid</b>			<b>25 High</b>	

From table 4.3 and table 4.4 that can be explained about the cumulative effect and its occurrence probabilities for 25 years. The most occurrence will be happened in 225 cm cumulative effect. It is caused by each water level input in that scenario has higher probabilities than the others. The main factor that made the different cumulative probabilities is the choice of wave height scenario. It is also happened in scenario 50 years (see table 4.5 and 4.6) as well.

**Table 4.5 Cumulative Effect of Water Level Input Calculation for 50 years Scenario**

	Scenario					
	MSLR 1% prob		MSLR 50% prob		MSLR 1% prob	
MSLR (cm)	37	37	68	68	98	98
HHWL (cm)	113	113	113	113	113	113
Wave Height (cm)	88	108	88	108	88	108
Cumulative Effect (cm)	238	258	269	289	299	319
	50 Low		50 Mid		50 High	

**Table 4.6 Cumulative Probabilities Calculation for 50 years Scenario**

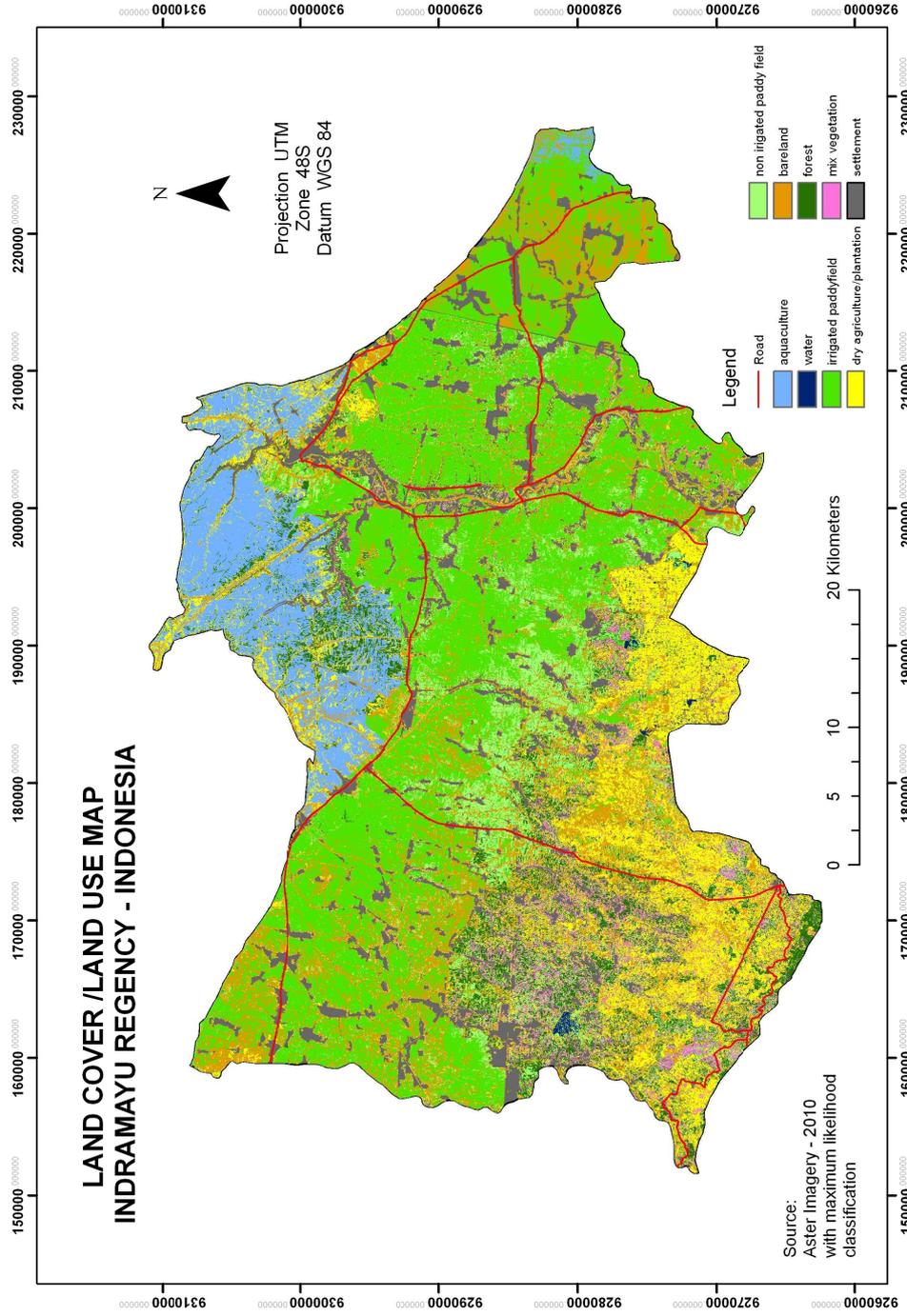
	MSLR 1% prob		MSLR 50% prob		MSLR 1% prob	
MSLR	0.01	0.01	0.5	0.5	0.01	0.01
HHWL	1	1	1	1	1	1
Wave Height	0.5	0.25	0.5	0.25	0.5	0.25
Cum. Probabilities	0.005	0.0025	0.25	0.125	0.005	0.0025
	50 Low		50 Mid		50 High	

## 4.2 Impact of Inundation to Land Cover/Land Use

### 4.2.1 Land Cover/Land Use Classification

For the production of the land cover/land use map an ASTER image of 2010 was used. The ground truth was derived from Google earth image. Then the image was classified using the Maximum Likelihood classifier (see section 3.3.2.1). The results are presented in figure 4.2 and 4.3 and table 4.7. It clearly shows that rice cultivation (irrigated and non irrigated) by at far the most important land use type in the area.





**Figure 4.3 Land Cover/Land Use Map**

**Table 4.7 Total Area of Each Land Cover/Land Use Class**

<b>Land Cover / Land Use Class</b>	<b>Area (Ha)</b>	<b>Percentage</b>
Aquaculture	17,622.38	8.66
Water body	300.08	0.15
Irrigated paddy field	62,454.04	30.69
Dry agriculture/ plantation	25,653.96	12.60
Non-irrigated paddy field	18,575.42	9.13
Bare land	35,137.10	17.26
Forest	17,849.05	8.77
Mix vegetation	9,338.96	4.59
Settlement	16,599.58	8.16
<b>Total</b>	<b>203,530.57</b>	<b>100</b>

For the accuracy assessment an independent validation set of 203 points was derived from error matrix assessment (see section 3.3.2.1). The results of the accuracy assessment are presented in table 4.8. The lowest accuracy occurred in class forest, mix vegetation, and bare land. From the table it can be seen that confusion happened between forest and mix vegetation. It is caused by the difficulty to separate their appearance when taking training samples. Confusion also can be seen between bare land and irrigated paddy field class. This misclassify might be caused by there is a time difference in capturing images between Aster and Google Earth. Overall accuracy in land cover mapping is classified good accuracy if it achieves 80-85% (Dewi, 2009 after Treitz, 2004). The overall accuracy resulted in this study area was 75.9%. It was not too far from the standard.

**Table 4.8 Error Matrix of Aster Image Classification**

<b>Class Name</b>	aquaculture	water	irrigated paddy field	dry agriculture / plantation	non irrigated paddy field	Bare land	forest	mix vegetation	settlement	<b>Total</b>	<b>User Accuracy</b>
aquaculture	<b>21</b>									21	<b>100</b>
water		<b>5</b>								5	<b>100</b>
irrigated paddy field			<b>29</b>		3					32	<b>90.6</b>
dry agriculture / plantation	1	1		<b>20</b>		3		3		28	<b>71.4</b>
non irrigated paddy field		1	1		<b>20</b>					22	<b>90.9</b>
Bare land		1	10			<b>15</b>		1	1	28	<b>53.6</b>
forest	3			3	1	2	<b>16</b>	4		29	<b>55.2</b>
mix vegetation						1	9	<b>15</b>		25	<b>60</b>
settlement									<b>13</b>	13	<b>100</b>
<b>Total</b>	25	8	40	23	24	21	25	23	14	<b>203</b>	
<b>Producer Accuracy</b>	<b>84</b>	<b>62.5</b>	<b>72.5</b>	<b>87.0</b>	<b>83.3</b>	<b>71.4</b>	<b>64</b>	<b>65.2</b>	<b>92.9</b>		<b>75.9</b>

#### 4.2.2 Land Cover/Land Use Loss

Based on section 3.3.2, inundation will impact to land cover/land use loss.

##### 4.2.2.1 Land Cover/Land Use Loss in 25 years Scenario

From figure 4.5 and table 4.9 it can be seen that in 25 years for 3 different scenarios, the most area that will be impacted by inundation are irrigated paddy field, and followed by aquaculture.

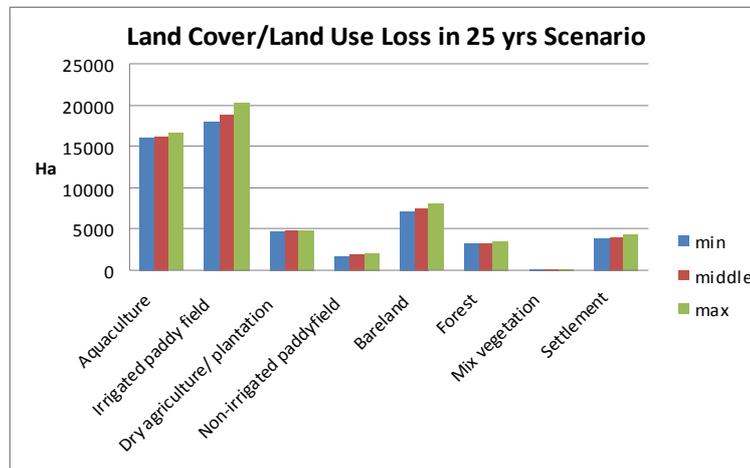
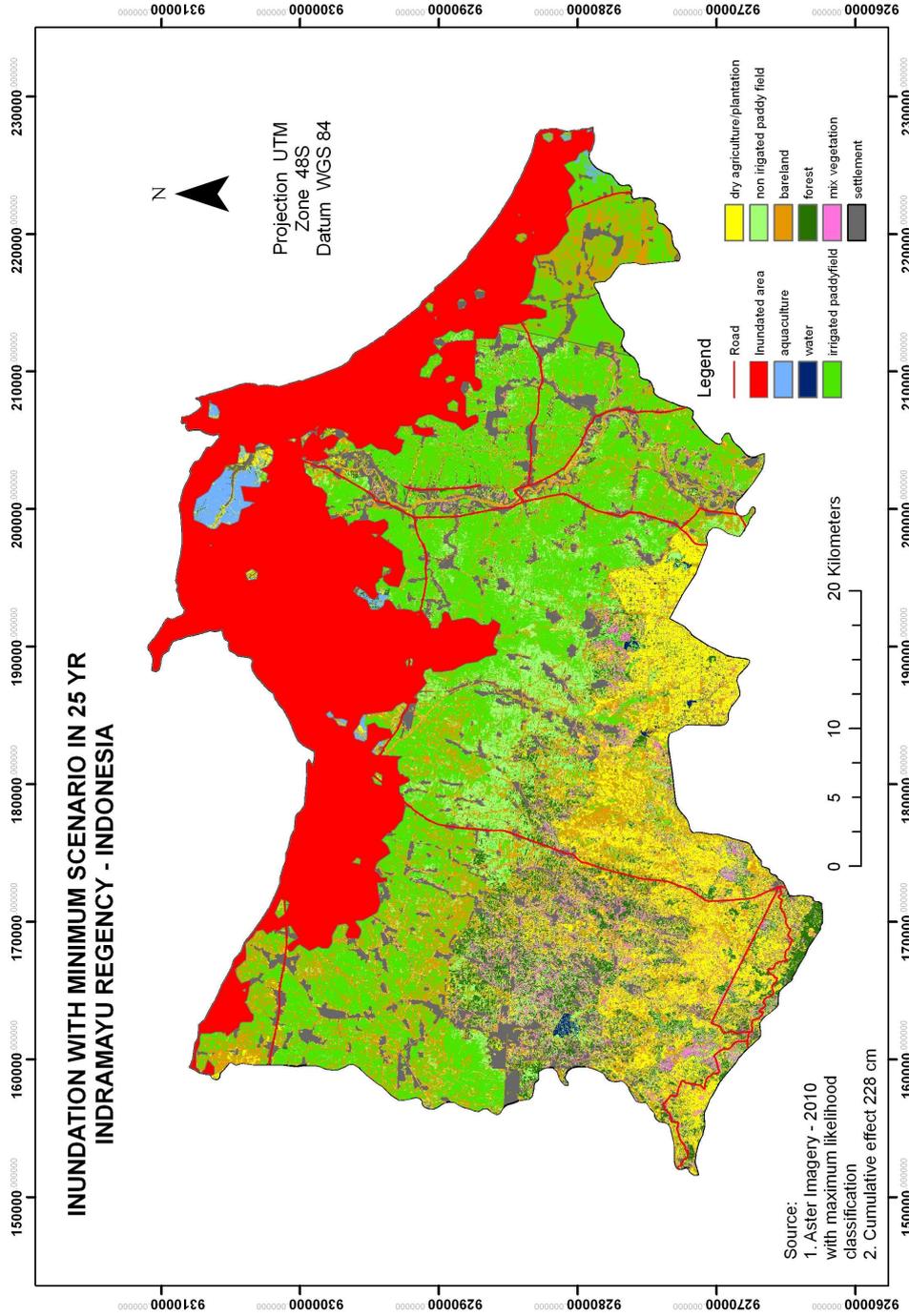


Figure 4.4 Land Cover/Land Use Loss in 25 years Scenario



**Figure 4.5 Inundation with Minimum Scenario in 25 yrs**

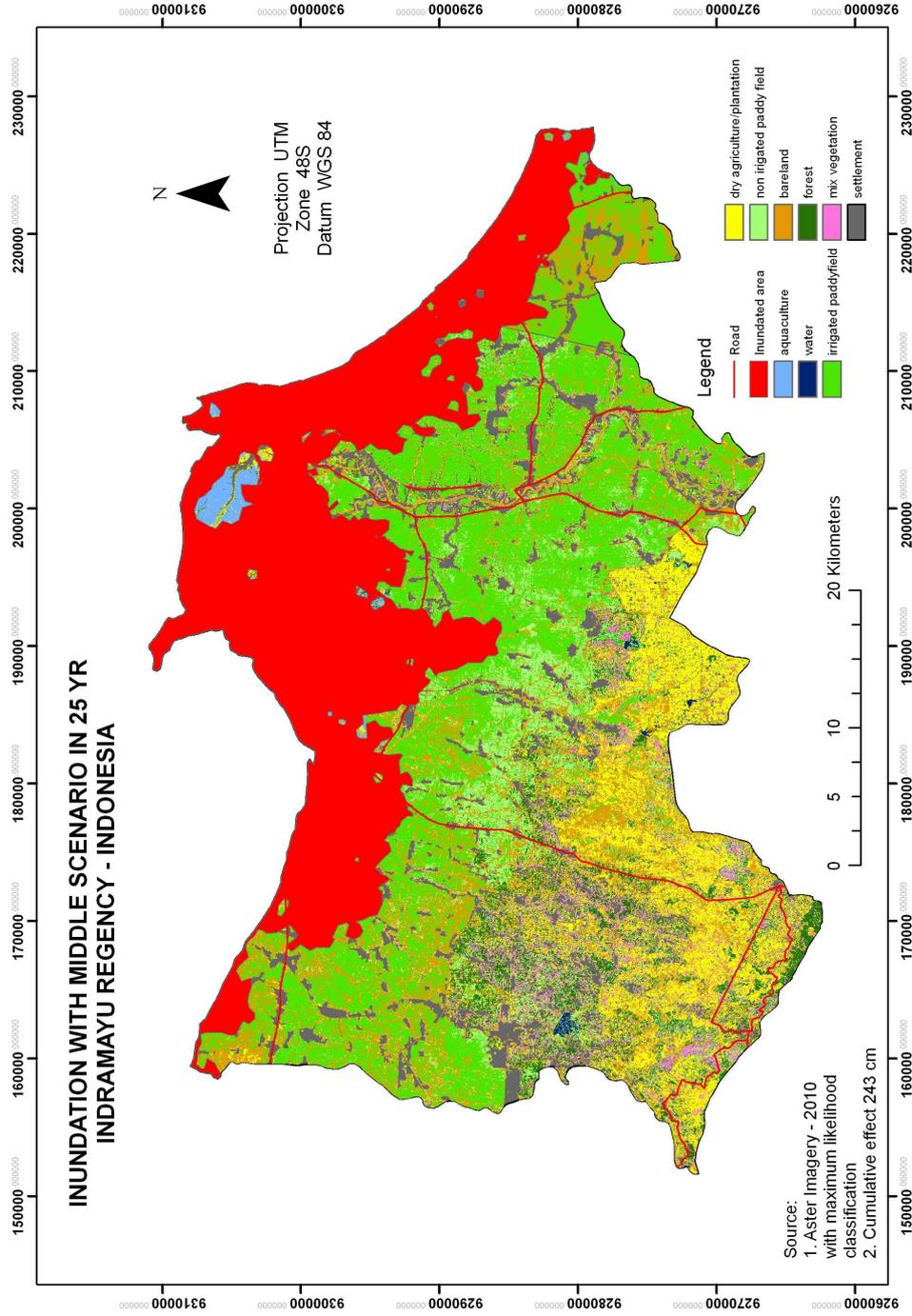
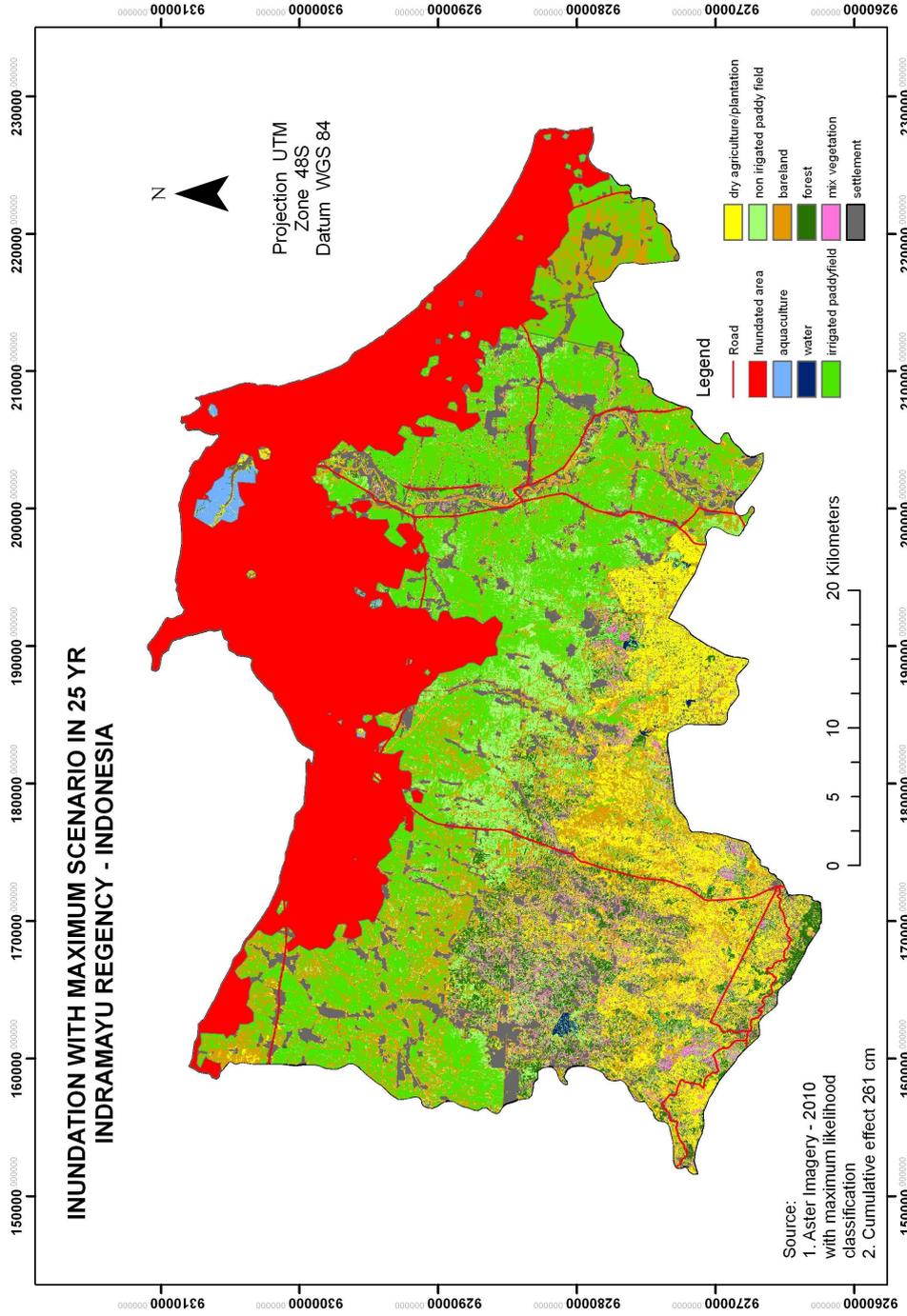


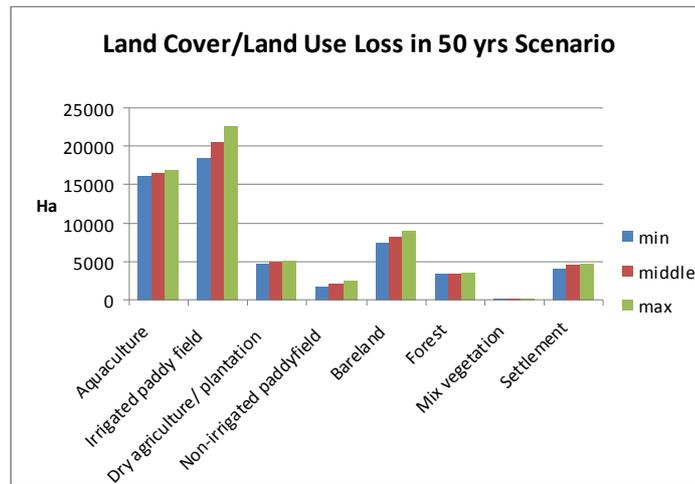
Figure 4.6 Inundation with Middle Scenario in 25 yrs



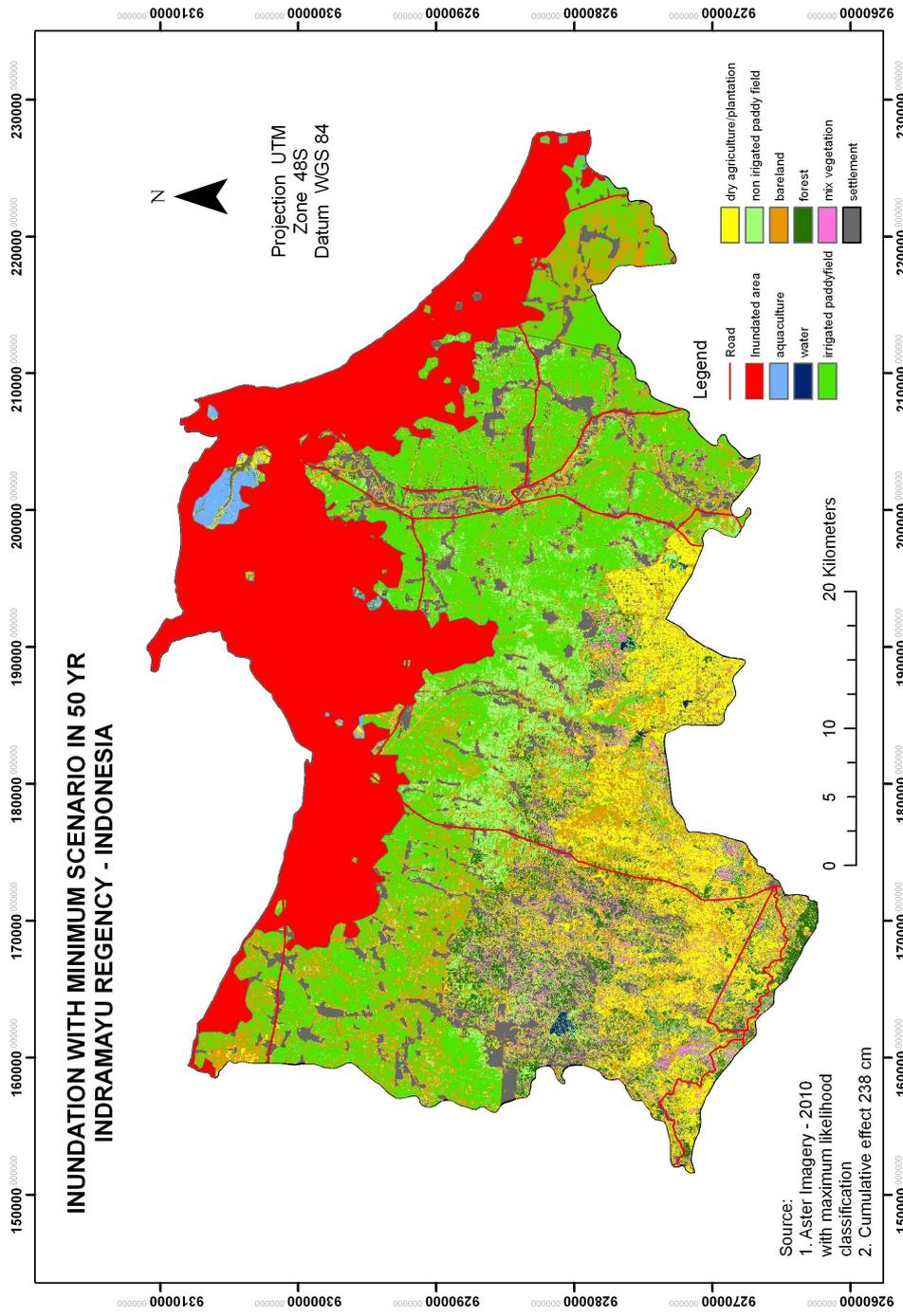
**Figure 4.7 Inundation with Maximum Scenario in 25 yrs**

#### 4.2.2.2 Land Cover/Land Use Loss for 50 years Scenario

From figure 4.9 and table 4.9 can be seen that in 50 years for 3 different scenarios, the most area that will be impacted by inundation are irrigated paddy field, and followed by aquaculture.



**Figure 4.8 Land Cover/Land Use Loss in 50 years Scenario**



**Figure 4.9 Inundation with Minimum Scenario in 50 yrs**

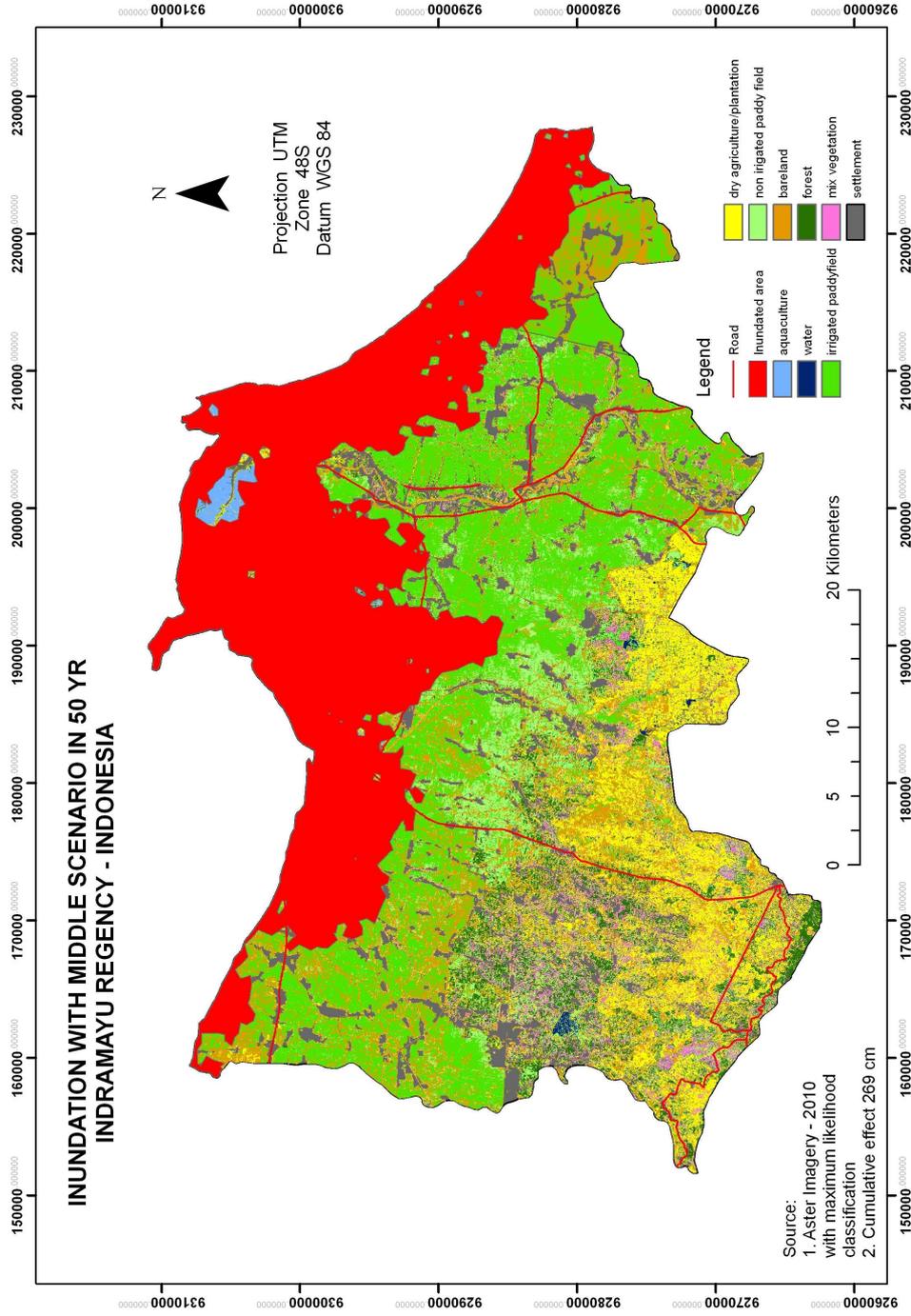


Figure 4.10 Inundation with Middle Scenario in 50 yrs

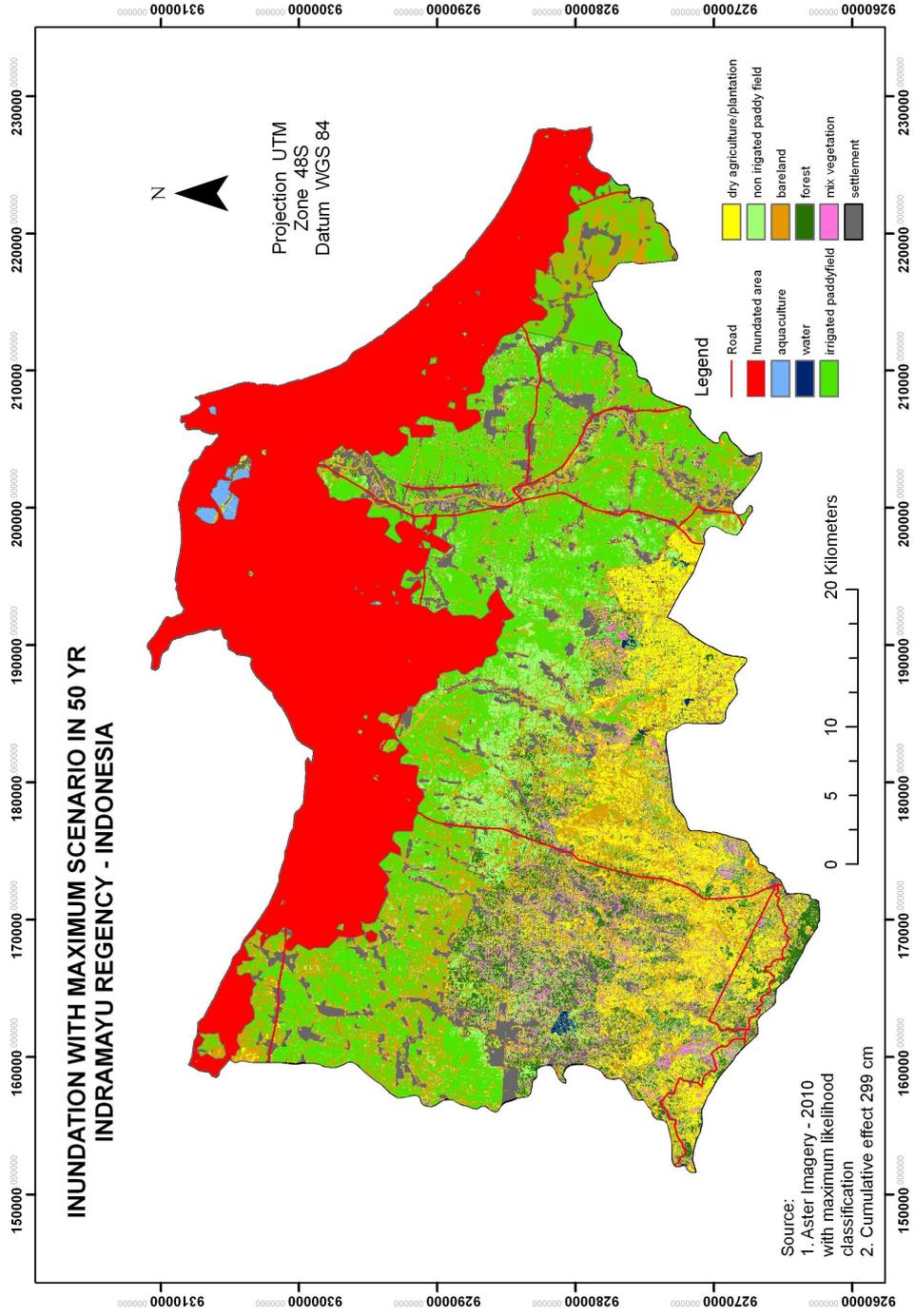


Figure 4.11 Inundation with Maximum Scenario in 50 yrs

In table 4.9 the effect of inundation of the various scenarios is summarized in tabular form.

**Table 4.9 Total Land Cover/Land Use Loss**

Class name	25 years			50 years		
	min	middle	max	min	middle	max
Aquaculture	16,001.19	16,319.52	16,580.95	16,228.91	16,674.08	17,045.80
Irrigated paddy field	17,939.66	18,822.26	20,208.35	18,522.45	20,678.56	22,735.24
Dry agriculture/ plantation	4,746.62	4,871.75	4,975.88	4,820.74	5,015.81	5,150.09
Non-irrigated paddy field	1,717.34	1,844.89	2,032.07	1,786.88	2,103.55	2,409.59
Bare land	7,187.81	7,568.10	8,033.15	7,432.65	8,224.36	8,924.54
Forest	3,314.95	3,364.52	3,426.91	3,342.65	3,455.24	3,535.85
Mix vegetation	163.10	171.52	191.75	168.57	196.07	215.35
Settlement	3,818.72	4,098.24	4,421.23	4,026.83	4,520.57	4,807.94
<b>Total</b>	<b>54,889.38</b>	<b>57,060.79</b>	<b>59,870.27</b>	<b>56,329.67</b>	<b>60,868.22</b>	<b>64,824.39</b>

As an alternative approach to measure the impact of inundation, vulnerability assessment was used for land loss calculation (see section 3.3.1). Table 4.10 shows that mostly in 25 and 50 years scenario, Indramayu Regency will be categorized as high vulnerable.

**Table 4.10 Vulnerability Class**

	25 years			50 years		
	min	middle	max	min	middle	max
<b>% Loss</b>	26.97	28.04	29.42	27.68	29.91	31.85
<b>Vulnerability Class</b>	High	High	High	High	High	Critical

### **4.3 Proposed Adaptation Options**

This sub chapter tried to identify several alternative adaptations options that could be carried out to deal with the inundation impact in Indramayu Regency, based on interview result from stakeholder (see section 3.3.1). These selected adaptations are:

1. shifting paddy fields to fish ponds
2. dredging the river outlet / drainage
3. embankment
4. seawall
5. small scale protection
6. silvofishery
7. mariculture
8. cultivate salt tolerant crops and fish
9. soft protection (beach nourishment)

Researcher tried to analyze further for each selected adaptation option with TOWS Matrix (Table 4.10) regarding to section (3.3.1).

**Table 4.11 TOWS matrix**

	<b>External Opportunities (O)</b> 1. Central government support regarding to the SLR impact 2. Dissemination of new aquaculture methods and information regarding to the SLR impact 3. Support from industries which located at the site	<b>External Threats (T)</b> 1. Sea level rise and extreme events
<b>Internal Strengths (S)</b> 1. Local Government Support 2. Awareness of all stakeholders to the vulnerability of SLR at their area. 3. Willingness of farmer to change the aquaculture methods 4. All stakeholders understand the benefit of natural protection	<b>SO</b> 1. Soft Structure 2. Silvofisheries 3. Shifting paddy field to fish pond	<b>ST</b> 1. Building structure along the coast as protection (sea wall, embankment)
<b>Internal Weaknesses (W)</b> 1. Limited budget availability to support adaptation activities 2. Social conflict that may occur because of applying adaptation strategy	<b>WO</b> 1. Mangrove Plantation 2. Cultivate salt tolerant crop or fish	<b>WT</b> 1. Increasing self awareness of coastal communities to the risk through dissemination.



From the TOWS matrix above, it can be explained clearly for each strategy.

- I. Combination of the Internal Strengths and the External Opportunities. The adaptation strategies from this combination are:
  1. Building soft structures which are used to protect coastal areas of Indramayu from the incoming of sea level rise in the future. There are supports from central and local government.
  2. Implementation of Silvofisheries method. This strategy supported by central government through the dissemination of environmental friendly aquaculture practices under auspices of Directorate General of Aquaculture, Ministry of Marine Affairs and Fisheries (MMAF). The willingness of fish farmer to adopt silvofisheries method will be valuable because silvofisheries method considered environmental and economical aspect. Fish farmer can continue their activities as the fish farmer and they also protect their land from erosion by planting mangrove around their pond.
  3. Shifting paddy field to fish pond. This strategy is a respond to the intrusion on salt water to the irrigation canal. This strategy could be categorized as accommodation strategy for the farmer at the study areas. By shifting from paddy field to fish pond that used brackish water is an alternative solution for the farmer to make their living from aquaculture activities. This strategy is supported by central and local government through dissemination and training for local farmer.
- II. Combination of the Internal Strengths and the External Threats. The adaptation strategy for this combination is:
  1. Building structure along the coast as the protection. This strategy is applying to the external threat such as increasing of sea level and abrasion of coastal lines. Hopefully this structure could be build from local government budget.
- III. Combination of Internal Weakness and the External Opportunities. The adaptation strategies for this combination are:
  1. Mangrove plantation along the coastal lines of Indramayu. This strategy is representing the internal strength the awareness of local people and stakeholders of Indramayu regency to the risk of sea level rise. The willingness of local communities to plant mangrove very important for the sustainability this program.
  2. Cultivate salt tolerance crop or fish. This strategy will depend much to the opportunities to get the wider customer for the fish product especially shrimp.
- IV. Combination of the Internal Weakness and the External Threats. The adaptation strategy for this combination is:
  1. Increasing self awareness of coastal communities to the risk through dissemination. This strategies will be the last available option strategy, because this strategy much depend on the willingness of the coastal communities and less effort and budget to be spent.

## 5. DISCUSSION

### 5.1 Inundation Mapping

As explained in chapter 3, the main factors for defining inundated areas are elevation and water levels expressed in probabilities of occurrence.

#### Sea Level Rise Projection

Sea level rise prediction with normalized projection has advantage in accommodating local sea level rise with all global scenario projection. The result gives not only average prediction, but also probabilistic of occurrence. It is not like other deterministic method that has been applied in previous research (using IPCC scenario and etc) which only give average value. This model has been applied in the adaptation plan of Punta Gorda City, Florida (Beever, 2009). For the planning purpose, this projection will give range scenario for decision maker. If the maximum scenario is applied, it will define where the maximum risk area is. Furthermore, the loss will diminish, but on the other side it will demand higher budget for development.

#### Cumulative effect

Cumulative effect from MSLR, tidal movement, and wave height, will give the picture from each scenario what would be happened. Basic idea is to give general picture how to put MSLR and extreme events into inundation modeling in this area. MSLR input in various probabilistic calculations gave an advantage to know different cumulative effect in various scenarios. Weakness from tidal movement input, derived from single observation, cannot give probabilistic picture. Ideally the use of HHWL data is derived from field time series data, so it can be predicted for long term projection. Since the data is not available, researcher assumed that single value data of HHWL can be used for various scenarios. Based on previous report (Ministry of Public Work, 2008), this single observation can be used for 18.6 year (1 lunar cycle), it is related to astronomical explanation which assumed that there is no significant changes of interaction behavior among the sun, moon, and earth. Indeed, it cannot be used for projected scenario for 25 and 50 years, at least it gave general picture how HHWL contribute to cumulative effect.

Wave height data is related to various return periods. It becomes an input in the selection of scenario. In this research, wave height maximum (Hmax) data that has been used, it was assumed constant.

### **Cumulative probabilistic**

From cumulative probabilistic calculation, it can be known the probabilistic of occurrence from cumulative effect in each scenario. Since, the tidal movement data only had 1 value, it affected to the cumulative effect result. Moreover, the probability of occurrence will be less precise. MSLR becomes main factor in the cumulative probabilistic calculation.

### **Digital Elevation Model (DEM)**

To achieve the expected result of inundated areas distribution, minimum vertical accuracy level ( $\Delta h$ ) of DEM has to be considered with local sea level rise rate ( $\Delta SL$ ). Even with a vertical input resolution on the order of 0.01 m, the distribution of elevation point itself is sparse compared to the width of research area (204 ha). The average distance between two points is around 0.4 km. It leads to the limitation of DEM generation, because the interpolation result turns into rough. Interpolation in average of the topographic surface, not give real condition. Detail topographic features, cannot be expected to be visualized through the interpolation of the point. It means in the reality (compared to smaller scale) the cumulative effect will not reach in the precision elevation height.

Since the RSME resulted for the elevation 0-3 m is 0.83 m, compared to selected cumulative effect from 228 to 299 cm, this result still can be accepted. RSME = 0.83 m, it is only precise for cumulative effect (m), not for MSLR (cm). For mapping inundation caused only by MSLR, it is needed better scale. In addition the RSME result will affect to the calculation of land loss caused of inundated.

### **Iteration process**

Advantage using iteration process in ILWIS will give better precision in defining inundated area with considering topographic features. This process calculated neighbor pixel value which has different height. If it is compared with other softwares, only calculate based on different height.

## **5.2 Land Loss**

Land loss calculation only considers land use loss, for better risk assessment needed detailed social and economic data. It is assumed there is no land use change until next 50 year. Land use loss was used as straight forward example of showing the effect on the elements at risk. For industrial sites, the loss can be visualized, but the effect of the loss is far more complex, for example loss of work, effect of the loss on connected enterprises etc.

## **5.3 Adaptation Options**

TOWS matrix analysis has advantage to mapping the strength and weakness from each adaptation option that has been identified. From this analysis will be known which adaptation option will be feasible. The adaptation options were focused on agriculture (irrigated and non irrigated paddy field), aquaculture, and settlement. Agriculture and aquaculture have big contribution in the economic sector. The consideration

factor are land value and total land loss. The other elements of risk were not taken into consideration, for example industrial sector. The loss from this sector cannot be measured directly, because it is related to the loss of central industry. The biggest impact from sea level rise to aquaculture and agriculture is increasing salinity and water column. For aquaculture, there are several solutions as follows:

- a. To overcome salinity problem, cultivate salt tolerant fish e.g. from shrimp (udang windu /*Penaeus monodon*) to udang putih (*Pennaeus vannamei*) or bandeng/milkfish (*Chanos chanos*).
- b. To overcome increasing water column, change species and propose polyculture (mix used) between shrimp (udang laut) and seaweed (*Gracillaria*).

In general the adaptation options for this land use are silvofishery (mix used between fishponds and mangrove) and mangrove plantation. For agriculture, the solutions include:

- a. cultivate salt tolerant paddy field
- b. mix used (mina padi), which outer part is used for fishponds and in the inner part is used for cultivating paddy field
- c. shift paddy field into fish ponds, For agriculture activities, the farmer is asked to shifting their activities to be fish farmer. This option is applied because no alternative income for the farmer if they abandon their agricultural land, so shifting their activity is the best choice for them.

For settlement, there are two options for adaptation:

- accommodation, such as building code, make a higher foundation  
Government should apply building code for settlement which vulnerable to the inundation. 2 floors building for all settlement, 1st floor is used as the empty space to let the inundated water flow through, 2nd floor will be the room for family or other activities.
- Retreat, such as near to infrastructure, utility disadvantage, it is difficult, social conflict (it is not easy to ask people move to another part), budget (government have to spend money).

Actually from 2 scenarios, the dominance of land cover/land use type that will be lost is same. The difference is only on the total area. So, the adaptation options that will be recommended, it will be the same also. In general proposed adaptive planning strategy in coastal area of Indramayu Regency based on 3 adaptation options:

- a. Protection adaptation option;  
This option will propose for industrial area that has high economic value (e.g. gas and oil industry). The physical measure is such as building of coastal defense like sea wall and dike.
- b. Accommodation adaptation option;  
These adaptations will be applied for agriculture, aquaculture and settlement.
- c. Retreat adaptation option  
This option will be applied for settlement if the effect becomes worst.

#### **5.4 Limitation of the research**

There are several obstacles that researcher faced while doing this research, such as:

- a. For DEM generation, researcher could not get more detail elevation point data in this area. It leads to the resulted accuracy that can not be used for inundation mapping only based on MSLR.
- b. There is no time series data available for tidal movement from the field observation. It will affect to the cumulative effect and cumulative probabilities calculation.
- c. Lack of detail from recommended adaptation options, since the identification of each factor in TOWS analysis is not specific.

## 6. CONCLUSION AND RECOMMENDATION

### 6.1 CONCLUSION

Based on research questions that are listed in chapter 1, there are several conclusions as follows:

- a. *What is the probability of occurrence in various scenarios 25 and 50 years of the cumulative effect of MSLR, tidal range, and wave height?*

Based on the input data and processing method described in section 3.3.1.2 and 4.1.3 respectively, the probability of the cumulative effect of mean sea level rise, tidal range and wave height scenarios was calculated for a number of scenario's. The probabilities of occurrence in 25 year scenario with 25 Low and 25 High is 0.005, and for 25 Middle is 0.25, as well as for 50 year scenario.

- b. *How much area will be inundated by cumulative effect over the next 25, and 50 years respectively?*

The obtained water levels of the previous step in combination with the DEM (see section 4.1) allowed mapping of the inundated area for each scenario. For 25 years scenario the inundated area was predicted with 25 Low, 25 Middle, and 25 High are 54,896 ha, 56,336 ha, and 57,067 ha. Likewise for 50 year scenario, the area that will be inundated are 60,875 ha, 56,336 ha and 64,831 ha.

- c. *What is the current land cover/land use in this area?*

The current land cover land use map was based of the supervised classification of an Aster image of 2010 in combination with an existing land cover/land use map and Google earth which were used for ground truth (see section 3.3.2.1). The newly compiled map consist of the following land cover/land uses classes and has an over all accuracy of 75.9% (see section 4.2.1).

Based on image classification result, land cover/land use in this area is consisted of Aquaculture, irrigated and non-irrigated paddy field, dry agriculture/plantation, bare land, forest, mix vegetation, settlement, and water body.

- d. *How much land per land cover/land use type will be inundated due to the cumulative effect over the next 25 and 50 years respectively?*

The various inundation maps (see 6.1.a) were superimposed over the land cover land use map (see 6.1.b) in order to establish the land cover/land use loss for the different scenarios (see table 4.9).

- e. *What kinds of adaptation options are feasible?*

Actually there are 3 adaptation options that can be applied in Indramayu Regency as follows, accommodation, protection and retreat. Based on TOWS matrix analysis, the most feasible is

accommodation option, even though protection option can be used for small scale and retreat option is used for the worst scenario.

Notwithstanding the limitations of the research (see chapter 5), it can be concluded that the approach in this research yield suitable information for adaptive strategy planning within the scope of adaptive strategy in coastal resources management in the face of sea level rise.

## **6.2 Recommendation**

- To get more precise prediction cumulative effect and cumulative probabilities, it is required time series data for tidal movement.
- To get more accurate on the assessment of digital elevation model in this area, the higher scale of elevation point data from topographic map or satellite imagery is needed.
- Social and economic data are useful for further research in loss assessment caused by inundation.

## References

- Baraldi, Andrea., Lorenzo Bruzzone, and Palma Blonda. 2005. *Quality Assessment of Classification and Cluster without Ground Truth Knowledge*. Ieee Transactions On Geoscience And Remote Sensing, Vol. 43, No. 4.
- Committee on Engineering Implications of Changes in Relative Mean Sea Level. 1987. *Responding to Changes in Sea Level (Engineering Implications)*. National Academy Press. Washington, D.C.
- Dale, Pat ER., Mike B. Dale, Julie Anorov, Jon Knight, Marc C. Minno, Bernie Powell, Richard C. Raynie, and Jenneke M.Visser. 2006. *9 Aspects of Adaptive Management of Coastal Wetlands: Case Studies of Processes, Conservation, Restoration, Impacts and Assessment*. Springer-Verlag Berlin Heidelberg.
- Daniels, Richard C. 1996. *An Innovative Method of Model Integration to Forecast Spatial Patterns of Shoreline Change: A Case Study of Nags Head, North Carolina*. The Professional Geographer, 48:2, pp 195-209.
- Dewi, Kristina.2009.*Forest Cover change and Vulnerability of Gunung Merbabu National Park*. Master Thesis. ITC. Enschede.
- Deyle, Robert E., Katherine C. Bailey, and Anthony Matheny. 2007. *Adaptive Response Planning to Sea Level Rise in Florida and Implications for Comprehensive and Public-Facilities Planning*. Florida State University. Milwaukee.
- [http://www.coss.fsu.edu/durp/sites/coss.fsu.edu.durp/files/WPS\\_08\\_02\\_Deyle.pdf](http://www.coss.fsu.edu/durp/sites/coss.fsu.edu.durp/files/WPS_08_02_Deyle.pdf)
- FAO Guidelines. 1998. *Integrated Coastal Area Management and Agriculture, Forestry and Fisheries*. FAO. Rome.
- Finkl, Charles W., Jr. 1994. *Coastal Hazards: Perception, Susceptibility and Mitigation*. the Coastal Education & Research Foundation, Inc. Florida.
- Frasseto, Roberto. 1989. *Proceedings of the First International Meeting, Cities on Water: Impact of Sea Level Rise on Cities and Regions*. Marsilio Editori. Venice.
- Hennecke, Werner G., Catharina A. Greve, Peter J. Cowell, and Bruce J. Thom. 2004. *GIS-Based Coastal Behavior Modeling and Simulation of Potential Land and Property Loss: Implications of Sea Level Rise at Collaroy/Narrabeen Beach, Sydney (Australia)*. Coastal Management 32:449-470, Taylor & Francis Inc.Report
- ILWIS. *User Guide-Tutorial*. 2001.
- IPCC. 2005. Assessment of Adaptation Practices, Options, Constraint and Capacity (IPCC WGII Fourth Assessment). <http://www.ipcc-wg2.org/index.html>
- Jelgersma, S., J. Oerlemans, J.C. van Dam, H.J. Liebscher, GHP Oude Essink, R.H. Boekelman, MCJ Bosters, W.J. Wolff, K.S. Dijkma, B.J. Ens, J.W. Day Jr., Didier Pont, Charles Ibanez, P.F. Henzel, L. Bijlsma, R. Hillen, R. Misdorp. 1993. *Sea Level Changes and Their Consequences for Hydrology and Water Management: Fundamental Aspects, Policy in Low Lying Coastal Regions and Deltaic Areas*. Tidal Water Division. The Hague.
- Maciver, D.C., and Francisco Dallmeier, 2000, *Adaptation to Climate Change and Variability: Adaptive Management* (Environmental Monitoring and Assessment 61: 1-8), Kluwer Academic Publishers – Netherlands.
- Malczewski, Jacek. 1993. *GIS and Multicriteria Decision Analysis*. John Wiley and Sons, Inc. Toronto.
- Marfai, M.A., 2007. *Coastal Flood Assessment by Means of GIS Technology*. UGM. Jogjakarta.
- Marfai, M.A., 2006. *Potential Vulnerability Implications of Coastal Inudation Due to the Sea Level Rise for the Coastal Zone of Semarang City, Indonesia*. Environ-Geol. Springer-verlag.

- Maune, D.F. 2001. *Digital Elevation Technologies and Applications: the DEM User Manual*. Bethesda.
- Milliman, John D., and Bilal U Haq. 1996. *Coastal Systems and Continental Margins (Volume II): Sea Level Rise and Coastal Subsidence (Causes, Consequences, and Strategies)*. Kluwer Academic Publishers. Dordrecht.
- Nicholls, Robert J. , and Nobuo Mimura. *Regional issues raised by sea-level rise and their policy implications*.  
<http://www.teamfortheworld.org/docs/articles/sealevel.pdf>
- Shataee, S. and J. Malek. 2008. *Flood Prediction and Assessment of Vulnerability Risk in the Southern Coasts of the Caspian Sea*. International Journal of Digital Earth, Vol. 1, No. 3, pp 291-303. Taylor & Francis Inc.
- Titus, James G., and Charlie Richman. *Maps of lands vulnerable to sea level rise: modelled elevations along the US Atlantic and Gulf coasts*. US EPA. Washington, DC.  
<http://www.int-res.com/articles/cr/18/c018p205.pdf>
- Titus, James G., and Vijay K. Narayanan. 1995. *The Probabilities of Sea Level Rise*. US-EPA. Washington DC.

## Appendices

### Appendix 1. Data and Material

**Table Data Used**

Data	Description	Source	Year	Resolution/Scale
Topography map	Map (shp file)	Bakosurtanal	2001	1 : 25.000
Elevation point	Map (shp file)	Bakosurtanal	2001	1 : 25.000
Sea level rise rate	Report	MMAF	2009	
Sea level observation	Report	Ministry of Public Works	2009	
Wave	Report	MMAF	2009	
Aster	Image	ITC	2010	15*15 m
Google earth	Interactive map	Google		
Indramayu Regency in Figure	Report	Central Statistics Agency	2006, 2007	
Strategic Plan 2006-2010	Report	Indramayu Marine Affairs and Fisheries Agency	2006	
Zoning Plan of Indramayu Regency Draft	Report	Indramayu Marine Affairs and Fisheries Agency	2008	
Indramayu marine and fisheries profile	Report	Indramayu Marine Affairs and Fisheries Agency	2006	
Mangrove distribution	Report	Indramayu Forestry Agency	1995 - 2007	
Disaster data in each district	Report	Indramayu Agriculture and Livestock Agency	2004 - 2006	
Aquaculture distribution map	Map (shp)	Ministry of Marine Affairs and Fisheries (MMAF)	2000	

<b>Data</b>	<b>Description</b>	<b>Source</b>	<b>Year</b>	<b>Resolution/Scale</b>
Aquaculture Spatial Plan of Indramayu Regency	Report	Indramayu Marine Affairs and Fisheries Agency	2007	
Zoning Plan of Indramayu Regency Draft	Report	Indramayu Marine Affairs and Fisheries Agency	2008	

**Table Software Used**

<b>Software</b>	<b>Used for</b>
ILWIS	- generating DEM - defining inundated areas
Erdas	- land cover/ land use classification
Arc GIS 9.3.1.	- spatial analysis land loss

## Appendix 2. DEM Detailed Flowchart

