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Quantitative assessment of vulnerability in aquaculture: climate change impacts on whiteleg shrimp (*Litopenaeus vannamei*) farming in East Java Province

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Abstract. Whiteleg shrimp (*Litopenaeus vannmaei*) commodities has a high economic value and a huge market demand. Changes in temperature and precipitation seems to be the most significant factors climatic that effect shrimp aquaculture production. The objectives are to understand of climatic factors influence on the whiteleg shrimp farming sector in Indonesia based on IPSL(Institut Pierre Simon Laplace)-CM5A-MR(Medium Resolution) model and to understand adaptability of whiteleg shrimp to climate change on vulnerable area. The projection of the model includes four Representative Concentration Pathway (RCP) scenarios, encompassing RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. These vulnerable map were created by overlaying the exposure maps (precipitation, maximum temperature and minimum temperature) and sensitivity map (production maps) in various time. Banyuwangi District was the most vulnerable area in East Java Province. The questionary has analysed descriptively and found that 92% of the respondents are aware of climate change. The respondents reveal that increased on rainfall (34%) and decreased of temperature (29%) has negative impacts on shrimp production. Decrease in production influenced by disease and climate factors. Either future threats or current threats related to climate change and disease. More deeply there are insignificant positive correlation between temperature and precipitation with production in Banyuwangi.

1. Introduction

Indonesia is an archipelagic country, traversed by the equator which makes Indonesia has rainy and dry season, remain throughout every year. Obviously it is very profitable for shrimp farming activities. Shrimp farming in Indonesia is a major export commodities help in increasing state revenues, compared to other fishery products such as tuna and blue swimmer crabs. Climate change that occurs as a result of excessive use of fossil fuels has a devastating effect on Indonesia, including for shrimp farming activities. In 2010 – 2012 whiteleg shrimp in East Java increased, but not in the following year, possibly due to reduced water quality and ecosystem environment. In this case, the uncertain climate change will affect the water quality in ponds [1].

The impacts of climate change could occur directly or indirectly on shrimp farming and cannot be attributed as one single factor, in the case of many aquaculture practices. Changes in average of temperature and average precipitation drives of climate change on shrimp aquaculture. Increased temperatures will affect pond of evaporation rates and the resultant temperatures for aquaculture on water quality in source water bodies. It could also increase the intensity and frequency of disease outbreaks. Change in amount of rainfall in this case decrease in the salinity, depletion of dissolved oxygen, algae blooms, particularly in summer months. It becomes difficult in inland and coastal areas of brackish water shrimp ponds can significantly impact to farm production [2].

The research predicts about the level of vulnerability in shrimp farming activities. The climate change scenarios (temperature and precipitation) for period 25 years are RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5. The goal of working with scenarios is not only to predict the future but also to provide a better understand about uncertainties and alternative futures. Geographic Information System (GIS) is employed in this study to conduct spatial analysis of the parameters associated with the process of identifying the impact of climate change that occurs in shrimp farming. The objective of this research are: 1) Determine vulnerable area of whiteleg shrim in response to climate change in East Java Province and concern to undestand perceptions of the shrimp farmer in selected vulnerable area, 2) Determine a relationship between climate factors with production in the most vulnerable district.

2. Metodology

2.1. Framework of Research

In climate change adaptation, there are two types of vulnerabilities: outcome vulnerabilities and contextual vulnerabilities [3,4]. This research uses outcome vulnerability to determine impact assessments. Sensitivity and adaptive capacity came as contextual vulnerability.

2.2. Conceptual Research

Vulnerability index as approached in this study has conducted by using quantitative assessment. In the case of vulnerability index, all the indicators were chosen by researcher that has potential impact on vulnerability of the region to climate change. The vulnerability map is calculated by summing the level of exposure and sensitivity. In the research, the exposure is indicated with precipitation and temperature (projection). Otherwise, the sensitivity indicated with production of shrimp farming. Adaptive capacity as additional information explains anything about shrimp farming condition related to climate change in a region.

2.3. Research Procedures

This research was divided into three main parts: data collection, data processing, and analysis process. 1) Data collection is belong to primary data such as; production of shrimp in East Java Province (2011-2015), production of shrimp in Banyuwangi District (2015-2016), projection climate data (2018-2042) consist of precipitation, maximum temperature, and minimum temperature in East Java Province, 2) Data processing: collected data of primary data and secondary data, arrangement in the form of rectangular matrix with columns representing indicators and rows representing regions, interpolate processing of climate data as indicators (i.e., maximum temperature, minimum temperature, and precipitation) using Geographic Information System (GIS) technical. Geostatistical analysis carried out by using kriging method, calculated normalization of indicators is using normalized formula (1), and it is important to identify the functional relationship between vulnerability and indicators previously (more vulnerable or less vulnerable).

$$X_{ij} = \frac{X_{ij} - Min\{X_{ij}\}}{Max\{X_{ij}\} - Min\{X_{ij}\}} \quad (1)$$

$$VI = \frac{\sum_{z=1}^{z=0} X_{ij}\ (z)}{K} \quad (2)$$

Where; $X_{ij} = |\uparrow|$ more vulnerable (Functional relationship between vulnerability and indicators), K = number of indicators.

Calculated vulnerability index was used equal weighting in method (2), to know impact of climate change in each region. Overlapping climate data and productivity data was able to make vulnerability map. Interview with stakeholders using questionnaire to know adaptive capacity. 3) Analysis process: integration between vulnerability map and questionary data were employed to know about climate change impact on shrimp farming.

2.4. Research Sites

This research is located in East Java where the largest of shrimp farming founded (Figure 1.). East Java Province consists of 38 district, 22 districts are belong to coastal area. They are Banyuwangi, Situbondo, Probolinggo, Probolinggo city, Jember, Lumajang, Malang, Lamongan, Pacitan, Tulungagung, Tuban, Bangkalan, Pamekasan, Surabaya city, Blitar, Pasuruan, Pasuruan city, Sumenep, Trenggalek, Gresik, and Sidoarjo.

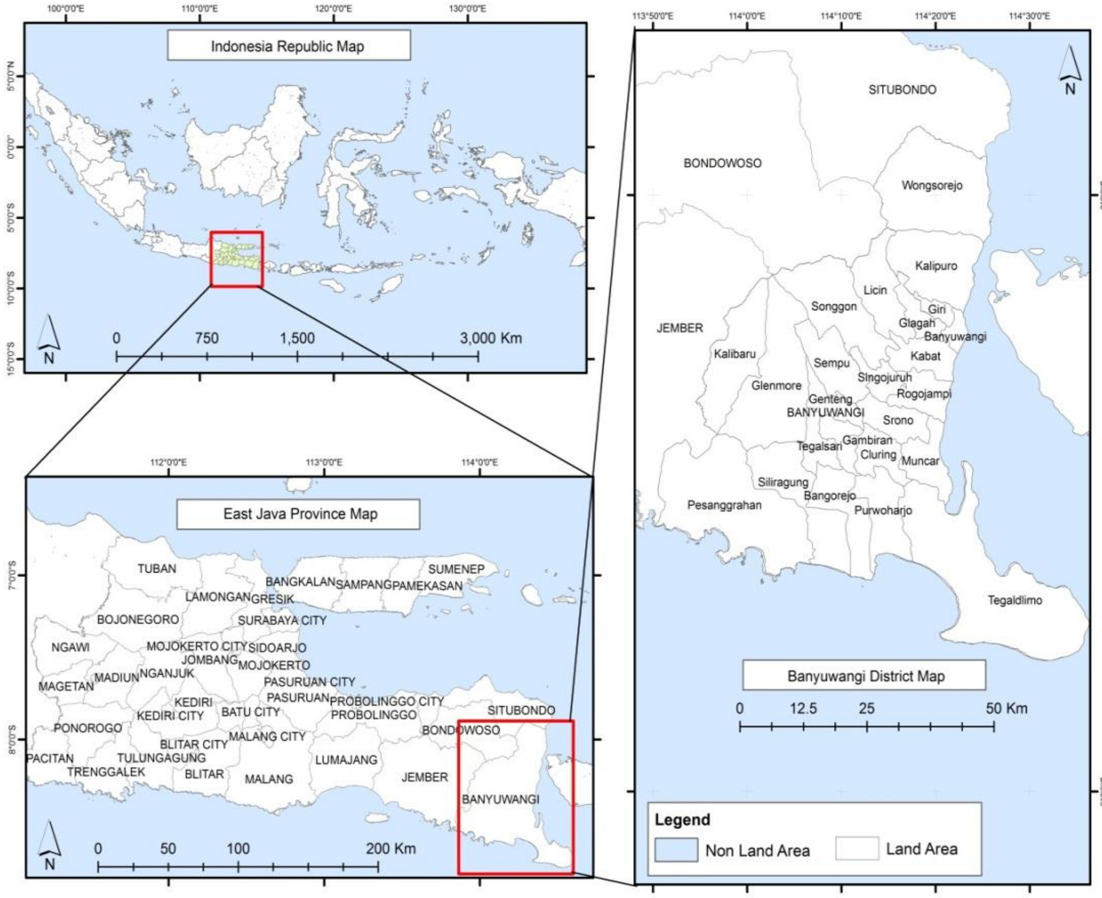

Figure 1. Research Location

2.5. Data Analysis

Analysis of this reseach is comprised into three parts: 1) Projection analysis of projection climate change (period 2018-2042) to determine characteristics of climate hazards for the future, 2) analysis of shrimp production in East Java Province and Banyuwangi District, 3) analysis of vulnerability maps with perception of farmers in East Java to know adaptive capacity on climate change in the region, and analysis of correlation using monthly climate data and monthly production data.

3. Result and discussion

3.1. Climate Variables Map Exposure Paramaters

One of key elements of vulnerability is exposure. The future climate factor used a climate models (i.e. IPSL-CM5A-MR models). In this case, exposure indicates with precipitation, minimum temperature and maximum temperature. The values of the figures are described as a color bar, where red color identify as a high value, and green color identify as a low value.

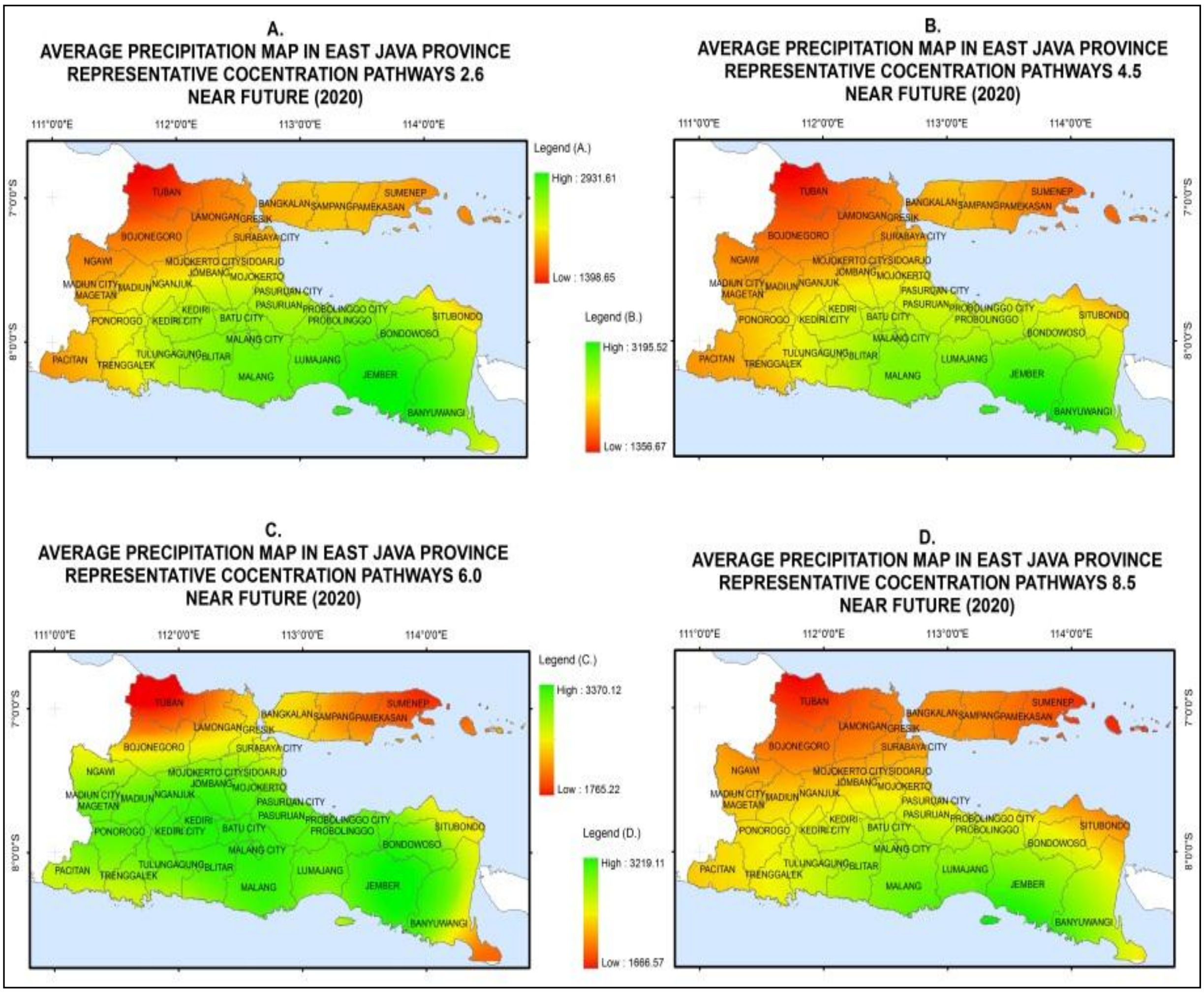

Figure 2. Exposure maps: average precipitation maps in 2020

Figures 2 give some information that the highest value of precipitation from period 2020 is 3370.12 mm/day under RCP 6.0 and the lowest value of precipitation is 1356.67 mm/day under RCP 4.5.

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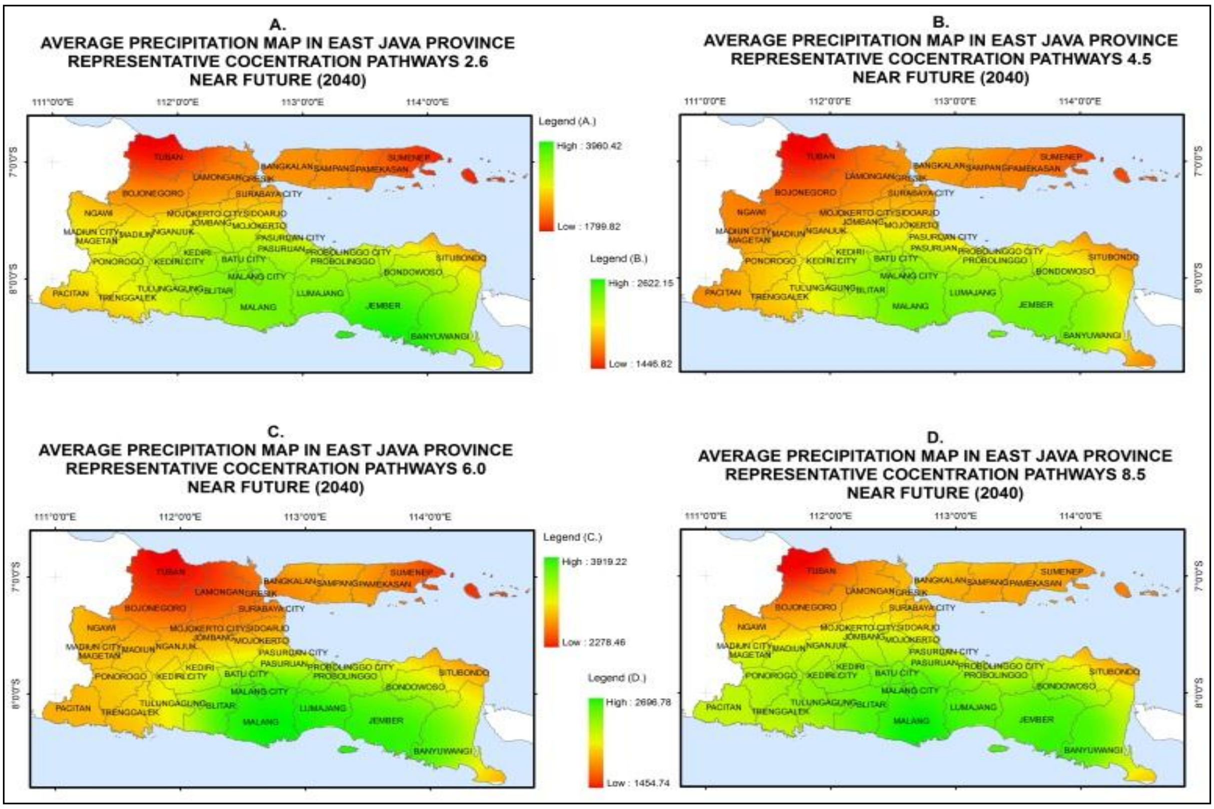

Figure 3. Exposure maps: average precipitation maps in 2020

In the period 2040, the highest values is 3960.42 mm/day under RCP 4.5 (Figure 3). Average precipitation for 25 years (2018-2042) explained that the highest values is 3022.73 mm/day under RCP 6.0 and the lowest values is 1371.08 mm/day under RCP 4.5 (Figure 4).

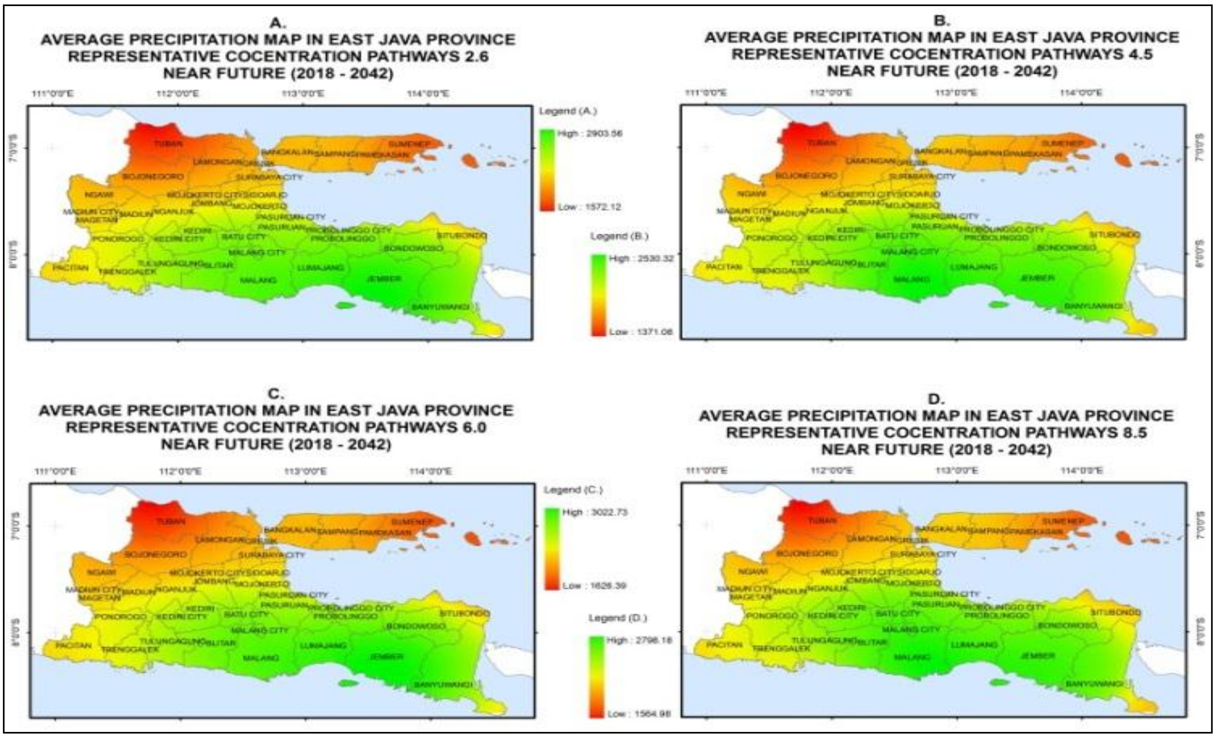

Figure 4. Exposure maps: precipitation maps for 25 years (2018 – 2042)

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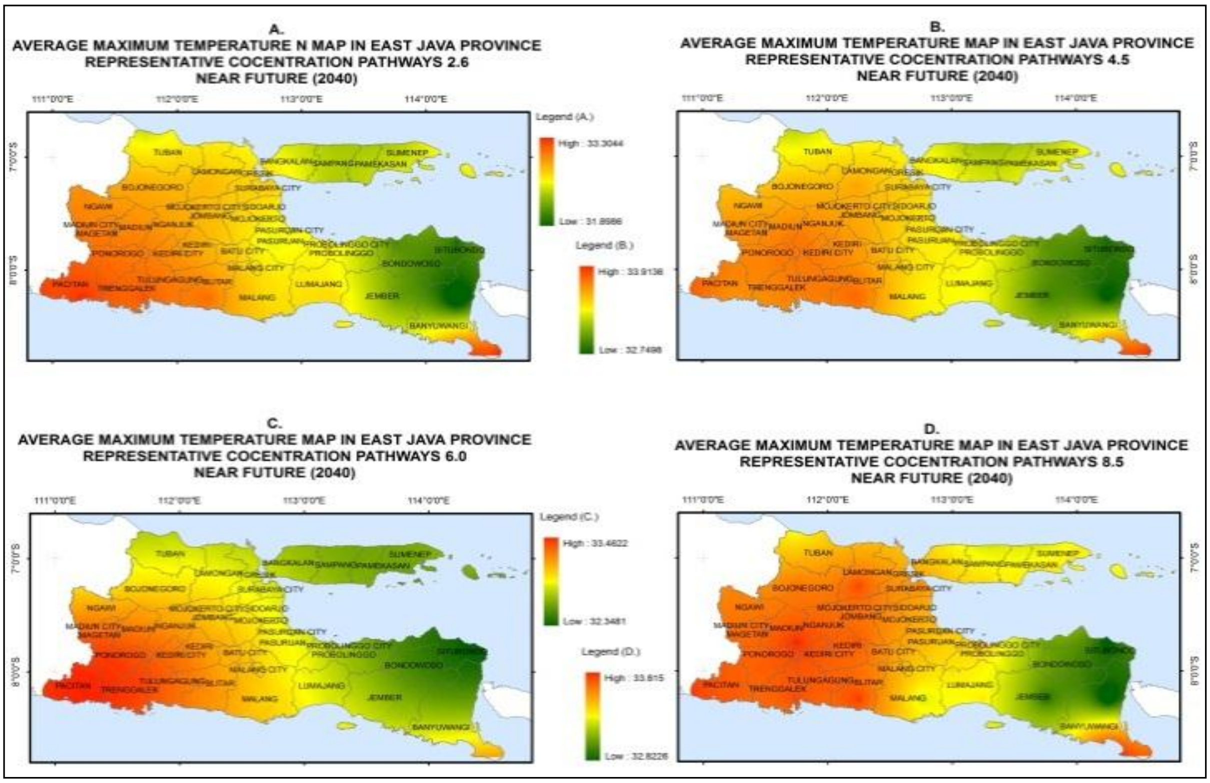


Figure 5. Exposure maps: average maximum temperature maps in 2020

The result of average maximum temperature map in East Java Province uses color bar to describing the level of average maximum temperature. The dark green color indicated low value, and the red color indicates as high value. The largest values of maximum temperature in 2020 is 33.27°C under RCP 8.5 and the lowest values is 31.74°C under RCP 2.6 (Figure 5).

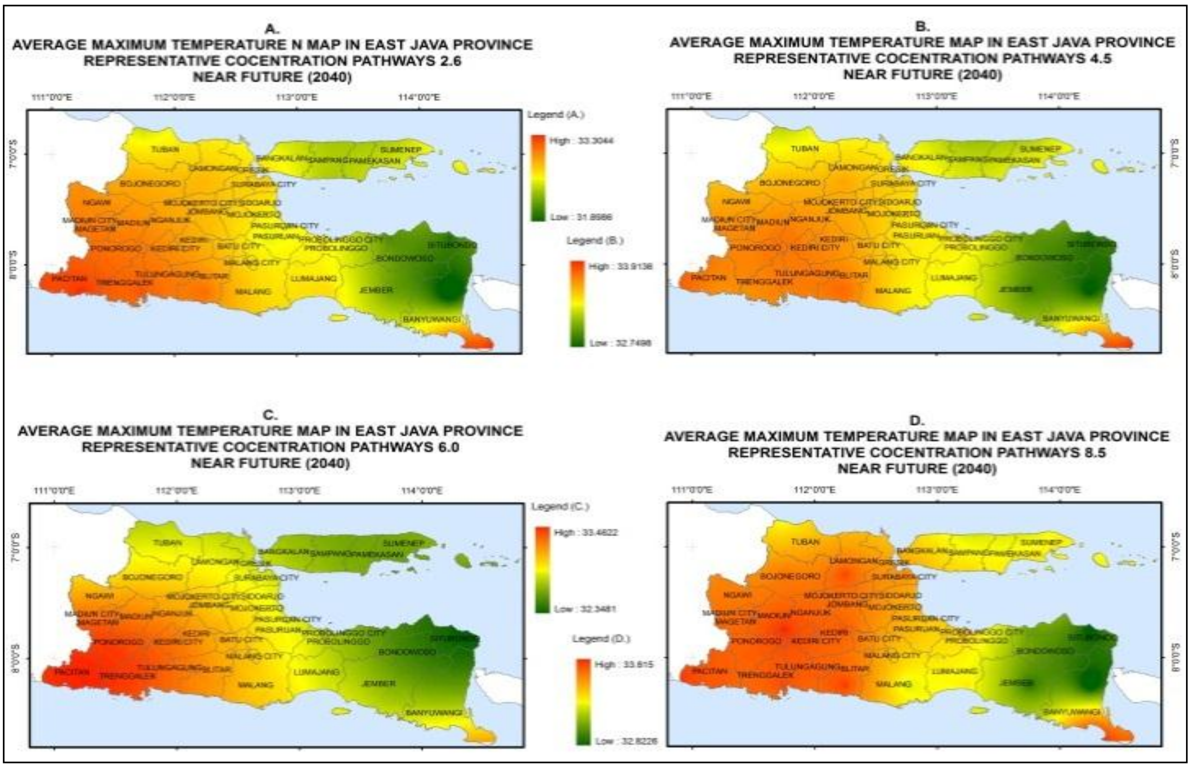


Figure 6. Exposure maps: average maximum temperature maps in 2040

In 2040, the largest values of maximum temperature is 33.91° under RCP 4.5 and the smallest values of maximum temperature is 31.89°C under RCP 2.6 (Figure 6). Map of averages for 25 years described that the highest values is 33.35°C under RCP 4.5 and the lowest values is 32.08°C under RCP 2.6 (Figure 7).

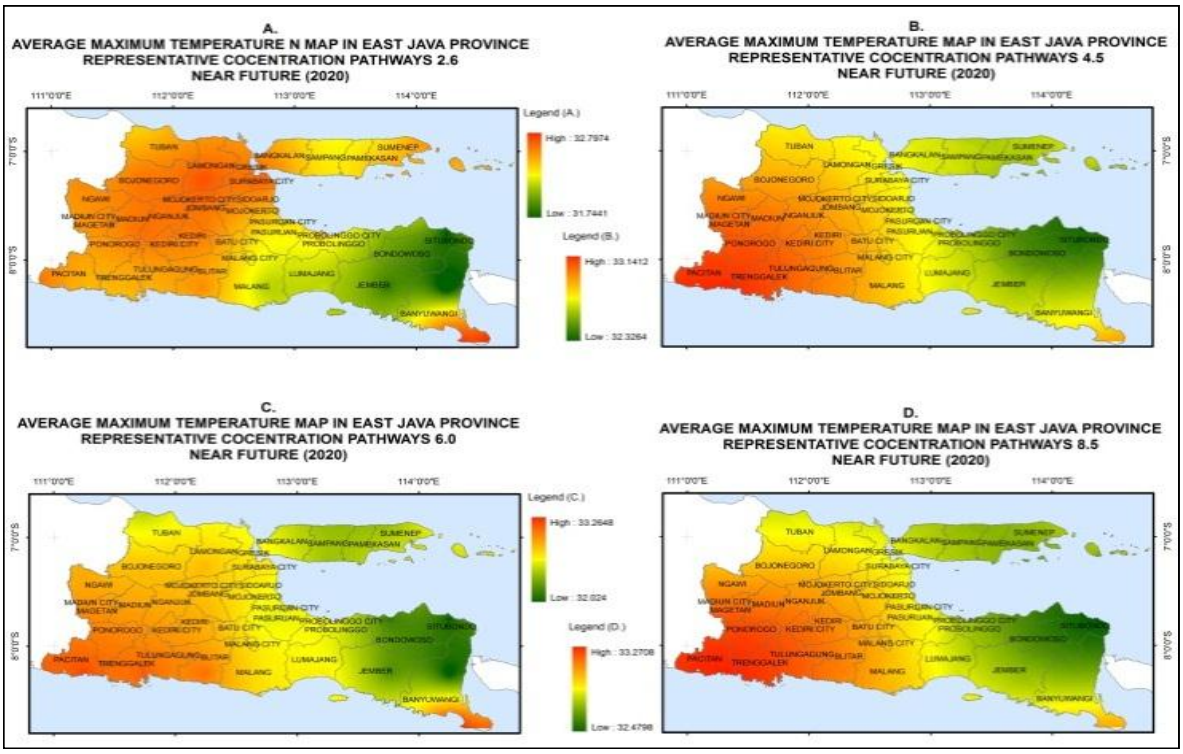


Figure 7. Exposure maps: average maximum temperature maps for 25 years (2018 – 2042)

The minimum temperature map in figure 8 for period 2020 shows that the highest values is 25.15°C under RCP 4.5 and the lowest value is 21.89°C under RCP 2.6.

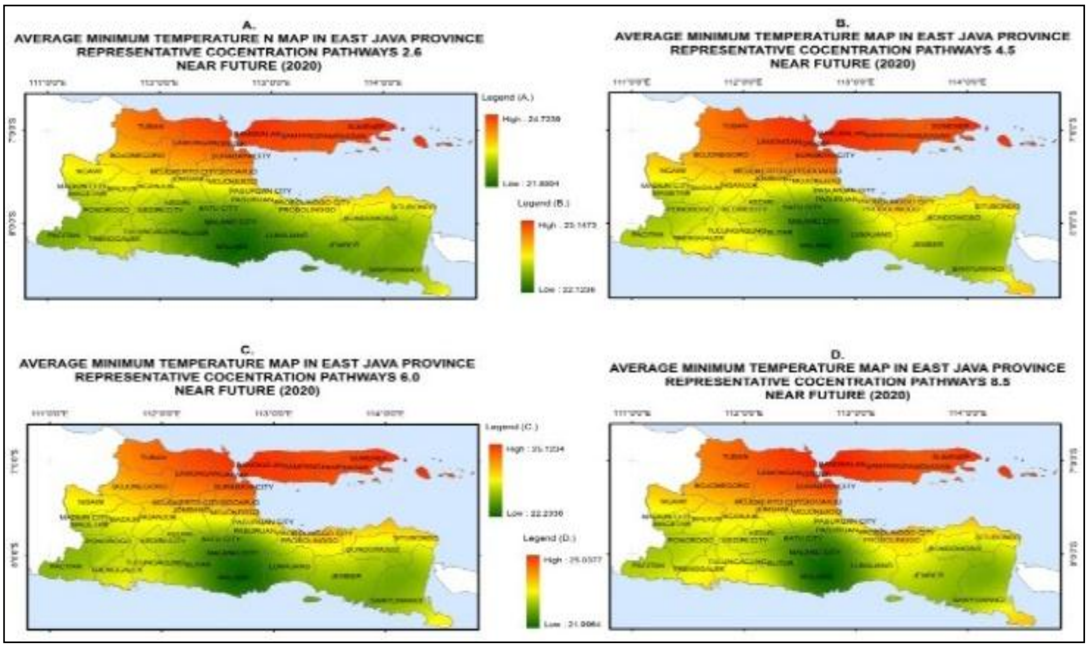


Figure 8. Exposure maps: average minimum temperature maps in 2020

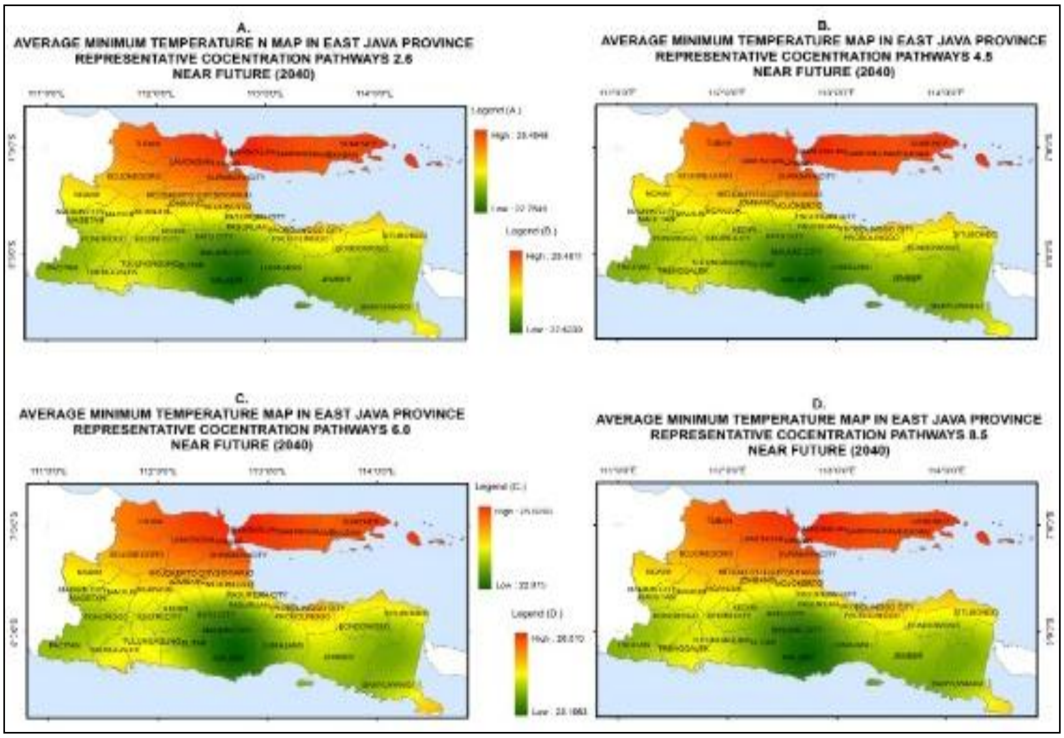


Figure 9. Exposure maps: average minimum temperature maps in 2020

The minimim temperature map in 2040 shows that the highest value is 26.01°C under RCP 8.5, while the lowest value is 22.62°C under RCP 4.5 (Figure 8). The average period for 25 years shows that the largest value is 25.37°C under RCP 8.5., and the lowest value is 22.12°C under RCP 4.5 (Figure 9)

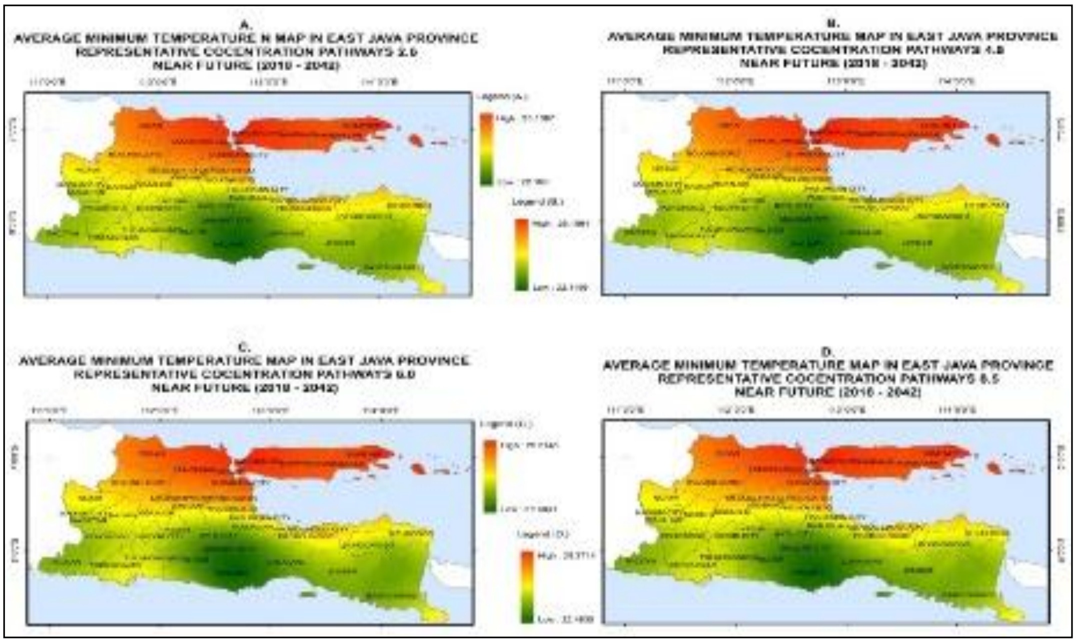
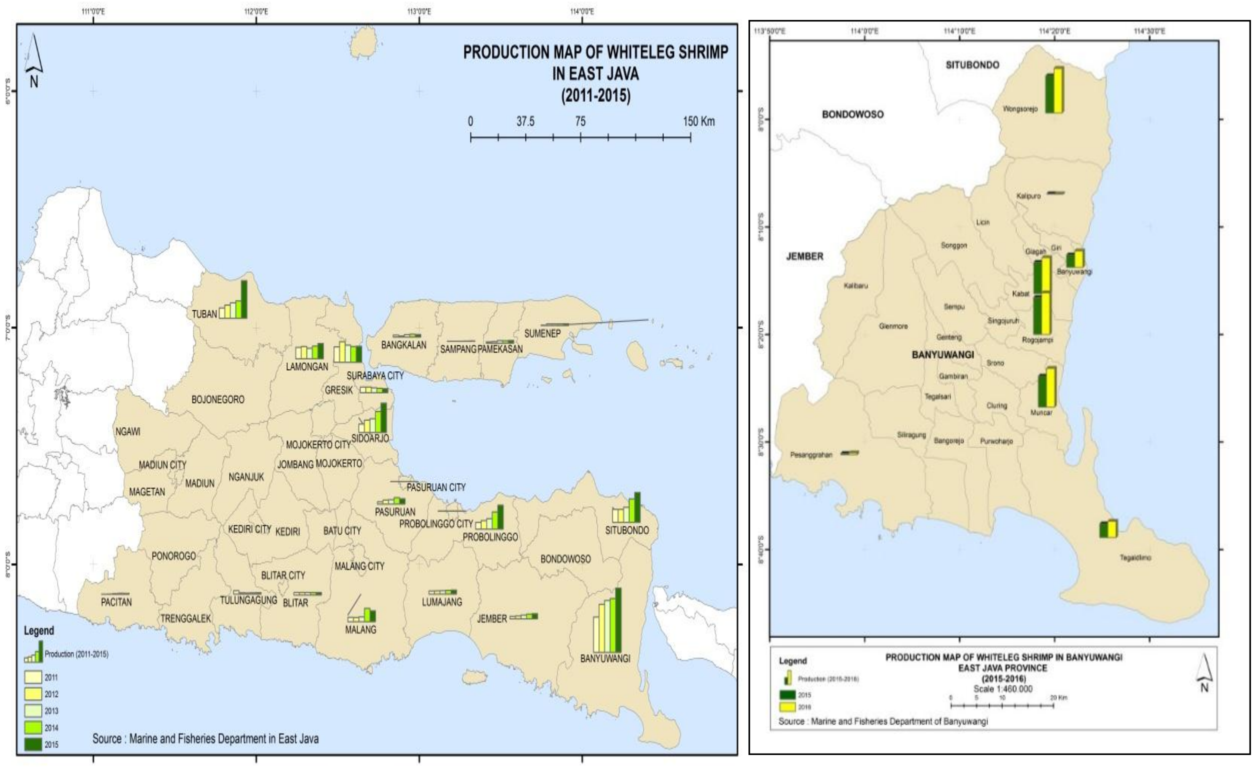


Figure 10. Exposure maps: average minimum temperature maps for 25 years (2018-2042)

3.2. Production Map as Sensitivity Paramaters

There are two kinds of production data. First is production data of whiteleg shrimp in East Java Province, which taken from Ministry of Marine and Fisheries (Figure 11a). The data shows production in each district of coastal area in East Java Province. Second is production data of whiteleg shrimp in Banyuwangi District, which taken from Fisheries and Food Security Department (Figure 11b).



a. b

Figure 11. a) Production map of whiteleg shrimp in East Java Province during 2011-2015, b) Production map of whiteleg shrimp in Banyuwangi District during 2015-2016

Figure 11a shows that the biggest value from the average of production data during 2011 – 2015 in East Java Province is Banyuwangi District (27.72%), follows by Situbondo (10.35%), Tuban (10.24%), Gresik (9.33%), Sidoarjo (9.28%), Probolinggo (7.32%), Lamongan (6.80%), Malang (4.14%), Surabaya (2.66%), Pasuruan (2.41%), Jember (2.04%), Lumajang (1.86%), Blitar (1.37%), Bangkalan (1.17%), Pamekasan (1.14%), Tulungagung (0.98%), Sumenep (0.71%), Pacitan (0.31%), Probolinggo (0.11%), Sampang (0.07%), Pasuruan (0.01%), and Trenggalek (0%).

Figure 11b shows that Wongsorejo sub-district is the highest value of average production data during 2015 – 2016 in Banyuwangi District, i.e., Wongsorejo (22.60%), Rogojampi (21.81%), Muncar (19.34%), Kabat (18.71%), Tegaldlimo (8.35%), Banyuwangi (8.09%), Pasanggrahan (0.88%), Kalipuro (0.23%).

3.3. Vulnerability Area in East Java Province

From production data in East Java only 21 District had production data. In Trenggalek District was not found production of whiteleg shrimp. Trenggalek District is captured as region with mountains area (48.31%) which is used as cultivation. Vulnerability map of East Java shows that in Banyuwangi District is the most vulnerable area under all scenarios data (Figure 12).

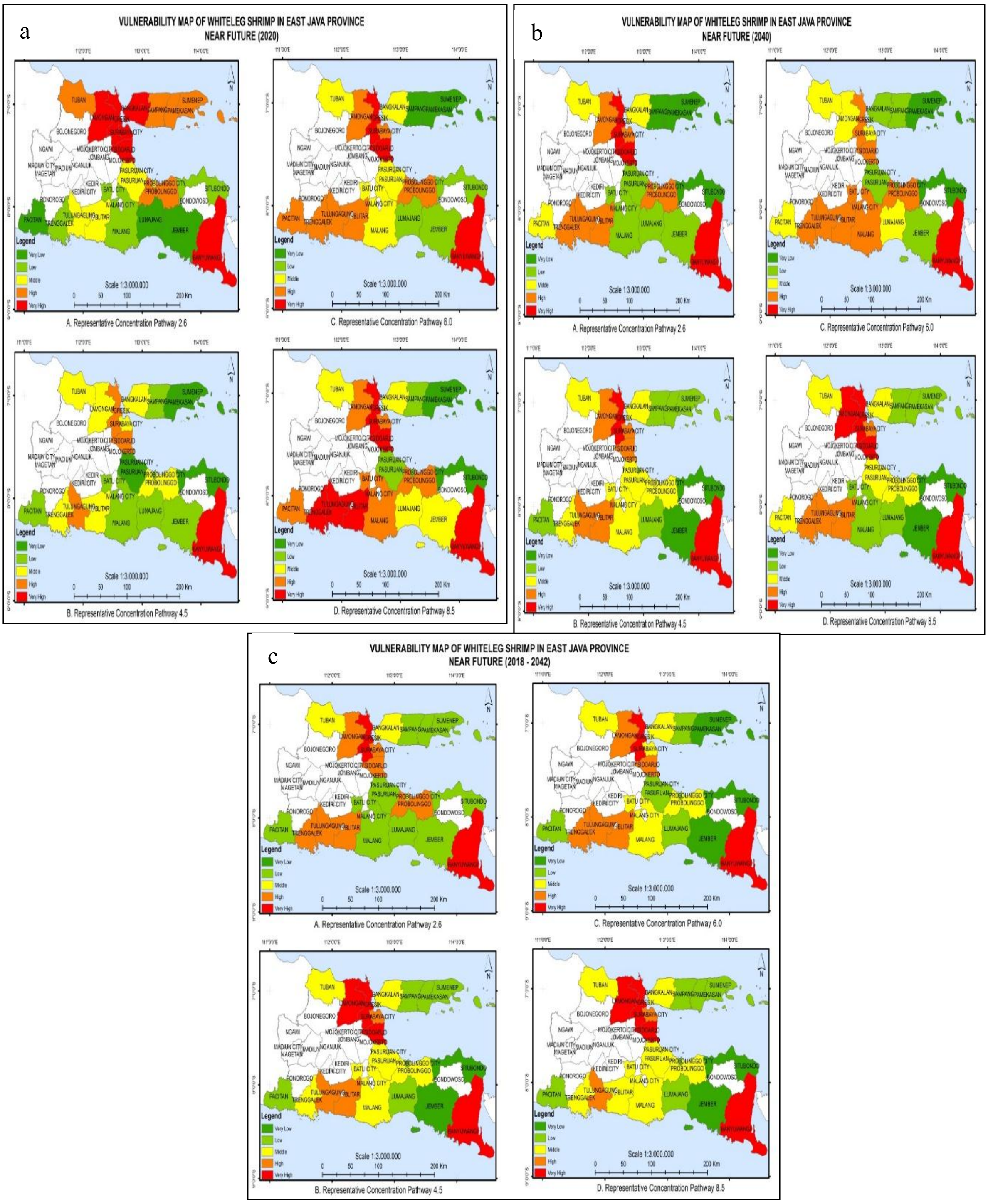


Figure 12. Vulnerability map in coastal area in East Java Province : a) 2020, b) 2040, c) 2018 – 2042 under RCP scenarios

3.4. Perception of the Whiteleg Shrimp Farmers in Banyuwangi District

3.4.1. General Information of Respondent.

Total of the respondents were 25 respondents. All the repondents were men and already married with had different background. The main job of the respondents were shrimp farmer (55.88%), fisherman (5.88%), others (38.24%) (as a farmer, technical man, distibutor, trader, and operator in the pond . It implies that married men were able to support the family with the main job as a shrimp farmer. It mentioned that 80% of the respondents (men) were married and implied that for income and livelihood to their family could be supported from aquaculture [5].

3.4.2. Trend of Productivity.

Trends shrimp production has fluctuated. The respondents mentioned that the production decrease more than 30% since 2014. All the respondents said there is influence between disease and climate factors. Some disease such as IMNV (Infectious Myo Necrosis Virus), WFS (White Feses Syndrome), WSD (White Spot Disease), and TSV (Taura Syndrome Virus) cause decrease in production. Temperature plays a crucial role in the occurrence of IMNV disease, and it can be attacked in all seasons. The possibility of the condition where the disease more virulent than ever occurred as a result of changes in temperature extremely or continuously [6]. 52% respondents mentioned that in rainy season disease more often arise. The whiteleg shrimp had ability to live against fluctuations in water quality, especially in dry season [7].

3.4.3. Awareness of Climate Change.

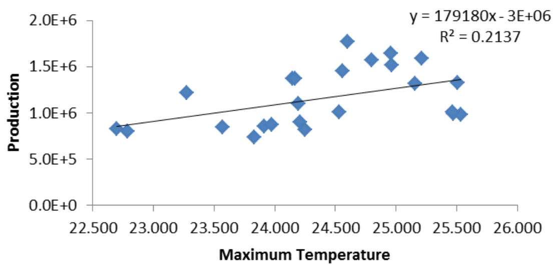
Some of the respondents (40%) had been informed about the weather and the rising sea levels. The unpredictable climate and absence of information relevant to the climate's issue create a problem for sustainability of shrimp production. The respondents acknowledged that the climate has changed. Most of the respondents (92%) were aware of climate change. In 2016, they feel climate was having an impact on production, increase precipitation (34.09%), and decrease temperature (2.55%) were the most factors influence of decreasing shrimp production. The heavy rain causes water salinity and temperature level decrease, affected to shrimp growth and productivity which was low water salinity with fluctuations water temperature (3°C - 4°C) causes the outbreak of WSSV in shrimp. This climatic condition affect to all pond systems [8]. For development skills, some of the respondents have received training related to the way of cultivation.. the respondents education and training expected to consider global climate change to be a more able to adapt in serious risk than the respondents with typical nonscientists [9].

3.4.4. Adaptive Ability.

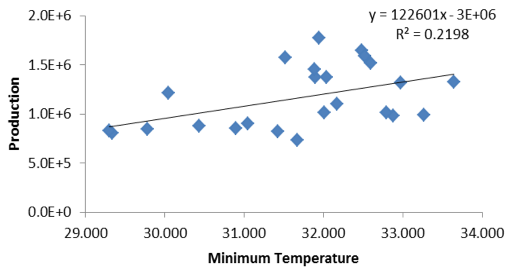
Most of the respondents aware that the biggest challenges that threaten the sustainability of aquaculture today is related to the weather, such as rain, wind, and temperature. There is relationship between aquaculture production with environmental conditions. It agreed which was mentioned that changes in the environment may have direct or indirect effects on the abundance of pathogens and parasites [10]. Also, it mentioned that the fundamentally success in aquaculture depend on aquatic environment, which is a major concern considering the wide rangin impacts on climate change [11]. In 2016 the farmers said that flood happen frequently. Some of farmers (12%) said that the flood happen no related to climate change but it was happen caused the improper of infrastructure. While treat in the future mentioned that is not different from the exist today, which is related to weather and disease. Some respondents also explained that land, capital, and water quality as another treat in the future. Respondents were hoping for increasing technical, financial and skill for help them to adapt. Others mentioned need for supervision and mentoring by an expert in any farming activities. This is because climate change as an attention so hard to detect if only based on personal experience, they thought that learning through an expert can be better to make decision [9].

3.4.5. Mitigation of Climate Change.
The mitigation action to the climate change is important for sustainability in aquaculture. One of the respondents had been taking appropriate action to reducing the impact of climate change, by using biodiesel as a substitute for diesel fuel. Respondents are ready to make changes to reduce the impact of climate change that occurred. Although they also says, that the reduction of fuel and electricity can affect to production. The chosen land for pond need to consider about mangrove as a buffer zone. 36% respondents said that their ponds were not in area of buffer zone, and 64% were in area of buffer zone. The buffer zone used to protect ponds from pollutant or spreading of parasites and disease [12].

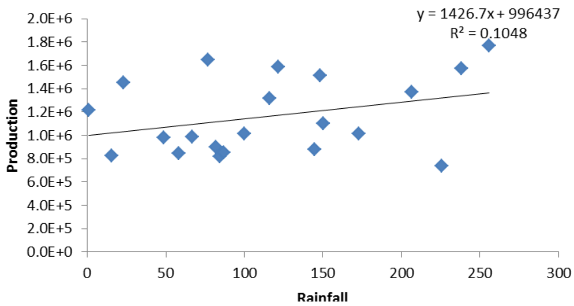
3.5. Correlation Between Production Data and Climate Data in Banyuwangi District
The collected data from Fisheries and Food Security Deparment in Banyuwangi District shows that the number of farm during 2015-2016 are not changed (i.e., 498). The area of ponds also no changes during 2015 – 2016, which are 1381.76 ha. The study finds that total of production in 2015 – 2016 is increasing although the area and number of farms experienced no changes. This study finds that the monthly maximum temperature data during 2015 – 2016 and the monthly whiteleg shrimp production is positively insignificant correlated ($R^2 = 0.2137$) (Figure 13a).



(a)



(b)



(c)

Figure 13. Correlation pattern between exposure parameters (temperature and rainfall) and sensitivity parameters (production data): a) maximum temperature, b) minimum temperature, c) rainfall

Figure 13b. explains that there are correlation between minimum temperature and production in Banyuwangi District during 2015 – 2016. The correlation is insignificantly positive increasing ($R^2 = 0.2198$). The study also finds that the monthly rainfall data during 2015 – 2016 and the monthly whiteleg shrimp production is positively correlated, with $R^2 = 0.1048$ (Figure 13c).

The other researcher explained about correlation of shrimp production with climatic parameters [13]. Within the research, the researcher also found that the annual shrimp production and temperature was insignificant positively correlated. It was also found for correlation between the annual shrimp production and rainfall, which was showed positively correlated and insignificant [13].

4. Conclusion

This study concludes several things, as follows : the most vulnerability area in East Java Province is Banyuwangi District, under projection climate data (encompassing RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5). Most of the respondents (92%) aware of climate change. The respondents reveal that increased rainfall (34%) and decreased temperature (29%) are the most contribute to cause a negative impacts on shrimp production. Decrease in production influenced by disease and climate factors, in rainy seasons the disease more frequently. Treat in the future, it is mentioned not much different from the treat that exist today, which is related to climate and disease. There are positively correlation between climate parameters (precipitation, maximum temperature, and minimum temperature) with production data (in Banyuwangi District) but it was insignificant.

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