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Brief Report
Hazard, Vulnerability and Risk Assessments of Kupang Watershed

Mercy Corps Indonesia

IPB University Bogor Indonesia

CoREM Center for Coastal Rehabilitation and Disaster Mitigation Studies

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01 INTRODUCTION

1.1 Background

Pekalongan City and Regency have been continuously affected by flood and tidal flood. From 2002-2020, 66 flood cases have been recorded in the area (BNPB 2020). The flood originate from a combination of intensive rainfall, changes in land use and river body, as well as the sea tides (Pasaribu *et al.* 2013). Historically, Pekalongan coastal area has been experiencing sea level rise of 5 mm/year (COREM-UNDIP 2020), which is higher than that of Java Sea, which is generally at 3.9 mm/year (Kismawardhani *et al.* 2018). The area also faces constant land subsidence, which was identified to range between 10-17 cm for the period of 2012-2018 (Tempo, 2019).

The recurring floods have caused not only physical (infrastructure) damages, loss of land due to permanent inundation, but also decreased community's income and increased their expense for flood anticipation. This condition has posed additional burdens to the directly-affected community as well as local government's fiscal situation.

The high level of dynamics in physical changes in the coastal area as well as area development have increased the complexity of flood events. Climate change impacts will further increase such a complexity. To formulate the appropriate controlling measures, proper understanding on flood causal factors, interaction between factors, and the area's ability in responding to flood are critical.

Reflecting on this condition, the development of an impact model capable of explaining the cross-factors interaction in a complex system is highly needed. The development of a Study on Climate Risks and Impacts Assesment in Pekalongan City and Regency is a preliminary process to build such an understanding.

The study will analyze the threat of flood and tidal flood facing the location, review the location's vulnerability (from physical, environmental ecological, social-economic, and institutional aspects), and analyze the risks developed from such threat and vulnerable condition. The results will serve as the basis for recommendation to enrich policies of Pekalongan City and Regency.

Landscape perspective and transboundary governance are two key terms that shall be adhered to by any stakeholder involved in the development of this study. The notion that Pekalongan City and Regency are located in one single landscape unit is the fundamental reason of using landscape perspective in the analysis process. The sub-systems interaction within the landscape unit is undoubtedly dynamic in which they influence each other. Any changes or interventions to be carried out in 1 location might bring about impacts to another location, which might be located within a different administrative area, thus making transboundary governance significant in any flood mitigation efforts.

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1.2 Geographic Scope

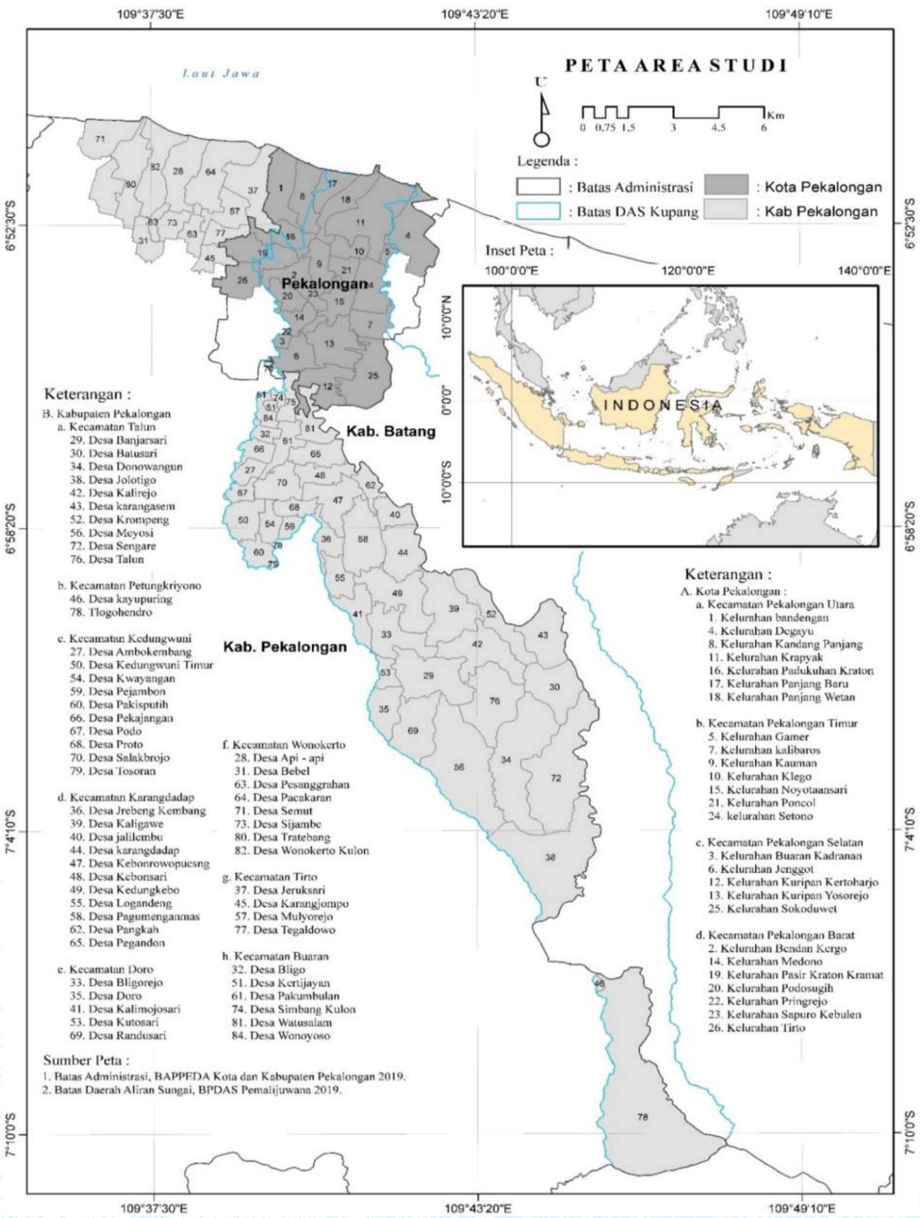
To represent the areas affected by flood and tidal floods, the focus of the study's geographic coverage was the upstream areas all the way to downstream areas of Kupang Watershed that are located within the administrative area of Pekalongan City and Regency, and the coastal area of Pekalongan City and Regency. There were a total of 84 villages/*kelurahans* covered in the study.

Although Kupang Watershed also passes across Batang Regency, for the purpose of this study, the villages in Batang District which are part of the Kupang Watershed were not included into the geographic scope.

1.3 Study Limitation

The study process contains several limitations that need to be recognized, namely:

- The villages/*kelurahans* within Kupang Watershed that are located in Batang Regency were not included into the study location, although they are still included as part of the model in climate and hazard modeling process to ensure that interactions between factors are still put into consideration.
- The rate of land subsidence was assumed to be constant every year, which was based upon data from the analysis results on land subsidence conducted during the study (data of 2019).
- Land use in the hazard analysis process was assumed to be constant throughout the projection period. However, land use change was accommodated in vulnerability and risk analysis process. The modeling of land use change tends to apply a relatively-controlled development scenario.
- Hazard analysis will only model inundation and hazard for decadal prediction and RCP 4.5 scenario (without RCP 8.5); RCP 4.5 will utilize the percentile 95 to represent the worst condition that might take place (although in mid-term and long-term, this scenario is considered moderate).
- Hazard and risk analysis processes utilize landscape analysis unit (grid scale), while vulnerability analysis utilizes village/*kelurahan* analysis unit.
- Due to limited data and types of indicators, not all indicators are projected dynamically in the process of vulnerability index projection.

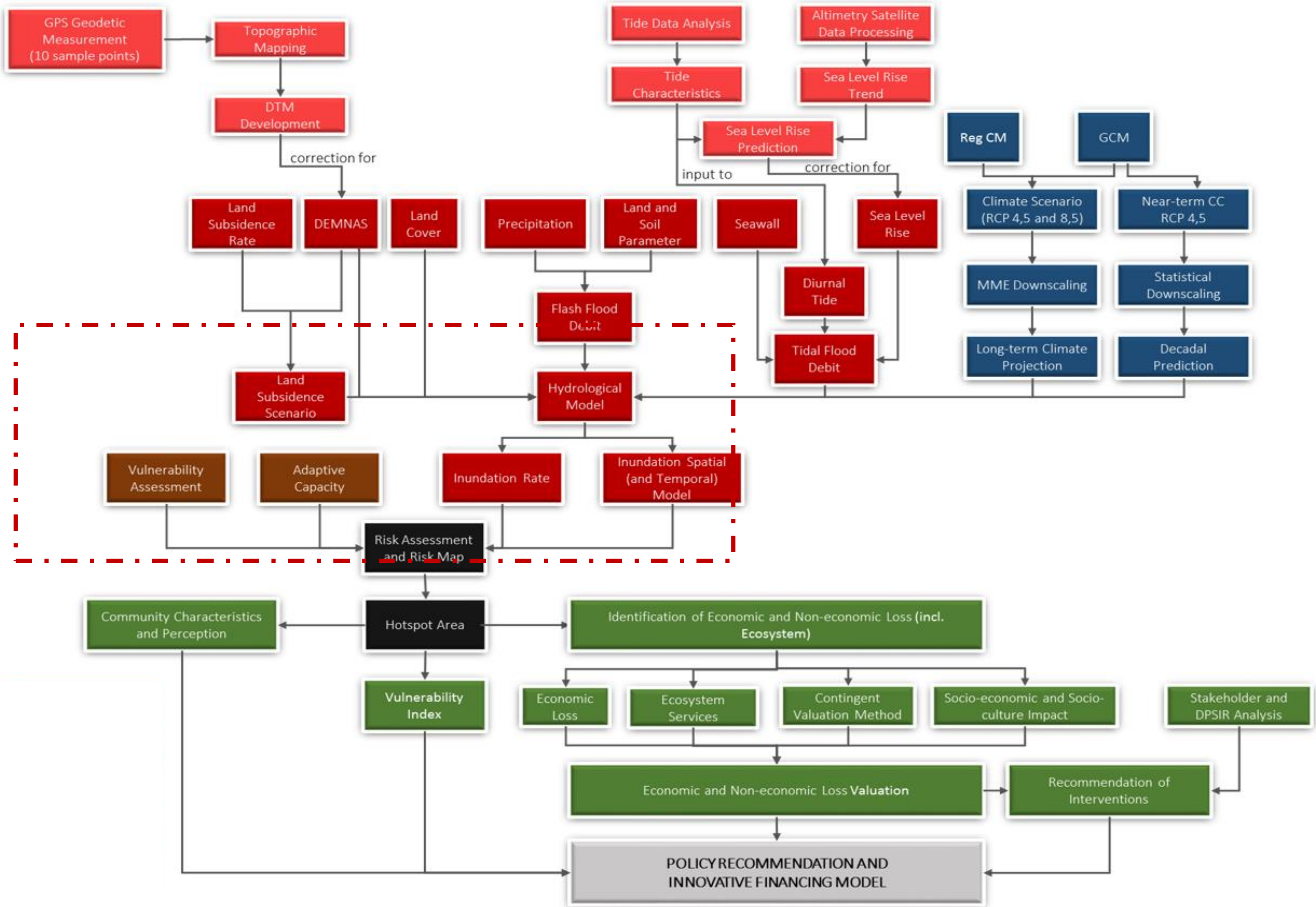


02 Methodology

2.1 General Framework

This general framework of Climate and Impact Risk Study refers to the Six Steps Approach (GIZ, 2018), which is mainly aimed at understanding the climate-related impacts and risks in a study system and identify the appropriate controlling steps.

The study consists of the processes of hazard analysis, vulnerability analysis, risk analysis, as well as economic and non-economic impact analysis of flood and tidal flood events. The four analysis processess highlighted the importance of interconnection and mutually complementary/verification process between various analysis components as shown in the flow chart.



2.2 Hazard Analysis Method

The steps of hazard analysis method within this study comprised climate modeling (climate change projection) in the study location, sea level rise projection, simulation of condition and projection of flood spatial model, and also hazard analysis. The analysis process was conducted for baseline condition and 5-yearly projection until 2035 (for decadal) and 25-yearly projection until 2095 (for long-term projection).

a. Climate Modeling

Climate modeling is commonly carried out to identify the influence of climate factor toward changes of intensity and frequency of flood and tidal flood in the study location, as well as impacts of the interaction between climate factor, land physical condition, and sea parameter to the flood event.

Considering the rapid physical changes taking place in the studied coastal area and the urgency for short-term recommendations for policy formulation purpose, the climate modeling process in this study will also involve **near-term projection (decadal prediction) in addition to long-term one**.

Decadal prediction utilized hindcast and forecast database published by Global Climate Model (GCM) from the Climate Model Intercomparison Project Version 5 (CMIP5) which was specially designed for projection of short-term climate change that was based on prediction of decadal and interdecadal climate variability. The global data was afterwards downscaled to capture the local characteristics of the studied location and reduce biases in the global model output. The downscaling calculation was also used to develop the National Mid-Term Development Plan (RPJMN) of 2020-2024. The decadal prediction for this study was developed for 5-yearly period covering 2020-2035, and the components that were analyzed were probability of monthly rainfall characteristics and wet extreme index.

Downscaling to the GCM was also used in the **long-term projection** process to increase the resolution of spatial and temporal data. The projection also utilized the daily resolution outputs from the Regional Climate Model (RCM) to calculate more detailed extreme index. Basically, climate projection was based upon the possibility of radiative forcing flow caused by the increase of green house gas emission. While the decadal prediction emphasizes on the influence of natural factors to low frequency climate variability, long-term climate projection stresses on the role of anthropogenic influence to future climate change, which is marked with the increase of GHG emission in the atmosphere.

The long-term climate projection was illustrated into 2 scenarios, namely RCP 4.5 to represent moderate scenario, and RCP 8.5 to represent extreme scenario. The **components that were analyzed** in the long-term projection were **rainfall** and **extreme index**.

	DECADAL PREDICTION	LONG TERM PROJECTION
USER	Policy and decision makers	Researcher
SCENARIO	Near term up to 2035	Long-term up to 2095 with RCP 4.5 and RCP 8.5
DATABASE	Statistical downscaling hindcast and and GCM forecast	Downscaling GCM and RCM
ANALYSIS COMPONENT	• Probability of monthly rainfall anomaly • Wet extreme index	• Rainfall • Extreme index (wet and dry)

Utilization of IPCC AR-5 Climate Model Processed for Study Location (Source: Moss et al. (2010))

b. Projection of Sea Level Rise

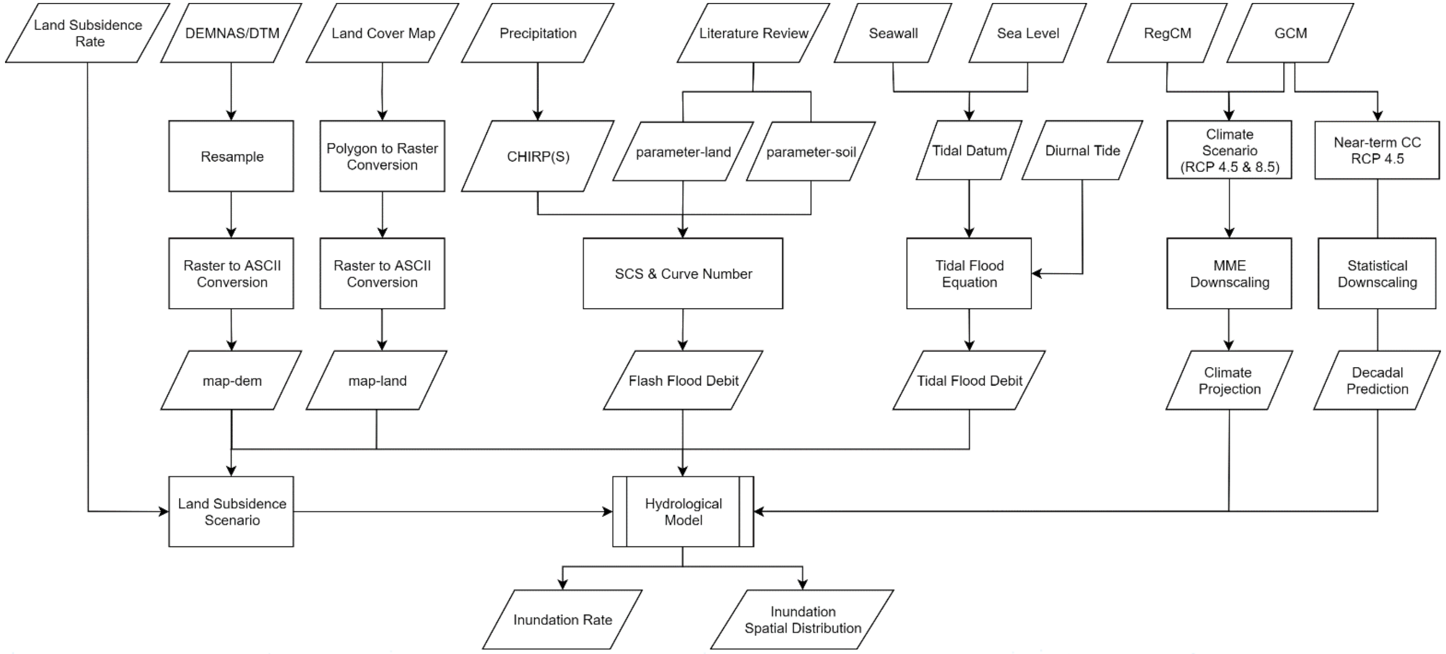
The projection of sea level increase until 2040 was carried out by utilizing the database on annual sea level from the outputs of RCP4.5 model (for Pekalongan and its surrounding area). The average spatial value of this model output was subsequently corrected with altimetric historical data from Copernicus.

c. Flood Model Development

The flood model was utilized by using the Agent-Based Modelling (ABM) process with spatial resolution of 30x30 m. ABM is a computational model that positions an agent as an object that can interact and respond to the land's physical condition (Condro and Widagdo, 2017).

In this study, rain water and sea water (in debit form) were set up as an agent, and the responses of both to the environmental condition were defined as the inundation level which has spatio-temporal dimension.

In the ABM simulation process, the rain water/sea water debit will move in every time unit. The movement is influenced by its interaction with the climate factor and land's physical properties, which in turn will generate the value of inundation level both temporally and spatially.



Framework of Flood Model Development for the Study Location (Author Team 2020)

The physical land anomaly is represented by data from Digital Terrain Model (DTM) which have been corrected with field measurement (with geodetic GPS), data on land subsidence, as well as data on land coverage and type of soil to calculate the abstraction of rain water and sea water within the study location.

d. Hazard Analysis

Floood hazard index for each projection period was determined based on the inundation level and land level from the ABM simulation result on every grid.

For locations with baseline land elevation under sea level, the inundation level value was made from sea level value minus the relative land height against the datum.

CATEGORY	INUNDATION LEVEL	INDEX VALUE
Not affected (NA)	0 cm	0
Very light (VL)	0.01-4.2 cm	0.2
Light (L)	4.2-31.7 cm	0.4
Moderate (M)	31.7-77.83 cm	0.6
High (H)	77.83-192.74 cm	0.8
Very High (VH)	>192.74 cm	1

Categories of Flood Hazard in the Study Location (Author Team, 2020)

2.3 Vulnerability Analysis Method

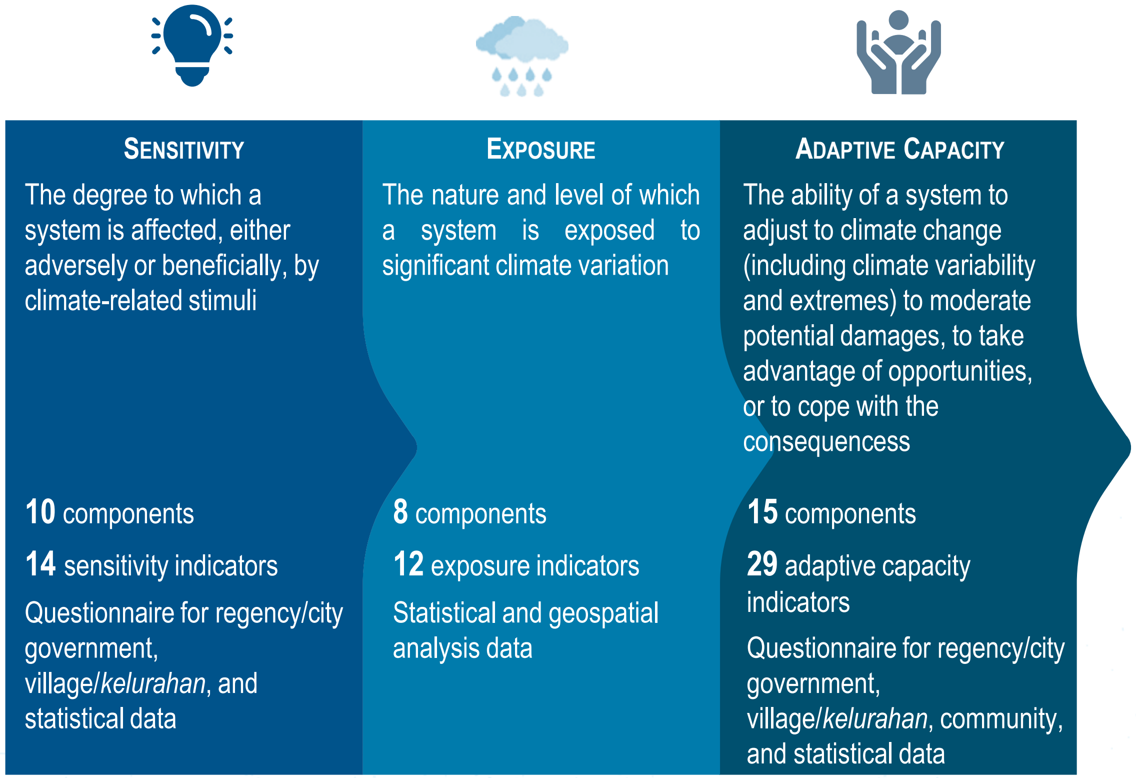
The Intergovernmental Panel on Climate Change defined vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. Thus, vulnerability can be measured with three dimensions, namely level of exposure, sensitivity, and adaptive capacity.

The steps of vulnerability analysis in this study comprised of sensitivity analysis, exposure analysis, adaptive capacity analysis, and vulnerability analysis. The analysis process is conducted for baseline condition and the 5-yearly projection (until 2035).

The process of vulnerability analysis involved a series of indicators that numerous literature studies and FGDs with expert team considered as being able to represent the condition of sensitivity, exposure, and adaptive capacity in the study location. In the analysis process for each vulnerability dimension, this indicator was classified into several components and were respectively given weights.

The database of indicators was obtained from primary and secondary data collection, both spatial and non-spatial ones, which comprised geospatial data analysis (for spatial-based data), questionnaire (community, regency/city governments, and village/*kelurahan*), and statistic data collection at village/*kelurahan* level.

In the vulnerability analysis process, an analysis on land use change and land subsidence was also conducted to further increase the accuracy of the analysis.



Building Blocks of Vulnerability in Climate Risks and Impacts Study *(Author Team, 2020)*

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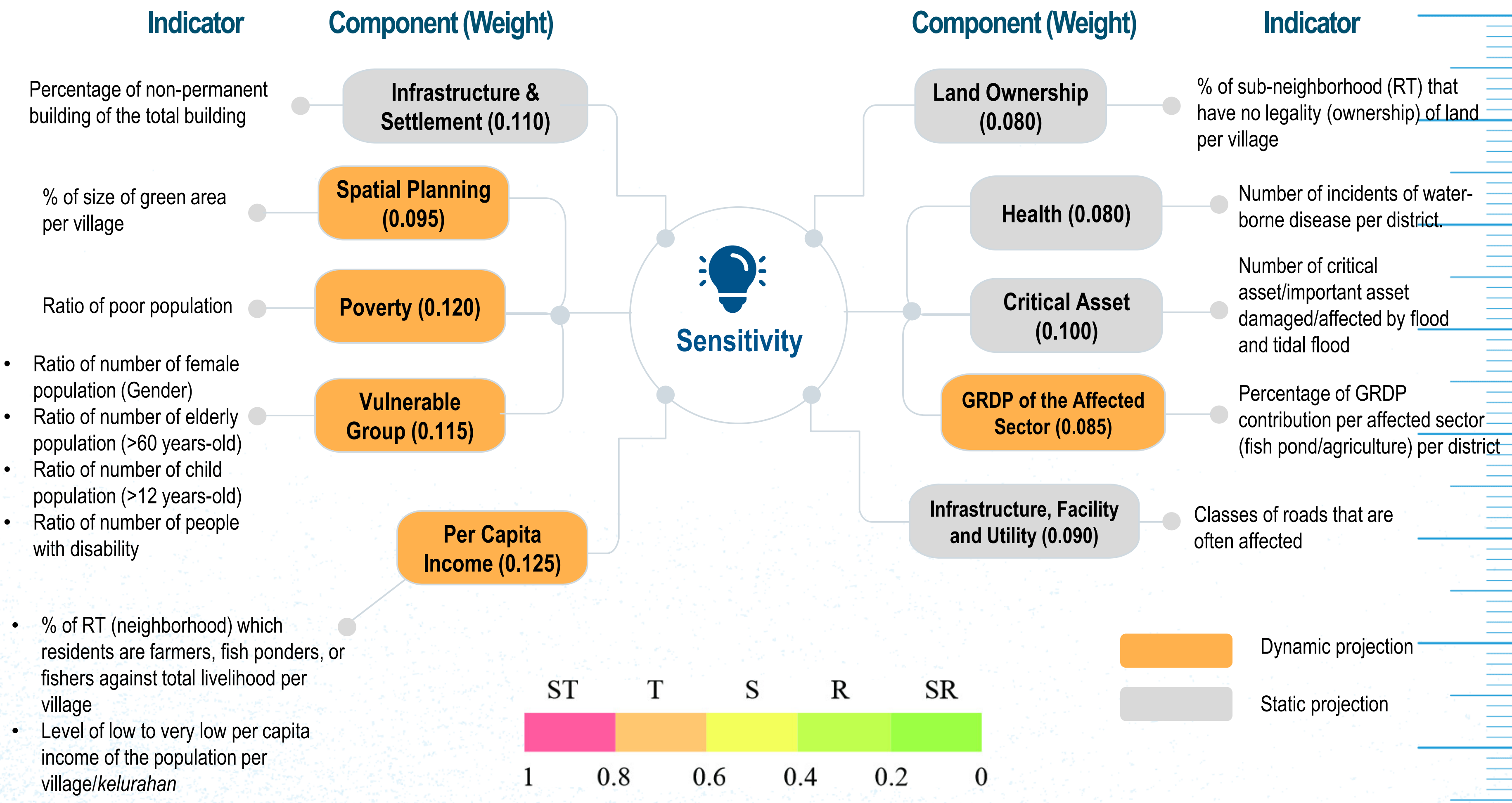
a. Sensitivity Analysis

The Sensitivity Index (S) is composed of 10 components that consists of 15 indicators that are considered as capable of representing the sensitivity dimension in the study location; each of the components and indicators are then given weight. The Sensitivity Index value was obtained from addition of values of all components being used in accordance with the weight given to each of those components. The index was afterwards divided into 5 classes, starting from very low to very high.

$$IS_i = \sum_{j=1}^{n} W_j * I_{Aij}$$

Description:
IS = Sensitivity Index
i = represents village/*kelurahan* number–i,
j = indicator number-j
Wj = weight for every sensitivity indicator



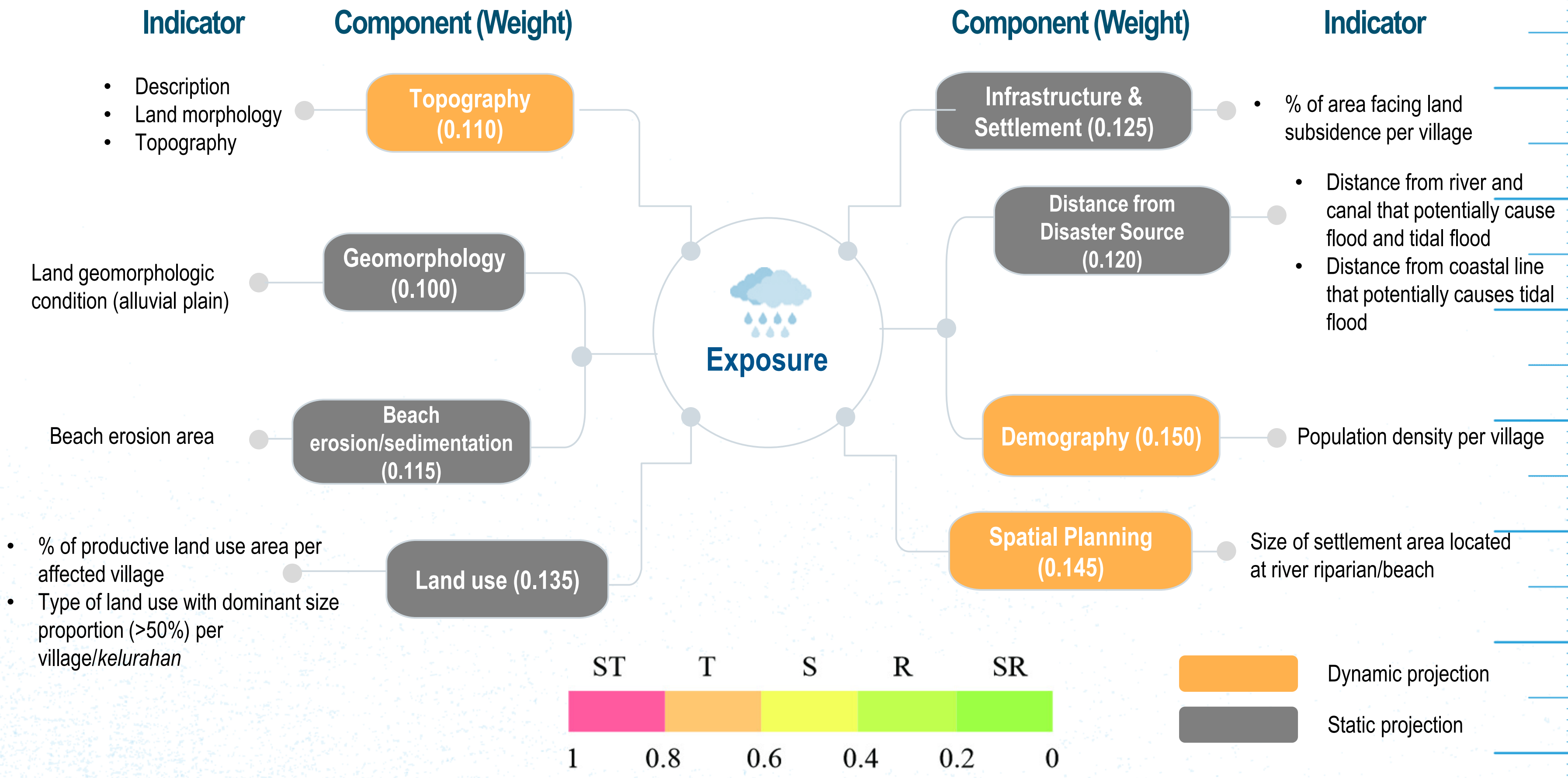
Component, Indicator, Weight and Class of Sensitivity Dimension (Author Team, 2020)

b. Exposure Analysis

Exposure Index (E) is composed of 8 components that consist of 12 indicators that are considered as capable of representing the exposure dimension in the study location; each component and indicator is then given weight. The exposure index value was obtained from the addition of value of all components being used in accordance with the weight given to each of those components. The index was afterwards divided into 5 classes, starting from very low to very high.

$$IK_i = \sum_{j=1}^{n} W_j * I_{Aij}$$

Description:
IK = Exposure Index
i = represents village/*kelurahan* number–i,
j = indicator number-j
Wj = weight for every exposure indicator



Component, Indicator, Weight and Class of Exposure Dimension Index (Author Team, 2020)

c. Adaptive Capacity Analysis

The Adaptive Capacity Index (AC) is composed of 15 components and 29 indicators that are considered to be able representing the adaptive capacity dimension in the study location; each component and indicator is then given weight. The value of adaptive capacity index was obtained from the addition of values of all components that were used in accordance with the weight given to each of those components. The index was afterwards divided into 5 classes, starting from very low to very high.

$$IKA_i = \sum_{j=1}^{n} W_j * I_{Aij}$$

Description:
IKA = Adaptive Capacity Index
i = represents village/*kelurahan* number–i,
j = indicator number-j
Wj = weight for every adaptive capacity indicator

SR R S T ST
0 0.2 0.4 0.6 0.8 1

Static projection
Dynamic projection

NO	COMPONENT (WEIGHT)	INDICATOR
1	Regulation and Planning (0.095)	Regulatory support from spatial planning aspect
		Mitigation of flood and tidal flood in RPJM (Mid-Term Development Plan)
2	Disaster Financing (0.080)	Local financing support for flood mitigation
3	Disaster Early Warning (0.055)	Existence of early warning system for flood
		Existence of early warning system for tidal flood
4	Institutional arrangement in form of Disaster Service Center (0.065)	Existence of service center and information dissemination for flood and tidal flood
		Quality of government/agency's service in flood preparedness
5	Institutional arrangement in form of Community Group (0.060)	Existence of resilient (prepared) community group
		Background of establishment of disaster resilient community group, such as KSB (Disaster Preparedness Group), TSBK (*Kelurahan* Disaster Preparedness Group), SIBAT (Community-based Disaster Preparedness), etc.
6	Disaster Program (0.090)	Existence of disaster mitigation program
		Existence of conservation/rehabilitation program to overcome flood and tidal flood
7	Education, Counseling, and Knowledge for Community (0.050)	Ratio of higher education (SHS/VHS, IHS, and University)
		Counseling and assistance for mitigating flood and tidal flood
8	Disaster Mitigation (0.085)	*Kelurahan*/village scale disaster mitigation plan document
		Document and implementation of RAD PRB (Regional Action Plan for Disaster Risk Reduction) of City/Regency BPBD
9	Preparedness and Contingency (0.080)	Plan and steps of preparedness activity to mitigate flood
		Existence of SOP for flood emergency (contingency) situation
		Speed of emergency (contingency) implementation by government/agency during flood.
		Plan and steps of preparedness activity to mitigate tidal flood
		Existence of SOP for emergency (contingency) during tidal flood
		Speed of emergency (contingency) implementation by government/agency during tidal flood.
10	Infrastructure for Flood and Tidal Flood Control (0.070)	Existence of polder, retention pool, sea dike, etc.
11	Community's Perception toward flood and tidal flood (0.045)	Community's direct perception (response/acceptance) to flood and tidal flood mitigation programs
12	Local Wisdom (0.035)	Local wisdom associated with flood and tidal flood
13	Well-being (0.075)	Percentage of prosperous family
14	Infrastructure, Facility and Utility (0.070)	Availability of education supporting facilities and infrastructures
		Percentage of household regarding 'main fuel' used to cook per village (%)
		Limited clean water source facility (percentage of number of family not using piped water (PAM/PDAM))
		Quality of drainage in the village/*kelurahan* administrative area
		Percentage of number of household having decent sanitation facilities in village/*kelurahan* administrative area.
15	Poor Family Health Insurance (0.045)	Proportion of poor community having the KIS (Healthy Indonesia Card)/BPJS

Component, Indicator, and Weight of Adaptive Capacity Dimension (Author Team, 2020)

d. Vulnerability Analysis

The vulnerability of study area toward flood and tidal flood was obtained from the multiplication function of the Sensitivity (S), Exposure (E), and Adaptive Capacity (AC). The result of the vulnerability model was then classified into 5 vulnerability index classes, from very low to very high, which result is shown spatially to provide an illustration on vulnerability level of each village/*kelurahan* in the study location.

$$V = \frac{S \ x \ E}{AC}$$

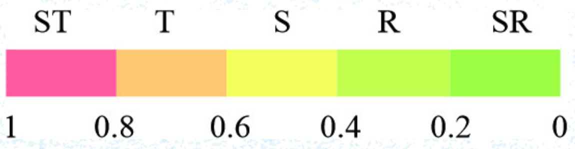
Description:

V = Vulnerability

S = Sensitivity

E = Exposure

AC = Adaptive Capacity



e. Projection of Vulnerability Index

Considering data limitation and characteristics of all indicators being used, not all indicators in the three dimensions were projected in the process of vulnerability index projection. The non-projected indicators included those associated with:

- Community perception (from questionnaire)
- Policy elements
- Natural physical conditions that tended to be stable for a long period of time

Other indicators that were not associated with the above three conditions were projected by using statistic method and spatial dynamic with cellular automata simulation.

The spatial **dynamic** method was only used **for the land use projection process**. There were 20 indicators used in this model, comprising:

- Existing land use;
- The driving factors comprising road network, distance from road network, transport hub, public and social facility, industrial plan spatial allocation, trade and service, beach tourism development, and centers of district/*kelurahan*/village;
- Limit of flood inundated area, limit of forest area, and limit of green area;
- Flood control infrastructure;
- Existing land use;
- Coastal line;
- Permanent inundation area;
- Weighted factors and constraints in settlement area, industrial area, inundation area land use, green area, and protection area; and
- River

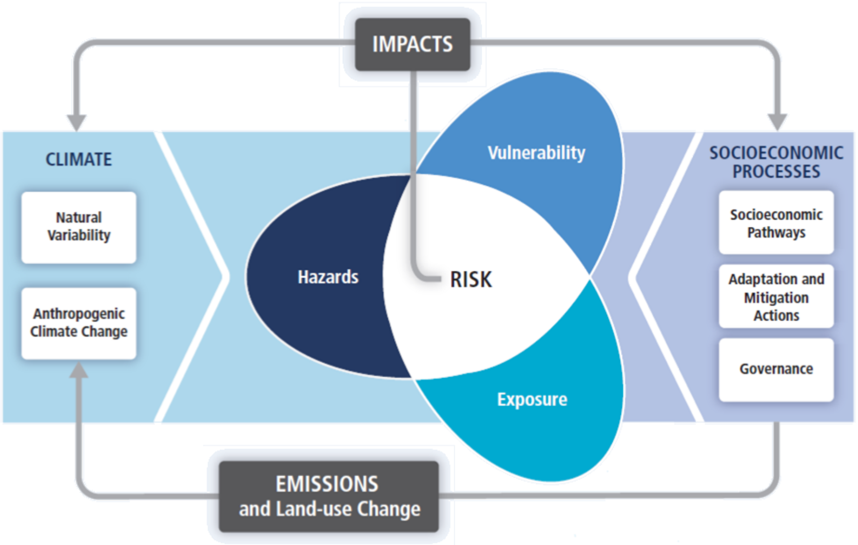
2.4 Risk Analysis Method

Risk is defined as a measure of potetial damage or loss in asset/anomaly, environment, and human, which can happen when a threat becomes a reality, including the level of severity that needs to be anticipated (IPCC, 2007).

In this study, risk is a function of parameters of hazard and vulnerability. The result of risk spatial modelling is then classified into 5 index classes, from very low to very high. The risk map produced has a grid-scale analysis unit, which displays overlayed with village administrative boundary.

Although the map displayed has a grid analysis unit, in the analysis process, it will show a maximum value of the entire grid in that particular village/*kelurahan* boundary. Thus, if a village/*kelurahan* had a very high risk area (while others are very low-high), the village/*kelurahan* would still be categorized as of very high risk, since the one taken would be the maximum value. This is conducted so as not to neglect the real condition that there are parts in that particular area having higher risk than the other areas. As for the map, the display with grid analysis unit was selected to provide a spatially more detailed description, particularly for the flood-affected areas. This way, spatial and non-spatial risk analysis could be generated.

Similar to the hazard and vulnerability analysis, the risk analysis process was also carried out for baseline condition and projection to 2035 (with 5-yearly projection period). The analysis process did not only look into the trend in risk index change in the study location, but also at the potential impact of flood inundation (permanent and the farthest) to the land use in that location from spatial perspective.



. Illustration from the Core Concept of IPCC WGII AR5 which Contains Scheme on Risk Study (IPCC, 2012, 2014)

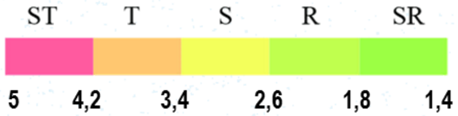
$$R = H \times V$$

Description:

R = Risk

H = Hazard

V = Vulnerability



2.5 DTM, Land Use and Land Subsidence

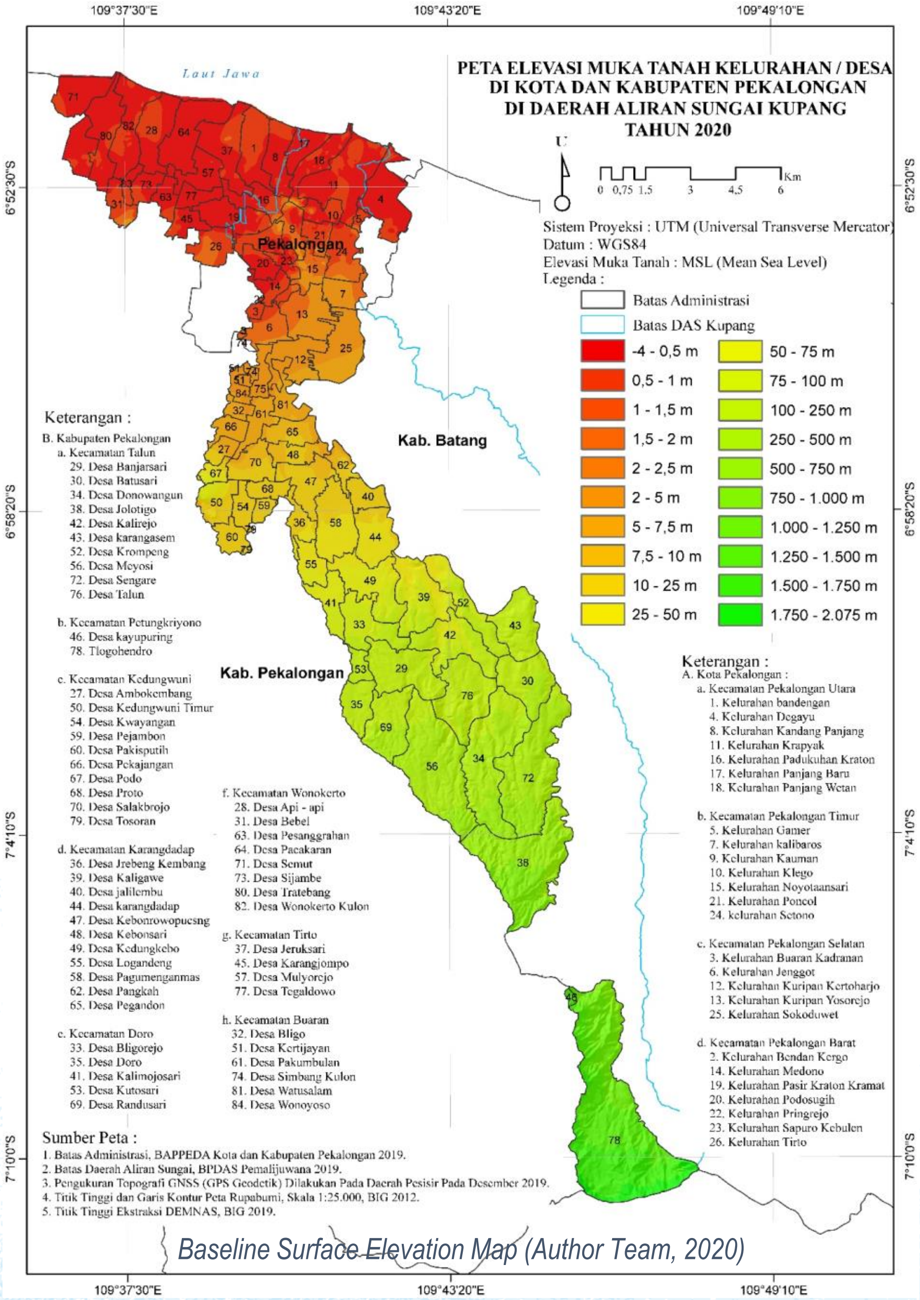
The three analyses were conducted to correct and increase accuracy from the spatial vulnerability analysis process and served as an input to the hazard analysis process.

a. Development of Digital Terrain Model (DTM)

The coastal area in the study location has very flat topography and highly influenced by the land subsidence. For spatial-based study process, particularly to analyze the coastal area, it is very necessary to have the location's topographic data with high accuracy, which currently has not been obtained yet from the secondary data. The available secondary data that are commonly used are the DEMNAS (Digital Elevation Model Indonesia). For the condition of the study location, DEMNAS did not possess sufficient accuracy and might therefore influence the study result. Thus, in this study, DTM was developed to provide more detailed spatial information.

The DTM development was initiated by mapping out the detailed land surface elevation using the Geodetic GPS instrument in a very flat area in the Pekalongan City/Regency coast, which was part of the study area. The data were then mosaicized with the DTM data formed from the topographic basic map of scale 1:25,000 to obtain the Digital Elevation Model (DEM) data of the entire study location.

The new DEM then became input data in the inundation modelling process, so that the constructed model would have higher accuracy and more representative of the study location's condition. The modeling results show that the **downstream and coastal areas have a relatively flat elevation**, yet it should be noted that there are **spots across the coastal area which elevation is lower than point 0** (even until -4 m) below surface. The areas are generally already permanently inundated. Starting from middle to upstream area, the land surface elevation becomes higher with the height range of 500-2,075 m; showing a rather high inclination in that area.



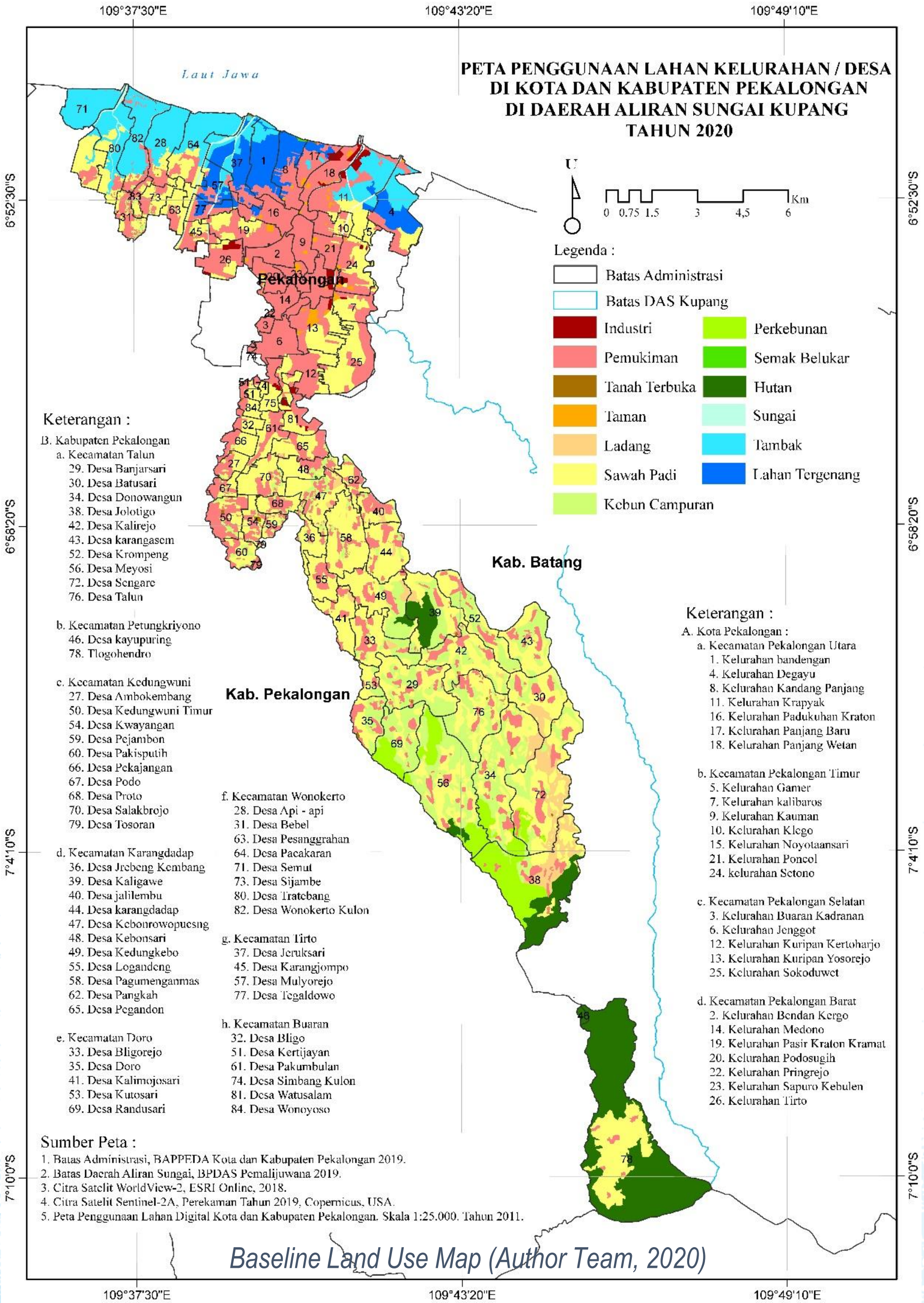
Baseline Surface Elevation Map (Author Team, 2020)

b. Land Use

The updating of land use was carried out on the last land use map of the Pekalongan Regency and City Governments, which used the Sentinel 2A high resolution satellite data in 2019 (Copernicus USA, 2019), and high resolution satellite data of World View-2 (ESRI Online Basemap, 2018). Land use from the existing digital map was reclassified by using the most recent satellite data, which was then mosaicized and split off in accordance with the study location. The most updated land use map was used to fill out the indicators of baseline condition in the analysis process and served as a basic map to conduct land use projection in every analysis period.

The land use update shows that in 2020, the **majority of coastal area are fish pond** and **inundated,** with little settlement area. **For downstream area, the land use is dominated by settlement area**, with little ricefield in the east and west side of the study location. As for the **middle area, the dominant land use is ricefield** with settlement area that are spread, yet with a relatively smaller size. The **domination of productive land and protected area become more visible in the upstream area**, where the types of land use constitute a mix between ricefield, combined garden, plantation, field and forest (protected and productive); with smaller settlement clusters that are spread across the area.

In the study process, **a land use projection was also carried out using the *cellular automata* simulation,** which is a spatial dynamic model to process the land development in serial-based from year to year. The land use projection **served as the basis to conduct vulnerability dimension projection**, particularly for the exposure and sensitivity components. In addition, the land use projection **was also used in the risk analysis process to look at the impacts of changes in inundation size (permanent and farthest) to the land use** in every period; which types of land use might be inundated, so as to ensure that the anticipative measures to be taken would be more effective. The land use projection was carried out by assuming that there was no changes in the total land size during the projection period.



Baseline Land Use Map (Author Team, 2020)

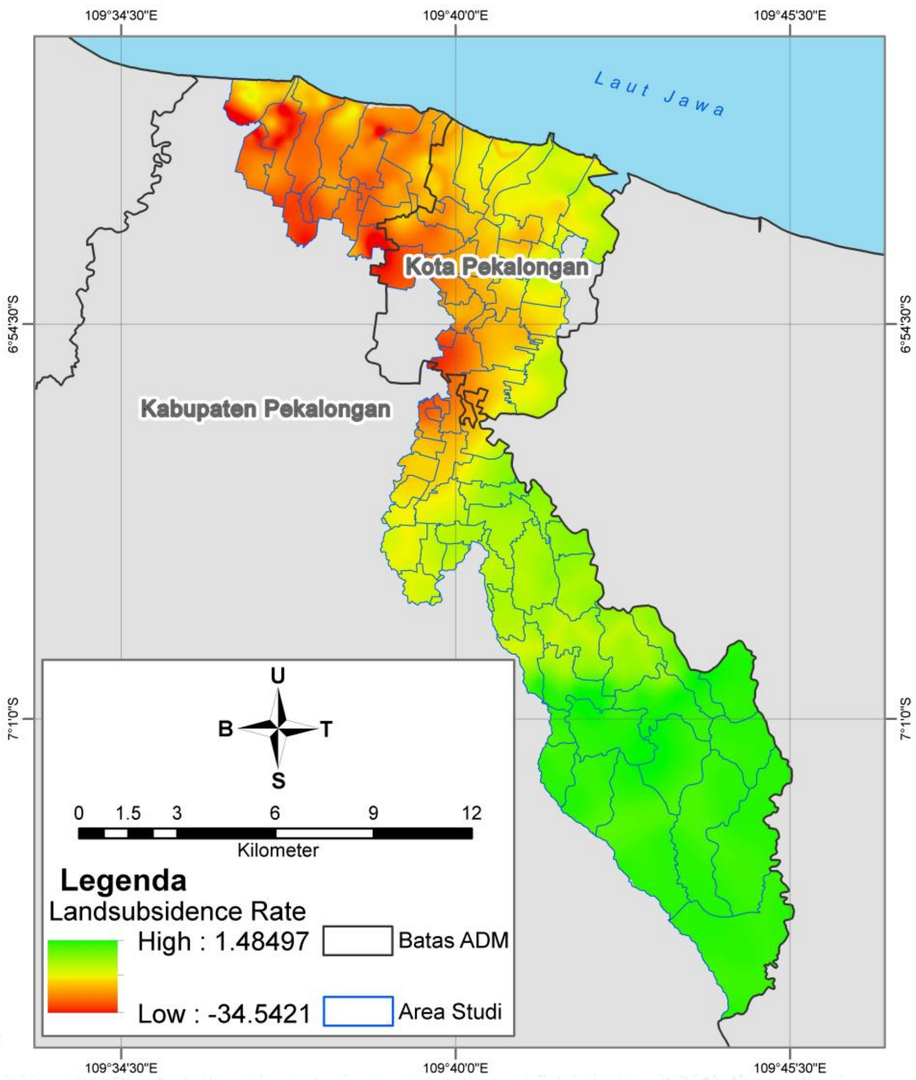
C. Land Subsidence

The data on land subsidence was needed in conducting the spatial analysis process to fill-out the data in the exposure index indicator, namely proportion (%) of area size undergoing land subsidence per village. In addition, the spatial distribution of the land subsidence was also utilized as one of the land physical factors influencing the flood modelling process in the hazard analysis, including the potential occurrence of permanent inundation.

In this study, the land subsidence data were obtained by using Sentinel-1 satellite data analysis that applied differential SAR interferometric method. The data obtained were land subsidence rate for 2019 (January-December). Throughout the study process, the rate was assumed to be constant every year (no increase nor decrease in rate).

The data processing results show that the **rate of land subsidence in the study location is relatively high**, which ranges between 0-34.5 cm/year (median ± 16.5 cm). For **coastal area, the land subsidence rate ranges between 11-34.5 cm.** It is visible that the study location in Pekalongan Regency coast generally has higher subsidence rate than that of Pekalongan City coast. **Semut Village, Tratebang, and Pacakaran, are the three coastal villages that have spots with land subsidence rate up to 34.5 cm/year, in addition to Bebel and Karang Jompo Villages in the downstream area.**

As for Pekalongan City, the highest land subsidence rate takes place in Kelurahan Tirto (i.e. up to **34.5 cm/year), Jenggot, and Buaran Kadranan.** The relatively higher land subsidence in Pekalongan City generally takes place in the downstream area and locations bordered with Pekalongan Regency.



Map of Land Subsidence Rate of 2019 (Author Team, 2020)

Another noteworthy aspect is the relatively high land subsidence in **the central area**, where there are locations with **land subsidence ranging from 11-23 cm/year.** These numbers, however, are still below those of the downstream and coastal area. However, the land subsidence trend in the middle area still needs to be anticipated.

Throughout the study process, the data were also spatially and non-spatially compared with other study results in Pekalongan area. The study conducted by ITB Geodesic Team suggested that the coastal area and downstream area of Pekalongan City experience average land subsidence of 1-10 cm/year in 2012-2018 study period; furthermore, various spots were also found with the land subsidence rate of 15-20 cm/year within certain time interval. Another study by Kemitraan suggested that the land subsidence rate from 2015-2017 in the coastal area and downstream area of Pekalongan City ranged between 11-30 cm (achieving 34 cm in certain spots) and became smaller down-south, with land subsidence predominantly took place in the eastern part.

Spatially, it can also be seen that both research and study results show a relatively similar spatial distribution of land subsidence rate. However, in 2019, the study results show that land subsidence area became wider, particularly heading west and southward, thus no longer dominant in the east part. Spatial and non-spatial perspectives-wise, it can be seen that the land subsidence data in this study are relatively in harmony with the historical data from other studies. It is noteworthy, however, that the two studies have not passed through the field correction step like that which has been conducted in this study.

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03 Hazard Analysis

3.1 Climate Scenario

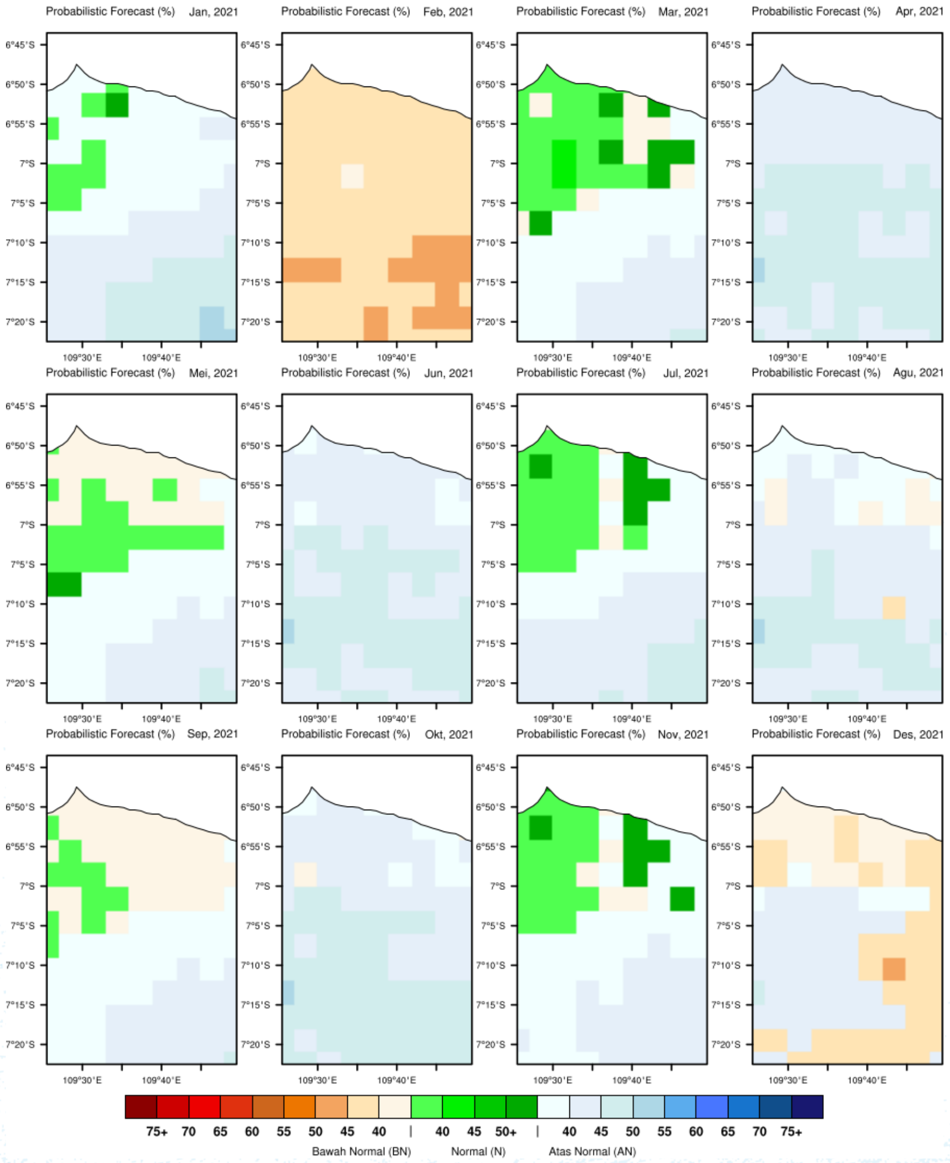
a. Decadal Climate Prediction

The probability of the monthly rainfall anomaly and the value and trend of wet extreme index are two aspects being analyzed in the decadal climate prediction for 2021-2035.

The analysis of probability of monthly rainfall anomaly shows **the tendency of domination of Above Normal (AN) rain anomaly.** As an example, AN rainfall in 2021 is predicted to take place more frequently in study location, except for February and December, particularly in the upstream and middle areas. Meanwhile, downstream and coastal areas in the same year shows the dominant tendency of Normal (N) rain anomaly. The dominant AN rain prediction was also found for the following years, with different spatial values and distribution characteristics.

The tendency of probability of more rain taking place in upstream area can be one of the indications of the need for a more comprehensive watershed system management that covers the entire parts from upstream to downstream. Upstream management must be focused on reducing runoff reaching the middle and downstream areas. This will ensure that the runoff passing through the downstream or coastal areas will not exacerbate the flood in those areas, particularly when the rains came together with the tide, which in turn would lead to tidal flood.

Wet extreme index that was analyzed under the decadal climate prediction comprise of: 1) Rx1day, which is the highest daily rainfall within 1 year; 2) **Rx5day,** which is the highest 5-daily cumulative rainfall in 1 year; and 3) **R20mm**, which is the number of rainy days in a year with daily rainfall value of more than 20 mm.



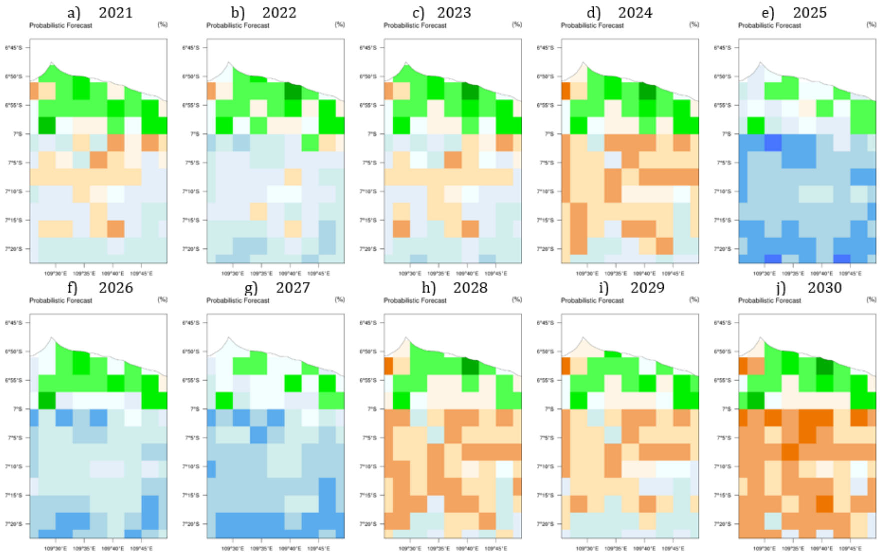
Decadal Climate Prediction - Probability of Monthly Rainfall anomaly for the Period of January-December 2021 (Author Team, 2020)

The historical and prediction data show the indication of decreasing amount of maximum annual daily rainfall intensity. The Rx1day prediction in the coastal area generally ranges between 60-70 mm, while that in the upstream area ranges between 80-90 mm. The Rx1day enhancement in the coastal area was predicted to take place in 2032-2034 with value range of 90-100 mm. From event probability side, the decadal prediction shows **dominant tendency of AN for Rx1day, with higher probability in upstream than downstream and coastal area.**

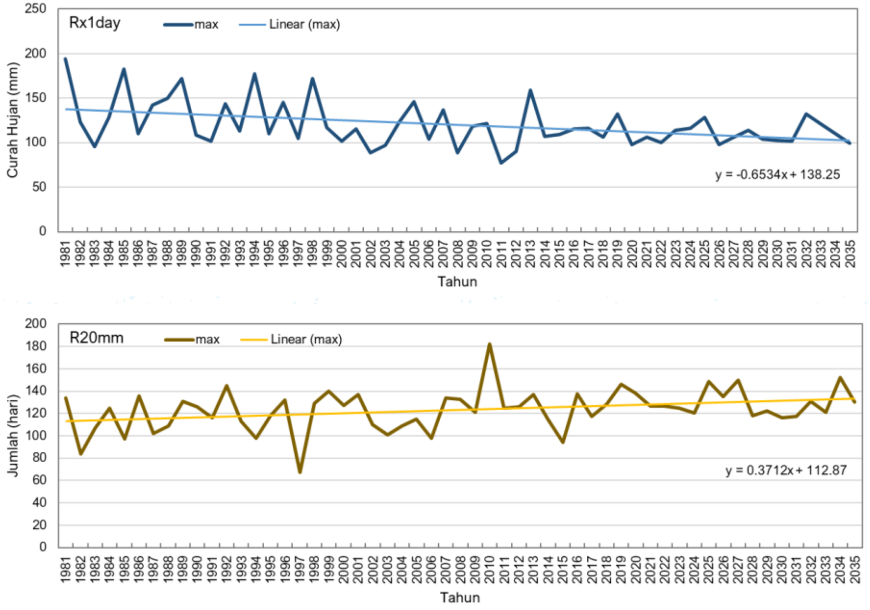
Similar to Rx1day, generally the prediction shows a decrease in Rx5day data variability as compared to that of historical condition. The prediction value for Rx5day in the coastal area tends to be stable with ranges between 160-180 mm, while in the upstream area it is predicted to increase in 2025 with the average value of 240 mm. From event probability side, **the dominant AN category probability was found more frequently in the upstream and downstream areas** as compared to the middle, **with domination area not as wide as the probability prediction of Rx1day index**.

Oppositely with Rx1day and Rx5day, for R200mm, there is **a tendency of increasing intensity of the prediction data** and location differences with tendency of AN probability domination. The probability prediction shows that **the AN condition has higher tendency to take place in upstream and middle areas**, while N condition potentially dominates the coastal area. Intensity-wise, the R20mm value is predicted not to experience any trend changes in the coastal area, which ranges at 60 days value, while the one in the upstream area is predicted to increase in 2025 and 2034 with average value of 130 days.

In general, the decadal climate prediction indicate **the possibility of decreasing intensity of wet extreme index**, yet **with an increasing number of wet extreme events.**



Prediction on the possibility of Wet Extreme Index anomaly of R20mm for 2021-2030 (Author Team, 2020)



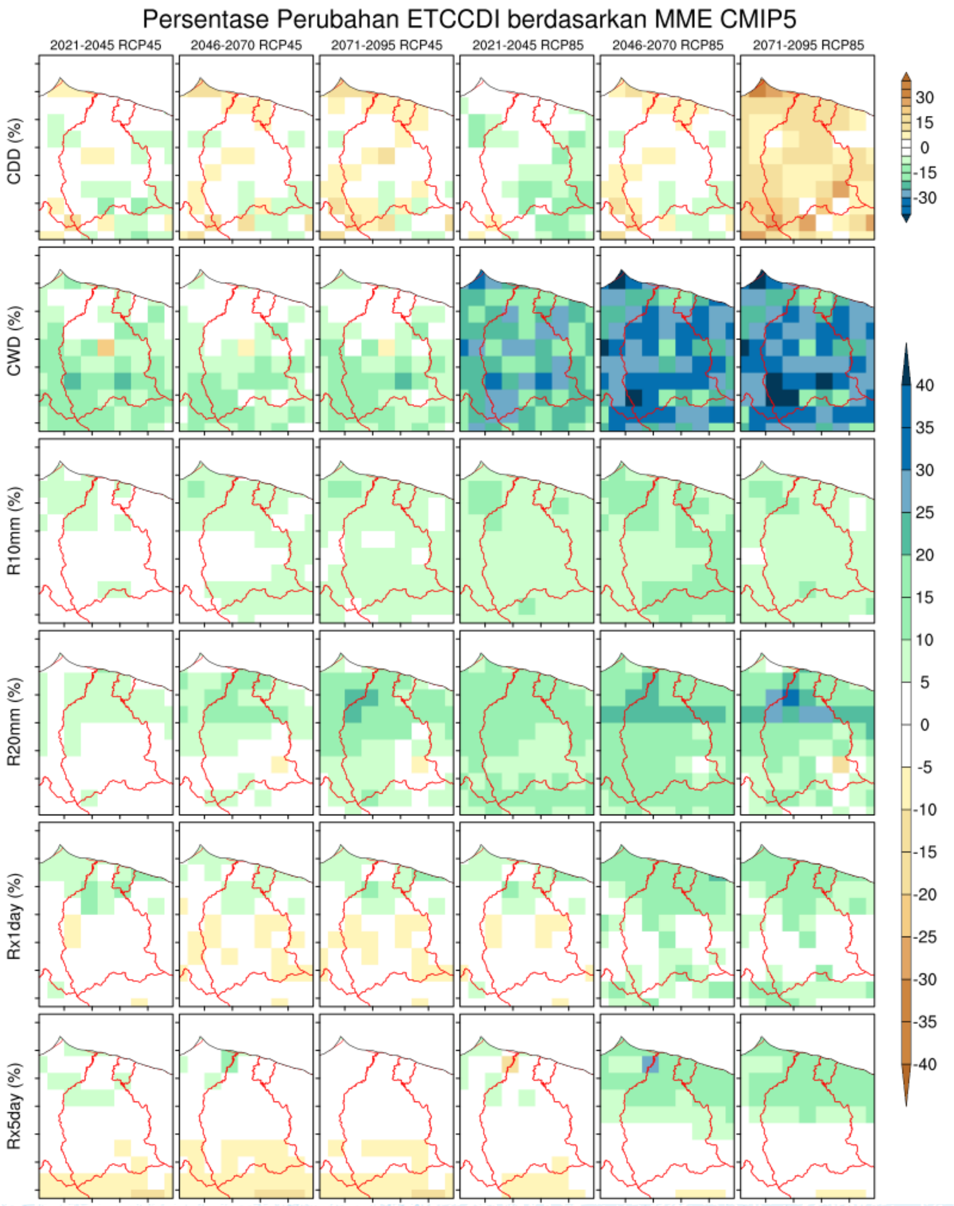
Historical Trend and Decadal Prediction of Rx1day Wet Extreme Index (above) and R20 mm (below) (Author Team, 2020)

b. Long-term Climate Projection

The long-term climate projection was carried out for two scenarios, namely 1) RCP 4.5 which represents moderate condition with moderate mitigation measures scenario to maintain radiative forcing level, and 2) RCP 8.5, which represents extreme condition with scenario of no measures conducted to limit the green house gas emission. The period used for the long-term climate projection is 2021-2095.

The **extreme index** analyzed in this project was **Consecutive Dry Days (CDD), Consecutive Wet Days (CWD), R10mm, R20mm, Rx1day, and Rx5day.** The **Rx1day, Rx5day, and R20mm indices** are the reference for wet extreme condition that is strongly interlinked with flood and landslide events. Meanwhile, CDD represents the dry extreme condition as it provides information on the longest period of a day without rain consecutively within certain period of time, hence very identical with drought.

The long-term climate projection results indicates that the **study location will experience wetter condition.** Spatial analysis shows an **increase of intensity percentage and frequency of extreme rainfall events particularly in coastal area**, as identified by the increase of percentage of changes of Rx1day, Rx5day, R10mm, and R20mm indices. Specifically for RCP4.5, the decrease of percentage of Rx1day and Rx5day indices in upstream area tends to be larger and wider than the increase of percentage in downstream area. The **CWD index projection strengthens the possibility of wetter area condition with longer rainy day row**, where in RCP8.5 scenario, the percentage increase is projected to be >40%. On the other hand, the dry day row represented by the **CDD value shows a not really significant change of percentage** in the future.

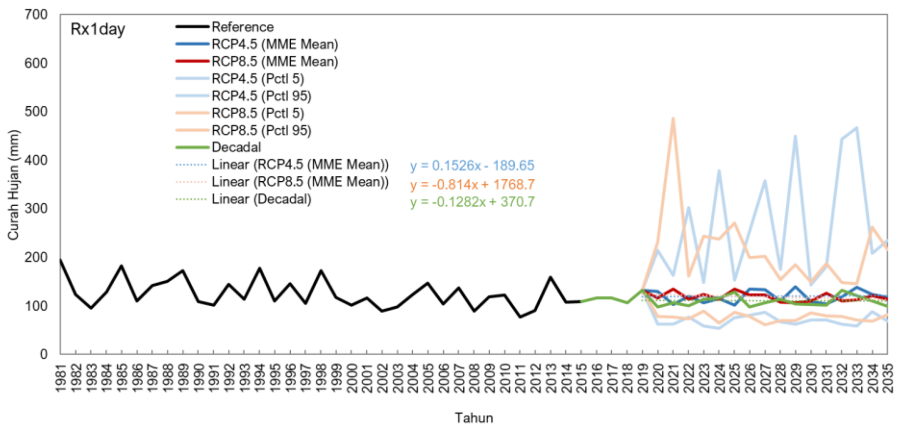


The Percentage of Changes in Extreme Index of Long-term Climate Projection (Author Team, 2020)

c. Range of Uncertainty

The climate modelling process was highly influenced by and strictly associated with uncertainty aspect. The two climate modelling processes in the study, namely the decadal climate prediction and long-term climate projection were not carried out to compare the results of both modelling processes, but rather to be used to identify the range of uncertainty of the simulation results.

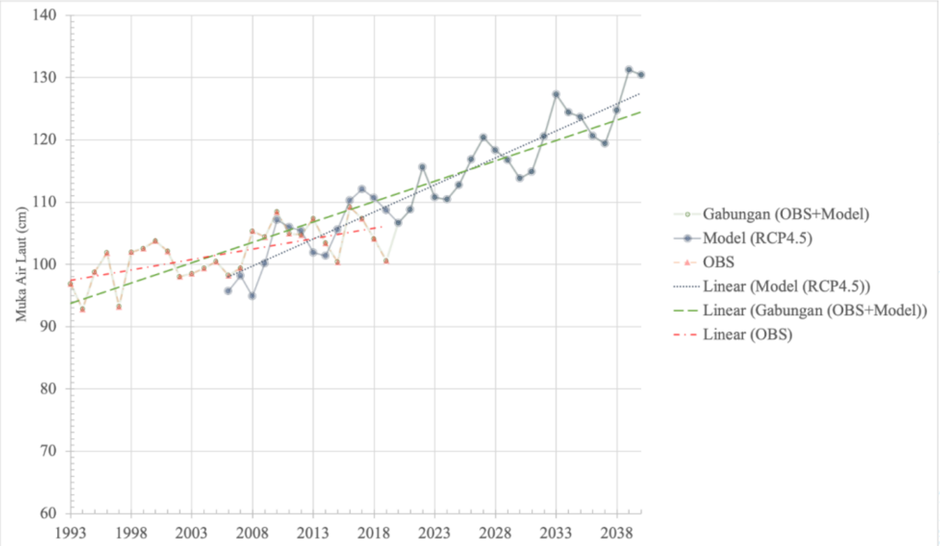
The trend analysis for the same period of data prediction/projection (period of 2021-2035) from the decadal and long-term predictions show an agreement with regard to Rx1day trend, namely the decreasing trend between decadal prediction and RCP8.5 scenario, with respective decrease rate of 0.13 and 0.81 mm/year. A different trend is shown by RCP4.5 scenario, which shows an increase rate of 0.15 mm/year. The trend's direction and rate from the relatively shorter data range (period of 2021-2035) might be different with that which will be produced using longer data (period of 2021-2095).



The range of uncertainty is represented by the value of 5th percentile and 95th percentile from each MME for RCP4.5 and RCP8.5 scenarios (Author Team, 2020)

3.2 Sea Level Rise

The sea level rise for Pekalongan area is projected to take place until 2040. The combined results between observation and output of RCP4.5 model show the **sea level rise in this area ranges around 0.81 cm/year with** R^2 = 0.8341. The increase value is consistent with the results indicated in the Indonesia Third National Communication Report of 2017. The increase rate is higher than the average increase rate in Java Sea, which is 0.39 cm/year. With such an increase rate, the sea level value in Pekalongan water will reach 130 cm value by 2040.



Projection of Sea Level Rise in Pekalongan Area (Author Team, 2020)

3.3 Inundation Modeling

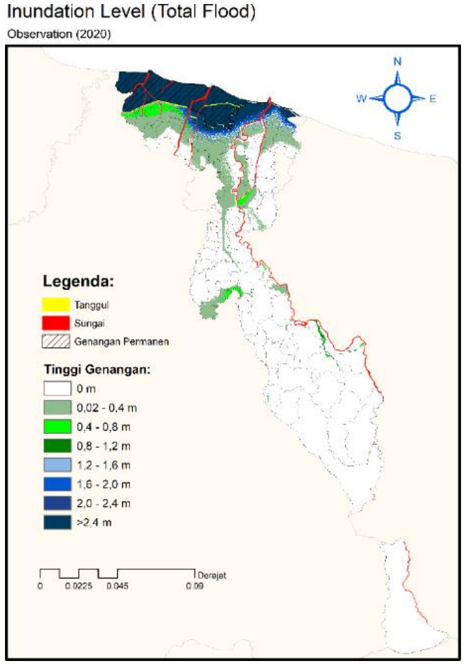
The inundation modeling was conducted by using the extreme values of each input. With regard to runoff, the data used were the maximum Rx1day data in each grid that are obtained from the decadal prediction calculation, and 95th percentile value for RCP4.5 and RCP8.5 scenarios. For tidal flood, the data used were the 90th percentage of tidal water level during observation period. For land subsidence, the data used were those from 2019 analysis that assumed constant decrease rate over time. The decadal prediction data were used to show the possibility based on natural factor influence to the climate variability within yearly and decadal period. Meanwhile, the 95th percentile value of RCP scenario was aimed at representing the most severe possibility of the uncertainty range produced by the model in each scenario.

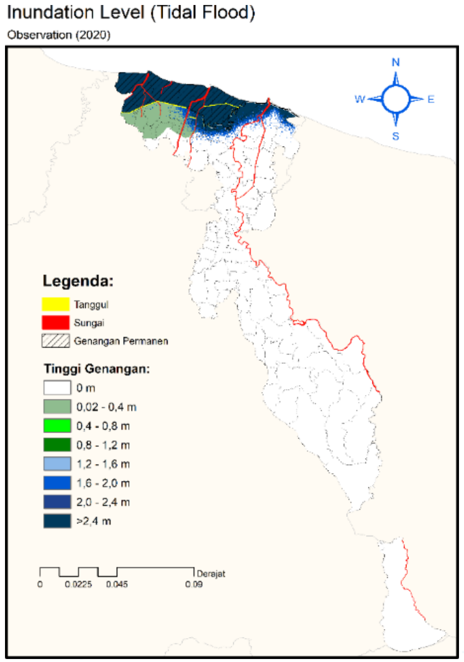
The simulation was conducted by looking at the situation during tide and extreme rain to incorporate the interaction between rain water and sea water. Other than rain data input, the rain water-sea water interaction also served as a differentiating factor between decadal prediction simulation with RCP4.5 scenario projection.

The inundation spatial model developed was divided into three groups, namely the total flood inundation model, which is the combination between tidal flood and flood due to extreme rain (rain flood), and a separate model for each tidal flood and rain flood.

a. Observation Period (2015-2019)

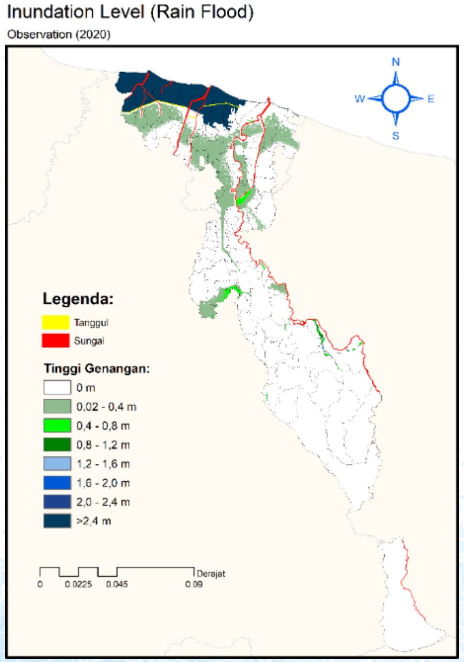
The inundation model simulation during the observation period served as the baseline to compare the outputs of prediction/projection results model with that of existing condition. The land elevation data used for this period's simulation were the corrected DTM of 2020, while for extreme rainfall, the data used were the maximum Rx1day value from 2015-2019 period.





During observation period, the total inundation height in the coastal area was dominated by tidal flood, whereas in coastal area that is directly bordered with the sea, the inundation might reach up to >2m high. Fairly high inundation (up to 0.8 m) were also found in the middle area such as Pakisputih, Pejambon, and Kuripan Yosorejo.

For areas located far from the coast, inundation occurrence is predominantly caused by flood due to extreme rain.

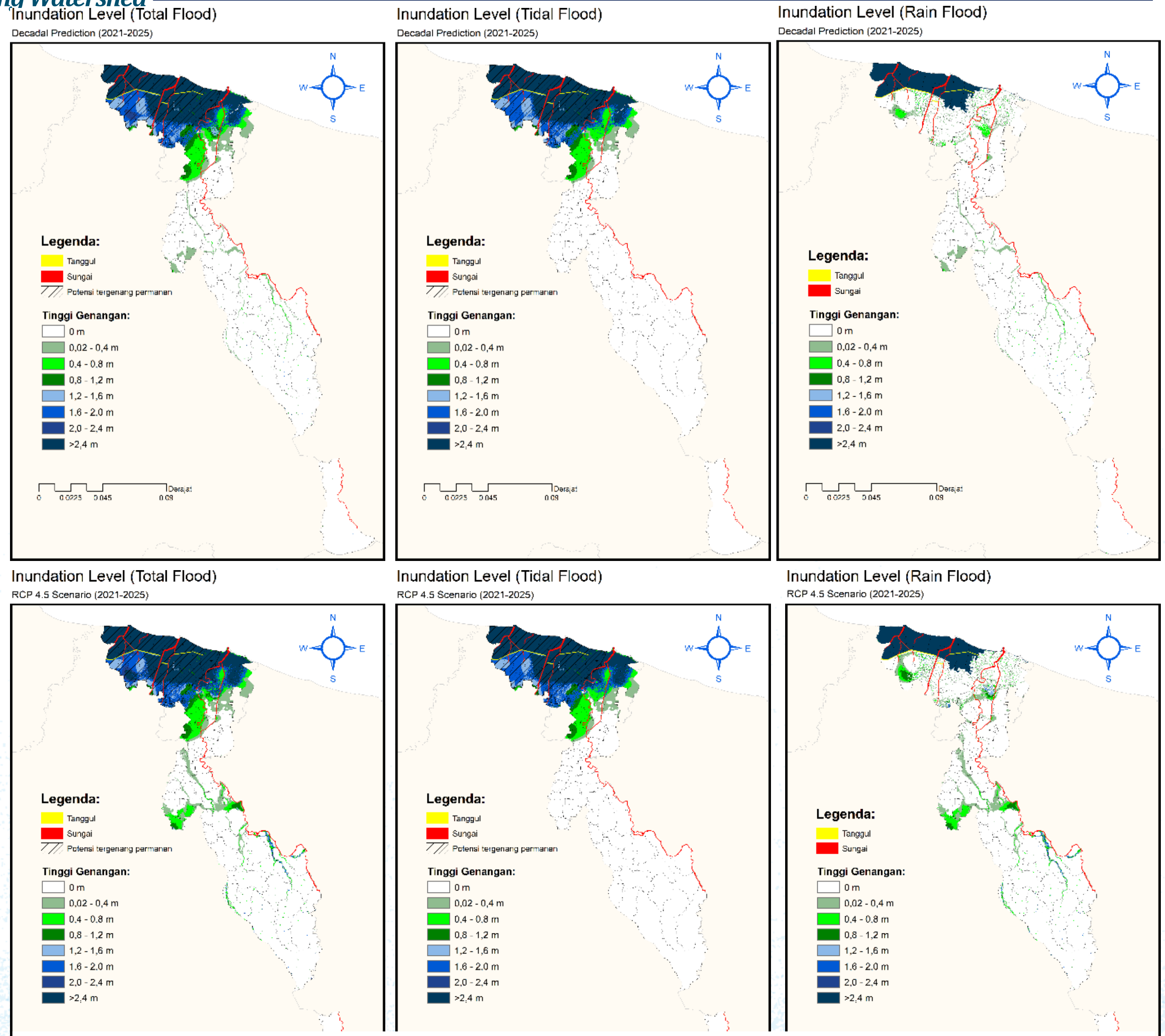


b. Inundation Modeling of 2021-2035

By including the sea level rise factor, constant land subsidence rate, existing land use and changes in rainfall intensity, the simulation shows that the inundation area will be broader in every projection period. In general, the discrepancy between RCP 4.5 and decadal simulation is more significantly visible in the inundation area caused by the flood.

The model simulation results show that the height of rain flood inundation ranges between 0-0.4 m and does not experience any significant changes spatially in various periods of time. **The highest increase of rain flood inundation occurs in several grids in the east and central areas** (such as Klego, Poncol, Wonokerto Wetan). In the periode of 2026-2030 the inundation will reach Pakisputih and Kalilembu with inundation height that will range between 0.8-1.6 m, **yet the affected area will be relatively small.** In middle area, there are also **areas sandwiched by tidal flood and flood, such as Klego, Poncol, and Wonokerto Wetan.**

A more significant increase in inundation size and height was found in the tidal flood simulation, which was concentrated in the coastal area. The inundation model simulation in various periods show the increase of inundation height until reaching >2.4 m by the end of projection period, with expanding inundation area.



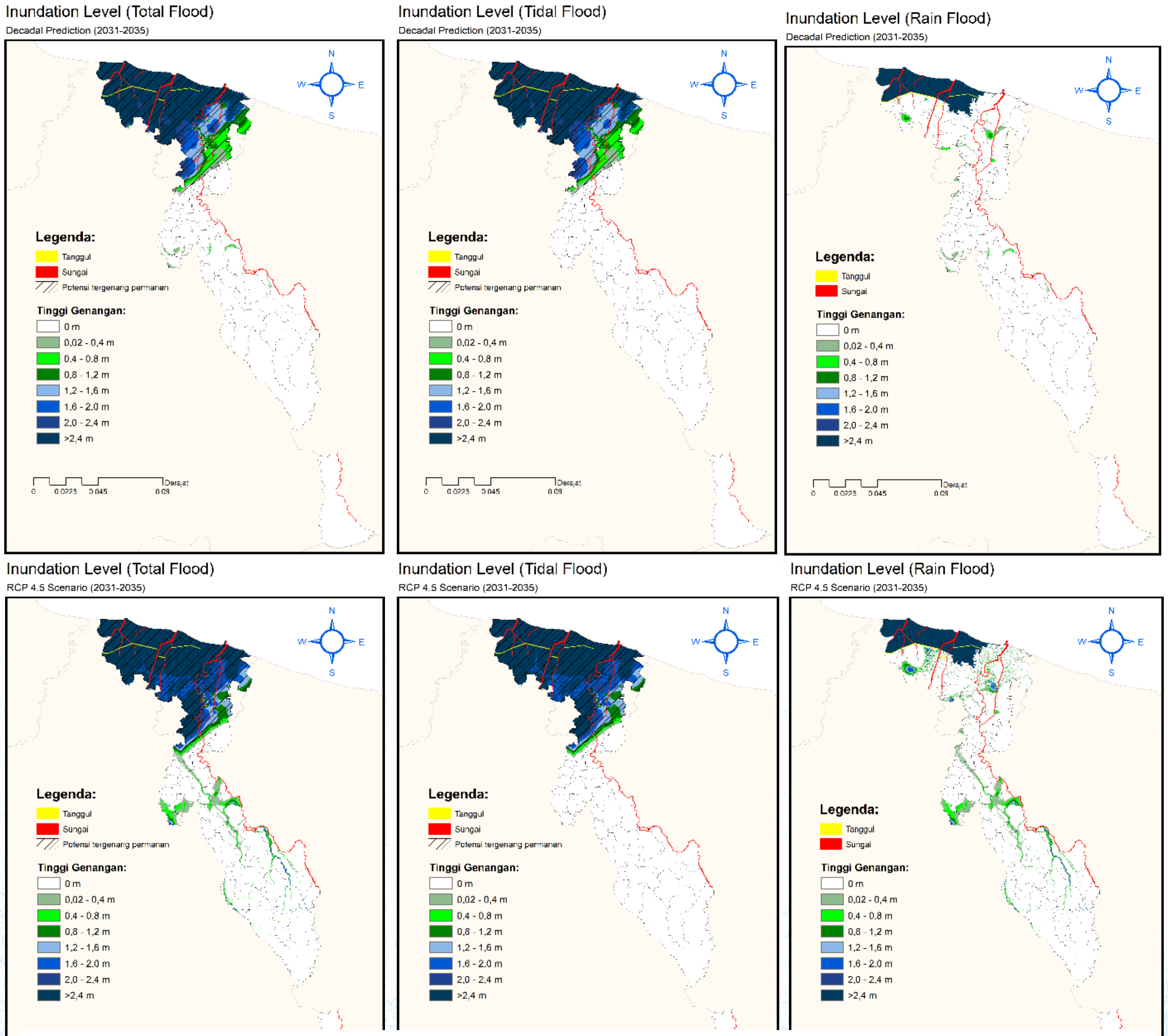
Simulation of Inundation Model for the Period of 2021-2025 for Decadal Prediction (above) and RCP 4.5 (below) (Author Team, 2020)

In the period of 2021-2025 (image in page 21), **inundation with height of >2 m are predicted to expand down south from the coastal area, and will expand also toward the east** (Degayu, Gamer, Setono, Klego, and Kauman, with inundation's height reaching 1.2 m) in the period of 2031-2035 (side image). The inundation near the coast is dominated by tidal flood.

Rain flood that occurs at or almost at the same time with tidal flood might exacerbate the inundation condition in the east area, with potential inundation's height achieving 2 m. The permanently inundated areas are also predicted to expand in every period. The expanding permanent inundation is caused by the expansion of areas with elevation lower than the average sea level in the study location.

By taking into account the changes in size and height of the inundation in every projection period, **some areas that potentially experience significant inundation increase are, among others:** Tirto, Pasir Kraton, Padukuhan Kraton, Karang Jompo, Tegaldowo, Bebel, Pesanggrahan, Sijambe, and Wonokerto Wetan. Meanwhile, other areas that need to anticipate inundation increase in the future include Sapuro Kebulen, Bendan Kregon, Medono, Podosugih, Pringrejo, Buaran Kradanan, Jenggot, Gamer, Kauman, Klego, and Poncol.

From the event's influence side, in various projection periods it can be seen that the **inundation formation tends to be influenced by tidal flood** rather than rain flood. However, **rain flood might exacerbate the inundation** in an area.



Simulation of inundation Model for Period of 2021-2025 for Decadal Prediction (above) and RCP 4.5 (below) (Author Team, 2020)

3.4 Hazard Modeling

The hazard index value was formulated by classifying the inundation's height in the study location into 6 classes, starting from the non-affected to very highly affected.

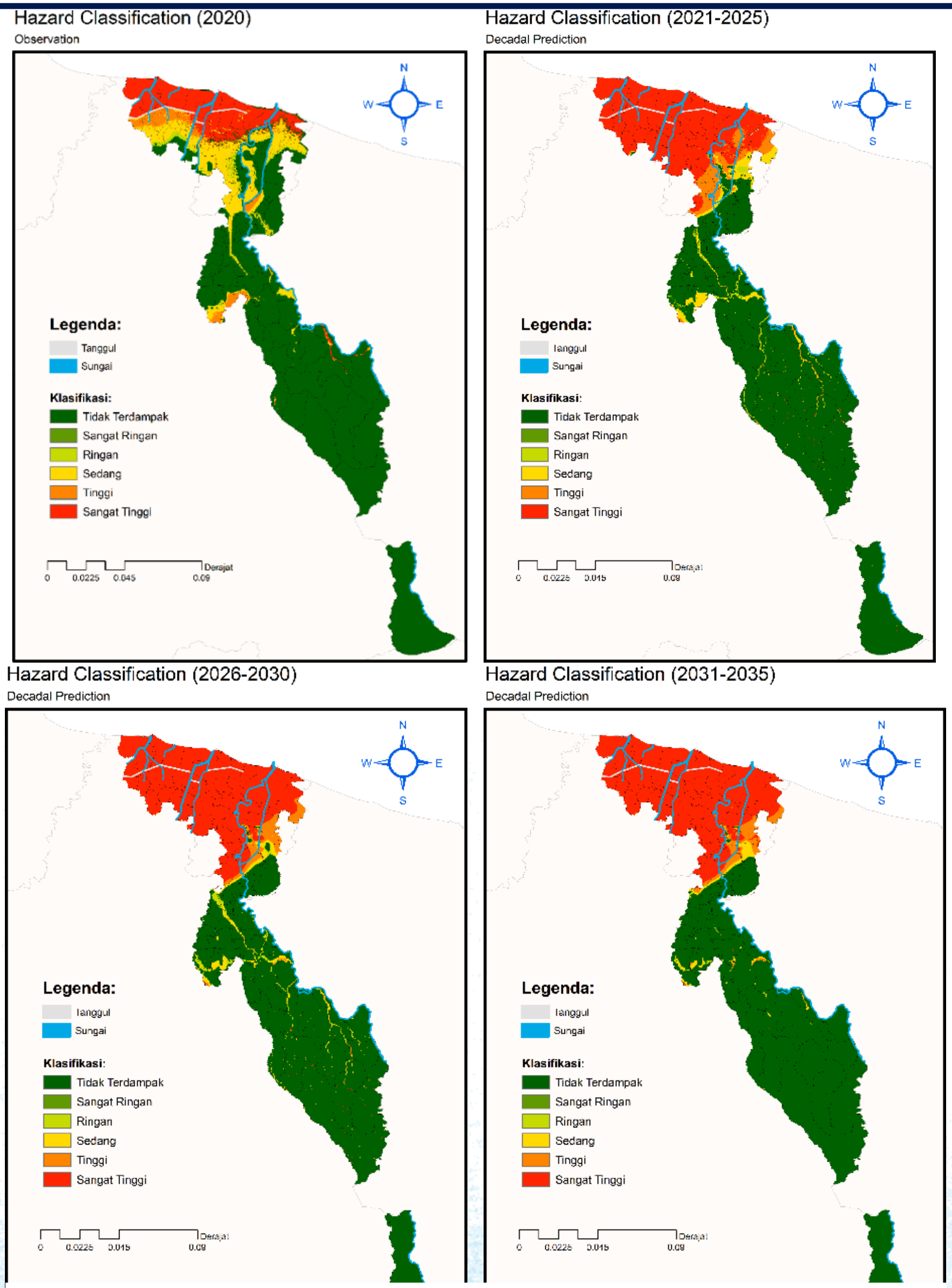
a. Observation Period

The hazard index in the **observation period shows that the hazard level in most of the coastal areas, with east coast as the exception (Degayu and Krapyak), are categorized to be very high.** The high category domination was found in the southern area of the seawall, including: Wonokerto Kulon, Tratebang, Wonokerto Kulon, Api-Api, Pecakaran; as well as some locations in middle area such as Pakisputih, Pejambon, and Kuripan Yosorejo. Other areas dominated by rain flood are facing moderate hazard index.

b. Projection Period (2021-2035)

The decadal prediction in every period shows hazard increase in the study location, particularly in the southern and middle areas. In 2021-2025 and 2026-2030, the hazard category will increase up to very high level in the southern parts of the seawall until Medono area. Similar increase was also found in the east coast, from moderate level to very high level category (for the majority). For the period of 2031-2035, the most significant change will take place in the southern area of Pekalongan City, which experiences increase of hazard category, from moderate or unaffected to high or moderate.

The development of hazard index with RCP4.5 scenario shows a not significantly different pattern from that of decadal prediction, although there is also tendency that the projection results will have higher hazard level as compared to that of the decadal simulation. The RCP 4.5 scenario was used to illustrate worse condition as compared to the decadal prediction.



Hazard Map from the Observation Period and Decadal Prediction (Author Team, 2020)

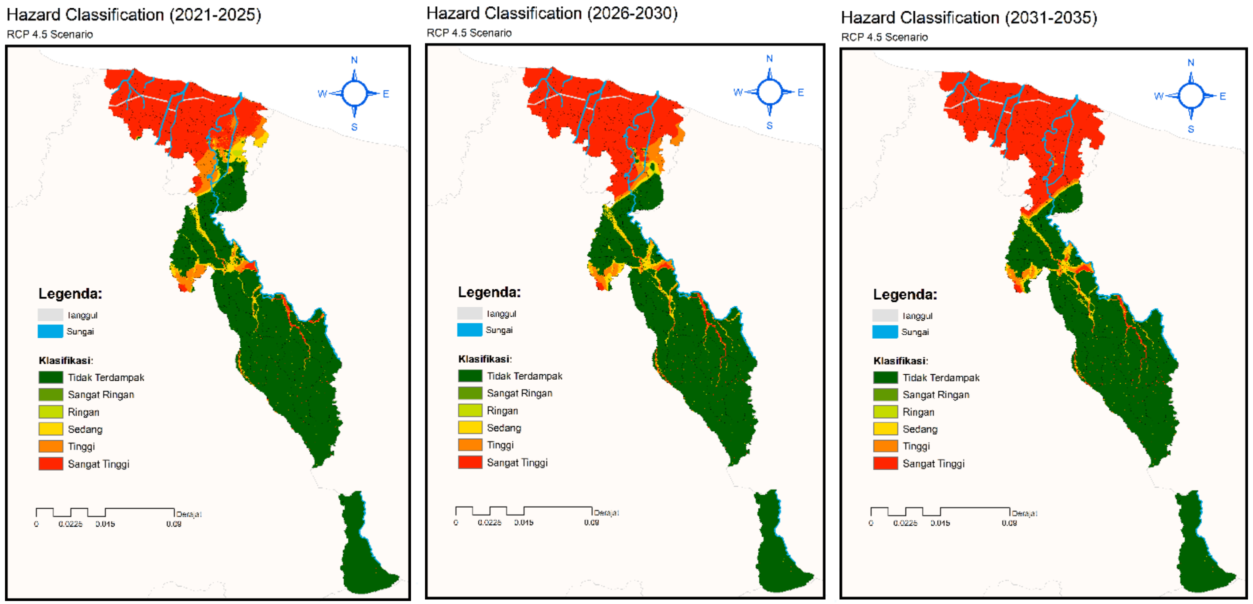
Similar to hazard level in decadal prediction, in general, the northern part of the study area experiences increasing hazard category from moderate/high to very high according to RCP 4.5 projection. The very notable difference was found in the middle section of the study area, which faces much higher hazard level compared to decadal prediction results.

Several locations in middle area such as Jalilembu, Pejambon, Pakisputih, and Kwayangan **have moderate to very high hazard category.** The high hazard level in this area is **caused by the fact that its topography is passed by stormwater runoff.**

With regard to the number of affected village, for Pekalongan Regency, both hazard projection schemes show that the number of villages having very high (VH) hazard level in the period of 2031-2035 will increase by two folds as compared to the observation condition (from 6 to 13-14 villages).

A more significant increase will take place in Pekalongan City, where during the period of 2031-2035, the number of *kelurahans* with VH hazard level will become 18-22 *kelurahans*, from initially 3 during the observation period. This increase will take place along with the decreasing number of *kelurahans* with very low (VL) and low (L) hazard level.

For the entire study area, the number of village/kelurahan with VH hazard index is estimated to increase from 10.7% during observation period to 25%, 32.1%, and 38.9% consecutively in 2021-2025, 2026-2030, and 2031-2035, according to the decadal prediction. Meanwhile, the RCP4.5 scenario projection suggested that the increase will reach 26.2%, 38.1%, and 42.9% consecutively in 2021-2025, 2026-2030, and 2031-2035.



Flood Hazard Index of RCP 4.5 Scenario Projection (Author Team, 2020)

Tingkat Bahaya	Observasi	Dasawarsa			Observasi	Skenario (RCP4.5)		
	2015-2019	2021-2025	2026-2030	2031-2035	2015-2019	2021-2025	2026-2030	2031-2035
Tidak Terdampak	17	5	12	21	17	4	3	4
Sangat Ringan	38	43	33	24	38	38	37	33
Ringan	12	3	4	1	12	6	5	4
Sedang	6	2	3	3	6	4	4	4
Tinggi	2	10	5	4	2	10	3	3
Sangat Tinggi	9	21	27	31	9	22	32	36

Number of Village/Kelurahan and Hazard Level in the Study Area (Author Team, 2020)

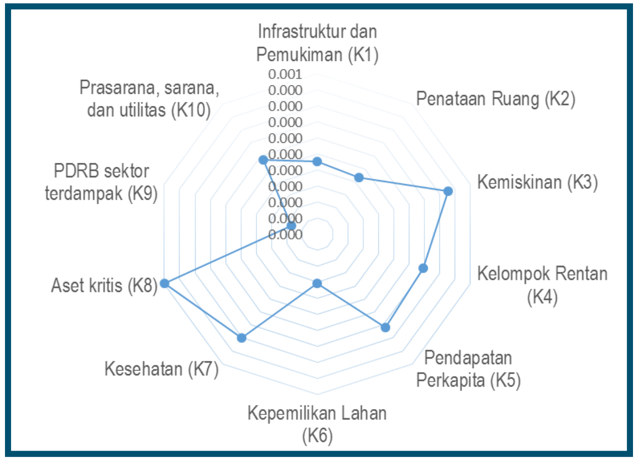
04 VULNERABILITY ANALYSIS

4.1 Baseline Condition

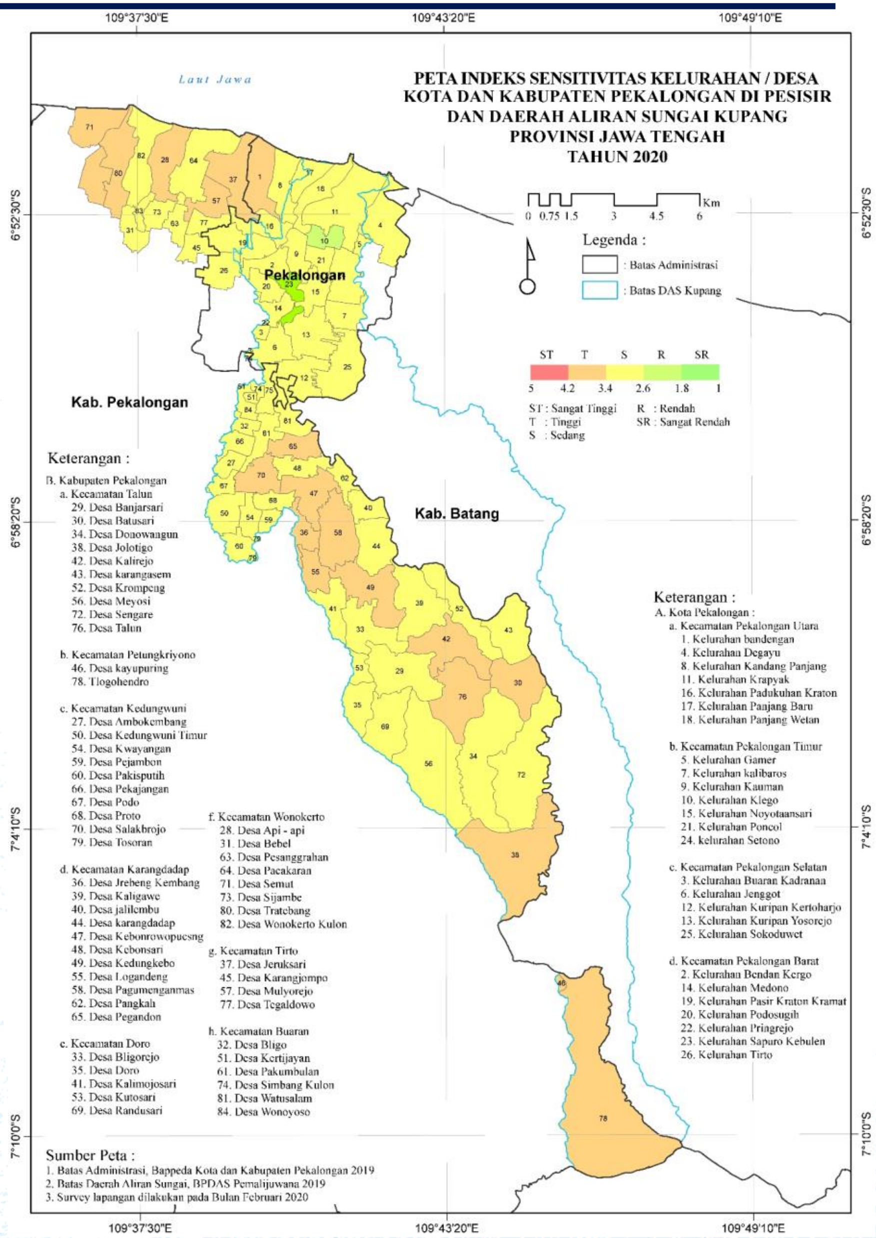
a. Sensitivity Analysis

The sensitivity level in the study location is generally situated at moderate-high, although some *kelurahans* show low (Klego) and very low (Sapuro Kebulen) levels. In coastal area, the analysis results show that **coastal villages in Pekalongan Regency tend to have higher sensitivity level as compared to the coastal *kelurahans* in Pekalongan City** (which are dominated by moderate sensitivity level, except for Kelurahan Bandengan).

With regard to building component, the sensitivity level in the study location is dominated by critical asset component represented by the indicator of number of critical assets affected by the flood. Being a dominant component, it shows a number of critical assets in the study location that are potentially affected. The more critical assets that might potentially be affected are, the more burdens that the local government have to bear to mitigate the disaster risk in that particular *kelurahan*/village.



Another component playing high influence to the study location's sensitivity is the health component represented by the indicator of number of incidents of water-borne disease per district. This incident is tightly related to the frequency and intensity of flood event in an area. The significant influence from this component to sensitivity level in the study location shows that incidents of water-borne disease occur rather frequently, particularly in the flood-affected districts.



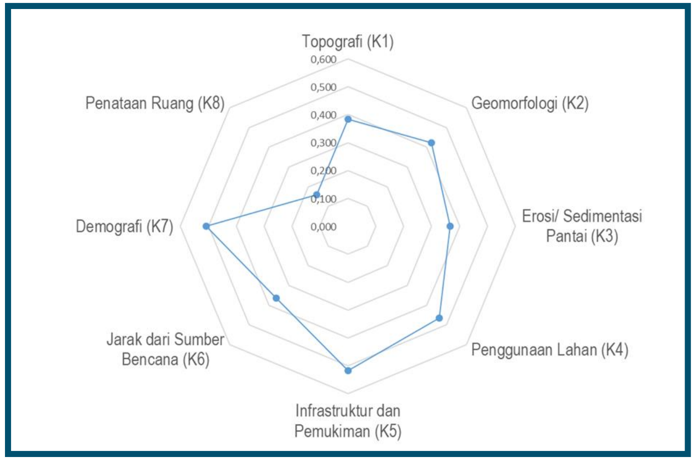
Map of Spatial Distribution of Sensitivity Index of 2020 (Author Team, 2020)

b. Exposure Analysis

The spatial distribution of exposure index shows **that the study locations have varied exposure level from very low to very high, with higher level found in upstream and coastal areas.**

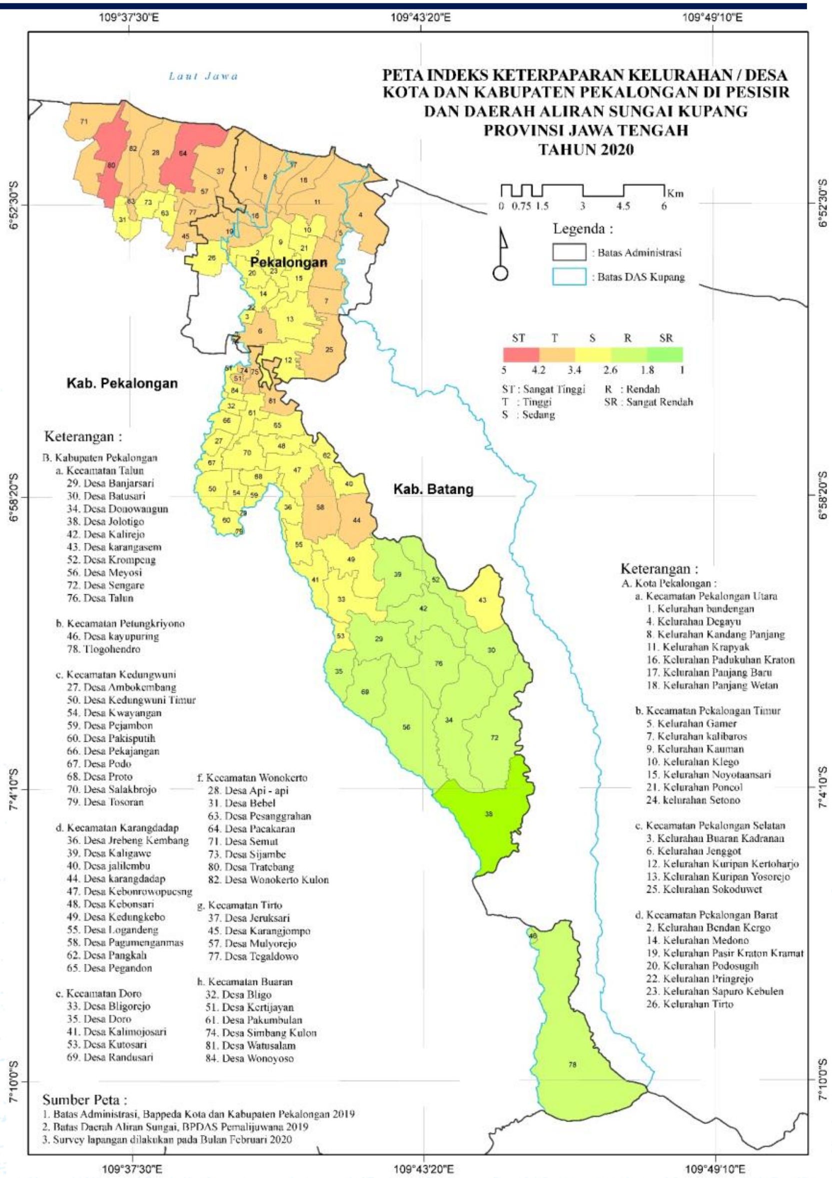
The high and very high exposure level dominate the downstream and coastal areas, particularly the coastal village/*kelurahan* (bordered by the sea); where there are **two villages with very high level of exposure, namely Pacakaran and Tratebang Villages.** The exposure dimension is strongly related to the potential of an area to be exposed to hazard potentials, so that it can be seen that coastal areas that have been exposed to tidal flood (and flood in downstream) and with relatively flat topography have higher exposure as compared to other areas. The high exposure level is very much influenced by population density and the highly developed land in the area.

The level of exposure of middle area **is dominated by moderate level**, although **some villages also show high exposure level.**



The emergence of high exposure level locations in middle area are generally caused by its locations that are situated close to water body, land use that is dominated by productive and settlement areas, land subsidence rate, as well as influence of topographic and geomorphological aspects. Meanwhile, upstream area is dominated by low level exposure.

Domination analysis shows that **demographic, infrastructure and settlement components are the most influential components to exposure level.** An aspect that ought to be considered is **the connectivity between demographic components with land use as well as infrastructure and settlement with topography.** The change of population density will influence change in land use, while topographic change will influence infrastructure and settlement. Both will change the potential impacts of a disaster incident.



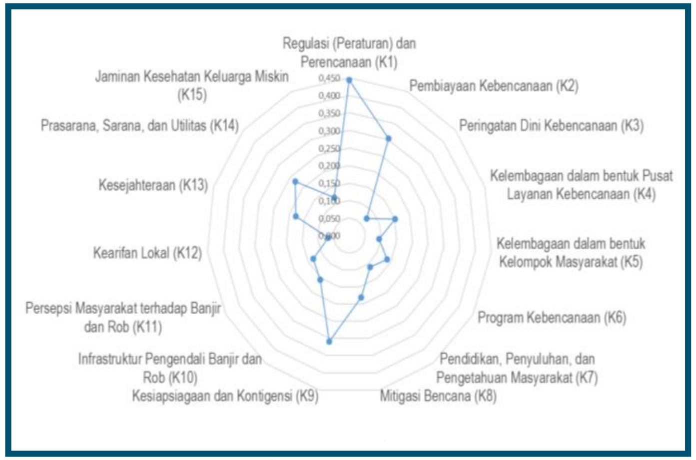
Map of Spatial Distribution of Exposure Index of 2020 (Author Team, 2020)

c. Adaptive Capacity Analysis

The adaptive capacity levels of the study location range from low to high, with regency area generally has lower level than that of city.

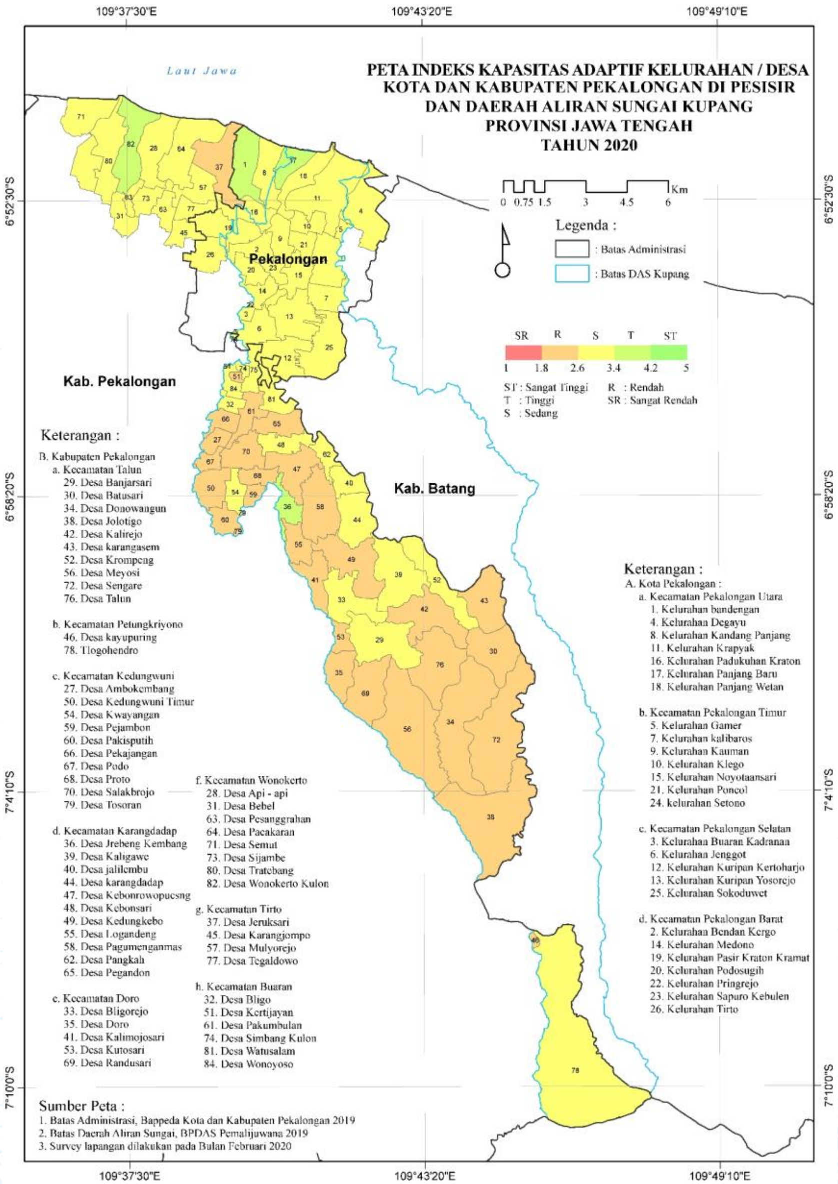
Moderate level adaptive capacity is currently dominating the coastal area, except Jeruksari Village (low) and Wonokerto Kulon Village, Kelurahan Bandengan, and Kelurahan Panjang Baru (high). Special attention is required to Jeruksari Village and Kelurahan Bandengan, which have rather different adaptive capacity, despite being located next to each other. This is because institutional-wise (regulation, financing, and early warning), Kelurahan Bandengan is at better level than Jeruksari Village.

For downstream area, the adaptive capacity is predominantly moderate. **The more inclined to the middle and upstream, the more the adaptive capacity of the study location decreases to the point where low level dominates**, except in Jrebeng Kembang Village (high). The condition is caused by the adaptive capacity building component, which is strictly related to the institutional framework of the local government to mitigate flood and community's "experience" in dealing with flood.



For middle and upstream areas, which currently rarely or have never experienced any flood, it is only natural if they are not being the main concern of the local government in flood mitigation. Likewise, the community's preparedness is hardly sufficient.

Looking at **the main components determining adaptive capacity level in the study location, it can be seen that the regulation and planning, disaster early warning, preparedness and contingency are the 3 dominant main components.** With regard to regulation, planning and early warning, generally the level is very low-low (except regulation in Pekalongan City that is already high), while the preparedness and contingency components are dominated by high-very high level.



Map of Spatial Distribution of Adaptive Capacity Index of 2020 (Author Team, 2020)

d. Vulnerability Analysis

The vulnerability level of the study area was developed in accordance with each area's level of sensitivity, exposure, and adaptive capacity. The lower the adaptive capacity and the higher the sensitivity and exposure are, the higher the area's vulnerability level will be.

In baseline condition, the analysis results show that the study location has moderate-very high vulnerability level. **The high vulnerability level dominates the study location (38% village/kelurahan)**, followed by moderate level (28% village/*kelurahan*). However, when observed from vulnerability building dimension, it can be seen that the moderate level has higher portion (the most number of village/*kelurahan*) in the components of sensitivity, exposure, and adaptive capacity, particularly for sensitivity component. However, after being aggregated, the high vulnerability level turns out to have larger proportion.

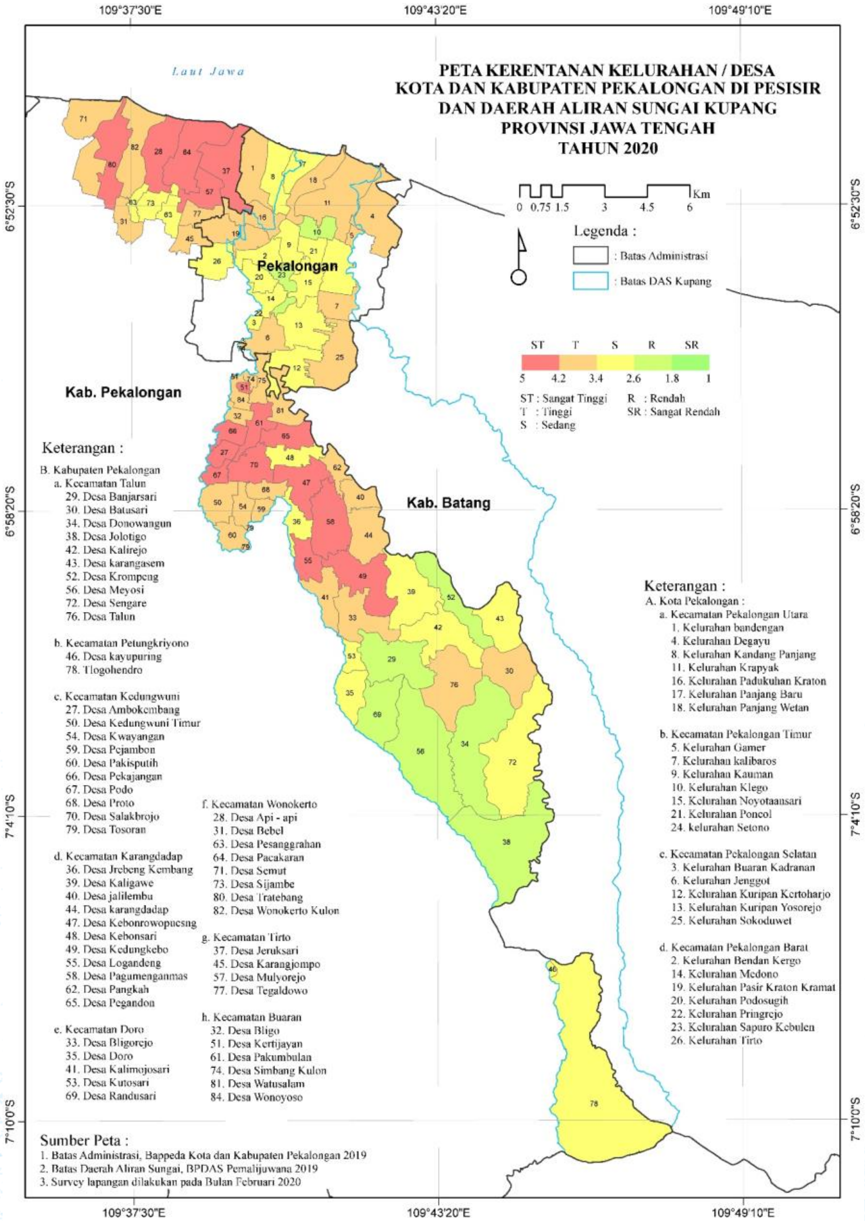
Very high vulnerability level was only found in 16 villages in Pekalongan Regency, which are spread across the coastal and middle areas. This shows that high vulnerability does not occur only in areas directly affected by the tidal flood.

For villages with **very high vulnerability level**, analysis shows that such a level **tends to be caused by their low adaptive capacity and high sensitivity.** Approximately 75% of the village/kelurahan with very high vulnerability have low adaptive capacity level, and 60% have high sensitivity level. Meanwhile, the high and very high exposure levels were found in 31% and 12.5% villages/*kelurahans*, consecutively.

The gap of adaptive capacity levels between Pekalongan Regency and Pekalongan City has led to different vulnerability levels between both areas.

Thus, to reduce the village/*kelurahan*'s vulnerability in the study location, it is necessary to increase the quality of the main component that influences adaptive capacity and local area's sensitivity levels, namely the critical assets: health; regulaton and planning; and disaster early warning.

Another matter that needs to be highlighted is the existence of villages with moderate and high vulnerability levels in the upstream area.



Map of Spatial Distribution of Vulnerability Index of 2020 (Author Team, 2020)

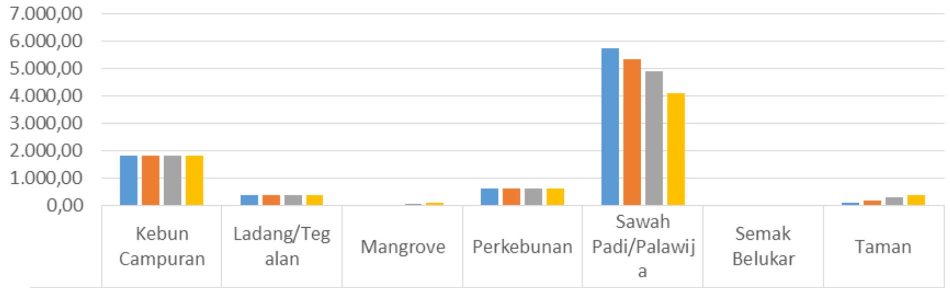
4.2 Projection Elements

a. Sensitivity Projection

The components that were dynamically projected for sensitivity were spatial planning, poverty, vulnerable group, per capita income, and GRDP of the affected sector.

❑ **Spatial Planning**

The premise of this component projection is that the dynamics of city development will suppress the development of green areas in the study location. The lower the size of green area is, the lower the water absorption capacity will be, which in turn will decrease the area's sensitivity. The projected changes in green area size in time series manner was carried out using the spatial dynamic model with *cellular automata*.



	Kebun Campuran	Ladang/Tegalan	Mangrove	Perkebunan	Sawah Padi/Palawija	Semak Belukar	Taman
2020	1.841,60	372,48	13,75	622,48	5.764,34	0,53	88,86
2025	1.841,70	372,48	44,89	622,48	5.345,92	0,06	194,42
2030	1.841,61	372,44	75,80	622,48	4.900,56	0,06	298,98
2035	1.841,64	372,39	106,85	622,48	4.114,71	0,06	404,81

■ 2020 ■ 2025 ■ 2030 ■ 2035

Projection of Green Area Size Changes (Author Team, 2020)

The modeling results in general indicate that there is no changes in size of the combined garden, field/moorland, and plantation. Meanwhile, **the decrease of land size might be identified in the ricefield/secondary crop field, which is caused by, among others, the developed area (settlement, industry, etc.).** The increase of land size can be found in mangrove and park, which reflects optimistic conservation measures by the local government.

❑ **Poverty Rate**

Poverty rate will affect the population's ability to deal with flood risk. The projection of poverty number will be conducted by looking at the trend of poverty number development in historical time series manner, poverty alleviation targets set out in the document and local policies, as well as influence from the potential population growth. The projection results show that poverty rate in Pekalongan Regency and Pekalongan City will decrease to 3.81% and 3.1%, consecutively.

❑ **Vulnerable Group**

Vulnerable groups (women, children, elderly, and person with disabilities) are community groups with relatively lower resilience and capacity to address flood issue as compared to those of other groups. The projection of vulnerable groups was conducted by using geometric statistical method by looking at historical growth trend. Projection shows that in the future, the number of vulnerable groups in both Pekalongan Regency and City will tend to increase, except that of children group in Pekalongan City, which will be relatively stable. The difference in growth trend will slightly influence the sensitivity level in both areas.

❑ Per Capita Income

The per capita income projection was carried out by using basic data, i.e. district statistic data in number to indicate per capita income per village/*kelurahan* and village/*kelurahan* statistics in number from the past 5 years. The projection method used was ETS Method.

The projection results indicate that per capita income for Pekalongan City will have a positive trend, and reach IDR 70,147 by 2035. Positive trend was also found in Pekalongan Regency, yet with relatively flat slope. By 2035, the per capita income of Pekalongan Regency was estimated to reach IDR 49,422.

❑ GRDP of the Affected Sector

Similar to per capita income, the GRDP projection of the affected sector was also carried out by using ETS method, using the historical per sector GRDP data taken out from the local government policy document. The affected sectors in this study comprise of agriculture, forestry, and fishery. From the projection results, it was found out that the affected sectors' GRDP in the Pekalongan Regency and City are, consecutively, IDR 2,767,409 and IDR 380,718.

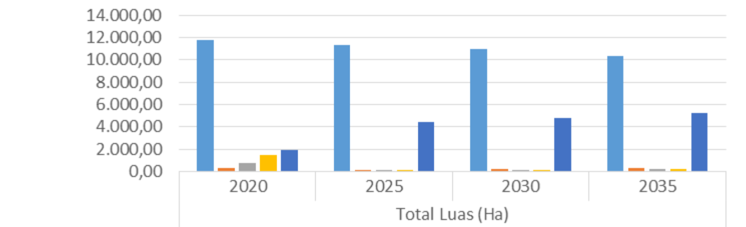
b. Exposure Projection

The components that are dynamically projected for exposure are topography, demography, and spatial planning.

❑ Topography

The premise of component projection is that villages/*kelurahans* located in slight inclination (slope) and relatively low land surface will be more exposed to flood since the water flow in the area will tend to be slow or hampered, and the areas will potentially be inundated by the tidal flood. The projection of inclination and land surface height was conducted by using DTM data reconstruction, using land subsidence data processed from InSAR data. The data was taken from Sentinel-1 satellite for every projection period.

The projection results show that there will be changes of inclination at every level, with the highest size growth to be found in inclination of <2º; while the other inclination levels will experience decrease of size. With regard to land surface elevation, there is a significant size decrease of areas with land surface elevation of >1.45 m and 0.35-0.7m, with size changes reaching 1.300-1.400 Ha until year 2035. Meanwhile, **for elevation <0,35 m , there will be substantially significant increase in size, with number of change reaching 3,300 Ha by 2035 as compared to that of 2020. This indicates that there are more areas that will be potentially affected by flood and tidal flood.**



	2020	2025	2030	2035
> 1.45 m	11.753,46	11.375,81	10.990,00	10.313,14
1.05 m - 1.45 m	315,54	161,60	224,20	328,85
0.7 m - 1.05 m	786,15	140,42	138,67	253,26
0.35 m - 0.7 m	1.513,77	170,34	150,78	204,03
< 0.35 m	1.959,60	4.465,55	4.810,06	5.214,37

> 1.45 m   1.05 m - 1.45 m   0.7 m - 1.05 m   0.35 m - 0.7 m   < 0.35 m

Projection of Size Change per Land Elevation Class in Study Location (Author Team, 2020)

❑ **Demography**

The demographic projection was carried out by using geometric statistic method against the historical trend of population density per village/*kelurahan*. The projection shows that there will be a linear increase of population density both in Pekalongan City and Regency, yet the number of population density in both areas are significantly different. The population density in Pekalongan City by 2035 is estimated to be 13,667 people/km^2, while that of Pekalongan Regency will be 3,641 people/km^2. This discrepancy is caused by the fact that urban spatial pattern has denser characteristics as compared to that of rural. Furthermore, land availability in urban area is more limited, thus making the settlement density higher.

❑ **Spatial Planning**

Projection in this component was carried out to identify the change of settlement size located in beach/river boundary. The projection was conducted by using spatial dynamic model. The modeling indicates that until 2035, there will be a steady increase of settlement size by 1,000 Ha in the study location. However, the increase will take place along with the increase of inundated and tidal flood affected areas. This indicates the potential expansion of settlement areas that will be inundated or affected by tidal flood. This should become a concern in area planning, as any growth of settlement prompted by population growth might be affected by land limitation that might be caused by inundation.

c. Adaptive Capacity Projection

The components that were dynamically projected for adaptive capacity are disaster programs, flood and tidal flood control infrastructure, and poor family health insurance.

❑ **Disaster Program**

The projection process for disaster program component was based on Pekalongan City and Regency Governments' programs on disaster and conservation that were planned to be implemented during each projection period. The policy used as the reference of this process was the Spatial Plan of each area.

❑ **Infrastructure for Flood and Tidal Flood Control**

Similar to disaster programs, the projection process for this component was conducted by studying the projection indications related to development/improvement of flood and tidal flood controlling infrastructure, such as dike, seawall, polder, retention pool, pump, etc. The policy used as the reference of this process was the Spatial Plan of each area.

❑ **Poor Family Health Insurance**

Health insurance projection was carried out by using historical data of the proportion of poor community having KIS (Healthy Indonesia Card) and employing linear regression method, which mainly focused on the use of subsidized BPJS. The projection results show that there is a periodic declining trend in the proportion of community using Subsidized BPJS. This condition indicates that community's well-being will improve in the future.

4.3 Vulnerability Projection (2021-2035)

Projection of vulnerability index and its dimension were obtained from the static and dynamic projection process against its building components.

a. Sensitivity Trend

Data processing results for the entire projection period shows that **sensitivity level in the study location generally shows a declining trend**, thus it can be said that the sensitivity of the study location is getting better. In baseline condition, the sensitivity level in the study location is generally ranges between moderate to high level. **By the end of projection period (year 2035), the sensitivity will be dominated by low and moderate levels,** with only 2 villages having high sensitivity level (in Pekalongan Regency).

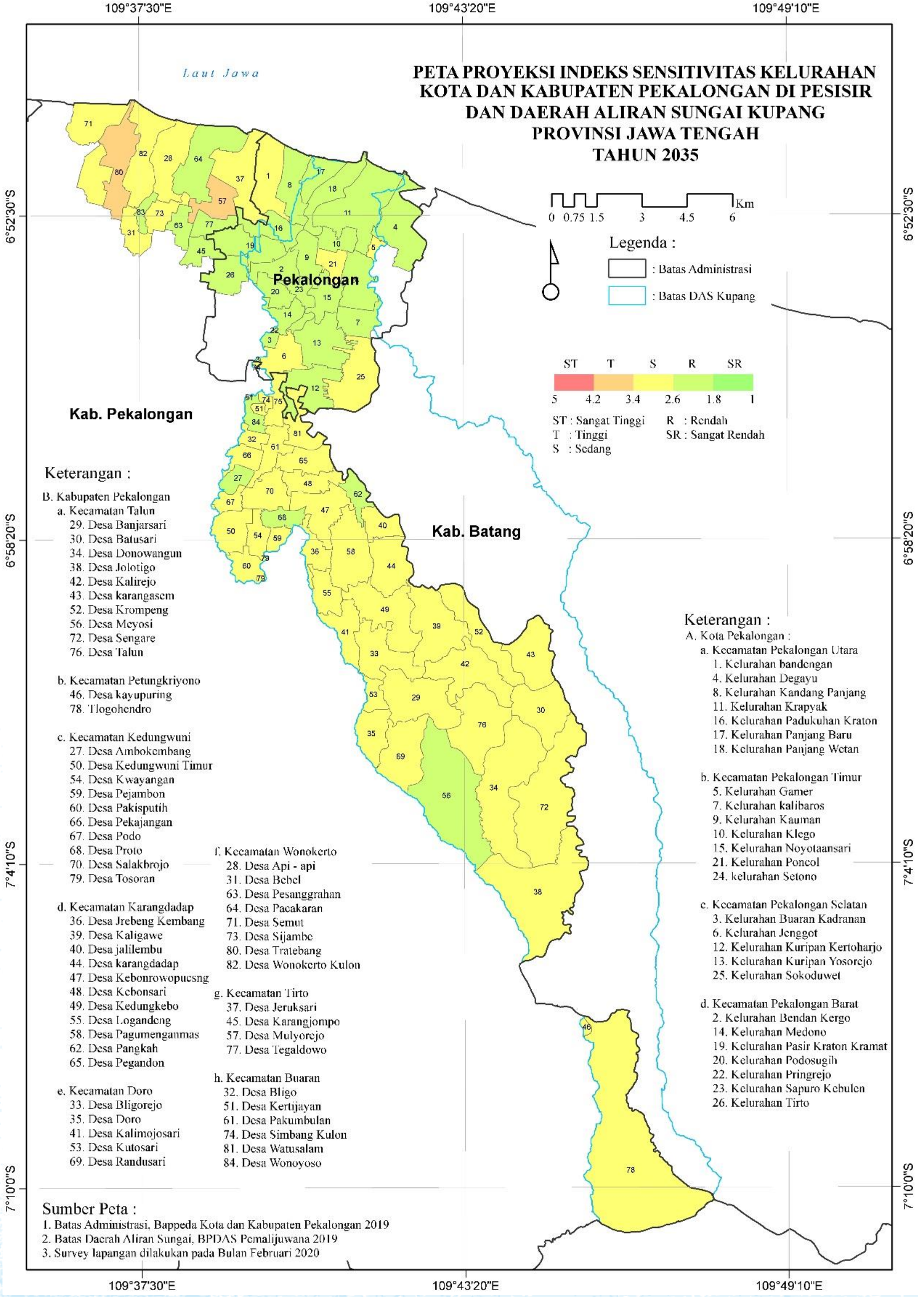
This change is influenced by the positive trend in poverty and per capita income components. By the end of the projection period, there will be no village/*kelurahan* categorized as high or very high levels in both components. In baseline condition, 54 village/*kelurahans* have such a range in poverty component, and which is similiar to the 25 villages/*kelurahans* for per capita income.

However, it should be noted that the **two components have their limitations, i.e. potential of bias in areas with varied characteristics, as it is inclined toward generalization.**

Comparing between Pekalongan City and Pekalongan Regency, it can be seen that both in baseline condition and projection, Pekalongan City has lower sensitivity level compared to Pekalongan Regency.

The sensitivity level of Pekalongan City by the end of projection period will be dominated with low level, with only 5 *kelurahans* are at moderate level, namely: Kelurahan Bandengan, Gamer, Jenggot, Poncol and Sokoduwet. Both Kelurahan Jenggot and Sokoduwet do not experience any change in sensitivity level from that of the baseline condition.

For Pekalongan Regency, its sensitivity by the end of projection period will be dominated by moderate level, particularly in middle and upstream areas. In coastal area, there are two villages with high sensitivity level, namely Tratebang and Mulyorejo Villages, which do not experience any index change from the baseline condition. There is also 1 village with low sensitivity level in the regency's coastal area: the Pacakaran Village.



Map of Spatial Distribution of Sensitivity Index of 2035 (Author Team, 2020)

b. Exposure Trend

By the end of the projection period, the exposure level in the study location varies between low to very high. In general, there is an increasing trend for village/*kelurahan* exposure level in the study location, particularly in coastal area and area near to the river.

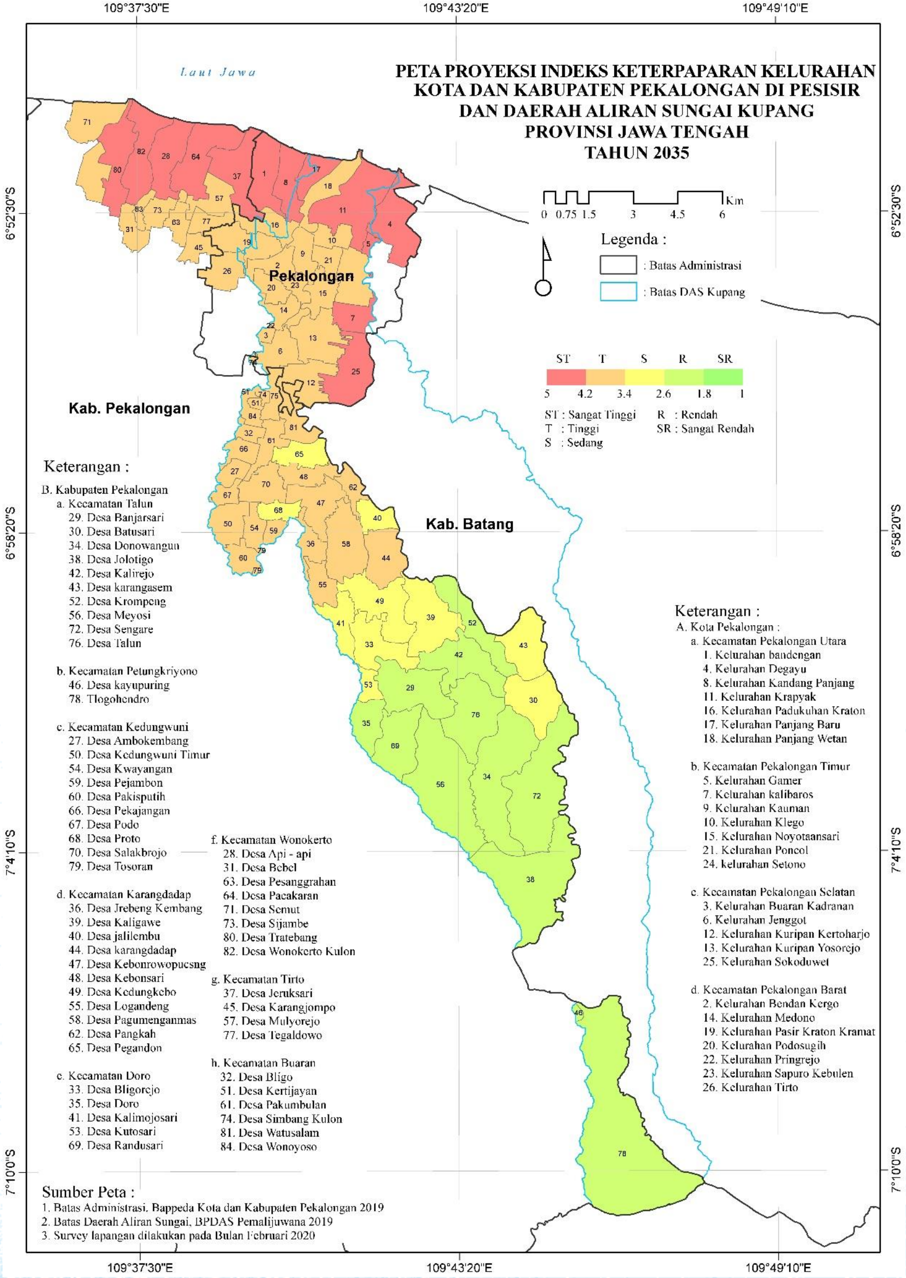
The increase of number of village/*kelurahan* having high-very high level in topographic and demographic components play major influence in the increase of exposure. The high level of topographic index results from the impact of the expansion of area with elevation of <0.35 m due to land subsidence, hence making the areas potentially exposed to flood wider. In addition, **the change is also influenced by land use component** which is projected to cause more villages switch to high-very high level.

The increased exposure seems to be relatively significant in downstream and coastal areas. The very high exposure level will dominate the coastal area, where out of 2 villages/*kelurahans* in the baseline condition, there will be 10 villages/*kelurahans* at very high exposure level by 2035.

Downstream area, which is initially dominated by moderate-high level, **will become high-very high level by 2035**, with very high level will occur in Kelurahan Kalibaros and Sokoduwet. In middle area, there will be changes in domination from moderate level in baseline to high level by the end of the projection period.

For upstream area, the change will be relatively insignificant. Low level will still dominate this area, with additional 1 village having high level (initially moderate during baseline: the Batusari Village) and 1 village having low level of exposure (from initially very low during baseline: Jolotigo Village).

The condition's change in downstream and coastal areas appear to be so visible from administrative perspective. Pekalongan City, which has moderate to high exposure level during baseline, by the end of the projection period will have high and very high levels of exposure. Pekalongan Regency will see the change in exposure level to reach the middle area. However, considering the appearance of villages with high exposure level at the upstream, there is possibility that the spatial distribution of high exposure level will move to upstream.



Map of Spatial Distribution of Exposure Index by 2035 (Author Team, 2020)

c. Adaptive Capacity Trend

The projection results in various periods show that the study location relatively does not experience significant changes on their **adaptive capacity level.** However, **a relatively positive trend can be found**, which is indicated from the adaptive capacity increase in several villages/*kelurahans*.

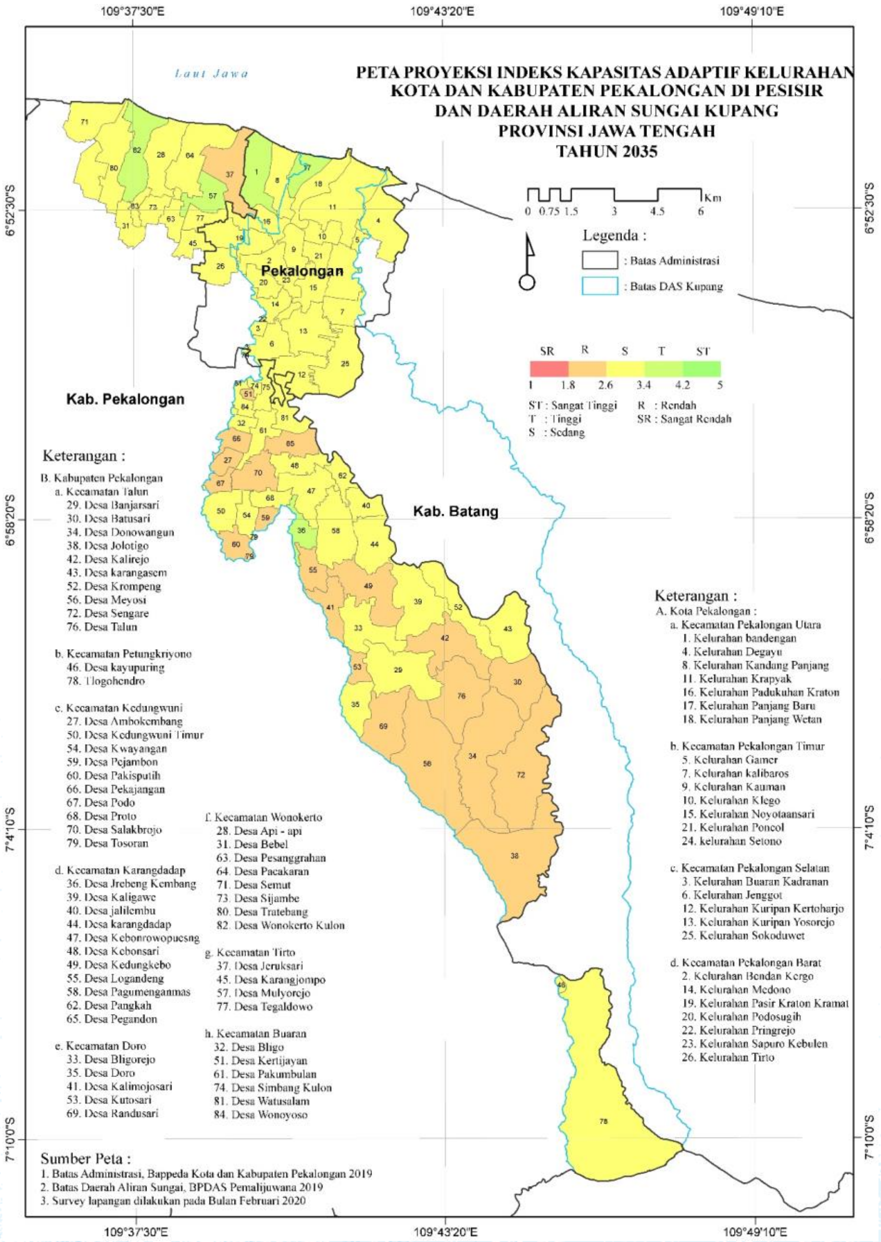
The changes tend to be caused by positive trend in the component of poor family health insurance program, which, during baseline, was dominated by low level (although few are of very high level), to moderate level in all villages/*kelurahans*.

In general, similar to baseline, **the study location is still dominated by moderate to low adaptive capacity, with increasing number of villages/*kelurahans* having moderate adaptive capacity level.** There are 7 villages/*kelurahans* that have been recorded to switch from low to moderate level, namely: Villages of Pakumbulan, Kedungwuni Timur, Proto, Kebonrowopucung, Pagumenganmas, Doro and Karangasem. The seven villages are located in the middle area of the study location.

In downstream area, there is 1 village experiencing adaptive capacity level change from moderate to high, namely Mulyorejo Village.

From administrative perspective, Pekalongan City in general has higher adaptive capacity level as compared to that of Pekalongan Regency, where almost all *kelurahans* are categorized as having moderate adaptive capacity level, with 2 having high level, namely *Kelurahan* Bandengan and *Kelurahan* Panjang Baru.

Meanwhile, Pekalongan Regency tends to be at low-moderate level, with three villages having high level, namely: Villages of Jrebeng Kembang, Mulyorejo and Wonokerto Kulon. **For Jeruksari Village, by the end of the projection period, the village's adaptive capacity level is projected to remain at low level.** This needs to be highlighted, since the village is historically the one facing tidal flood most frequently.



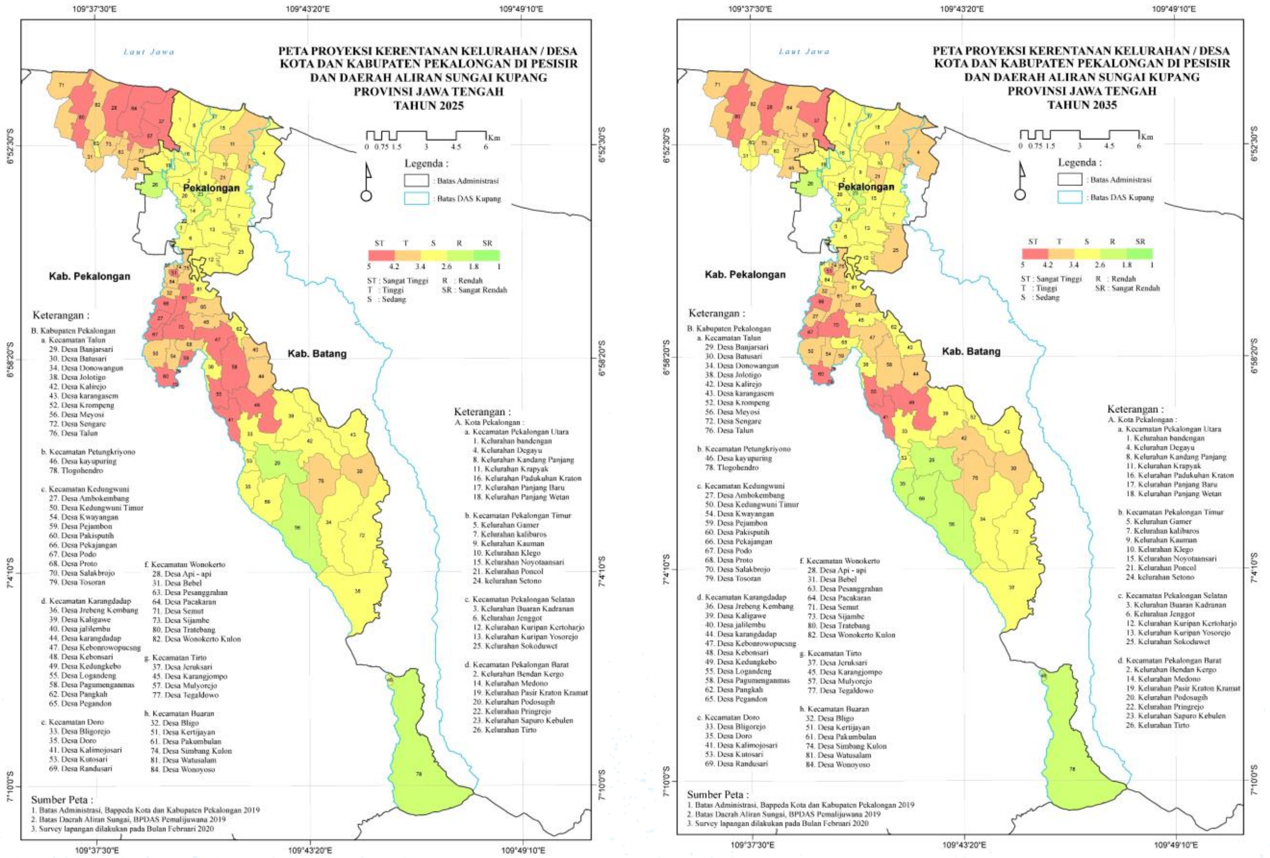
Map of Spatial Distribution of Adaptive Capacity Index of 2035 (Author Team, 2020)

d. Vulnerability Trend

The projection of vulnerability level in each period shows a rather different trend for each segment of the study location, yet in general, the changes that take place are not too significant.

In upstream area, there are several locations with increasing vulnerability level from low to moderate. The four villages are located within Talun District. However, in the same (upstream) area, there is also a village experiencing decrease of vulnerability level from moderate to low, namely Tlogohendro Village. The analysis results show that **the increasing vulnerability in upstream area tends to be caused by the increase of exposure in that area**, with relatively minor changes in sensitivity and adaptive capacity.

Vulnerability level for midstream area tends to decrease from the baseline year to the end of projection period. By 2035, there will be 4 villages experiencing changes of vulnerability level from very high in the baseline year to high, and 3 villages experiencing changes from high to moderate. However, there are also 3 villages found to experience increase of vulnerabiilty from high to very high, namely the Villages of Pakisputih, Tosoran and Kalimojosari. **The changes in vulnerability in the middle area tend to be influenced by the declining sensitivity and increase of adaptive capacity**; however, some areas still experience increase of exposure, particularly in comparison between the baseilne condition to projection condition by 2025.



Map of Spatial Distribution of Vulnerability Index of 2025 (left) and 2035 (right) (Author Team, 2020)

The downstream and coastal areas also experience a rather declining trend. The Villages of Pecakaran and Mulyorejo experience changes from very high vulnerability level during baseline condition to high by the end of projection period. The decline of vulnerability level is also experienced by the Kelurahans of Bandengan, Panjang Wetan, and Tirto. However, there is also an increase of vulnerability in this area in Kelurahan Poncol. **The decreasing vulnerability level in the area tends to be influenced by the decrease in sensitivity level and increase of adaptive capacity** in the areas. The exposure level in several locations in the area is actually also increasing, yet the influence seems to be relatively minor as compared to the sensitivity and adaptive capacity.

05 RISK ANALYSIS

The discussion on risk level will be separated between coastal and non-coastal areas. For this analysis, coastal area in the study location consists of 22 villages/*kelurahans* (13 villages in Pekalongan Regency and 9 *kelurahans* in Pekalongan City) as presented on the side image.

5.1 Baseline Condition

a. Pekalongan Flood Context

The analysis results in the previous step show that the increase of sea level height is not the only contributor to the inundation increase in Pekalongan coastal area. The high rate of land subsidence also significantly contributes to the more rapid increase of permanently and farthest inundated areas in the coastal area.

The condition is exacerbated by recurring current and tide of sea water and extreme rainfall. The analysis result and climate modelling in this study show that historically, there has been changes in climate variability, and this change will keep happening in the future, including extreme rainfall and its frequency of occurrence.

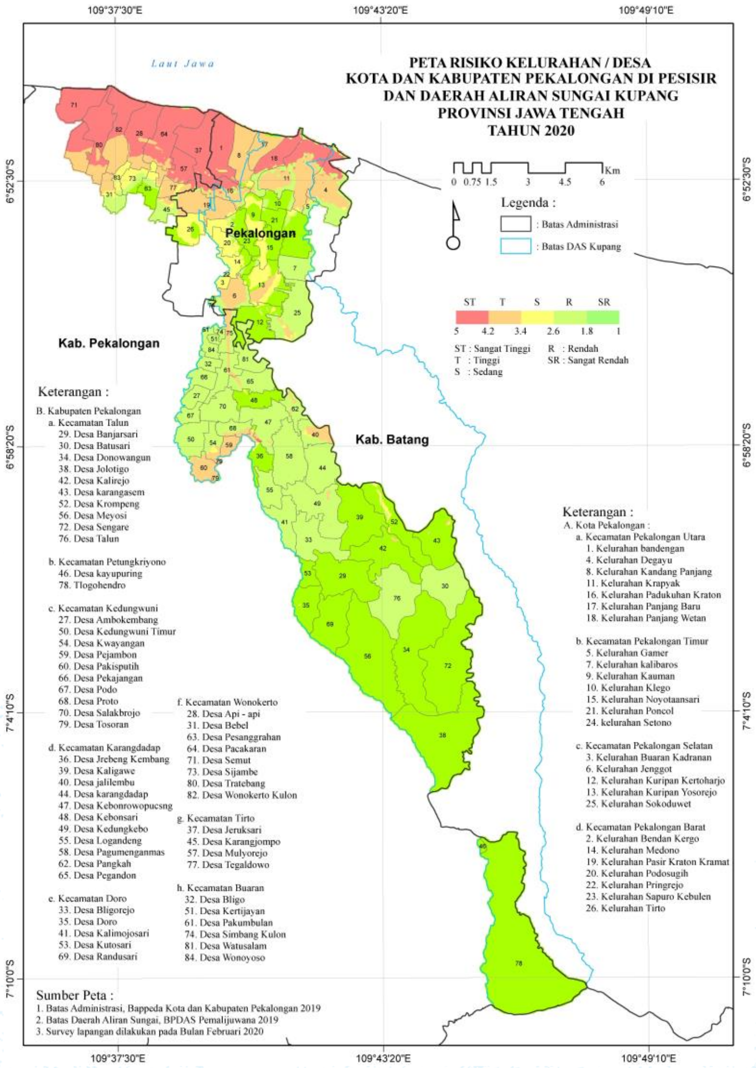
As for extreme rain, BNPB's historical data show that the flood hazard due to extreme rain does not only affect the coastal area, yet also the middle and upstream areas, particularly along the river flow, as well as other areas with lower elevation or slope.

Vulnerability analysis also indicates that the level of exposure, sensitivity, and adaptive capacity in the study location can also influence the flood risk.

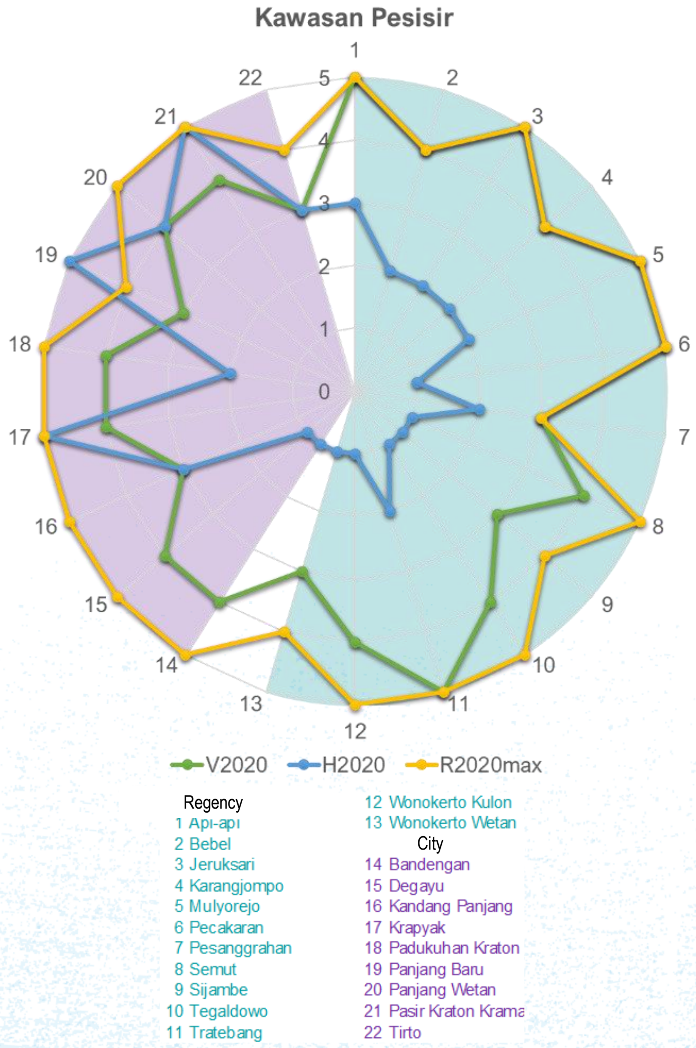
b. Baseline Risk in Coastal Area

The increasing hazard level in the coastal area will increase the risk in that area, particularly areas with high vulnerability level.

Comparison of hazard, vulnerability, and risk dimensions of all coastal villages/*kelurahans* in the study location show that **in general, the villages/*kelurahans* have high and very high risk level, except for Pesanggrahan Village.** This is because the village has very low hazard level and moderate vulnerability level. Other villages such as Bebel and Karangjompo also have very low hazard level, yet very high risk level due to its high vulnerability level.



Map of Spatial Distribution of Baseline Risk Index (Author Team, 2020)



Visualization of Vulnerability Index (V2020) and Hazard (H2020) that Compose Flood Risk (R2020max) in the Coastal Area (Author Team, 2020)

The vulnerability level was found to be in line with exposure, sensitivity, and adaptive capacity of the area, which is also at moderate-high level. Similar to the condition of Pekalongan Regency, most of *kelurahans* in Pekalongan City show moderate adaptive capacity level.

Deeper analysis was conducted on vulnerability level of coastal area to see the influence of each vulnerability component to its flood risk level, as well as to identify non-mitigational measures can be carried out to reduce the risk.

The high flood risk in the coastal area of Pekalongan Regency seems to not only caused by the high level of exposure, but also by its moderate-high sensitivity level; with adaptive capacity level in general situated under or equal to its exposure or sensitivity level, except for the Wonokerto Kulon Village.

Villages with very high vulnerability level such as the Villages of Api-api, Jeruksari, and Tratebang, were identified to have high exposure and sensitivity level, with low-moderate adaptive capacity. Thus, ideally, the adaptive capacity in those villages must be built to reduce the risk level.

For Pekalongan City, the high flood risk in the coastal area is also influenced by the level of area's vulnerability that ranges between moderate-high. The *Kelurahans* of Kandang Panjang, Panjang Baru, and Tirto, have moderate vulnerability level, while another *kelurahan* has high vulnerability level.

The fact that there is no village in Pekalongan City and Regency coastal area that show low and very low vulnerability level indicates further attention is needed. Well-planned adaptation measures are highly needed to increase the community's adaptive capacity, especially in dealing with the increasing flood hazard.

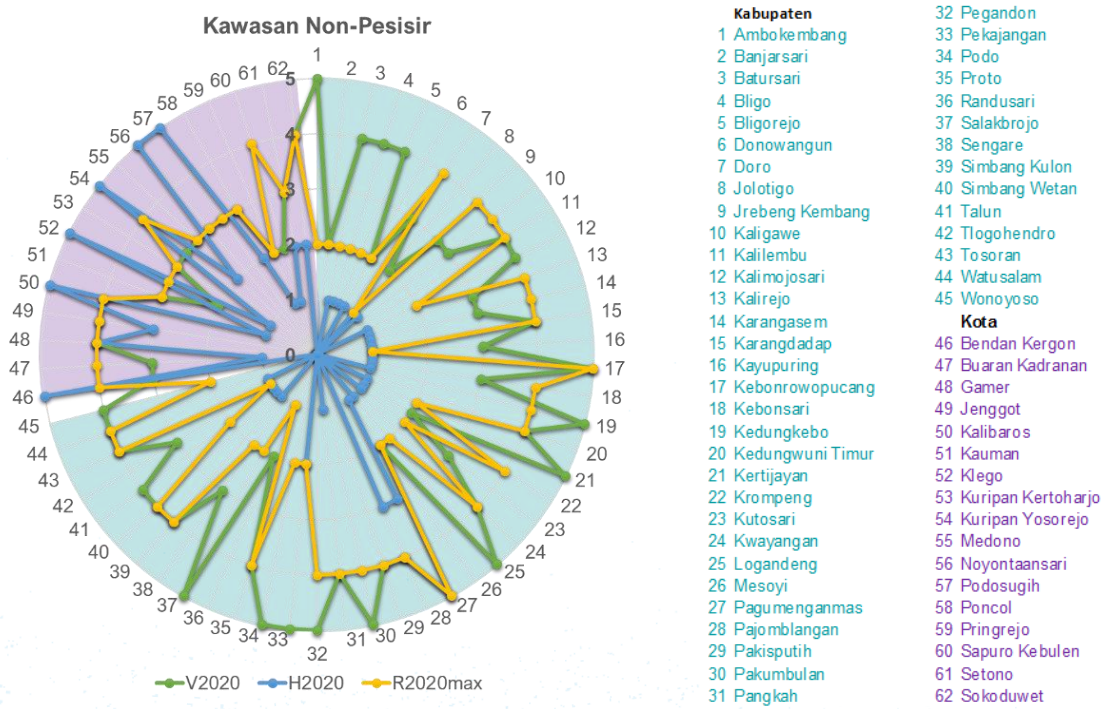
In addition, the potential of permanent inundation occurrence in the coastal area need more comprehensive adaptation options, which do not only focus on increasing the adaptive capacity, but also in formulating and implementing policies associated with supports to economic activities, infrastructure development, etc.

c. Baseline Risk Level in Non-Coastal Area

The non-coastal areas referred to herein encompasses middle, upstream and downstream areas of Kupang Watershed, which are mostly dominated by Pekalongan Regency area.

The vulnerability level of non-coastal villages in Pekalongan Regency is in general at high level, although some villages were found to be at very high vulnerability level, such as Ambokembang, Kebonrowopucang, Kedungkebo, Kertijayan, Logandeng, Pagumenganmas, Pakumbulan, Pegandon, Pekajangan, Podo and Salakbrojo. **The condition is caused by the sensitivity and exposure levels that are generally at moderate level and the averagely low adaptive capacity.**

The averagely high vulnerability level then causes the non-coastal villages in Pekalongan Regency in general to have high risk. However, risk calculation also shows that **some villages with high-very high vulnerability level have low risk level**, such as the Villages of Batursari, Bligo, Talun, Wonoyoso, Ambokembang, Kertijayan, and Pekajangan. The low risk level of these villages is **due to the very low flood hazard level in the area.**



Visualization of Vulnerability Index (V2020) and Hazard (H2020) that Compose Flood Risk (R2020max) in the Non-Coastal Area (Author Team, 2020)

The averagely high risk level was also found in non-coastal *kelurahans* in Pekalongan City, although some *kelurahans* also have low and moderate risk levels. **The risk level is caused by the combination of relatively high flood hazard in the area and the relatively moderate vulnerability level.** The moderate vulnerability level is composed of the relatively moderate sensitivity, exposure, and adaptive capacity of the area.

However, some *kelurahans* have low and very low vulnerability level, which is influenced by its low-very low sensitivity level. On the other hand, some *kelurahans* have high vulnerability level, namely *Kelurahan* Gamer, Jenggot, and Kalibaros.

Kelurahan Pringrejo is the only *kelurahan* with low risk level. Such a low risk was contributed by its low vulnerability level, although it has moderate level of flood hazard.

With regard to flood hazard, the non-coastal areas in Pekalongan CIty has higher flood hazard level as compared to the non-coastal areas of Pekalongan Regency. This is due to the fact that some areas face risks of tidal flood and flood caused by extreme rainfall.

What requires more attention regarding baseline condition of the non-coastal area is the fact that there are areas with low risk level yet high vulnerability level. Considering the relatively low adaptive capacity in the area, capacity building measures are necessary to strengthen the community's capacity in facing various potential hazards (other than flood).

Special attention is also required for areas with low risk level, although they might have moderate hazard level, such as *Kelurahan* Pringrejo. During flood risk mitigation, particularly when it comes to hazard mitigation, the *kelurahan* needs to be prioritized

5.2 Risk Projection (2021-2035)

Proper understanding on the historical condition related to flood hazard and information associated with its prediction and projection in the future is important in the risk analysis process. This baseline and projection information will help formulating the appropriate adaptation and mitigation strategies in the future.

Following the risk analysis approach used for the baseline condition in the previous part, the discussion on the risk projection analysis results was also conducted by using an analysis approach that differentiated between coastal and non-coastal areas.

a. Coastal Area Risk Level Projection

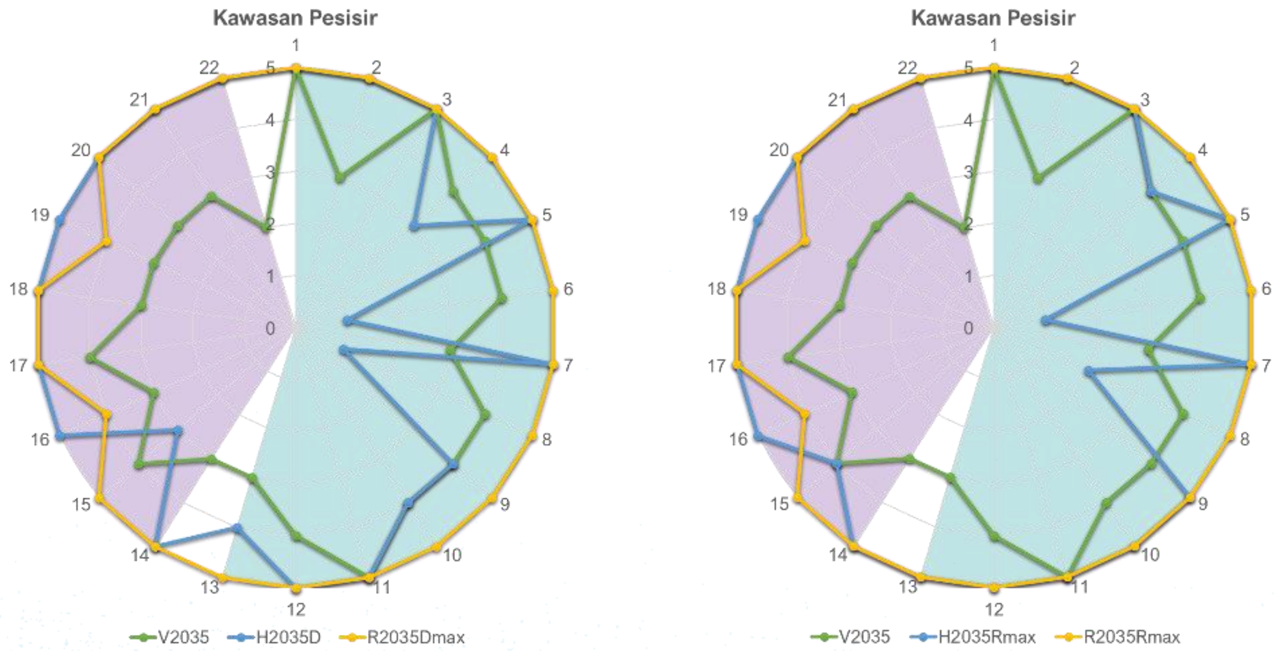
During baseline period, majority of villages/*kelurahans* in the coastal area have been in high and very high risk level, except the Pesanggrahan Village (moderate). The changes in hazard and vulnerability level in the future will certainly affect the risk level in the future.

The risk projection results, both produced by decadal prediction analysis and the RCP 4.5 scenario projection, almost entirely and consistently **show an increase of risk level in various projection periods, particularly from high to very high risk level**, although some vulnerability decrease also occurs in various areas.

The increasing risk is particularly caused by the tendency of increasing hazard to very high level that takes place in most of the villages/*kelurahans* in the coastal area, such as *Kelurahan* Bandengan, Degayu, Kandang Panjang, Krapyak, Padukuhan Kraton, Panjang Wetan and Pasir Kraton Kramat; as well as Villages of Api-api, Jeruksari, Mulyorejo, Pecakaran, Semut, Tegaldowo, Tratebang, and Wonokerto Kulon. Meanwhile, *Kelurahan* Kandang Panjang oppositely experiences decrease from very high to high level.

The combination of sea level increase rate (±0.81 cm/year) and land subsidence rate (which reaches 34.5 cm/year) are the main contributing factors to the increasing hazard level in the future. The condition is exacerbated with changes of wet extreme index.

Furthermore, the inundation projection shows that there is potential increase of inundation size in coastal area, which will definitely contribute to the increasing flood risk. The changes of risk level to very high in almost all villages/*kelurahans* in coastal area, and the potential increase of inundation area size show the importance of selecting and strengthening the adaptation strategies.



Visualization of Vulnerability Level (V2035) and Hazard (H2035) that Compose Flood Risk (R2035max) in Coastal Area by 2035 with Decadal Prediction (left) and RCP 4.5 Projection (right) (Author Team, 2020)

The area should be considered as the main focus in disaster risk reduction and climate change adaptation programs. The increase of flood risk and size can harm people's lives, due to the increasing number of exposed population, loss of productive and settlement areas, disrupted economic activities, as well as disrupted infrastructure service in the coastal area.

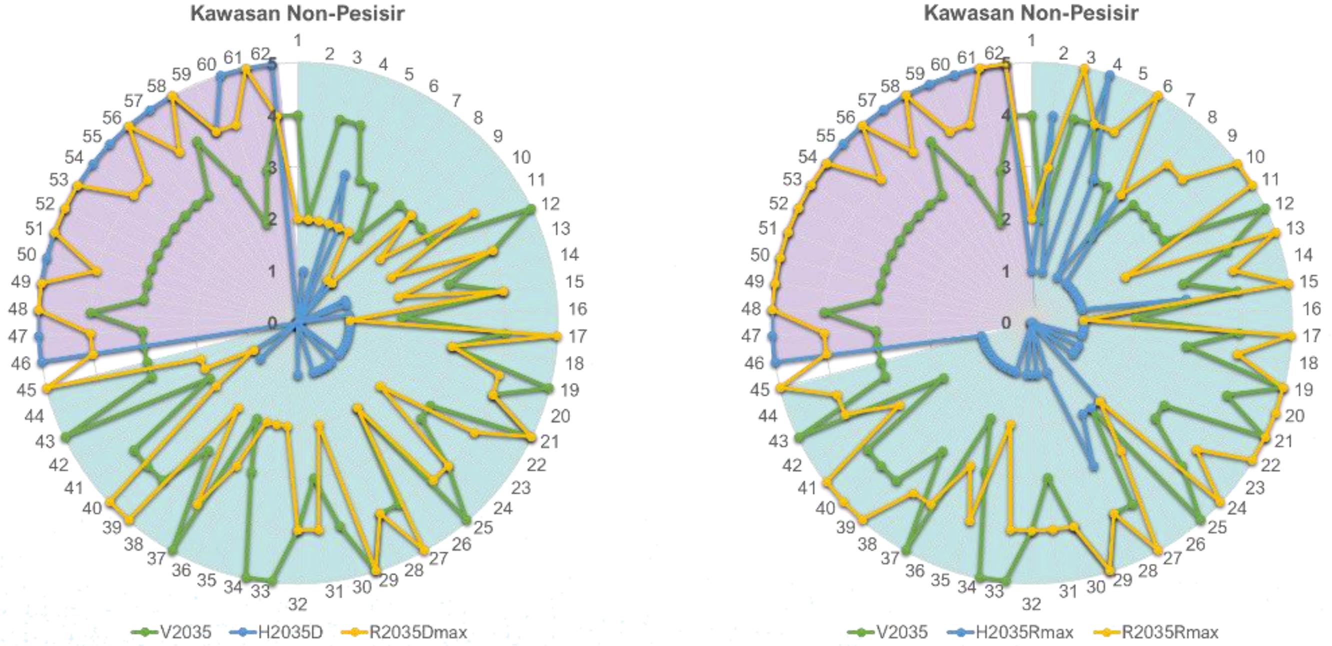
b. Non-coastal Area Risk Level Projection

The risk level projection for non-coastal area shows rather varying results with different dominant factors for both administrative areas. For Pekalongan Regency, the vulnerability level factor tends to be more dominant in influencing the risk level; while for Pekalongan Regency, the risk level is more influenced by the hazard level.

In general, the non-coastal areas of Pekalongan City are projected to have high risk level. The condition is caused by the predominantly moderate vulnerability level and very high hazard level.

Meanwhile, the vulnerability level of non-coastal areas of **Pekalongan Regency** is mostly at high-very high level, with average flood hazard level at not-affected-very low; **thus several villages with high-very high risk level can be identified. However, several villages with low and very low risk levels can also be found.**

The variation of risk level in a village/*kelurahan* due to the use of grid analysis unit in the risk analysis process is clearly visible for non-coastal areas as compared to coastal ones, particularly those situated near to the river. As an example, in the Villages of Pagumenganmas and Kalilembu, the high-very high risk level only occurs at grid area that has high-very high hazard level, while other areas have low risk.



Visualization of Vulnerability Level (V2035) and Hazard (H2035) that Compose Flood Risk (R2035max) in Non-Coastal Area by 2035 with Decadal Prediction (left) and RCP 4.5 Projection (right) (Author Team, 2020)

By using the maximum value-based analysis approach, the significance of the condition of Pagumenganmas and Kalilembu Villages can show up, and might serve as one of the indicative locations for addressing flood risk from hazard mitigation aspect. If the risk assessment was made by using the average value, there would be a fair probability that both villages will have lower risk, and thus their high hazard level can be ignored.

b. Risk Level Projection in the Study Location

The analysis results show that in baseline year, in total, the study location is composed of 36 and 17 villages/*kelurahans* that have high risk and very high risk levels, consecutively. The number of villages/*kelurahans* with both risk levels will keep increasing up to 23 and 35 villages/kelurahans, consecutively, to high and very high levels by 2035 according to the decadal prediction.

As for RCP 4.5 scenario, the high and very high risk levels will be found in 25 and 49 villages/*kelurahans* consecutively by 2035.

Looking at the administrative area, **in Pekalongan City**, the number of *kelurahans* that will experience higher risk level increase consistently, and by the end of the projection year, the entire *kelurahans* in the study location will have high-very high risk level both in decadal prediction scenario as well as RCP 4.5 projection; while in baseline year, the percentage of *kelurahan* with such a risk level is ±65%.

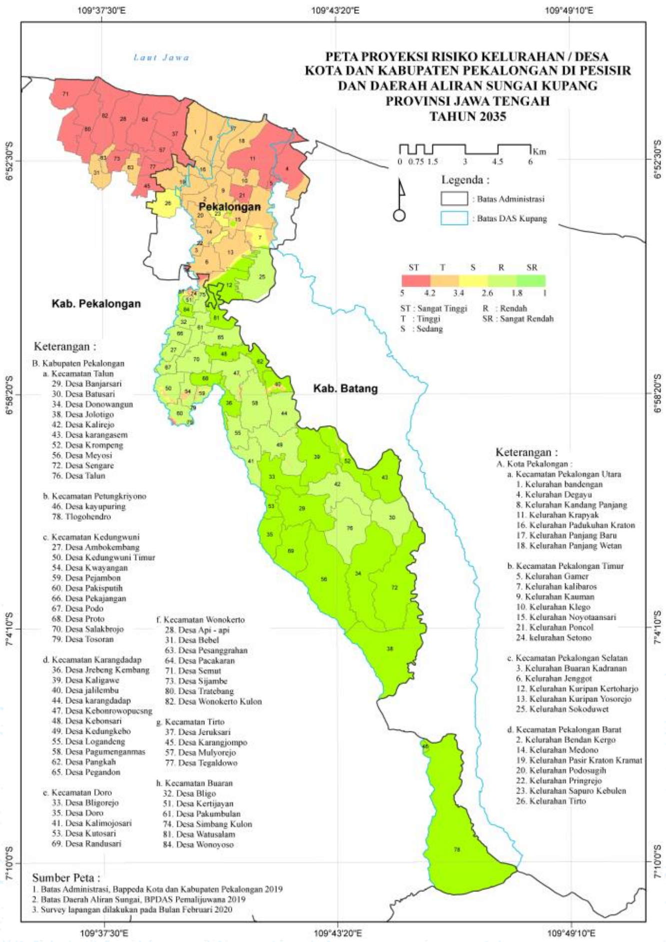
For Pekalongan Regency, obvious difference was found between the projection results from decadal prediction and RCP4.5 projection. In baseline year, 36 out of 58 villages have high-very high risk level. By the end of the projection period, the number shifted to 32 villages and 48 villages for decadal prediction and RCP 4.5 projection, respectively. The decadal prediction shows a decrease in number of villages with high-very high risk level, while RCP 4.5 shows an increase. In decadal prediction, increase is more obviously occurring at moderate risk level. The difference in changes of risk level in decadal and RCP 4.5 predictions **show that the change of rainfall as the factor shaping hazard level influences the risk level in Pekalongan Regency.**

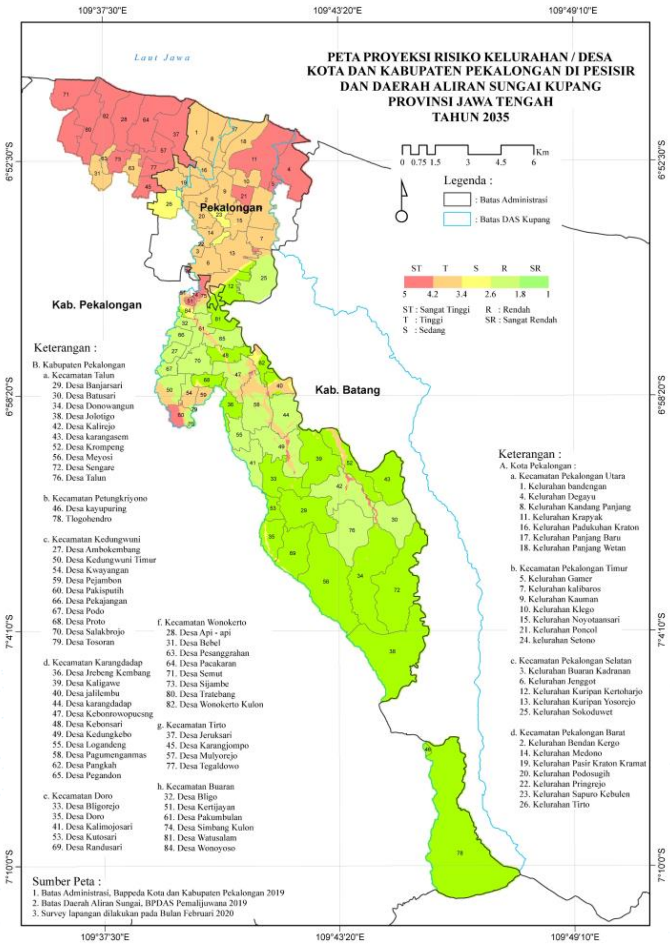
Upon comparing the coastal and non-coastal areas in Pekalongan City and Regency, an obvious difference occurs regarding the characteristics of flood vulnerability, hazard, and risk levels between the compared areas. The differences in characteristics of vulnerability and hazard are obvious between city and regency, particularly in the non-coastal areas.

The distribution of risk level and its shaping factors indicate the importance of observing various building factors of vulnerability level and factors influencing the hazard level, so as to take the appropriate adaptation strategy for flood risk reduction in the future.

The difference of characteristics of vulnerability level and hazard level can be used to determine the most suitable adaptation option, either one that will focus on decrease of exposure and sensitivity level, or one that will focus on adaptive capacity, although basically both matters shall be carried out simultaneously.

In addition, the spatial distribution using the grid analysis unit can also help in directing to the right locus area to implement the formulated programs and activities.





Spatial Distribution of Risk Level in Risk Area by 2035 with Decadal Prediction (left) and RCP 4.5 Projection (right) (Author Team)

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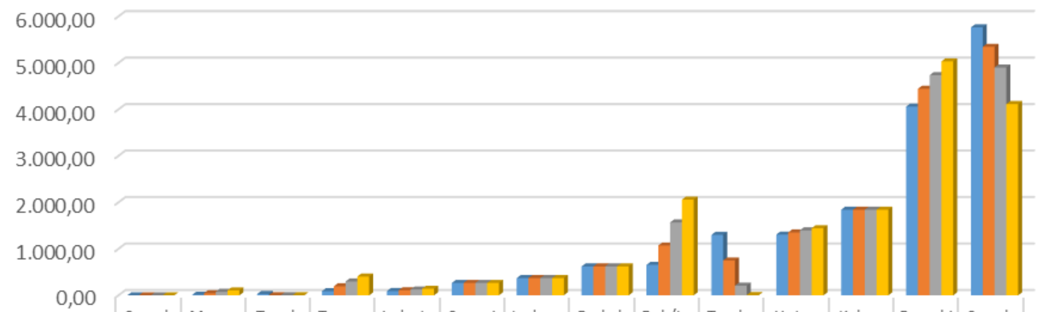
5.3 Interlinkage between Land Use Change and Inundation

The analysis was carried out to look at the spatial impacts of the change in inundation size (both permanent and farthest) to land use in the study location, so that the policies and programs formulated for the area can be highly effective and efficient.

Land use classification utilized in the projection is the same with that of the baseline condition. One of the classifications used is the tidal flood/inundated land. This refers to the existing condition where there are areas in the study location that are permanently inundated. The land use locus of 'tidal flood/inundated land' of this land use projection is different from the 'permanent inundation' and farthest inundation' generated from hazard analysis process.

In this study, a premise was made, that the overlay areas between land use of 'tidal flood/inundated land' with 'permanent inundation' are areas with the t**highest probability** o be permanently inundated in the future, since two different analysis processes show an identical result.

The overlay between the permanent inundation and farthest inundation within the land use other than tidal flood/inundated land will indicate the classification of potentially-affected land use.



	Semak Belukar	Mangrove	Tanah Terbuka	Taman	Industri	Sungai	Ladang /Tegalan	Perkebunan	Rob/Lahan Tergenang	Tambak	Hutan	Kebun Campuran	Pemukiman	Sawah Padi/Palawija
Total Luas (Ha) 2020	0,53	13,75	28,15	88,86	93,16	267,02	372,48	622,48	656,99	1.301,89	1.306,84	1.841,60	4.059,79	5.764,34
Total Luas (Ha) 2025	0,06	44,89	1,78	194,42	109,51	266,95	372,48	622,48	1.071,75	750,37	1.352,90	1.841,70	4.442,88	5.345,92
Total Luas (Ha) 2030	0,06	75,80	1,78	298,98	125,95	267,16	372,44	622,48	1.567,92	208,12	1.398,80	1.841,61	4.736,38	4.900,56
Total Luas (Ha) 2035	0,06	106,85	1,78	404,81	142,25	267,33	372,39	622,48	2.059,16	6,05	1.444,84	1.841,64	5.033,73	4.114,71

Change of Land Use in the Study Location for 2020-2035 (Author Team, 2020)

a. Trend in Land Use Changes

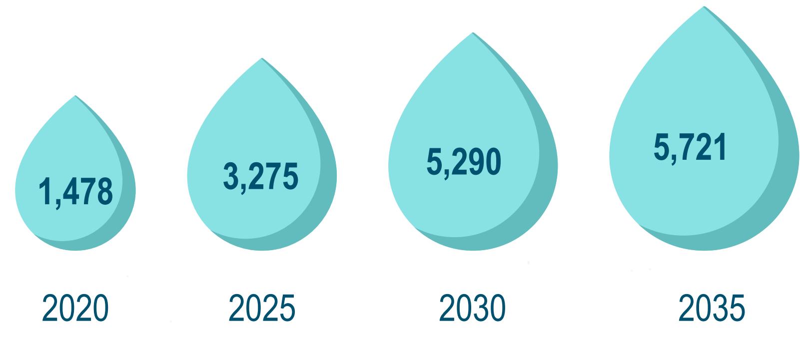
The projection indicates that by the end of the projection period, land use in the study location is still dominated by settlement and ricefield, in addition to forest. This shows that agricultural activity will still run as one of the main community's income sources.

Looking at the change trend, significant change in land size was also found in the classification of settlement, ricefield, fish pond, and tidal flood/inundated land.

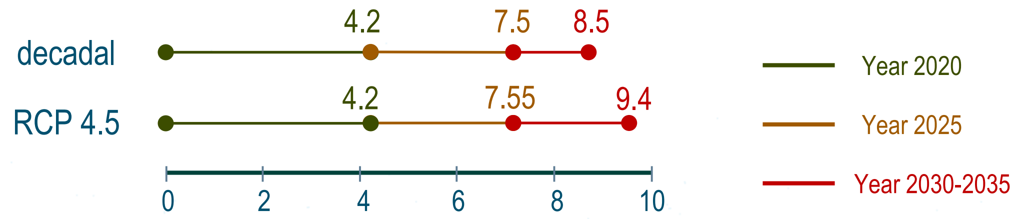
There is an increasing trend for the settlement size (±1.000 Ha) and **tidal flood/inundated land** (± 1.400 Ha), while for **ricefield and fish pond**, there is a declining trend involving change of land size of approximately 1,600 Ha and 1,300 Ha, consecutively. Looking at this figure of change, it can be assumed that the expansion of tidal flood/inundated land and settlement areas takes place by changing the form of ricefield and fish pond.

Further analysis was conducted by looking into land use change in the coastal and non-coastal area segments to show the trade-off of the land use. For coastal area, it is obvious that the increase of **tidal flood/inundated land occurs in line with the decrease of fish pond size;** while settlement's size in the area tends to slightly increase. This shows that it is fish ponds that are commonly converted into inundated land.

For non-coastal area, the most significant size increase occurs in the settlement land use. Meanwhile, **the most significant size decrease occurs in ricefield.** Thus, it can be concluded that the settlement development in this area generally occurs through the cooptation of ricefield.



Change of Permanent Inundation Size in the Study Location from 2020-2035 (in Ha) (Author Team, 2020)



Changes in Farthest Inundation Distance in the Study Location by 2020-2035 (in km) (Author Team, 2020)

b. Permanent Innudation and Farthest Inundation

Permanent inundation is the type of inundation that permanently inundates the land use on it. The inundation is formed when the land level in that area is situated below the average sea level, so that the inflowing water cannot flow out. With regard to decadal prediction and RCP 4.5 projection, there won't be any difference in permanent inundation size. Whereas, the farthest inundation reflects the spatial distribution of potential inundation that might take place due to flood and tidal flood, yet with subsidable characteristics.

The spatial inundation modelling results show that there will be a **significant change in permanent inundation in the study location**, which is 1,478 Ha during baseline year, to 5,721 Ha by the end of the projection period.

By 2025, the **expansion of permanent inundation will be heading toward eastern and southern part of the study location.** It is visible that the inundation will reach *Kelurahan* Tirto in the south and some parts of *Kelurahan* Padukuhan Kraton and Pasir Kraton Kramat in the east.

By 2035, the expansion of permanent inundation wil be heading further south and reach some parts of Villages of Kertijayan and Simbangkulon in Pekalongan Regency, and *Kelurahan* Kalibaros and Kuripan Yosorejo in Pekalongan City.

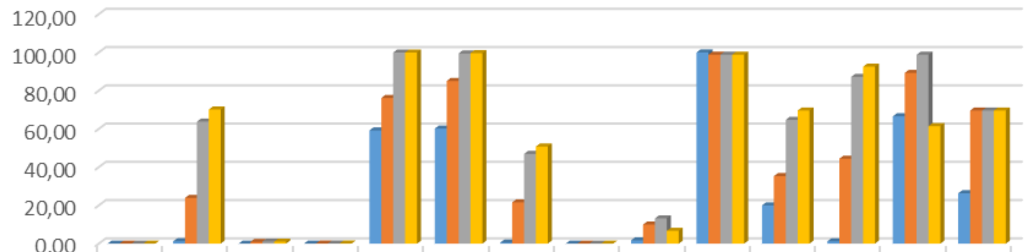
The land subsidence rate is very high in the coastal and downstream areas, which influence significantly the formation of the permanent inundation, in addition to being contributed by the sea level rise and current.

With regard to the farthest inundation, the projection results show that by 2035, the inundated area size will reach 5,700-5,900 Ha (using the decadal prediction and RCP 4.5 projection). The occurrence of inundation is the impact of interaction between various factors: land subsidence, rain intensity, current, and sea level rise.

Specifically for RCP 4.5 projection scenario, there is no changes in the farthest inundation size from 2025-2030 and 2030-2035 periods. During the period, there will be no changes in the farthest distance affected both in decadal prediction as well as RCP 4.5 projection.

The affected distance of the farthest inundation in the baseline year is found to be 4.2 km away from the shore. **By 2025, the distance of the farthest inundation in decadal prediction and RCP 4.5** projection show a rather insignificant difference from each other, namely **7.5 km and 7.55 km from the shore, consecutively.** Both models show that the inundation can reach Kelurahan Degayu, Kuripan Yosorejo, Noyontaansari, and Jenggot.

By **2035, the farthest distance of affected area will increase up to 8.5 km and 9.4 km** from the shore consecutively for decadal prediction and RCP 4.5 projection. In this period, for decadal prediction, it can be seen that the permanent and farthest inundation are spatially intersected; with farthest spot of inundation reaching Villages of Simbangwetan and Wonoyoso, as well as *Kelurahan* Sokoduwet and Kuripan Kertoharjo.



	Hutan	Industri	Kebun Campuran	Ladang/Tegalan	Rob/Lahan Tergenang	Mangrove	Pemukiman	Perkebunan	Sawah Padi/Palawija	Semak Belukar	Sungai	Taman	Tambak	Tanah Terbuka
Total Luas (Ha) 2020	0,00	1,24	0,00	0,00	59,22	60,18	0,53	0,00	1,73	100,00	20,01	1,22	66,61	26,37
Total Luas (Ha) 2025	0,00	23,91	0,91	0,07	76,16	85,09	21,59	0,00	9,99	98,80	35,33	44,41	89,28	69,62
Total Luas (Ha) 2030	0,00	63,86	1,04	0,07	99,97	99,49	46,93	0,00	13,22	98,80	64,73	87,22	98,81	69,62
Total Luas (Ha) 2035	0,00	70,15	1,07	0,07	99,96	99,64	50,83	0,00	6,73	98,80	69,61	92,58	61,48	69,62

Total Luas (Ha) 2020 · Total Luas (Ha) 2025 · Total Luas (Ha) 2030 · Total Luas (Ha) 2035

Proportion of Permanently Inundated Area to the Total Size Per Land Use Classification (Author Team, 2020)

Meanwhile, RCP 4.5 projection in the same period shows that the farthest inundation might reach *Kelurahan* Kuripan Kertoharjo, *Kelurahan* Sokoduwet, and Wonoyoso Village.

C. Land Use Affected by Inundation

Comparing the spatial distribution of land use with the distribution of permanent inundation, it can be seen that **periodically there is an increase of the affected area size, particularly related to the tidal flood, mangrove, bush, and park land uses.** In fact, by the end of projection period, **>90% of the areas of the four land uses will be covered by permanent inundation.**

Further attention is required for the high proportion of the **affected area (>50%) for settlement, fish pond, open land, and industrial land uses.**

The increase of the affected settlement area size increases gradually from 0.53% in 2020, 21.59% by 2025, 46.9% by 2030, to **50.83% by 2035,** and it shows that the areas projected to be developed **into settlement area are potentially located in areas vulnerable to permanent inundation.**

Since settlement is a basic need for the population which number will keep increasing over time, an appropriate spatial planning and adequate mitigation plan are required.

The urgency to control and mitigate the development of settlement area becomes even more critical upon seeing the spatial distribution of farthest inundation and land use, particularly for the period of 2020-2025 and 2025-2030. In both periods, **the farthest inundation might inundate approximately 48-49% of the settlement land use, while permanent inundation ranges between 21-46%.** Mitigation measures are needed to maintain the sustainability of domestic and non-domestic activities in the settlement areas affected by farthest inundation.

Mitigation measures, control measures and zonation arrangement are also needed for areas projected to serve as fish pond and industrial land uses. This will become important since the two land use are strongly related to the community's livelihood, in addition to contributing to the local GRDP.

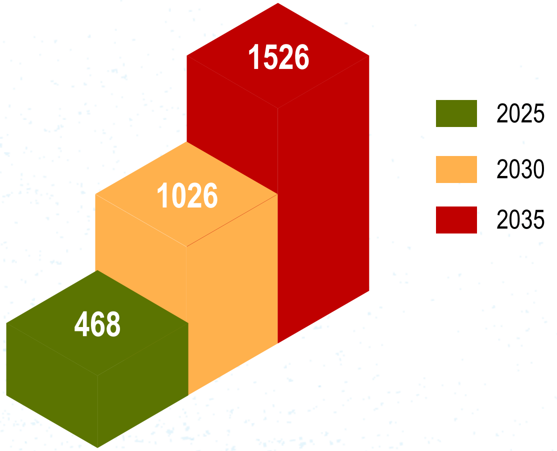
Open land, on the other hand, is commonly used for development of developed and non-developed areas. However, looking at the condition that >60% of this land use might potentially be permanently inundated by 2035, there needs to be an appropriate development plan for open lands that are potentially inundated.

Previously it has been stated that >90% of the tidal flood land use will be permanently inundated by the end of 2035. The inundated area will increase gradually in every period of projection. **The areas with intersection between tidal flood and permanent inundation areas will be the lands with high probability** to be inundated throughout the period.

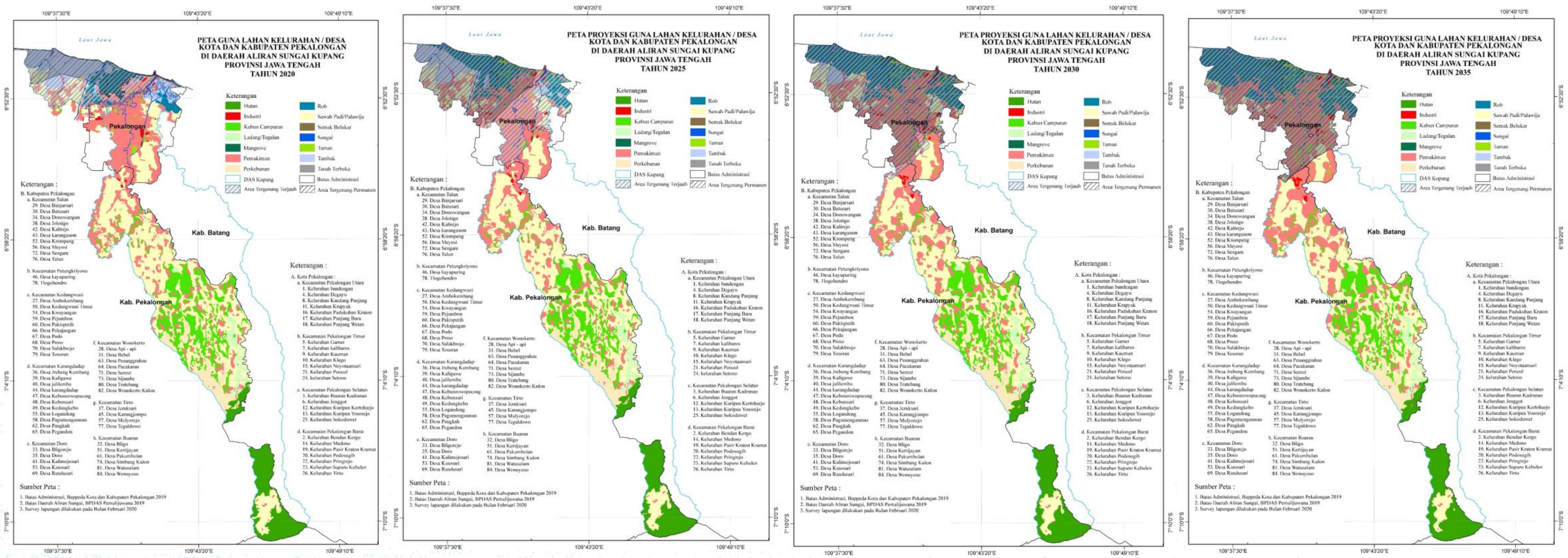
The analysis shows that **468 Ha of land have high probability to be completely inundated throughout the period by 2025.** The land uses with high potential to be inundated are generally **settlement, fish pond, and park**, other than the existing lands that are permanently inundated lands during baseline condition. **By 2030, the inundation with highest probability might expand up to 1,026 Ha,** with the largest addition of inundated land use to be the **fish pond in the west side, as well as ricefield, settlement, and industry in the coastal area and east side** of the study location.

By 2035, the size of high probability inundation will increase up to 1,526 Ha, which will inundate **the ricefield and fish pond areas in the west side and ricefield in the east side** of the study location**.**

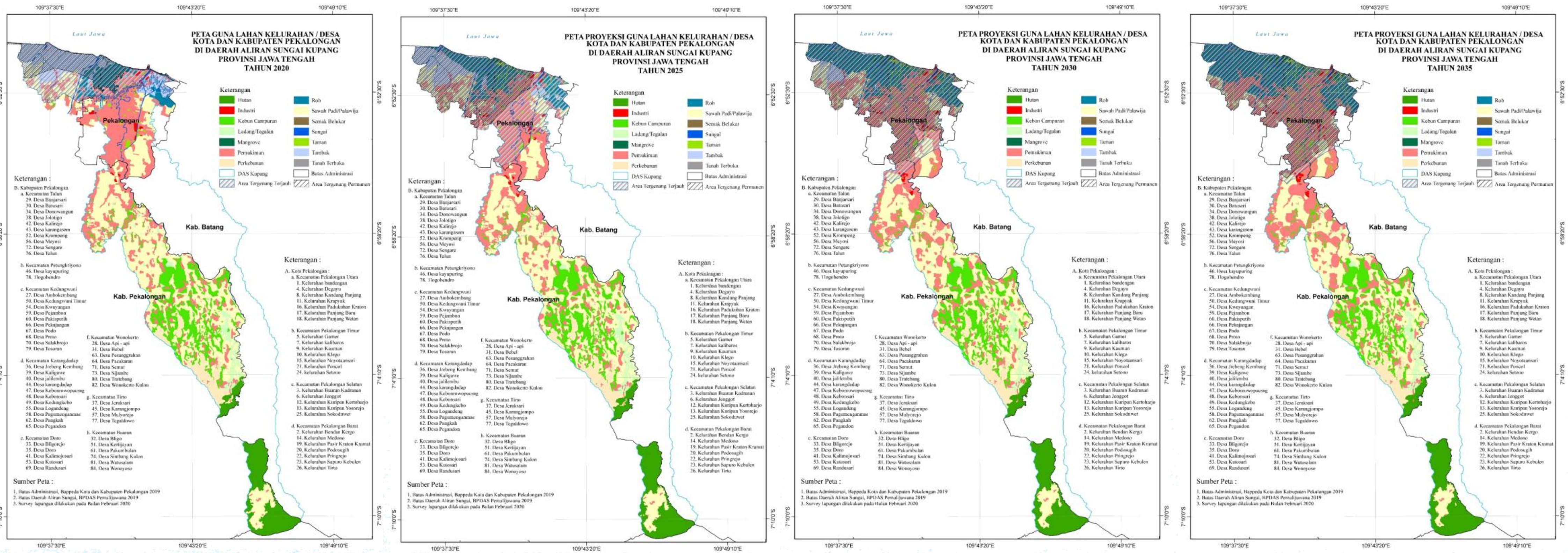
The areas with high probability need to be prioritized in any flood and tidal flood control measures. From the types of land with increasing size of inundation in every period, it can be seen that the fish pond and ricefield are two most dominant land uses. Therefore, an appropriate strategy in economic sector is critically needed to ensure that the local community's and area's economic growth will not be hindered by the loss of land.



Change of Size of High Probability Inundation in the Study Location (in Ha) (Author Team, 2020)



Potential Impacts of Permanent Inundation and Farthest Inundation to Land Use in Baseline Condition (left), by 2025 (middle), and by 2035 (right) with Decadal Prediction (Author Team, 2020)



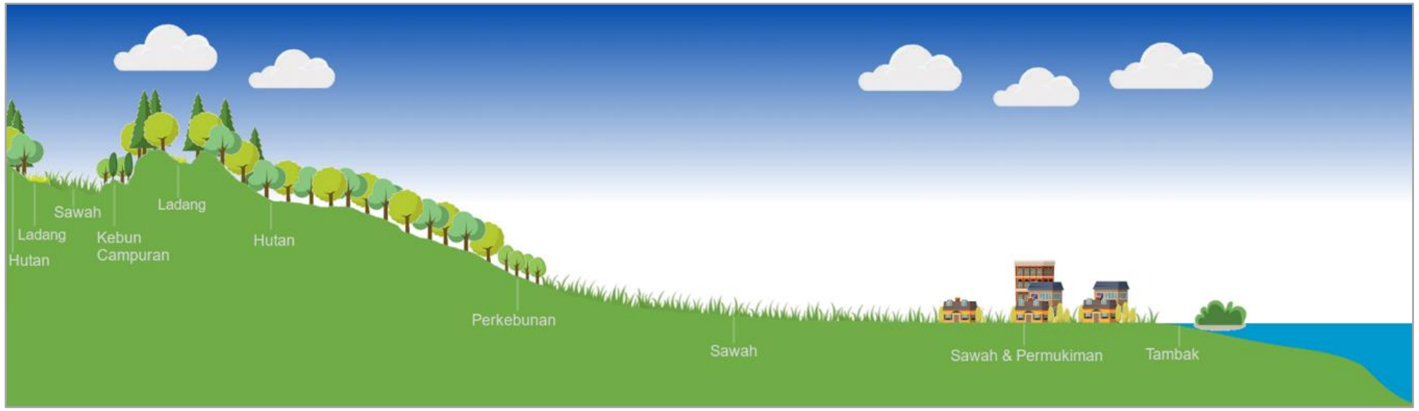
Potential Impacts of Permanent Inundation and Farthest Inundation to Land Use in Baseline Condition (left), by 2025 (middle), and by 2035 (right) with *RCP 4.5 Projection* (Author Team, 2020)

5.4 Risk in Landscape Context

Risk analysis on landscape context in this study was conducted **to identify the influence of landscape change toward the risk experienced by the study location, particularly those related to the issue of water resources management.** The way climate variability and changes of water catchment area's function in a watershed system will influence the hydrological system in that particular watershed.

In carrying out the risk analysis, the landscapes covered in the study scope are not only those located within Kupang Watershed, but also the entire areas of Pekalongan Regency and City so as to capture the interaction within the system more comprehensively.

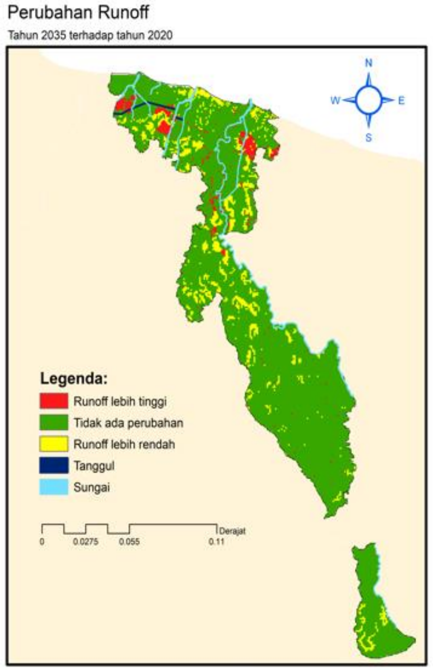
By looking at the domination of land cover per landscape segment, it can be seen that the **upstream area is spatially still dominated by the forest** which definitely has rather high infiltration rate, thus it can be said that the upstream segment's capacity in absorbing water is still fairly well. The land use projection also shows that until 2035, the forest land use will still dominate the upstream area. The condition causes an increase in size of areas with lower runoff value than that of baseline condition.



Landscape in Each Segment in Baseline Condition (Author Team, 2020)

What should be highlighted in this segment **are the areas dominated by ricefield/secondary crop land uses.** The **value of surface runoff** in this land **is higher than that of forest**. This condition will not only lead to an increase of **flood potential** in the middle and downstream areas during extreme rain, but will also **decrease the number of water that will infiltrate** into ground water reserve. Thus, the issue will not only occur during rainy season, yet also during dry season. The climate prediction shows that there are years where R20mm index in the upstream area is below normal, so that there will be an opportunity to reduce the rain intensity, although the CDD projection value relatively won't undergo any significant changes.

To anticipate such a condition, there needs to be appropriate upstream area management measures to ensure that the opposite scenario from that of land use projection will not take place. The size of forest area must be preserved and not coopted by any other land use, which would in turn disrupt the upstream's ecological functions.

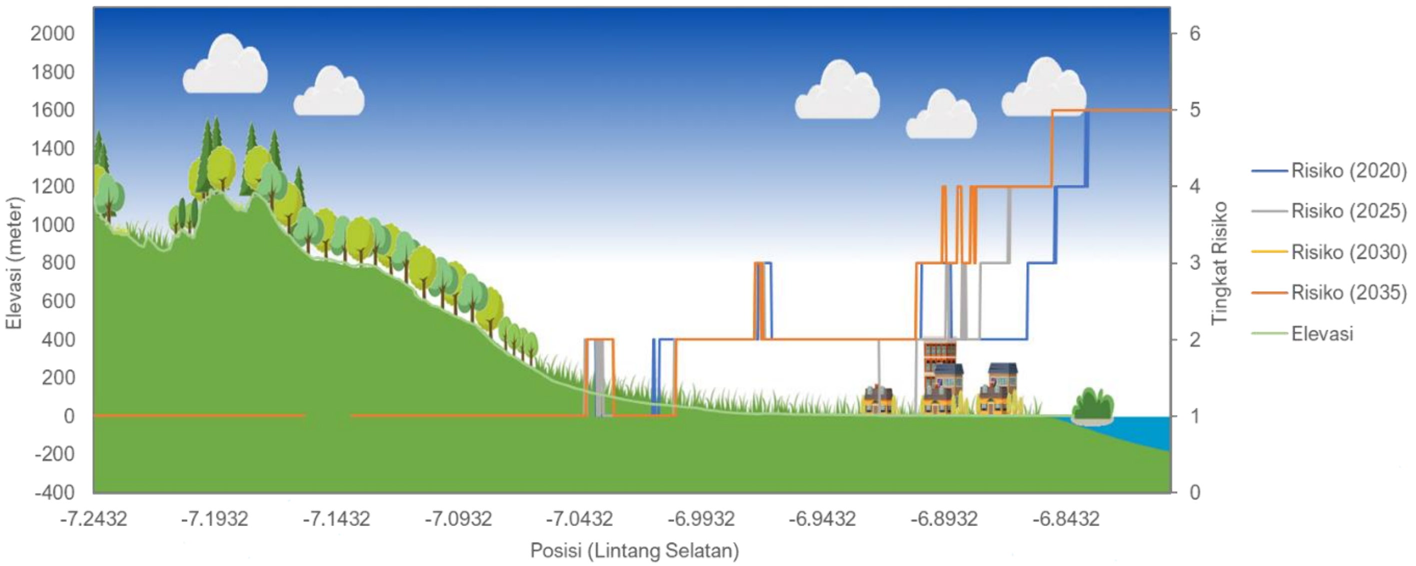


Changes in Runoff Value by 2035 (Author Team, 2020)

In the upstream-middle areas transition segment, the land use is dominated by plantation; while the **middle area is dominated by ricefield**, hence settlement area can also be found within. As mentioned previously, ricefield has higher runoff coefficient than that of forest, thus there is potential flood to occur in the segment, which in turn will affect the areas under. The flood events can bring about negative impacts to the economic activities going on in the area. **Flood can lead to harvest failure and crop damage, which leads to decrease of ricefield productivity.**

The **increasing risk** for the middle segment which is dominated by ricefield is also **influenced by the potential drought hazard**, which in Indonesian context is usually caused by **El Nino or IOD positive.** The increasing drought hazard will lead to the decrease of agriculture's productivity and thus farmers' well-being.

For middle segment, the mitigation might be focused on villages with high or very high vulnerability level, without taking into account the flood risk level. This is because the village is categorized as having high risk to various disaster events (in addition to floo), such as drought, landslide, etc.; thus it is very crucial to prepare the village in facing various threats.



Elevation and Risk Level Profile from Upstream to Coastal Area of Pekalongan (Author Team, 2020)

Changes in landscape pattern does not only influence the water quantity that infiltrate and overflow throughout the watershed, but also the water quality going through every segment. The change might increase the amount of pollutant and foster the declining quality of river water since the **landscape pattern contributes to control the biogeochemical and physical process of a watershed.** In Kupang Watershed, declining quality of river water takes place due to the contamination by waste water and solid waste from industrial and settlement activities.

As an edge of a watershed, **the issue of increasing runoff and decreasing water quality bring about the highest impacts to the downstream and coastal segments.** The segment will receive runoff from the upper area, and will also be constrained by the issue of limitation of surface water.

In the study location, **the downstream segment is dominated by settlement and ricefield land uses; with highest concentration of settlement was found in the urban area.** The land use projection shows that there will be an increase in land use conversion from ricefield into settlement, industry, and fish pond.

The **potential land use conversion** will **lead to various impacts**, particularly upon looking at the increasing flood **risk trend in downstream and coastal areas.** By the end of the projection period, the risk level in this segment is dominated by high to very high levels. The impacts will be, among others, the increasing surface runoff in the area, which is caused by the expanding developed areas, expansion of inundation area, and the increasing number of affected population.

Realizing the interconnection between upstream, middle, and downstream areas, the mitigation in downstream and coastal areas cannot be undertaken separately, yet rather shall be integrated with the management of the upper segment.

5.5 Preliminary Recommendation

By taking into account risk analysis conducted, the study found that the measures to control flood risk cannot be carried out partially in every watershed segment. The interconnection between upstream, middle, and downstream areas further highlights the need to apply holistic and integrated approaches in developing policy framework and flood risk control programs in Kupang Watershed. Flood risk control cannot be conducted only by using disaster approach, yet also needs to consider a comprehensive landscape perspective from upstream to coastal areas.

Departing from that perspective, flood risk control measures in the Kupang Watershed will need the following:

- ❑ Applying holistic approach such as Integrated Water Resource Management (IWRM), Ecosystem Management (EM), and Sustainable Landscape Planning (SLP). The three approaches consider all aspects of problems related to water resources in simultaneous manner, including landscape ecology, adaptive management, and land use conversion.
- ❑ Taking into account the landscape characteristics in each segment, the potential of land use conversion that might take place and the impacts of interaction between land uses with hazard (including climate variability) in the segment.
- ❑ Climate variabilities that require attention are not only the wet extreme condition which might cause flood, but also potential drought that influences the availability of water in the Pekalongan Regency and City. Unlike the flood that affects limited area, drought has wider impacts and might influence the areas unaffected by flood. Thus, if an area has a rather high vulnerability level, it will potentially have higher risk of drought.
- ❑ Developing an early warning system containing information on impact and risk-based weather and climate prediction. The system needs to be developed simultaneously with the community awareness building efforts to use the information, as part of the community adaptive capacity building measures.
- ❑ Giving particular attention to the areas with high and very high vulnerability level in the coastal and non-coastal areas, through adaptive capacity building that is conducted in parallel manner with efforts to decrease of sensitivity and exposure levels. The efforts must be carried out in line with the infrastructure construction and other efforts to reduce disaster risk.
- ❑ Strengthening ecological functions of the coastal area, particularly in areas with mangrove ecosystem to preserve the physical, chemical, biological, economic, and other functions that can be given to the coastal area and water area.

To obtain more accurate recommendations and ones that are in harmony with the local's interest and urgency, the preliminary recommendation will be articulated deeper through a series of discussion processes with various stakeholders and follow-up analysis. The enrichment to this recommendation will be put into a separate Strategic and Policy Recommendation document from this study document.

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06 Follow-up

Climate Risk Study and Policy Recommendation

- **Validation of assumptions** in flood vulnerability, hazard and risk study, through **finalization of study** by the end of October 2020
- **Formulation of adaptation strategy** recommendations and their relevance with existing policies in the period of October 2020-March 2021
- Assistance in inclusion of study results into relevant policies until December 2021

Study on Economic and Non-Economic Impacts and Loss

- **Agreeing on the scope of analysis** (sectoral and spatial aspects) for the economic and non-economic impacts study by October 2020
- **Data collection and initial analysis** are targeted to be completed by December 2020
- **Finalization of impacts study** and formulation of priority adaptation actions in January-April 2021
- Assistance in inclusion of study results into relevant policies until December 2021

Facilitation of Interconnectedness with National Policy

- Fostering **Pekalongan City and Regency as a sub-priority areas for RAN API (National Action Plan for Climate Change Adaptation)** for coastal, water, and agricultural sectors
- Ensuring **that local interest is taken into account in RAN API implementation strategy**
- Ensuring that information from the risk study results are **taken into account into the formulation of Land Subsidence Roadmap Implementation Strategy** (and its connection with IWRM Program in Greater Pekalongan) by involving the Land Subsidence Working Group

Appendices

Appendix A Hazard Analysis Data Input

Appendix B Modeling of 2026-2030 Inundation for Decadal Prediction (left) and RCP 4.5 Projection (right)

Appendix C Flood Hazard Level Index per Village in Pekalongan Regency for Decadal Prediction (left) and RCP 4.5 Projection (right)

Appendix D Flood Hazard Level Index per *Kelurahan* in Pekalongan City for Decadal Prediction (left) and RCP 4.5 Projection (right)

Appendix E Sensitivity Components and Indicators

Appendix F Exposure Components and Indicators

Appendix G Adaptive Capacity Components and Indicators

Appendix H Land Use Change Projection Indicators

Appendix I Land Use Change Trend by 2020-2035

Appendix J Decadal Prediction Flood Risk Projection (2025-2035)

Appendix K RCP 4.5 Scenario Flood Risk Projection (2025-2035)

Appendix L Number of Villages/*Kelurahans* in Study Location per Risk Level

APPENDIX A

Hazard Analysis Data Input

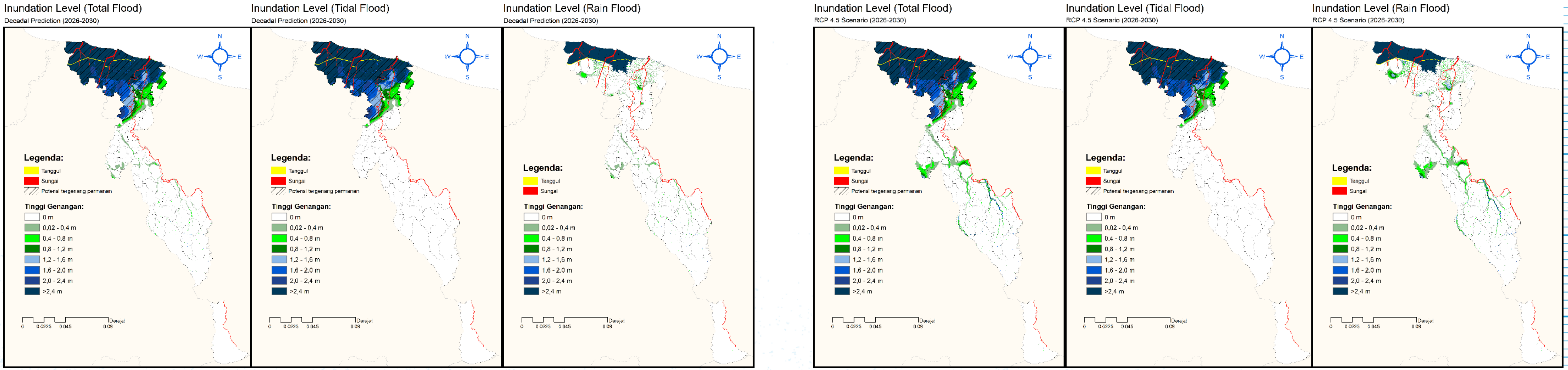
NO	DATA	SOURCE	TYPE OF DATA
Flood Model			
1	DTM (20 x 20 m is resampled to 30 x 30 m)	CoREM	Spatial
2	– Land Cover Map – Land Use Map	CoREM	
3	SHP of Kupang Watershed	BPDAS of Pekalongan	
4	Meteorological Data: – Rainfall (RF/CF)	Pusdataru of Pekalongan City, BMKG, CHIRPS (Funk et al., 2015), POWER NASA/ECMWF	Tabular
5	Land Parameter and Soil Parameter	Bibliography	
6	Land subsidence rate	CoREM	
7	- Tidal Elevation – Long Term Mean Sea Level – Annual Mean Sea Level Projection	CoREM, Copernicus BIG	
8	Daily Tide	CoREM	
9	Flood Event Data (Spatial, spot, and temporal)	City BPBD, field survey	
Climate Projection Simulation			
10	Global Climate Model	https://climexp.knmi.nl/selectfield_cmip5.cgi?id=someone@somewhere.	Spatial
11	Regional Climate Model (RegCM)	Faqih et al. (2016), TNC Indonesia (2017), BIG	
12	CHIRPS: Rainfall Estimates from Rain Gauge and Satellite Observations	CHIRP data that have been corrected with observation data (1981-2019)	

GCM CMIPS Model

MODEL'S NAME	INSTITUTION	SPATIAL RESOLUTION	REFERENCES
ACCESS1.0	Australian Community Climate and Earth System Simulator coupled model (ACCESS-CM)	1,25˚×1,875˚	(Bi et al. 2013)
CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	2,8˚×2.8˚	Chylek et al. 2011
CMCC-CM	Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC), Italy	0,75˚×0,75˚	Scoccimarro et al. 2011
CMCC-CMS	Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC), Italy	1,875˚×1,875˚	Scoccimarro et al. 2011
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia	1,875˚×1,875˚	Jeffrey et al. 2013
FGOALS-s2	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), China	2,8˚×1,4˚	Qing et al. 2013
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory (GFDL), USA	2,5˚×2,0˚	Dunne et al. 2013
HadGEM2-ES	Met Office Hadley Centre, UK	1,875˚×1,25˚	(Martin et al. 2011)
IPSL-CM5B-LR	L'Institut Pierre-Simon Laplace (IPSL), France	3,75˚×1,875˚	Dufresne et al. 2013
MIROC5	Model for Interdisciplinary Research on Climate (MIROC), Japan	1,4˚×1,4˚	(Tatebe et al. 2012)
MIROC-ESM-CHEM	Model for Interdisciplinary Research on Climate (MIROC), Japan	2,8125˚×2,8125˚	Watanabe et al. 2011
MPI-ESM-LR	Max Planck Institute, Germany	1,875˚×1,875˚	Block dan Mauritsen 2013

APPENDIX B

Modeling of 2026-2030 Inundation for Decadal Prediction (left) and RCP 4.5 Projection (right)



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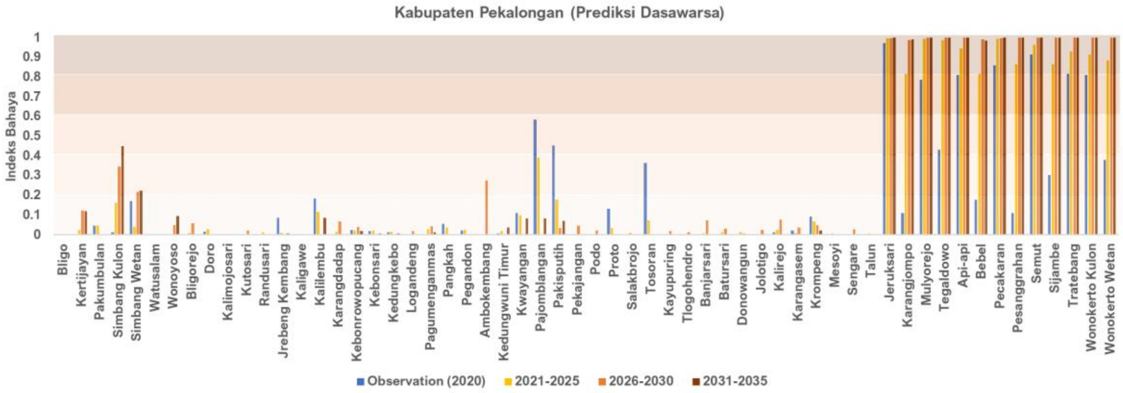
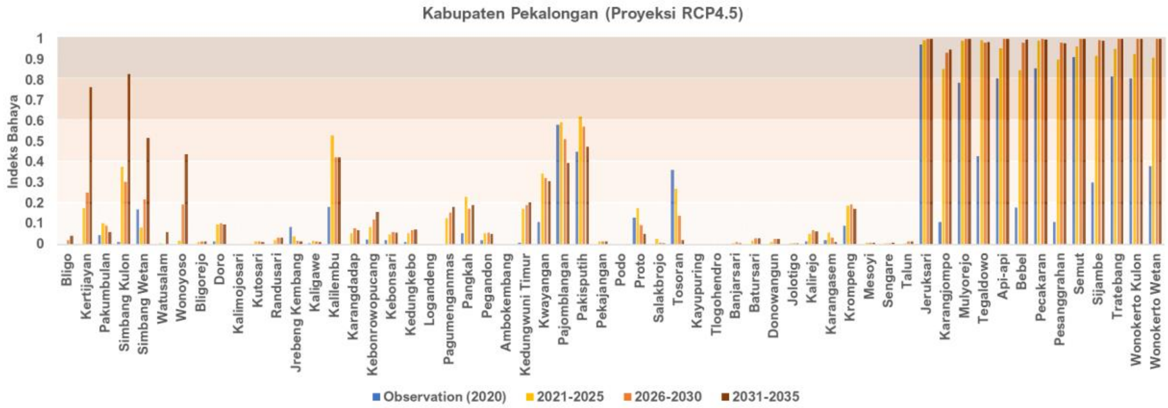
APPENDIX C

Flood Hazard Level Index by Village in Pekalongan Regency for Decadal Prediction (left) and RCP 4.5 Projection (right)

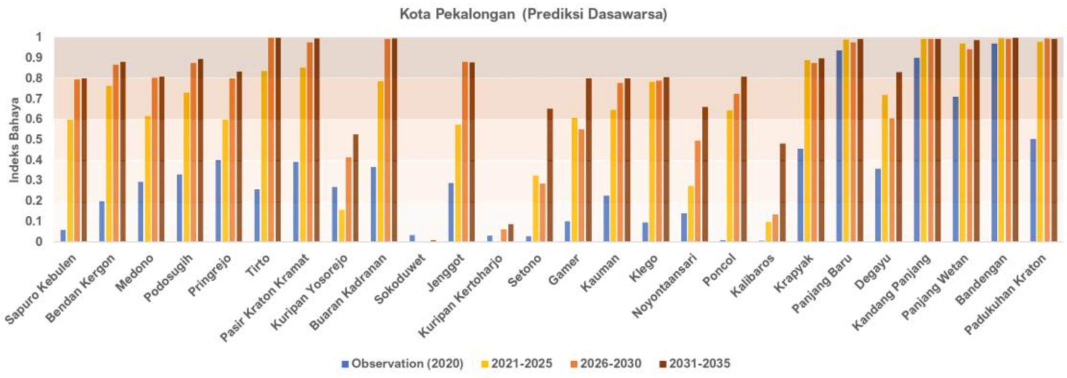


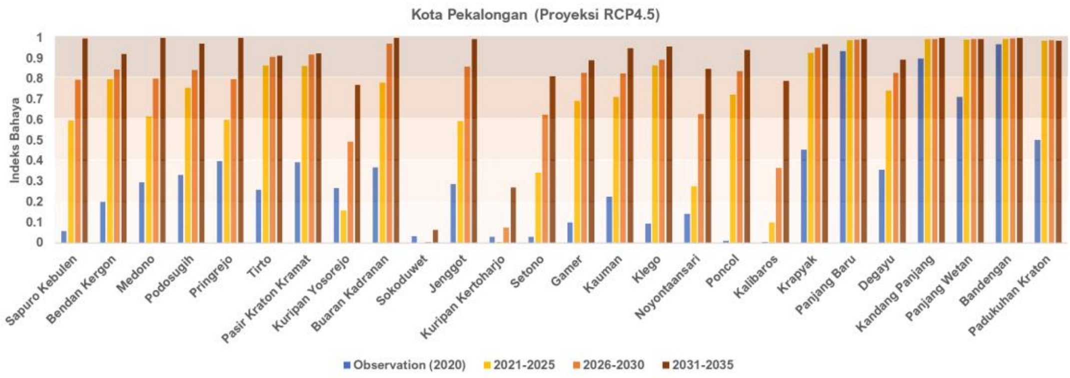


a) Kabupaten Pekalongan								
Tingkat Bahaya	Observasi	Dasawarsa			Observasi	Skenario (RCP4.5)		
	2015-2019	2021-2025	2026-2030	2031-2035	2015-2019	2021-2025	2026-2030	2031-2035
Tidak Terdampak	17	4	11	21	17	4	3	4
Sangat Ringan	28	40	31	22	28	34	35	32
Ringan	3	1	3	1	3	4	4	3
Sedang	3	0	0	1	3	2	3	4
Tinggi	1	0	0	0	1	1	0	1
Sangat Tinggi	6	13	13	13	6	13	13	14

APPENDIX D

Flood Hazard Level Index by *Kelurahan* in Pekalongan City for Decadal Prediction (left) and RCP 4.5 Projection (right)





b) Kota Pekalongan								
Tingkat Bahaya	Observasi	Dasawarsa			Observasi	Skenario (RCP4.5)		
	2015-2019	2021-2025	2026-2030	2031-2035	2015-2019	2021-2025	2026-2030	2031-2035
Tidak Terdampak	0	1	1	0	0	0	0	0
Sangat Ringan	10	3	2	2	10	4	2	1
Ringan	9	2	1	0	9	2	1	1
Sedang	3	2	3	2	3	2	1	0
Tinggi	1	10	5	4	1	9	3	2
Sangat Tinggi	3	8	14	18	3	9	19	22

Appendix E

Sensitivity Components and Indicators (1)

NO	COMPONENT	INDICATOR	DESCRIPTION
1	Infrastructure and Settlement (K1)	Percent of houses unable to endure disaster by village	Non-permanent buildings with lower capacity to endure the impacts from climate variability and extreme climate such as flood and tidal flood
2	Spatial Planning (K2)	Percentage of green area size by village	The wider the green area is, the wider the water absorption area will be, thus making the *kelurahan*/village have low sensitivity towards flood/tidal flood
3	Poverty (K3)	Ratio of poor population	Poor population with low financial capacity will suffer the highest impacts from climate variability and extreme climate such as flood/tidal flood, and need more time to achieve recovery
4	Vulnerable Group (K4)	• Ratio of number of female population (Gender) • Ratio of number of elderly population (>60 years-old) • Ratio of number of child population (>12 years-old) • Ratio of number of people with disability	Vulnerable population with lower resilience and ability to overcome flood/tidal flood
5	Per Capita (K5) Income	Percentage of households which members work as a farmer, fish ponder, or fisher to total livelihood by village	The lower the population's income in a *kelurahan*/village, the more significant the impacts of flood/tidal flood they will suffer

Sensitivity Components and Indicators (2)

NO	COMPONENT	INDICATOR	DESCRIPTION
6	Land Ownership (K6)	Percentage of number of households without land legality (ownership) by village (%)	The higher the percentage of households without land legality (ownership) in a *kelurahan*/village is, the higher the sensitivity value of that kelurahan/village will be
7	Health (K7)	Number of incidents of water-borne disease by district.	Climate variability and extreme climate will influence the frequency and intensity of flood/tidal flood events that lead to the increasing number of water-borne disease incidents in the area
8	Critical Asset (K8)	The number of critical/vital assets/facilities damaged/affected by flood and tidal flood (health, infrastructure, market, energy, transport, etc.).	The more critical assets are damaged due to flood impacts, the higher the burden will be for the community and local government to mitigate and recover the disaster impacts in the *kelurahan*/village.
9	GRDP of Affected Sector (K9)	Percentage of GRDP contribution per affected sector (fish pond and ricefield) per district.	The more sectors are affected by flood/tidal flood, the higher the sensitivity index will be
10	Infrastructure, Facility and Utility (K10)	Classes of road (transport) that are frequently affected.	The more frequent transport facilities are affected, the higher disturbance to transportation flow, which will lead to numerous other aspects

Appendix F

Exposure Components and Indicators (1)

NO	COMPONENT	INDICATOR	DESCRIPTION
1	Topography (K1)	• Inclination • Land Morphology • Elevation	Areas with low inclination, flat land morphology and low elevation have relatively higher exposure to flood and tidal flood
2	Geomorphology (K2)	Alluvial Plain	The *kelurahans*/villages which most areas are located in alluvial plain have higher exposure level
3	Beach Erosion / Sedimentation (K3)	Beach erosion area	The eroded beach will experience higher erosion level caused by extreme climate, which might lead to stronger sea wave and current and increase the erosion rate in that area
4	Land Use (K4)	• Proportion of productive land use (%) • Type of dominant land use by village	The *kelurahans*/villages which productive and dominant land use productive are predominantly settlement and industry have a relatively high level of exposure
5	Infrastructure and Settlement (K5)	Proportion of area size experiencing land subsidence by village (%)	The areas experiencing land subsidence will increase the potential inundation from flood and tidal flood in that area.

Exposure Components and Indicators (2)

NO	COMPONENT	INDICATOR	DESCRIPTION
6	Distance from Disaster Source (K6)	Distance from river and canal that potentially cause flood and tidal flood	The closer an area from river and beach is, the higher its potential exposure to flood will be, since the area is closer to the disaster source
7	Demography (K7)	Population density by village	*Kelurahans*/villages having more dense population will have more population exposed to climate-related disaster, which will lead to flood and tidal flood
8	Spatial Planning (K8)	The size of settlement area that are located along river bank/coast (%)	Settlements in such locations have higher exposure value as they are located in areas with potential flood and tidal flood, which reduce the protection function of green area

Appendix G

Adaptive Capacity Components and Indicators (1)

NO	COMPONENT	INDICATOR	DESCRIPTION
1	Regulation and Planning	• Regulatory support from spatial planning aspect • Mitigation of flood and tidal flood in RPJM (Mid-Term Development Plan)	Adaptive capacity is strongly determined by spatial policy directives on disaster, and disaster mitigation program in the RPJM (Mid-Term Development Plan)
2	Disaster Financing	• Local financing support for flood and tidal flood mitigation • Existence of early warning system for flood • Existence of early warning system for tidal flood	The more economic sources is available, the higher the adaptive capacity in a particular area
3	Disaster Early Warning	• Existence of early warning system for flood • Existence of early warning system for tidal flood	Disaster early warning system is critical, since adequate adaptive capacity can accelerate community's action
4	Organization in form of Disaster Service Center	• Tidal-related disaster information center • Quality of government's service in tidal flood preparedness	It can be shown through the relevant institution or agency's capacity in conducting adaptive measures toward floods which frequently occur in certain areas.
5	Institution in form of Community Group (PokMas)	• Existence of disaster resilient community (Masyarakat Tangguh Bencana) • The background of the community group establishment are:	Through government facilities, the community group can become the parameter of disaster resilience, since factors supporting disaster resilience action and initiative might trigger short and long-term changes

Adaptive Capacity Components and Indicators (2)

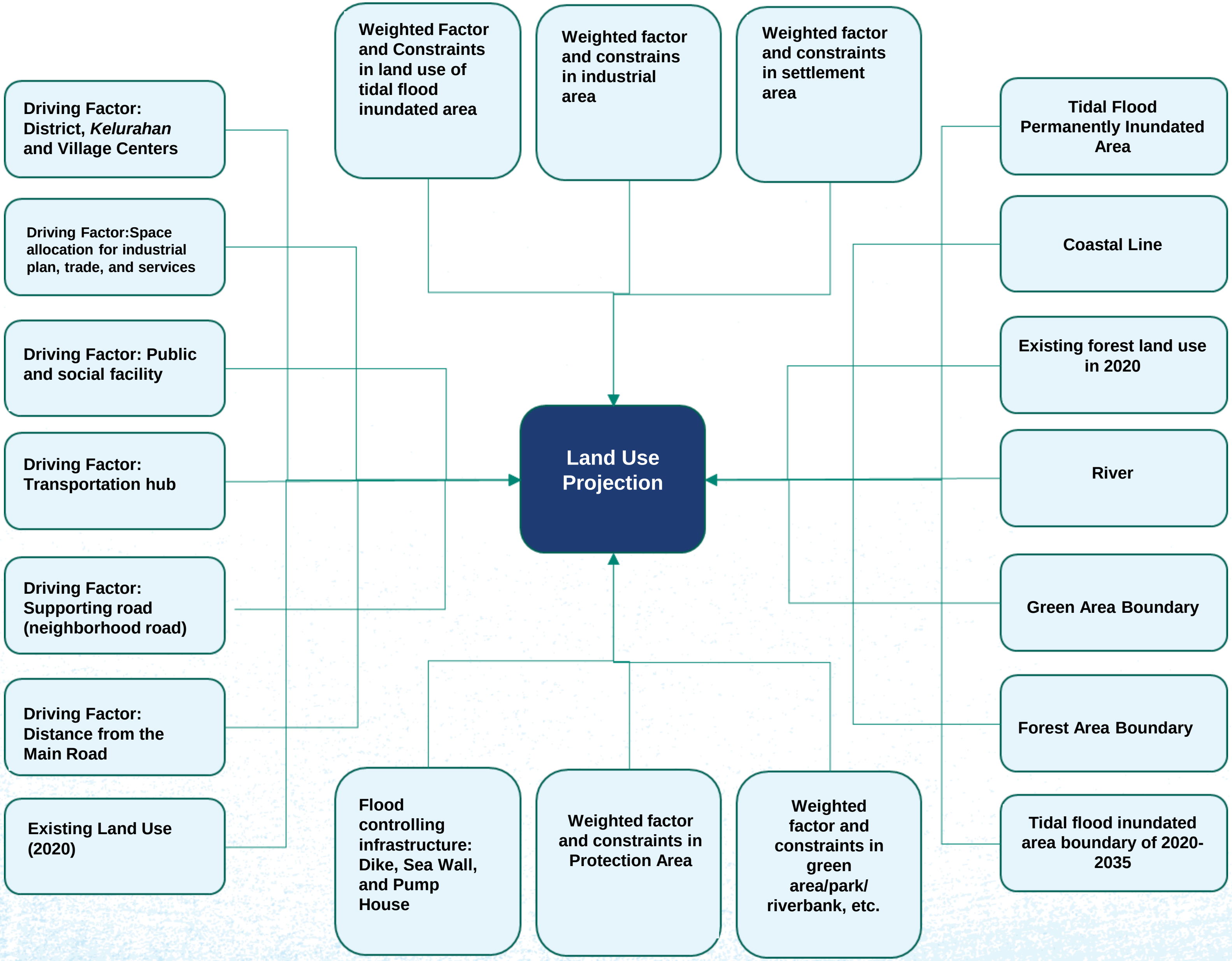
NO	COMPONENT	INDICATOR	DESCRIPTION
6	Disaster Program	• Existence of disaster mitigation program • Existence of conservation/rehabilitation program to overcome flood and tidal flood	Existence of a disaster program might increase the adaptive capacity of a city and or an area
7	Education, Counseling, and Knowledge for Community	• Ratio of higher education • Counseling and assistance on tidal flood	Adaptive capacity highly depends on trainings and information on disaster
8	Disaster Mitigation	• Disaster plan document at village scale • Local Action Plan for DDR (RAD PRB) implementation document	Disaster-related planning document and a systematized implementation action are one of the marks of adequate capacity to address tidal flood
9	Preparedness and Contingency	• Preparedness plan and steps to mitigate flood • Existence of SOP for disaster emergency (contingency) • Speed of emergency response (contingency) implementation, planning and steps of preparedness in mitigating tidal flood	Tactical ability of a government institution to address a disaster in emergency situation reflects its adaptive capacity in mitigating flood and tidal flood
10	Infrastructure for Flood and Tidal Flood Control	Existence of polder, retention pool, sea wall, etc.	Existence of infrastructures related to flood and tidal flood control will increase the adaptive capacity

Adaptive Capacity Components and Indicators (3)

NO	COMPONENT	INDICATOR	DESCRIPTION
11	Community's Perception toward Flood and Tidal Flood (Programs)	Community's direct perception (response/acceptance) to flood and tidal flood mitigation programs	Community's perception toward tidal flood program might influence the community's resilience
12	Local Wisdom	Local wisdom associated with flood and tidal flood	Community's creativity (local wisdom) can affect the adaptive capacity in an area
13	Well-being	Percentage of prosperous family	The percentage of prosperous family shows the volatility level of a community in facing shocks and stresses caused by flood and tidal flood disasters
14	Infrastructure, Facility and Utility	• Availability of education supporting facilities and infrastructures • Percentage of household in main fuel used to cook by village (%) • Limited clean water source facility. (percentage of number of family not using pipe water (PAM/PDAM))	Existence of social and general life supporting facilities and infrastructures are the factors that preserve the sustainability of life and resilience of a disaster-affected community
15	Poor Family Health Insurance	Proportion of poor community having the KIS (Healthy Indonesian Card)/BPJS Card	Limited health insurance available for poor family might decrease the adaptive capacity of a community group due to the lower life expectancy it causes.

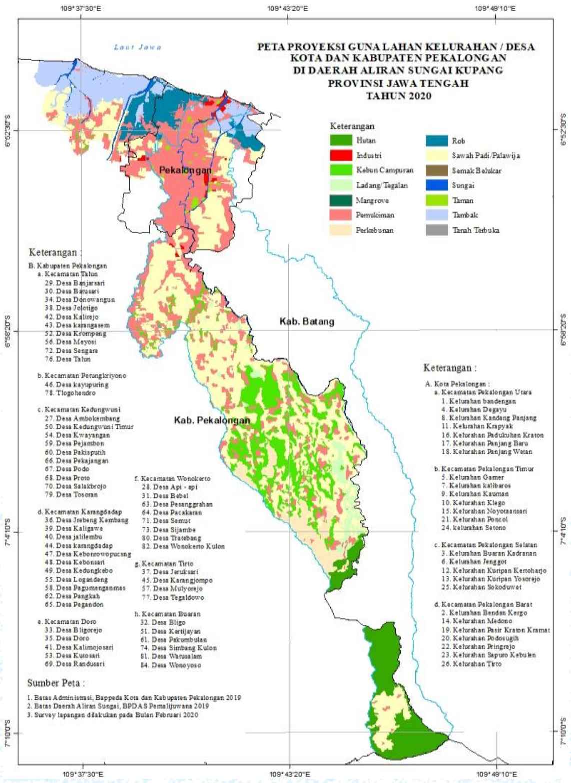
APPENDIX H

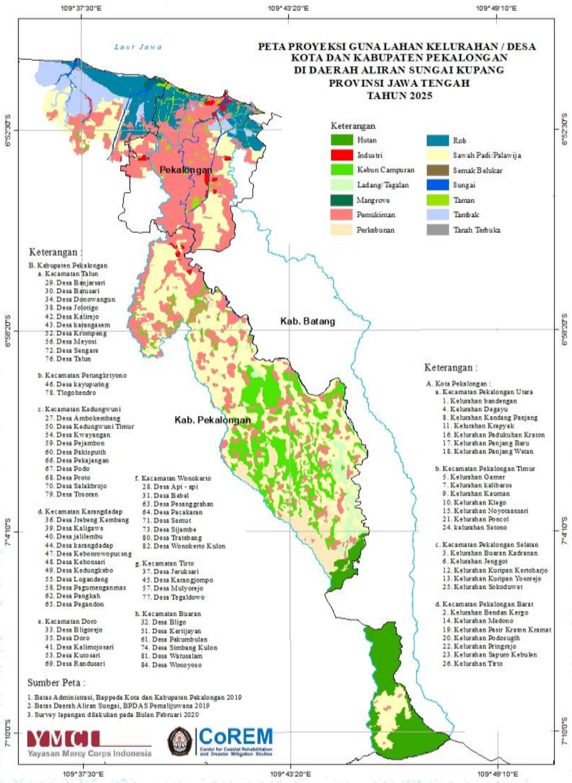
Land Use Change Indicators

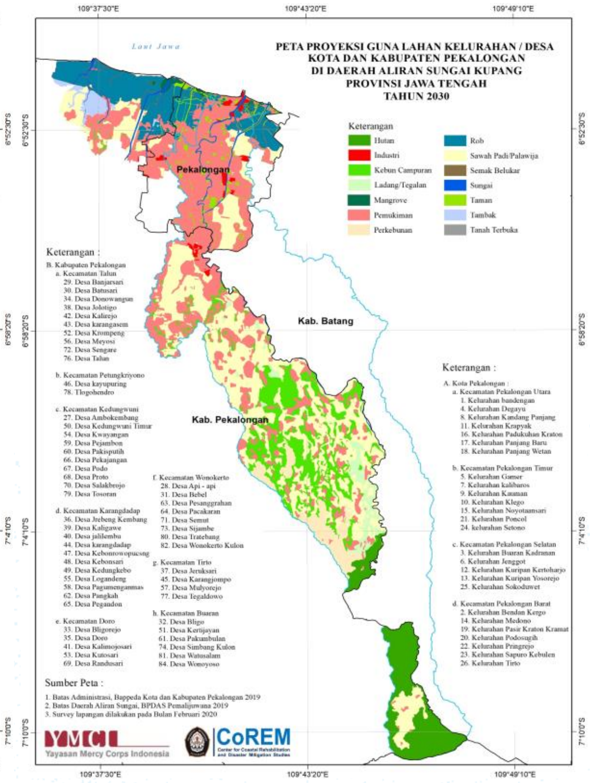


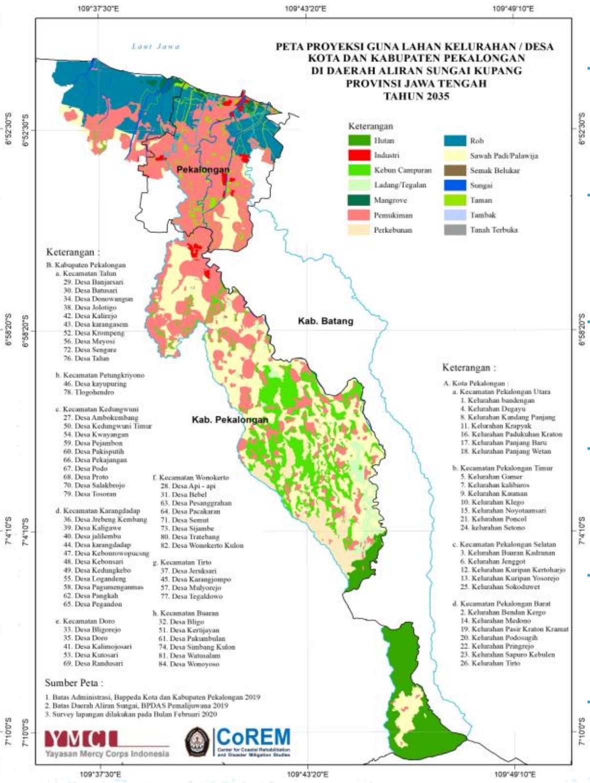
APPENDIX I

Land Use Change Trend by 2020-2035



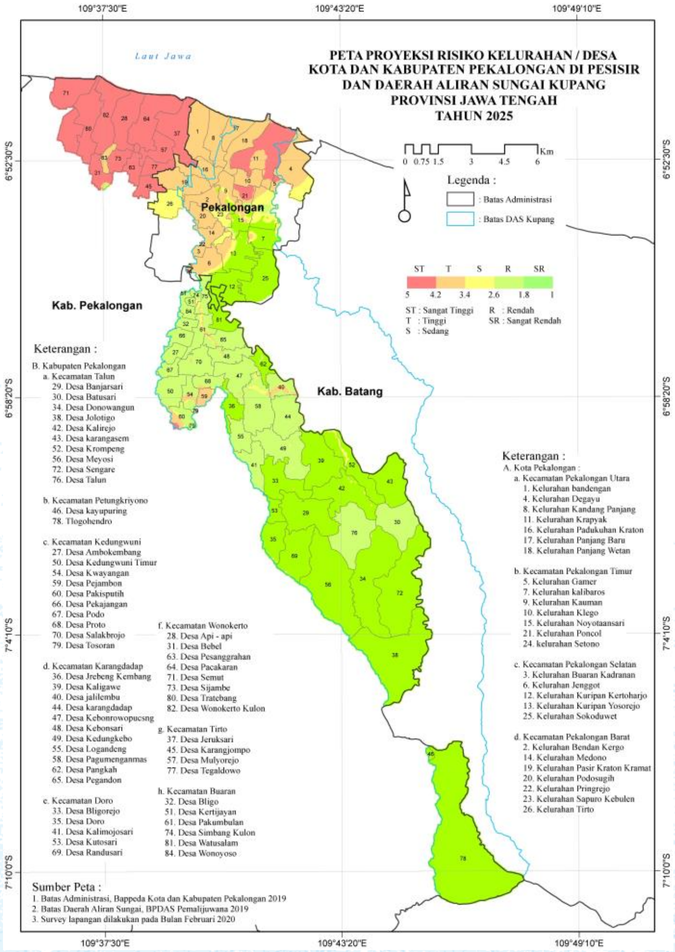


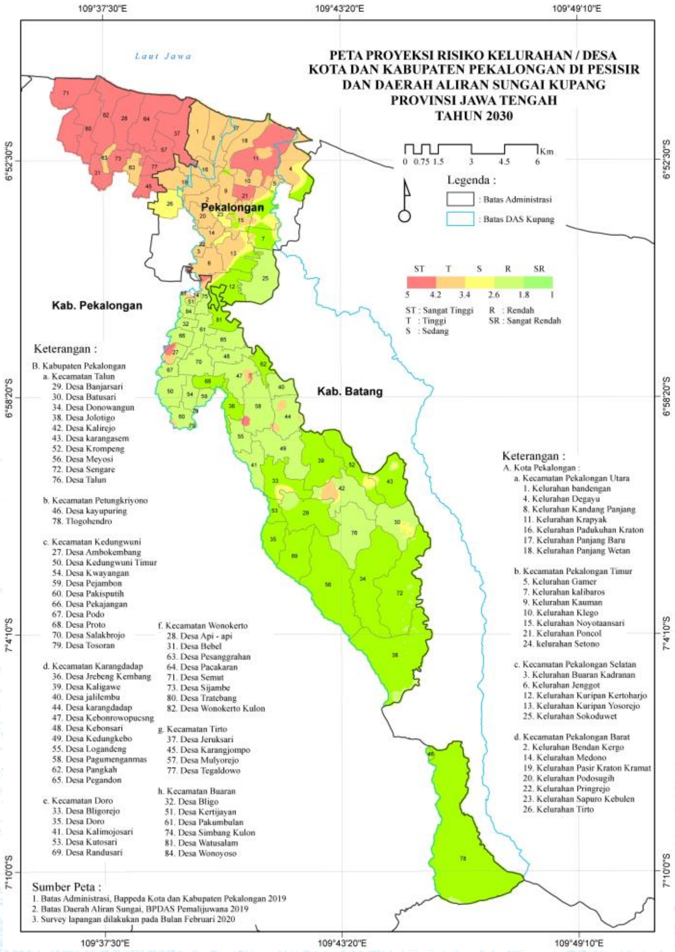


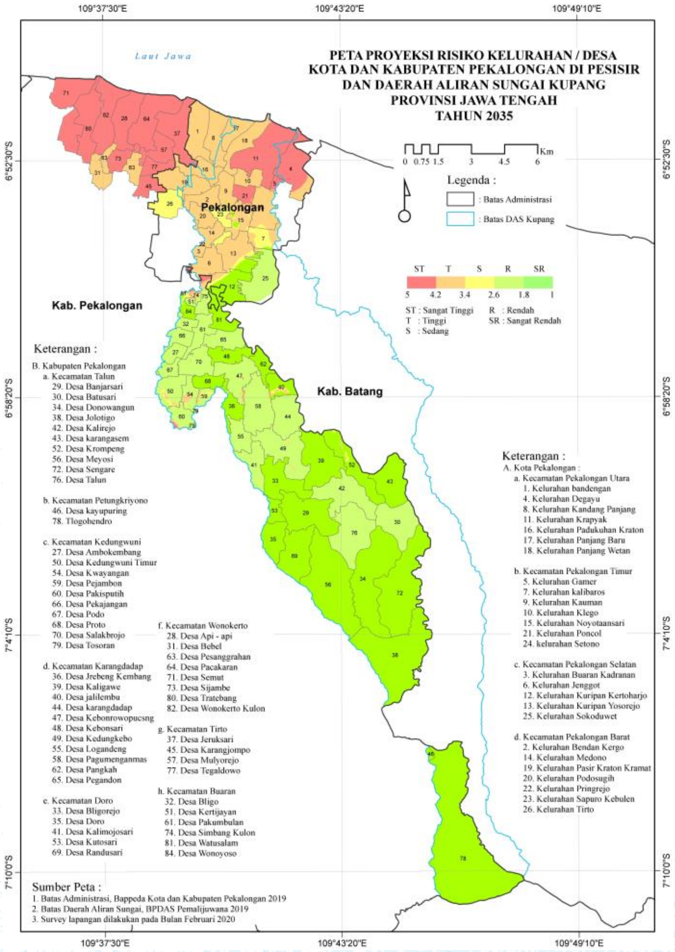


APPENDIX J

Decadal Prediction Flood Risk Projection (2025-2035)

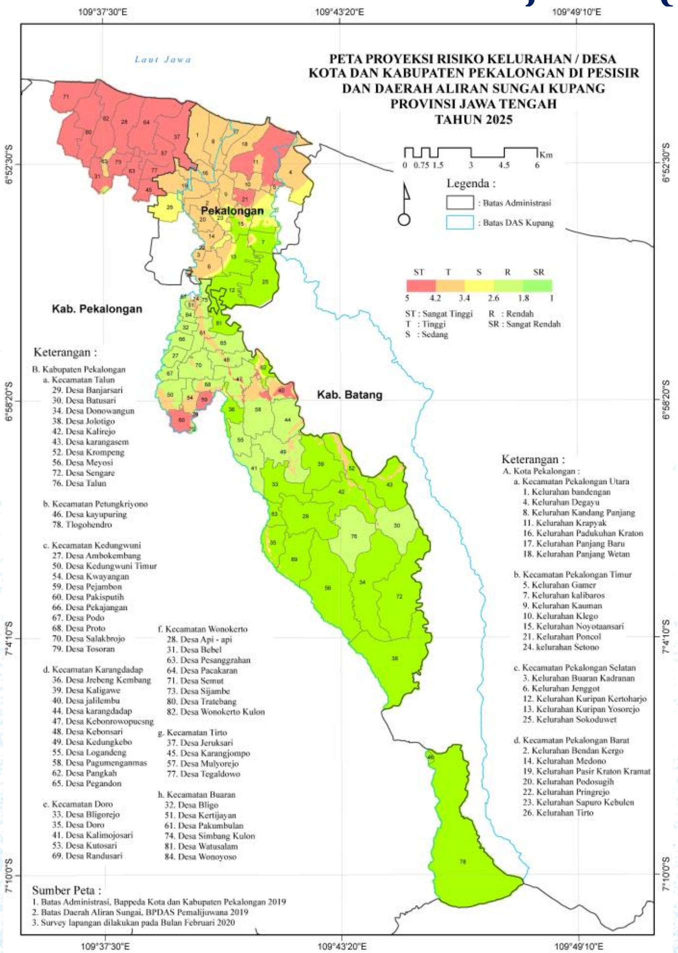


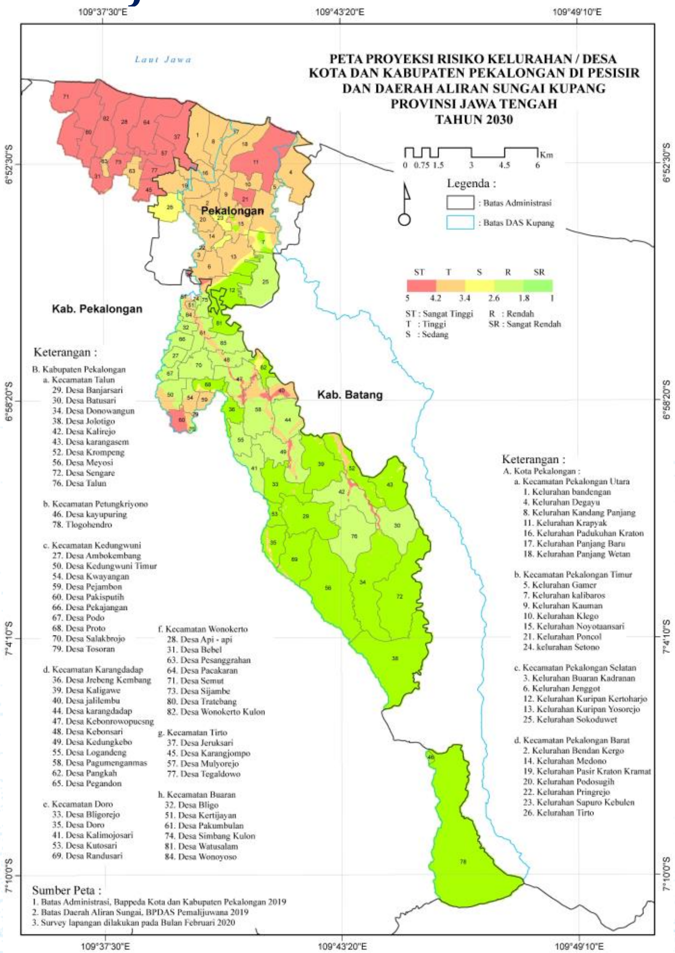


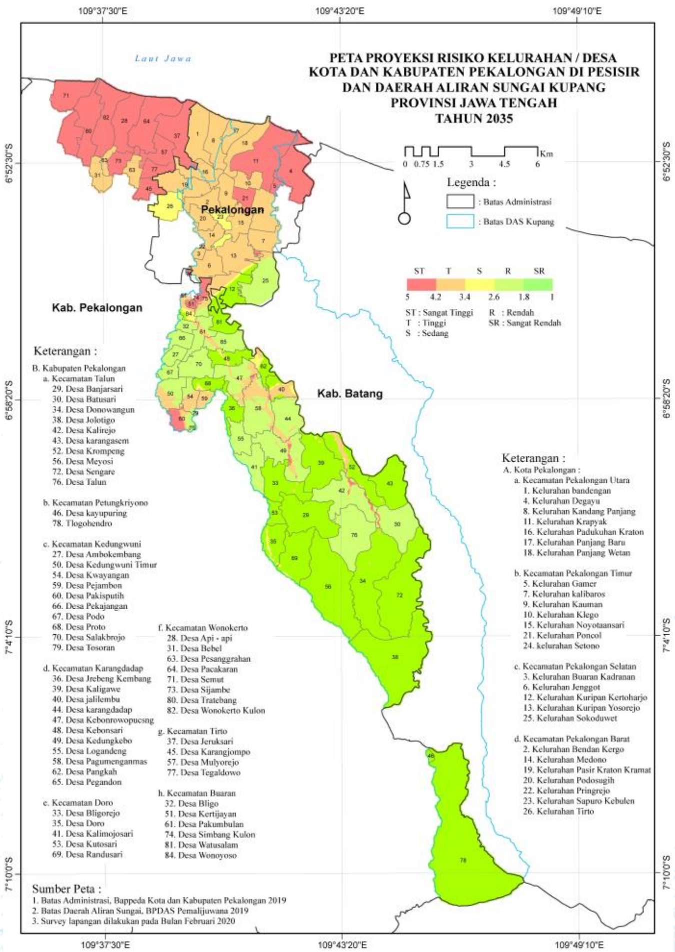


APPENDIX K

RCP 4.5 Scenario Flood Risk Projection (2025-2035)

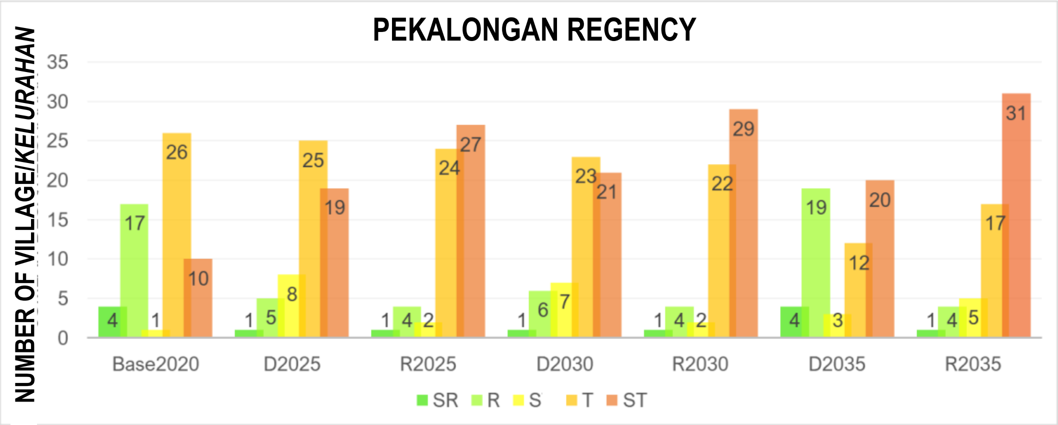


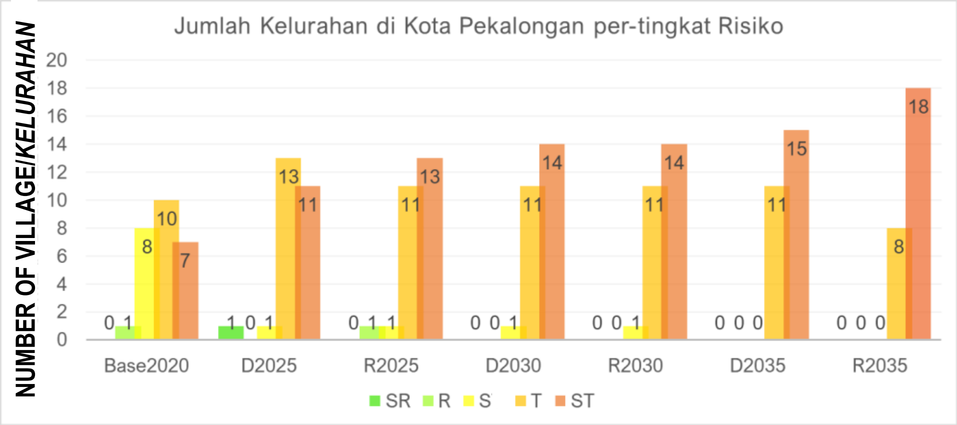


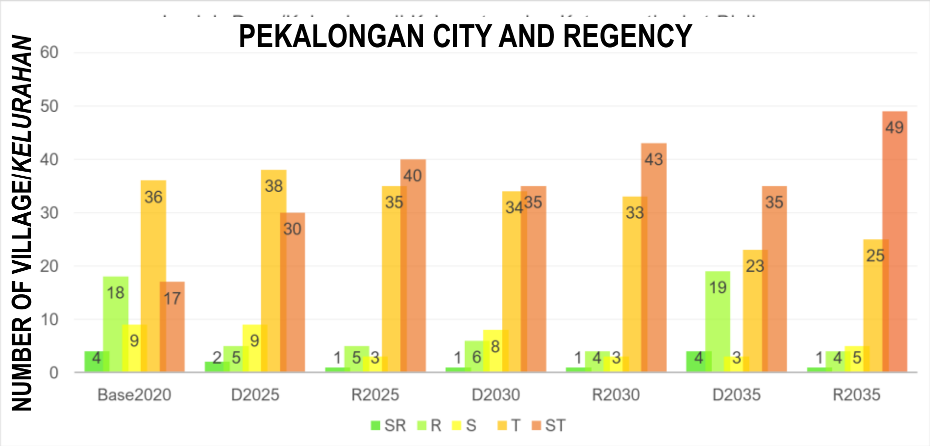


APPENDIX L

Number of Villages/*Kelurahans* in Study Location per Risk Level







Flood Resilience Alliance

Thank you.

Mercy Corps Indonesia

IPB University
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CoREM
Center for Coastal Rehabilitation and Disaster Mitigation Studies

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