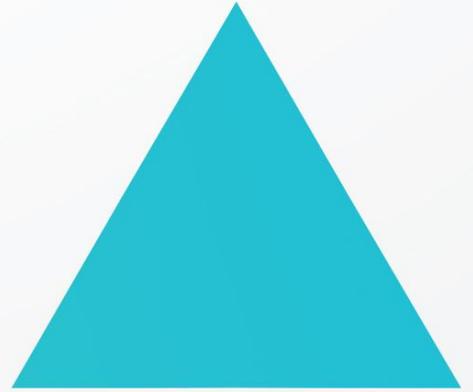


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The Effect of Changes in Land Cover and Vegetation Density on Urban Heat Island in Semarang City

Susiyowati Indah Ayuni¹, Arief Adhika Widyatama², Nanda Mutiara Zani³

¹ Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan, Institut Teknologi Bandung, Bandung, Indonesia

² Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan, Institut Teknologi Bandung, Bandung, Indonesia

³ Sekolah Arsitektur, Perencanaan, dan Pengembangan Kebijakan, Institut Teknologi Bandung, Bandung, Indonesia

E-mail: ¹254200061@mahasiswa.itb.ac.id, ²25421020@mahasiswa.itb.ac.id, ³25421031@mahasiswa.itb.ac.id

Abstract

The urbanization process can be seen not only as influenced by increasing population growth but also the phenomenon of urbanization. The city of Semarang from 1999 to 2019 saw an increase of half a million people with a total population of around 1.81 million people. Along with population growth that occurs, land conversion to meet the needs of life often clashes with the presence of vegetated land. As a result, the area of vegetated land slowly decreases. On the other hand, the massive build-up of this area makes it easier to reflect and absorb solar heat. As a result, the average surface temperature of the city gradually rises which causes the formation of hot spots that cause changes in climate and weather elements, thus triggering the formation of an Urban Heat Island (UHI). The increase in temperature in urban areas affects not only the comfort of cities but also the health of urban communities, which will impact various city line activities. This urban heat island study, related to changes in land use in Semarang, is urgently needed to make wiser spatial planning decisions. In line with the problems above, this study is aimed at analyzing the effect of changes in land cover and vegetation density on the area of Urban Heat Island (UHI) in Semarang City. The approach used is forecasting with multiple regression analysis methods. Sources of data used are secondary data and population data. The data used is time series data. Based on the statistical analysis results indicate that the variables of land cover and vegetation density have a significant influence on the distribution of surface temperature. The land cover component has a positive effect while the vegetation density component harms the surface temperature distribution area. The appearance of the trendline results in an increasing area of surface temperature distribution in 2030 with 3 scenarios, namely, pessimistic, moderate, and optimistic. The preparation of a planning scenario in which an optimistic scenario can be adopted by the government so that the area of high urban surface temperatures does not expand and have an impact on the level of community vulnerability to extreme weather.

Keywords

Forecasting Analysis;
Land Cover Change;
Surface Temperature
Distribution; Urban
Heat Island; Vegetation
Density.

1. INTRODUCTION

The urban area is a function of the central residential area, which has a relatively large population with a high density, has a limited area, and is usually non-agricultural. The denser the population who inhabit an urban area, of course, will result in the activities and services of the city undergoing a reasonably rapid development change (Pontoh & Kustiawan, 2009). One form of this rapid development can be seen in the large number of large cities that were born or expanded where more and more people live in them (Mirzaei, 2015; Sobirin & Fatimah, 2015). The world's urban growth is increasingly rapid, and the size of cities is getting bigger. Concurring to 2019 World Bank data, the population in the world's cities is 55.71%. This indicates that more than half of the world's population has occupied land and has activities in urban areas. While in Indonesia, World Bank data (2019) shows that the population in urban areas is 55.99%. This percentage is slightly higher than the world average. This implies that more than half of Indonesia's population is scattered and lives in large urban areas such as Greater Jakarta, Surabaya, Semarang, Medan, Makassar, and other cities.

Of course, the higher the population and the high level of urban development will result in changes in land use and the emergence of the issue of limited space (Arie, 2012). As a result of this limited space, changes in

land use for development and fulfillment of living needs are unavoidable, even in some cases, there is a mismatch between the designation plan and the land use. This, of course, can guide to a reduction in the quality of the urban environment due to the conversion of vegetated land. According to (Afriana & Others, 2013; Eko & Rahayu, 2012; Fawzi & Nahari, 2013), this urgent development of vegetation land allocation has a broader goal. Where vegetated land will be converted into built-up lands such as asphalt and concrete for roads and other buildings and structures, which are easier to absorb heat and raise surface temperatures in urban areas (Hardyanti, Sobrim, & Wibowo, 2017), these activities trigger the emergence of new hot spots and the longer the existing hot spots will cause changes to the elements of climate and weather. The increase in surface temperature occurs in the downtown area, and the temperature will be more relaxed in the suburbs. Generally, the annual mean temperature in urban areas will be around 4°C-8.2°C higher than in suburban areas (Estoque, Murayama, & Myint, 2017).

Such a situation, when the average annual temperature in urban areas is greater than in the suburbs, is called Urban Heat Island (Adiningsih, Soenarmo, & Mujiasih, 2001; Belgaman, Lestari, & Lestiana, 2012). Urban Heat Island itself is one of the most critical urban environmental problems and a challenge for many cities to find alternative solutions to the problem. IPCC (Intergovernmental Panel on Climate Change) as an international climate organization in the IPCC Special Report on Global Warming calls for countries in the world to limit the increase in the earth's temperature to around 1.5°C. It was explained that an increase of 1°C would have quite dire effects such as extreme weather, sea level rise, melting of ice in the Arctic continent, and other impacts. It is expected that with the 1.5°C limitation, sea level rise will be 10 cm lower. However, achieving this requires cooperation from various aspects of society.

One of the urban areas in Indonesia that has significant population growth and land conversion is the city of Semarang. Administratively, The provincial capital of Central Java is Semarang City. Situated on Java Island's northern shore. Semarang City is in the traffic lane connecting the region with conditions like this, Semarang City has become a city of trade, industry, and manufacturing and is growing quite rapidly. Currently, in 2019 there are nearly 1.8 million people with a population growth of 0.47%. Until the span of 5 years (2016-2021), the population density in the city of Semarang increased. With an area of almost 378 km², with a population of 1.8 people, which means that the population density of Semarang City reaches 4.79 per square km. Currently, the city government is also trying to increase green space, one of which is through planting 58,000 tree seedlings which are expected to be able to neutralize the existing heat because the temperature in the Semarang urban area is already quite hot around 33°-36° Celsius. Studies related to the urban heat island in Semarang are currently being carried out a lot. However, this is the first time anyone has specifically discussed how far the effects of changes in land use and vegetation density have on the urban heat island. Many of them only conduct correlation research but do not further examine the magnitude of the effect. Therefore, this research is urgently needed to support decision-making and prevention of extreme climate change in the city of Semarang by looking at the vitality of the city of Semarang. This study aims to analyze the effect of changes in land cover and vegetation density in the Urban Heat Island (UHI) area in Semarang City which is expected to be the basis for making spatial planning decisions and enrich scientific knowledge related to urban heat islands, especially in Semarang City.

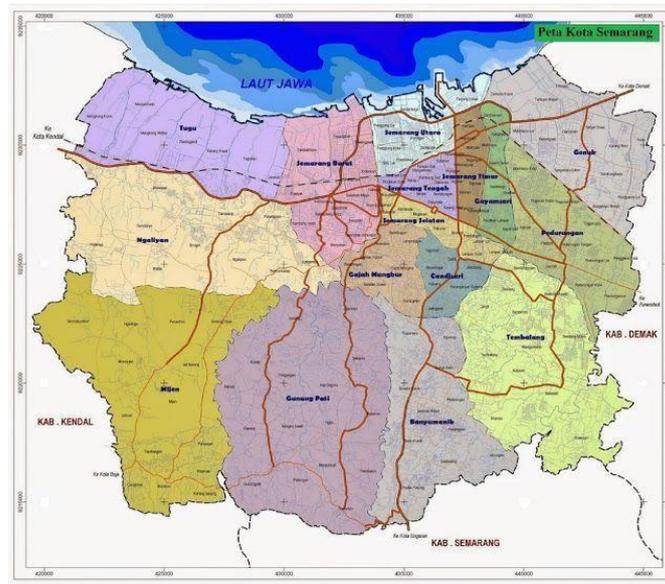


Figure 1. Semarang City Administration Map

Based on the urgency above, this research points to analyze the effect of land cover changes and vegetation density on the Urban Heat Island (UHI) area in Semarang City. While the research questions to be answered are as follows:

1. Are changes in surface temperature significantly affected by land cover and vegetation density variables?
2. What is the projected urban heat island trend in Semarang City until 2030?

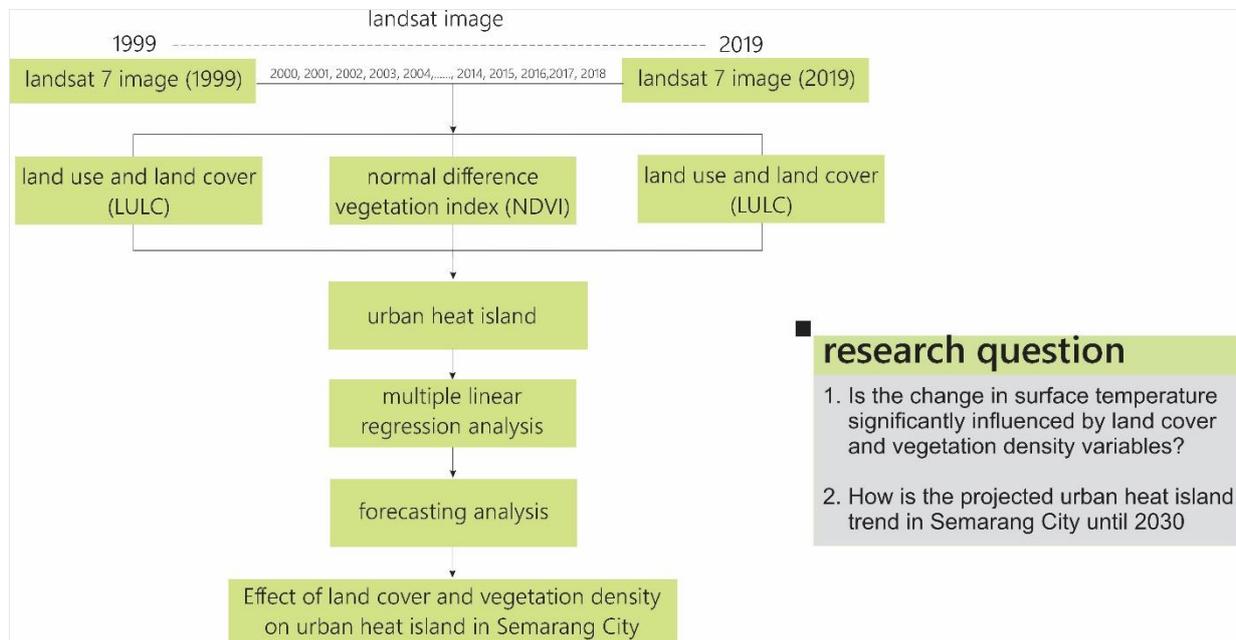


Figure 2. Research Flowchart

2. LITERATURE REVIEW

Urban Heat Island is a phenomenon of thermal pollution in urban areas which is higher than suburban areas. Increasing temperature not only has an impact on comfort but also health. Heat stress can cause death in certain people. In addition to health, which can be fatal for certain groups, an increase in temperature can also increase the need for electrical energy so that more fossil fuels will be used and then exacerbate the greenhouse effect (Nuruzzaman, M. (2015). In addition, a decrease in water quality will also decrease when an increase in temperature occurs which will certainly have an impact on marine ecosystems (Vujovic, S., et al. (2021).

Urban heat islands can be caused by several things, namely the low amount of evapotranspiration due to vegetation, absorption of solar radiation due to low albedo, airflow resistance due to higher rugosity, high amount of anthropogenic heat release (Nuruzzaman, M. (2015). Several studies also state that UHI is affected by urban urbanization, urban sprawl, and increasing population (Mohajerani, A., et al, T. (2017). Other causes are urban structures that absorb heat and the greenhouse effect and urban air pollution (Madhumathi, A., et al (2018). In line with previous research, Ramakreshnan, L, et al (2018) stated that urban heat islands are caused by urbanization, vegetation density, urban materials, land use change, high sea level, urban geometry, landscape morphology.

Specifically, several studies have attempted to explore the characteristics of an urban heat island in the city of Semarang. Some of them stated that there was a positive relationship between land use change, urbanization, and decreased vegetation density with increasing temperature in the city of Semarang. But so far no one has revealed how far the influence of this variable has on the urban heat island phenomenon in Semarang City. The following is a synthesis of previous research that has been done.

Table 1. Synthesis of Previous Research In Semarang

Author	Title	Method	Data	Results	Comparison	Annotation
Pamungkas, B. A., Munibah, K., & Soma, S. (2019)	Land use changes and relation to urban heat island (case study Semarang City, Central Java)	Spatial Analysis	-Landsat TM 5 of 2008 year -Landsat 8 OLI of 2018 year path images 120 rows 065.	-The surface temperature in Semarang has increased -The highest surface temperature values were in the landuse of built-up area and bare land, which were 26-30 C in 2008 and 30-34 C in 2018, respectively.	examine the relationship of land change with UHI	There is no research that looks at the effect of changes in land use and vegetation density on urban heat island in Semarang
Delarizka, A., & Sasmito, B. (2016)	Analisis fenomena pulau bahang (urban heat island) di Kota Semarang berdasarkan hubungan antara perubahan tutupan lahan dengan suhu permukaan menggunakan citra multi temporal landsat	Corellation analysis	-Landsat 7 -Landsat 5 -Landsat 8	changes in land cover and vegetation index have a correlation with surface temperature	examine changes in land cover with surface temperature	vegetation density on urban heat island in Semarang
Sejati, A. W., Buchori, I., & Rudiarto, I. (2019)	The spatio-temporal trends of urban growth and surface urban heat islands over two decades in the Semarang Metropolitan Region	Stochastic Cellular Automata	-Landsat 5 T M -Landsat 8 OLI	SUHI mitigation scenarios through the Spatial Planning instrument	make predictions using CA, not focusing on seeing the influence of urban growth on UHI	
Darlina, S. P., Sasmito, B., & Yuwono, B. D. (2018).	Analisis Fenomena Urban Heat Island Serta Mitigasinya (Studi Kasus: Kota Semarang)	Corellation Analysis using Regression	- Landsat 8 year 2009, 2013, 2018	UHI mitigation that can be done is: physical modification of buildings, in the form of using materials with high albedo, application green walls, green roof, green parking lot, as well as dditional vegetation around the building and along the road. Besides It is also necessary to monitor changes in land use and their suitability with the RTRW of Semarang City which has been set.	do a correlation analysis to produce recommendations regardless of how much influence	
Sasmito, B., & Suprayogi, A. (2017).	Model of Environmental Criticality Index with Urban Heat Island Algorithm in Semarang City	Spatial Analysis	-Landsat 8 TIRS -Landsat 8 OLI	- The northern and central areas of Semarang were identified as the most critical environmental areas based on LST and availability of vegetation cover	identify critical areas using the environmental index criticality model, regardless of impact or influence	

Author	Title	Method	Data	Results	Comparison	Annotation
Mubarok, R., Septiarani, B., Yesiana, R., & Pangi, P. (2021)	Pengaruh Tutupan Lahan Terhadap Fenomena Urban Heat Island di Kota Semarang	Spatial Analysis	-	“The surface temperature value will be inversely proportional with vegetation density”.	look at the effect, but only on land cover, not on changes in land use and vegetation density	

3. METHODS

3.1 Type of Research

The research approach is descriptive, explanatory research, where the data is processed. Then each variable component is explained through hypothesis testing, while the research approach is a forecasting research approach.

3.2 Sources and methods of data processing

The data source is secondary data, and 20 units of population data are used in the time series from 1999 to 2019. The data collection method used is a literature study by taking information relevant to the research and downloading Landsat data sourced from the usgs.gov website. The data used are Landsat 7 satellite imagery for 1999-2017, 2015, and 2016. In addition, Landsat 8 data is also used for 2014, 2017, 2018, and 2019.

Landsat data is then processed using ENVI and ArcGIS software so that data are obtained in the form of 1) the land cover area; 2) the area of vegetation density; and 3) the surface temperature distribution area, which is divided into the following components:

- Land cover data: divided into components of water bodies area, croplands, vegetated areas, and build-up areas;
- Vegetation density data: divided into very dense, dense, medium, rare, and very rare vegetation components
- Surface temperature area data: divided into areas for temperatures <21; 22-23; 24-25; 26-27; 28-29; >30;

Table 2. Data source

Years	Surface temperature distribution area > 30° C (ha)	Land buildup area (Ha)	Very dense vegetated land area
1999	2497.84	7427.77	12713.81
2000	3729.19	10086.01	11013.04
2001	3415.58	9184.88	11257.69
2002	3881.69	11695.11	10561.17
2003	4347.81	11205.34	9864.66
2004	4813.93	12619.99	9168.15
2005	5280.04	12049.89	8471.64
2006	5746.16	12693.77	7775.12
2007	5304.54	12007.37	7801.46
2008	5417.53	12934.08	8373.02
2009	7467.67	15188.63	7328.94
2010	8226.38	15058.02	8263.06
2011	8219.21	15356.48	8073.01
2012	8722.63	15654.94	7882.96
2013	9098.40	15953.40	7185.23
2014	8708.32	16970.31	7013.97
2015	8918.23	16651.91	6053.01
2016	9519.81	16533.51	6859.43
2017	9641.00	16715.11	7658.72
2018	9115.53	16726.63	5750.48
2019	9260.05	17745.72	5727.92

3.3 Data analysis methods

Before deciding which analytical method to use, studies related to similar previous studies and analytical models were carried out in the analysis.

Table 3. Synthesis of Analytical Methods

Author	Methods
Dararat Khamchiangta & Shobhakar Dhakal Imaam Nahib	The forecast is a time series to ascertain how Bangkok's urban heat island is related to land use and land cover in 1991, 1997, 2005, and 2010. The forecasting used is the Cellular Automata (CA) model and binary logistic regression, which predict the dynamics of built-up land in Semarang City in 2022 and 2032.
Semdi Akhmad Al-Mumin, Arwan Putra Wijaya, Abdi Sukmono	The forecast used is a simple regression test to determine changes in the land cover area, vegetation index, and surface temperature distribution in Cirebon City in 1999, 2007, and 2004.

Subsequently, it can be concluded that multiple linear regression and trendline forecasting analysis approaches are used to determine changes in land cover and vegetation density to the area of distribution of surface temperatures.

3.4 Multiple linear regression analysis

The data analysis method is causal forecasting utilizing time series multiple regression analysis. It explains the pattern of relationships between the independent variable (land cover) and the dependent variable (surface distribution area) (Kachigan, 1986). Multiple linear regression is suitable when the data used uses several variables with ratio interval data types. Before carrying out the regression, a classic assumption test is also carried out to produce an excellent BLUE (Best Linear Unbiased Estimation) model. This method was chosen because it is considered able to explore effects more measurably. The following is the formula used for multiple linear regression analysis below (Gujarati, 1995):

$$Y' = a + b_1X_1 + b_2X_2 + \dots + b_kX_k \quad (1)$$

$$Y_i = (Y') + e_i \quad (2)$$

Y' = prediction of the value of the criterion variable;

A, b = regression coefficient determined from sample data;

E_i = the error value of the difference between Y and Y'.

The stages of multiple linear regression analysis are as follows:

Variable Formulation	Variable Selection	Assumption Checking Predictor	Model Accuracy Check	Model Significance Test
↓	↓	↓	↓	↓
The formulation is based on theory, logic, and data availability.	Selection of independent variables and dependent variables.	Checking assumptions with linearity, normality, multicollinearity, homoscedasticity, and autocorrelation tests.	Check the model's accuracy by looking at the value of the correlation coefficient and determination.	Testing by calculating the F value (overall test)

a. Assumption Test

Data normality test

A normal distribution test-like pattern is a sign of good data. The distribution of the data is neither left- nor right-skewed. The normality test is used to examine whether the data distribution, or distribution having a bell-shaped form, is near to the normal distribution. Histograms and p-plot graphs can be used to perform normality tests. Assume that the remaining points spread out and move along the diagonal line's general direction. In that situation, the regression model fulfills the assumption of normality. The regression model, however, does not meet the condition of normality if the remaining points are dispersed far from the diagonal line and do not follow the diagonal line's direction. This is because a decent regression model has a normal or nearly normal data distribution.

Multicollinearity test

The presence of multicollinearity affects the regression model. Assume that all or some of the independent variables in the regression model have a precise and exact linear relationship. Correlation between variables in regression analysis is avoided so that the data obtained will not be over-estimated and have significant errors. With multicollinearity, the Least Square assumption that must be met in all causal analyses will not be achieved. Correlation analysis and VIF calculations are two methods for detecting multicollinearity between independent variables. A variable is deemed to be highly linked if its VIF exceeds 10 and its R2 value exceeds 0.90.

Heteroscedasticity test

Heteroscedasticity is a situation where the variance of the confounding factor is the same for all observations or observations on the independent variable. If the value of the variance of the dependent variable increases due to the rise in the independent variance, the variance of the dependent variable will be unequal or not constant, called heteroscedasticity. One method that can be used to detect the presence or absence of heteroscedasticity is by looking at the scatterplot graph. Suppose there is a particular pattern, such as forming a regular pattern on the scatterplot graph. In that case, it indicates the existence of heteroscedasticity.

Autocorrelation test

Autocorrelation test Autocorrelation can occur in cross-section research. If there is a relationship between the variables and the residuals, autocorrelation will happen. To detect the occurrence of autocorrelation in the regression model by looking at the Durbin-Watson value.

b. Model Accuracy Test

Correlation Coefficient (R)

The correlation coefficient, which may be calculated by taking the root of the coefficient of determination, is used to assess the degree of association between variables. Utilizations for correlation analysis include:

1. As the direction of the relationship between the two measures

Tendency to move in opposite directions, either simultaneously (positively correlated), one after the other (negatively linked), or not at all (uncorrelated).

2. As an Association Power

If the correlation between the two measures of association increases as the absolute value of the correlation increases away from zero, it is likely that there is a linear relationship between the two measures of association. Let's say there is a non-linear relationship between the two steps. In that case, the correlation coefficient will not be able to express the strength of the relationship between the two measures.

The following is an interpretation of the correlation analysis:

- If the value of r is positive, then there is a positive relationship between variable X and variable Y . That is, if the value of X increases, then the value of Y also increases or vice versa;
- If the value of r is negative, then there is a negative relationship between the X variable and the Y variable. That is, if the X value increases, the Y value decreases or vice versa;
- If r is close to 1, then the relationship between the variables X and Y is very close;
- If r is close to 0, then the relationship between X and Y is not very close;
- If $r = 0$, there is no linear relationship between variables X and Y .

Coefficient of Determination (R^2)

In regression analysis, the coefficient of determination (R^2) is a crucial metric that indicates the accuracy of the estimated model. R^2 calculates the proportion of the variance in the dependent variable Y that can be accounted for by the independent variable X . The coefficient of determination R^2 has a value that varies from 0 to 1, and it represents how well the estimated model matches the data. Assume that $R^2 = 0$. It implies that X in the scenario cannot account for the variation in Y . All observation points are directly on the regression line with a high level of model appropriateness if $R^2 = 1$. (Makridakis, 1995).

c. Model Significance Test

The F test/overall test is employed in this investigation. The F test is used to determine the effect of the independent variables simultaneously (simultaneously) on the dependent variable. Significant means that the relationship that occurs can apply to the population.

Hypothesis Formulation:

- $H_0 \rightarrow$ together, the independent variables have no significant effect on the dependent variable;
- $H_i \rightarrow$ together means that the independent variables significantly influence the dependent variable.

With the following test criteria:

- If ($\alpha=0.05$) and $F_{count} > F_{table}$ are significant, then H_0 is rejected, and H_1 is accepted, indicating that the independent factors have a significant impact on the dependent variable;
- H_0 is accepted and H_i is rejected if significance $> (\alpha = 0.05)$ and $F_{count} < F_{table}$, indicating that there is no significant interaction between the independent factors and that has no significant impact on the dependent variable.

3.5 Trendline forecasting analysis

Forecasting analysis is a method used to predict or predict future events by considering past and current data and information (Makriakis, 1983). Kachigan (1986) in his book states that with similar events, things that used to happen in the past can happen in the future. Trend data patterns define a tendency to go up or down continuously. There is no significant stability. Some forms of trendline models are exponential, linear, logarithmic, polynomials, power, and moving average.

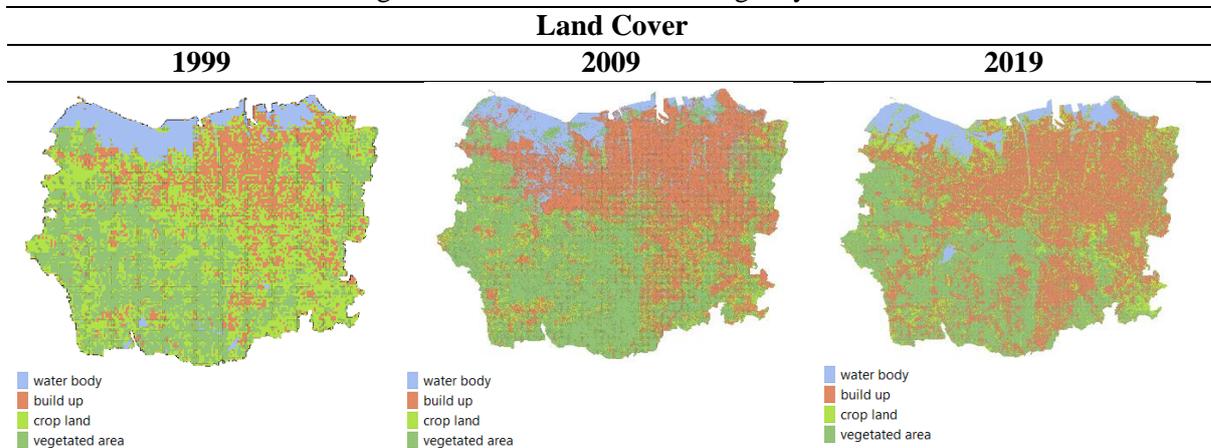
4. RESULT AND DISCUSSION

Semarang City, the capital of Indonesia's Central Java Province and the fifth-largest metropolitan region in the country after Jakarta, Surabaya, Medan, and Bandung, is the subject of the study. Semarang City, one of the most developed cities on the island of Java, is home to more than 1.8 million people, and during the day, that number can increase to 2 million. The following is an analysis and discussion for the study of land cover changes and vegetation density in the urban heat island in Semarang City.

4.1 Identification of land cover changes

The following is the result of the identification of land cover in the city of Semarang using ArcGIS analysis:

Table 4. Changes in Land Cover in Semarang City in 1999-2019

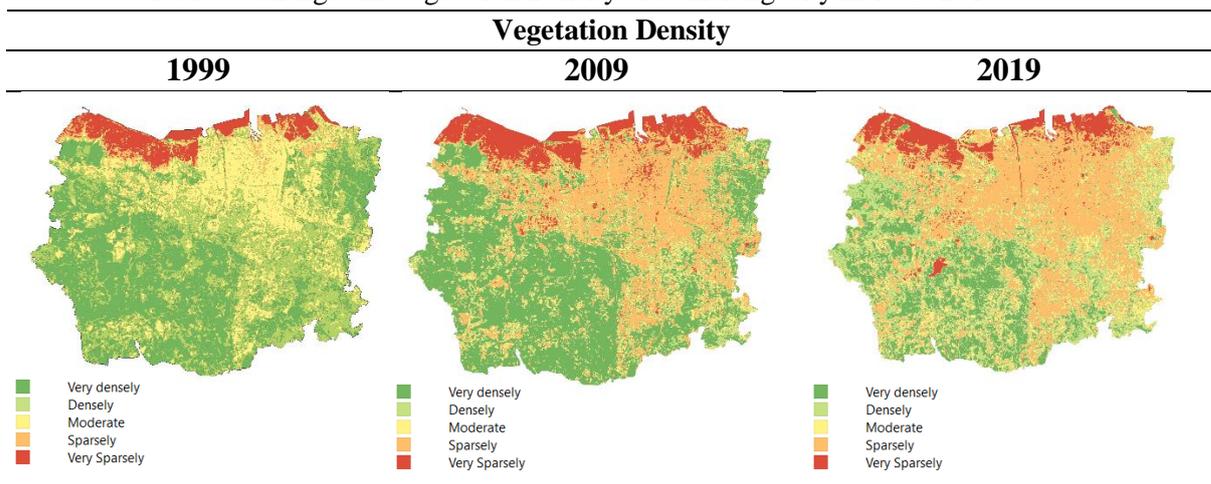


The build-up area increased from 7427.77 Ha in 1999 to 17,745.72 in 2019, or an increase of 58%, indicating the widening of urban growth towards the periphery, indicating that development favors the vegetated area. The vegetated areas decreased from 17,947.43 in 1999 to 11,350.31, or 37%. Red areas replace vegetation areas, meaning that buildings or roads have replaced them. There is the conversion of vegetated land and cropland into the built-up area; the cropland area increased from 5365.03 ha to 7393.90 ha, but the vegetation area decreased from 1469.98 ha to 11350.31 ha. Identification of the decreased area of open space with time series using Landsat imagery has been carried out in various regions as in the research of Peijun, et al (2010), Wessels, et al (2012), and et al (2023).

4.2 Identification of vegetation development

The following is the result of the identification of land cover in the city of Semarang using ArcGIS analysis:

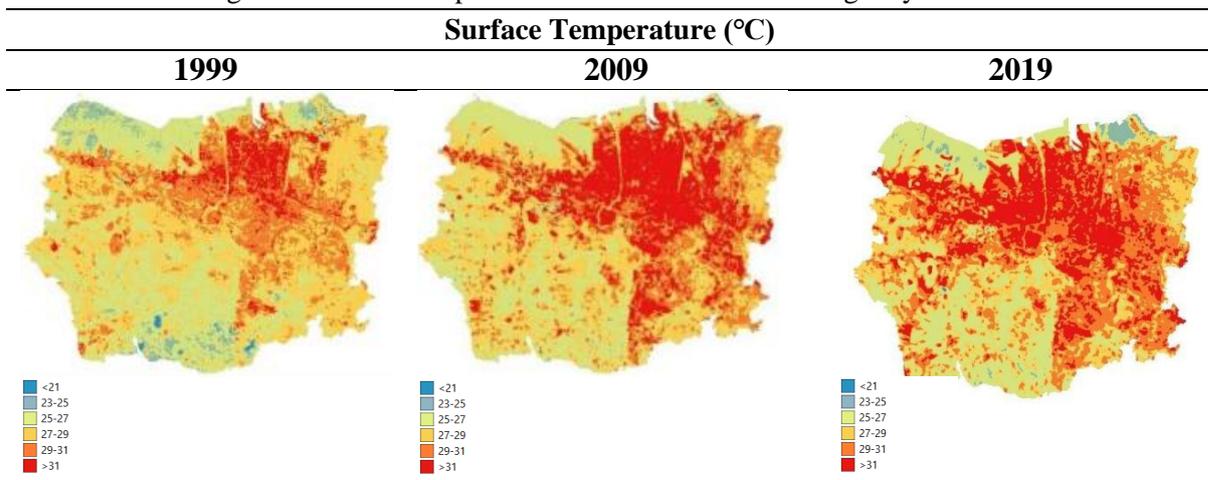
Table 5. Changes in Vegetation Density of Semarang City in 1999-2019



The area of very densely vegetated land has decreased from 12,713.81 Ha in 1999 to 5,727.92 Ha in 2019. There has been a 55% decrease around vegetation density. The area of densely vegetated land has decreased from 13,532.49 Ha to 8,404.20 Ha in 2019 or by 38%, and there are indications that green open space is shrinking. The city is declining. Reviewing past studies reveals that, as in the studies of Solangi et al. (2019), Guha and Govil, (2020), and Rahaman, a decrease in the quality of green open space can significantly contribute to an increase in surface temperature (2022).

4.3 Identification of surface temperature area

Table 6. Changes in Surface Temperature Distribution of Semarang City in 1999-2019



The land area with a temperature > 300 C increased from 2,497.84 Ha in 1999 to 9,260.05 Ha in 2019 or 73%. There is an increase in the maximum temperature in Semarang City from 330 C in 1999 to 360 C in 2019. It suggests the development of the UHI phenomenon, which is characterized by the formation of new hot spots and a higher average temperature in urban regions than in the suburbs.

4.4 Multiple linear regression analysis

To determine how the independent variable affected the dependent variable and to explain the pattern of association between the two variables, multiple linear regression analysis was carried out (Kachigan, 1986). After formulating the variables in the previous section, it was found that: Variable Y: Surface Temperature Distribution (land temperature > 300C); Variable X1: Land Cover (build-up area); Variable X2: Density of vegetation (very dense).

Regression analysis using the SPSS ver.22 application and using the "Entered" method to produce multiple regression models as follows:

Table 7. Results of the Regression Equation

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 (Constant)	-2787.477	2784.278		-1.001	0.33
Land cover	0.747	0.101	0.91	7.384	0
Vegetation density	-0.106	0.188	-0.069	-0.563	-0.58

The table above shows the regression equation model, where the regression equation model is as follows:

$$Y = -2787.477 + 0.747X1 - 0.106X2 \quad (2)$$

- The constant value -2787.477 means that the land cover (X1) and vegetation density (X2) when they have a constant value / 0 then the area of the distribution of soil surface temperature in Semarang City will be -2787.477;
- If the value of the land cover variable increases by one unit (ha), it will increase the Y value by 0.747% assuming that land cover (X1) and vegetation density are constant concerning the surface temperature distribution area (Y);
- If the value of vegetation density increases by one unit (ha), it will decrease the Y value by 0.106%;

In the table above, the regression results also display the Standardized Coefficients (beta) value so that you can identify the variable that has the most impact and contributes the most to the Y variable. Because the land cover variable has the greatest Beta value, the Standardized Coefficients (beta) results demonstrate that it is

the most significant variable. That is equal to 0.910 with a positive direction, and the density of vegetation has an effect of 0.69 with a negative direction.

4.5 Assumption check

The classical assumption test includes 4 tests: multicollinearity, autocorrelation, heteroscedasticity, and normality.

- Multicollinearity Test

In a multiple linear regression model, multicollinearity is the existence of a linear relationship between independent variables (Gujarati, 2003). A perfect linear relationship (perfect) and a less-than-perfect linear relationship are both examples of a linear relationship between independent variables (imperfect). A model without multicollinearity in the independent variable is a good example of a linear regression model. This test determines whether the correlation coefficient value for the relevant variable is outside the acceptable range (critical value). can determine the presence of multicollinearity by examining the VIF value (Variance Inflation Factor). Assume the VIF value is less than 10.00 and the tolerance value is more than 0.01. In that situation, multicollinearity is said to be absent from the regression model. The results of the multicollinearity test are summarized below:

Table 8. Level of Collinearity

Model	Collinearity Statistics	
	Tolerance	VIF
1 (Constant)		
Land cover	.196	5.111
Vegetation density	.196	5.111

The VIF value of each independent variable is 5.111, where this value is less than 10.00, and the tolerance value of 0.196 is more significant than 0.10, according to the results of the collinearity statistical study. The regression model does not have multicollinearity issues based on the two criteria.

- Autocorrelation Test

When incorporating time series data into regression models, it's crucial to test for autocorrelation. To determine whether there is autocorrelation, utilize the Durbin-Watson statistic. The acceptance or rejection criteria that are formed based on the dL and dU values, which are determined based on the number of independent variables (n) in the regression model (k) and the number of samples, will alter if there is autocorrelation:

- Number of independent and dependent variables = $k = 3$;
- Number of population = $n = 20$ data units;
- Value $dL = 0.9976$;
- Value of $dU = 1.6763$;

Table 9. Durbin-Watson Test Results

Model	R	R-Square	Adjusted R-Square	Std. Error of the Estimate	Durbin-Watson
1	.973 ^a	.946	.941	581.70452	1.367

Autocorrelation test: $DL < DW < (4-d)$

After knowing the lower limit value and dU value, it is necessary to find the upper limit by the formula $(4 - d) = 4 - 1.367 = 2.633$. So that the equation $0.9976 < 1.367 < 2.633$ is obtained. Furthermore, positive and negative autocorrelation will be carried out based on these equations with the following results:

- If $dw > dL$ then there is no positive autocorrelation, based on the calculation of the value of $dw = 1.367 > dL$ value = 0.9976 so that there is no positive autocorrelation;

- If $(4 - dw) > dU$ then there is no negative autocorrelation, based on the calculation of the value $(4 - dw) = 2.633 > dU$ value = 1.6763, so there is no negative autocorrelation.

- Heteroscedasticity

In a decent regression model, heteroscedasticity is absent. Examining the scatterplot graph is one way to determine whether heteroscedasticity is present or absent. Let's say there is a pattern, like a regular pattern appearing on the scatterplot graph. In that situation, it shows that heteroscedasticity exists. Imagine, nevertheless, that no distinct pattern emerges or that the dots are dispersed. In that situation, it shows that heteroscedasticity is absent.

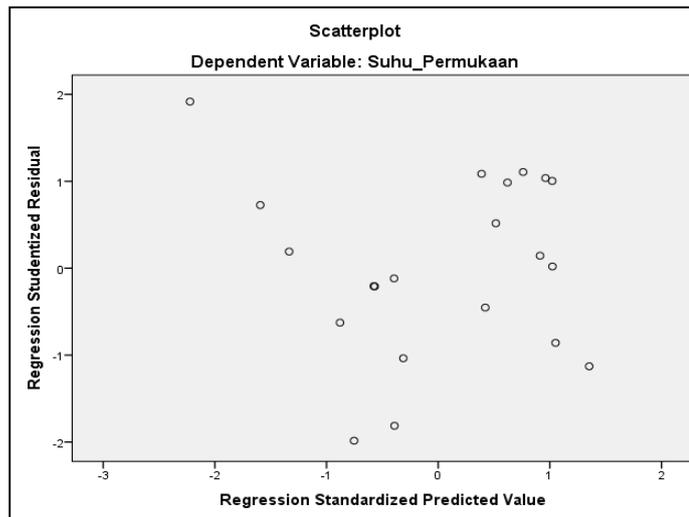


Figure 3. Scatterplot Results

The illustration above demonstrates that the distribution of points does not follow a particular shape or flow, such as a wavy or conical one, and that they are distributed both above and below the Y-axis value of 0. It can be said that homoscedasticity happens, or that there is no heteroscedasticity.

- Normality

The purpose of this normality test is to determine whether the residuals from a research regression are normally distributed. The residuals of a good regression model should be normally distributed or very close to it. The histogram and p-plot display the results of the normality test. It is important to keep in mind that the residual (data) created by a normally distributed linear regression model, not the independent variable or the dependent variable, is what the normality assumption alluded to in the study's classical assumption refers to.

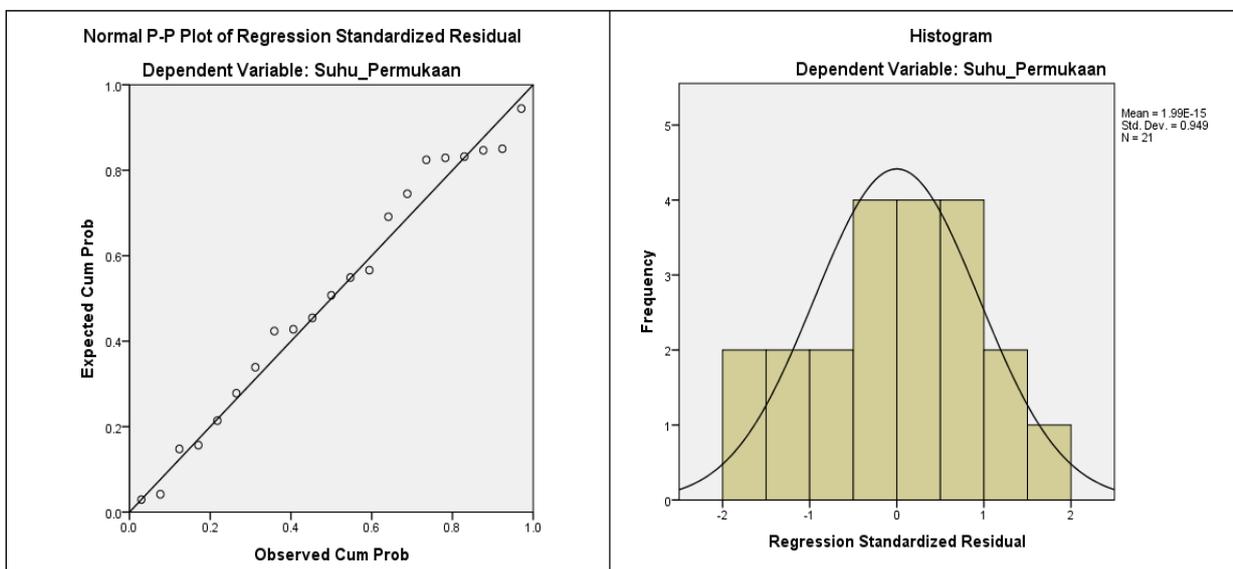


Figure 4. A) P-Plot Graph; B) Histogram Graph

The histogram shows the frequency value of the regression analysis residuals on the dependent variable. On the histogram curve, the model meets the assumption of Normality if the curve is symmetrical, and the data distribution is bell-shaped. According to the histogram curve's results, which indicate that the curve is symmetrical in shape, the regression model is normally distributed. If the points on the curve correspond with the diagonal line on the normal line p-plot, the model satisfies the assumption of normality. By looking at the distribution of points on the diagonal axis, it is possible to determine whether the residuals are normal. If the data or points spread out along the diagonal line and move in the same direction as the diagonal line, statistics is thought to be regularly distributed. It can be inferred that the residuals are normally distributed because the distribution of points on the P-P Plot Normal Diagram is near to a straight line. This result aligns with the classical assumption of linear regression using the OLS (Ordinary Least Square). The difference between the squares of the distance between the variable points and the line formed is minimal.

4.6 Testing the accuracy of the model

- Correlation Test (R)

The correlation test (R) shows the relationship between each variable and the magnitude of the influence of these variables. It is seen based on the Pearson Correlation value. Suppose the magnitude of all variables is close to 1. In that case, the relationship between each variable can be said to be quite close or strong.

Table 10. Correlation Results

		Surface Temperature	Land Cover	Vegetation Density
Pearson Correlation	Surface Temperature	1.000	.972	-.886
	Land cover	.972	1.000	-.897
	Vegetation Density	-.886	-.897	1.000
Sig. (1-tailed)	Surface Temperature	.	.000	.000
	Land cover	.000	.	.000
	Vegetation Density	.000	.000	.
N	Surface Temperature	21	21	21
	Land cover	21	21	21
	Vegetation Density	21	21	21

Based on the output table above on the Pearson correlation row and column, the results obtained are as follows:

- o The land cover variable with the surface temperature distribution correlates with 0.972, indicating a strong relationship between the two variables. The direction of the relationship between the two variables is positive (+), where the greater the value of the unit area of land cover (for built-up land), the greater the distribution area of surface temperature above 30 degrees C;

- o The vegetation density variable with the surface temperature distribution correlates 0.886, indicating a strong relationship between the two variables. The direction of the relationship between the two variables is negative (-), where the more significant the unit area value of the very dense vegetation density, the smaller the distribution area of surface temperature above 30 degrees C.

- Multiple Determination Test (R²)

The value of multiple determination R² is meaningful as the contribution of the influence given by the independent variable or the independent variable to the dependent variable. In other words, the value of the coefficient of determination aids in predicting and determining the extent to which variable X and variable Y are both simultaneously influencing each other.

Table 11. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.973 ^a	.946	.941	581.70452	1.367

The value of the coefficient of determination (R²) is 0.946. It demonstrates that the land cover (build-up area) and vegetation density are responsible for 94.6% of the variation in the distribution of land surface temperatures (very dense). Several factors not looked at in this study have an impact on the remaining 6.4% of the population. This research. This considerable influence shows that the variables of land cover and vegetation density simultaneously have an essential role in distribution of surface temperature in Semarang City.

4.7 Test of model significance

The regression model of this study uses population data of 20 Semarang City units taken in time series. So to test the significance of this study, using the comprehensive test or F test, where the F test is used to test all independent variables (land cover and vegetation density) as a whole have a significant influence on the dependent variable (distribution area of surface temperature).

Table 12. Table ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	107726355.399	2	53863177.700	159.179	.000b
	Residual	6090842.712	18	338380.151		
	Total	113817198.111	20			

Hypothesis Formulation:

- H₀ : land cover and vegetation density variables do not significantly affect the dependent variable, the area of land surface temperature distribution;
- H₁ : land cover variable and vegetation density significantly affect the dependent variable, the area of land surface temperature distribution.

Testing Criteria:

- If the significance is $\leq \alpha$ ($\alpha = 0.05$) and $F_{count} > F_{table}$, then H₀ is rejected, and H₁ is accepted;
- If the significance $> \alpha$ ($\alpha = 0.05$) and $F_{count} < F_{table}$, then H₀ is accepted and H₁ is rejected.

It is known that the value of N₁ = 2 and N₂ = 18 and the value of F_{table} = 3.55. So it can be concluded that H₀ is rejected and H₁ is accepted because:

- The value of $F_{count} > F_{table}$ is $159.179 > 3.55$ and a significance value of 0.000 so that the variables of land cover and vegetation density as a whole have a significant influence on the area of distribution of surface temperature;
- H₀ is rejected, and H₁ is accepted because the calculated F value is more significant and the significance value is less than 0.05, which is 0.000.

4.8 Trendline forecasting analysis

Forecasting is an assessment or attempt to see conditions in the future. This trendline forecasting method is characteristic that the data analyzed are in series and can show periodic time. The purpose of conducting a trendline analysis of the land cover variable (build-up area) and very dense vegetation density is to help see the projection until 2030. Microsoft Excel has been provided instantly for trendline analysis. There are 5 (five) types of trendline analysis methods, along with considerations for their application.

Table 13. Usage considerations

Methods	Judgments
Exponential	Land cover : $R^2 = 0.8603$ Vegetation Density : nilai $R^2 = 0.8507$ Not used because the value of R2 tends to be smaller
Linier	Land cover : nilai $R^2 = 0.914$ Vegetation Density : nilai $R^2 = 0.8277$ Used because the value of R is high, and the result is linear with the constant addition
Logarithm	Land cover: $R^2 = 0.9132$ Vegetation Density : nilai $R^2 = 0.909$ Not used even though the R2 value is high but the projection results are curved
Polynomial	Not used even though the R2 value is high but the projection results are curved Not used even though the R2 value is high but the projection results are curved
Power	Land cover: nilai $R^2 = 0.9395$ Vegetation density $R^2 = 0.858$ Not used even though the R2 value is high but the projection results are curved

4.9 Forecasting land cover trendline (built-up area)

After analyzing the trendline forecasting, the trend results for land cover with a simple regression formula are $Y = 447.8x + 8905.6$ with a coefficient of determination $R^2 = 0.9148$ with the following results:

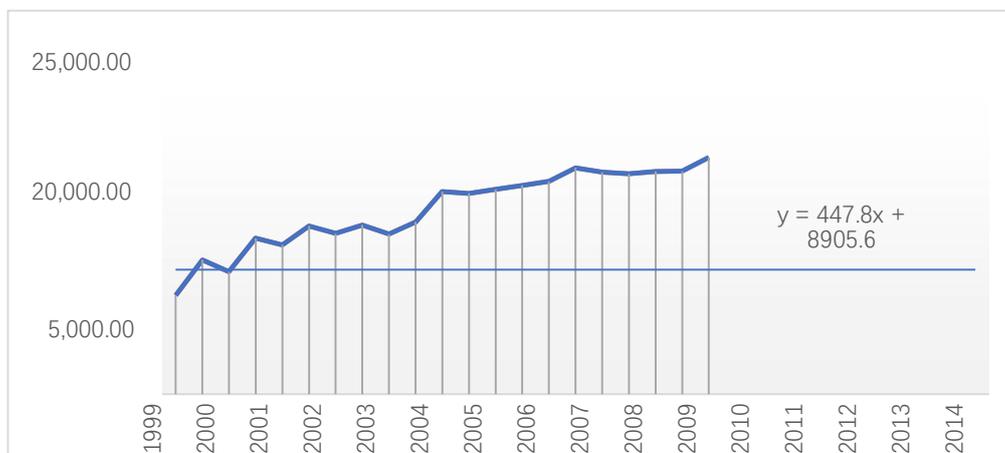


Figure 5. Land Cover Trendline – Build-Up Area 1999 – 2030

4.10 Forecasting vegetation development trendline (very delicious vegetation)

After conducting trendline analysis, the trendline results for very dense vegetation density with a simple regression formula are $Y = -272.67x + 11323$ with a coefficient of determination $R^2 = 0.8277$ with the following results:

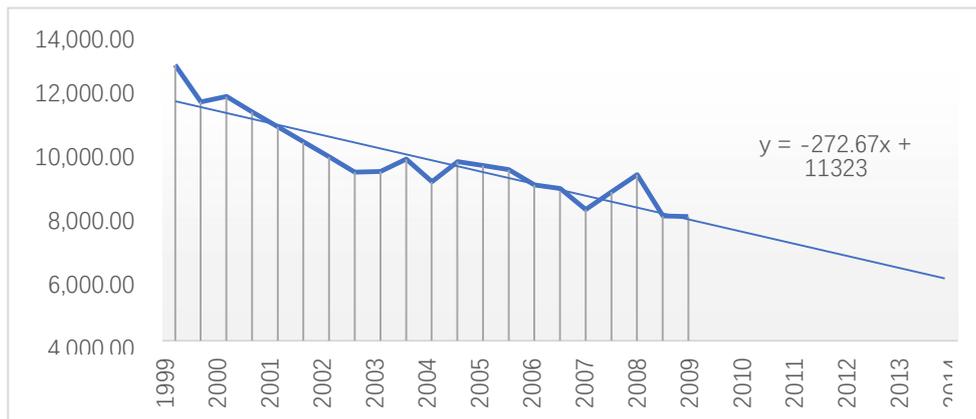


Figure 6. Vegetation Density Trendline – Very Dense 1999 – 2030

4.11 Planning scenario

The analysis of the influence of land cover and vegetation density on the surface temperature has significant implications for the area of regional and urban planning. By utilizing the linear regression analysis results in the previous analysis section, the planner can provide input to relevant stakeholders about what kind of policy/planning can be taken. More broadly, this is also related to the global plan presented by the IPCC (Intergovernmental Panel of Climate Change) in the IPCC Special Report on Global Warming, where the increase in global temperature is no more or limited to 1.5o C. This also implies future expectations. The area of land with hot surface temperatures in the city center is not increasing because it will impact the vulnerability of urban communities to extreme temperatures. The following is a planning scenario that can be an illustration of policymaking by local governments, especially the City of Semarang.

4.12 Pessimistic scenario

It is assumed that the condition of land cover change for the build-up area continues to increase constantly with a trend of $Y = 447.8x + 8905.6$ for each year. Furthermore, the condition of changes in vegetation density for very dense vegetation areas continues to change with a trend of $-272.67x + 11323$, where the value of land area with very dense vegetation constantly decreases every year.

4.13 Moderate scenario

It is assumed that the condition of land cover change for the build-up area continues to increase constantly with a trend of $Y = 447.8x + 8905.6$ for each year. Furthermore, the condition of changes in vegetation density for very dense vegetation areas has a fixed value. Government intervention is limited to maintaining the current condition of vegetation and green open spaces.

4.14 Optimistic scenario

It is assumed that the condition of land cover change for the build-up area continues to increase constantly with a trend of $Y = 447.8x + 8905.6$ for each year. The condition of changes in vegetation density for very dense vegetation areas is increasing with government intervention by adding green open space and reforestation by 10% every year.

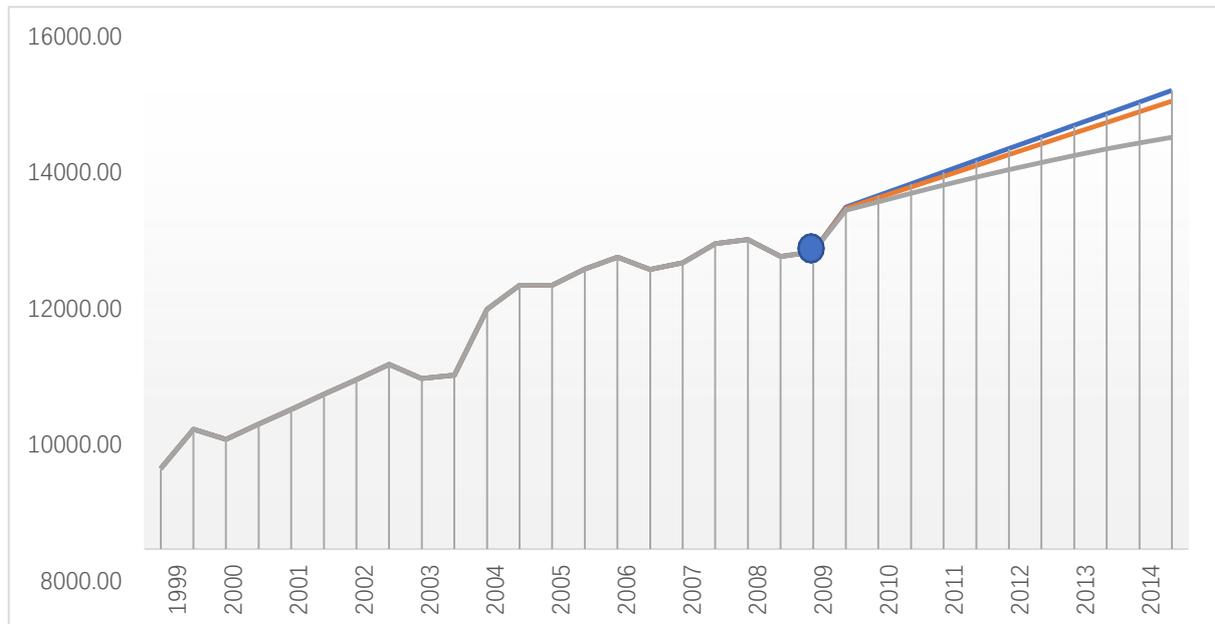


Figure 7. Forecasting of Surface Temperature Area above 300 C Semarang City 1999-2030

5. CONCLUSION

Based on a review of the findings from studies on how variations in land cover and vegetation density affect the area of surface temperature distribution in the city of Semarang, specifically:

- The variables of land cover and vegetation density as a whole have a significant effect on the distribution of surface temperature with the regression equation $-2787.477 + 0.747X_1 - 0.106X_2$;
- The land cover component has a positive impact on surface temperature with a magnitude of 0.747 units;
- The vegetation density component harms the surface temperature with a magnitude of 0.106 units;
- The trendline results in an increasing area of surface temperature distribution in 2030 in Semarang City with 3 scenarios. Where with a pessimistic scenario, the land area with a temperature of >300 C is 14293.88 ha. With a moderate scenario, the land area has a temperature >300 C is 13962.06 ha, and with an optimistic scenario, the land area has a temperature > 300 C is 12836.92 ha.

In the research that has been carried out, some recommendations can be made by various parties, including:

- The government can use this analysis for decision-making, especially policies with the provision of urban green open spaces;
- Following Indonesia's commitment to the global agenda of the Climate Change Convention, Indonesia plans to reduce carbon emissions by 29% by 2030 and agrees to a global agenda to limit the increase in temperature to 1.5%;
- So that the optimistic planning scenario can be carried out, if the government does business, as usual, the urban temperature will continue to increase it will have an impact on the level of community vulnerability to increase;
- The drawback of this research is that no geometric and field corrections are made to the available secondary data so that further research or research is carried out.

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Comparative Study of Performance between International Roughness Index (IRI), Pavement Condition Index (PCI), and Bina Marga Method on Roadways

St. Maryam H¹, Bulgis², Rustam Madami³

^{1,2}Department of Civil Engineering, Universitas Muslim Indonesia, Makassar, Indonesia

³Site Supervision Engineering, PT. Yodya Karya, Ternate, Indonesia

E-mail: ¹Stmaryam@umi.ac.id, ²bulgis@umi.ac.id

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Pavement Condition Index (PCI); International Roughness Index (IRI); Bina Marga Method; Flexybel Pavement; Road Damage Assessment

Abstract

In this research, a comparative study is conducted between the International Roughness Index (IRI), Pavement Condition Index (PCI), and Bina Marga method on roadways with a flexible pavement structure. The objective is to compare the results of road damage evaluation using these three methods and formulate appropriate treatment programs. The research findings indicate that overall, the IRI method provides an overview of the road surface roughness level. The majority of the analyzed data falls under the "Moderate" category with a value of 7.2. The PCI method measures the physical condition of the road infrastructure, which is categorized as "Fair" with a value of 41.2. On the other hand, the Bina Marga method assesses the type of road maintenance, which is categorized as "Routine Maintenance" with a value of 6.8. Enhancing road maintenance practices is necessary to address minor damages such as small cracks or surface irregularities that affect road user comfort.

1. INTRODUCTION

Roads are important transportation infrastructure for facilitating economic and social activities, as well as for achieving the goal of connecting one place to another for all traffic passing through them (Maulana et al., 2020; Sanjaya et al., 2017; Zulmi et al., 2017). They play a significant role in the development and progress of a region in terms of economy, tourism, and socio-cultural aspects (Husen et al., 2023; Prasetyo et al., 2021; Ramadhan et al., 2020). According to (Bunga et al., 2019; Kamba & Rachman, 2018; Sukirman, 2007), road networks serve as the lifelines of national economy. Therefore, roads become crucial transportation means for advancing the economy and improving the welfare of society. In order to achieve smooth operation of road networks, good road infrastructure is necessary, as approximately 95% of passenger transport and 92% of freight transport in Indonesia rely on roads (Sangle et al., 2021).

Currently, many roads experience deterioration, although they have not reached their planned lifespan (Yunus, Said, & Alifuddin, 2022). Such conditions can disrupt the comfort and endanger road users (Shtayat et al., 2022). The management of highway infrastructure aims to improve traffic safety (Adeli et al., 2021). Road pavement networks require constant maintenance and repairs due to gradual deterioration caused by factors such as aging of pavements due to climate and increased traffic volume (Kulkarni & Miller, 2003; Patrick & Soliman, 2019). Condition surveys of pavements are essential in the pavement management process (Chin et al., 2019). These surveys provide valuable information needed to analyze pavement performance. Additionally, pavement condition surveys are crucial in predicting pavement performance, anticipating maintenance and rehabilitation needs, determining maintenance priorities, and allocating the necessary funding (McQueen & Timm, 2005). Accurate condition assessment using evolving methods or technologies will impact the effectiveness and efficiency of determining the appropriate maintenance types for a road section (Hermawan et al., 2016). Therefore, studies on methods and supporting instruments to assess the existing and evolving road conditions, particularly in Indonesia, are necessary (Samsuri et al., 2019).

According to (Sihombing et al., 2021), one of the important routine activities in road management is road investigation. This investigation involves measuring the performance of road pavements, both in terms of functional and structural damages. However, in Indonesia, performance measurements based on functional damages have not been adequately conducted. This is due to budget limitations for road construction and maintenance. Therefore, the types of functional damages are still under research. Meanwhile, structural damages are important parameters in assessing road performance and serve as references for handling roads during their planned lifespan.

Structural damage on roads occurs when pavements fail or experience damages in one or more of their components, rendering them unable to withstand traffic loads. According to (Yoder & M.W. Witczak, 1975) as cited by Iskakbayev et al. (2017), structural damages are characterized by damages to pavement materials (Iskakbayev et al., 2017). Paterson (1987) as cited by Alinizzi et al. (2017) categorizes structural damages into 3 modes: cracking, disintegration, and deformation (Alinizzi et al., 2017). Bina Marga (2017) divides road damages into cracking, deformation, surface disintegration, polished aggregate, bleeding, and utility cut depression (pekerjaan umum dan perumahan Rakyat, 2017). Since there are various types of road damages, according to Paterson (1987) as cited by Alinizzi et al. (2017), all types of road damages and their repairs (patching) interact and relate to each other, ultimately resulting in unevenness (roughness). Roughness is the consequence of various types of damages, especially potholes and deformations, and is the outcome of a series of mechanisms of different road damage modes (Alinizzi et al., 2017). Depkimpraswil (2001) as cited by Sihombing (2010) defines roughness as the characteristic profile of a road surface traversed by vehicle wheels, affecting driving comfort. Roughness occurs due to the interaction between the road surface profile and vehicles passing over it (Sihombing et al., 2021).

To qualify the measurement results of roughness, the World Bank funded a research team from several countries known as the International Road Roughness Experiment (IRRE). They conducted research to determine the most satisfactory roughness scale. Eventually, the International Roughness Index (IRI) was adopted as the roughness scale according to Sayers et al. (1986) as cited by Huang (2004) (H.Huang Yang, 2004). Over time, IRI was further developed to be associated with comfort or serviceability levels. Examples include the present serviceability rating (PSR) in HDM III in 1987 by the World Bank (Paterson & Attoh-Okine, 1992), the Road Condition Index (RCI) by Bipran, CDO in 1989, PSR for asphalt and concrete roads by Al-Omari and Darter in 1994 (Al-Omari & Darter, 1994), and the present serviceability index (PSI) AASHTO road test asphalt/concrete sections by Hall and Corea in 1999 (Hall & Muñoz, 1999).

In Indonesia, road damages are generally measured using methods such as the Pavement Condition Index (PCI) (Kiehl & Briegleb, 2011), Surface Distress Index (SDI) (Anonymous, 2011), Road Pavement Condition Index (IKP) - Pd-01-2016-B (PUPR, 2016b), International Roughness Index (IRI) (H.Huang Yang, 2004), and Bina Marga road condition assessment method (Direktorat Jenderal Bina Marga, 1990b), (PUPR, 1987). The IRI method is widely used internationally to measure road roughness levels (Makwana & Kumar, 2018). Comparing road damage assessment methods is important because it can provide more comprehensive and accurate information about road conditions. By comparing several methods, a more comprehensive picture of road damage can be obtained, including the types and levels of damage that occur. In addition, comparing methods can also help determine the most appropriate method to use in certain conditions. For example, the IRI method is more suitable for measuring road roughness, while the PCI method is more suitable for assessing damage to road surfaces. Therefore, the use of several assessment methods can help in making better decisions regarding the necessary repairs and maintenance of roads (Yunusov et al., 2019).

When conducting research on road damage assessment methods, it is important to compare different methods to obtain comprehensive and accurate information about road conditions (Ayu et al., 2022). By comparing the IRI, PCI, and Bina Marga methods, researchers aim to identify the most effective method for making informed decisions regarding road repairs and maintenance in Indonesia (Khurshid et al., 2009). The

initial hypothesis indicate although the PCI method is more specific in identifying 19 types of road damage, compared to the Bina Marga method which only identifies 6 types of damage, the Bina Marga method is easier and faster to use. However, both methods have relatively similar accuracy. The IRI method only measures road roughness and does not provide information on the types of damage. There are no relevant search results for references to support the statement. However, the statement highlights the importance of the study in creating a deeper understanding and valuable contribution regarding the comparison of IRI, PCI, and Bina Marga methods for national roads in Indonesia. The study aims to provide updates and breakthroughs in the field of road damage evaluation that can be used as a reference for decision-making and the development of better road infrastructure. Despite several studies on road damage evaluation using IRI, PCI, and Bina Marga methods, the number of studies comparing these three methods is still limited, particularly in the context of national roads.

2. LITERATURE REVIEW

2.1. IRI (International Roughness Index) Method

The International Roughness Index (IRI) is a parameter used by the World Bank in the process of assessing road pavement conditions since 1980. IRI is a quantitative value of the unevenness of the road surface, expressed in units of meters ups and downs per kilometer of road length (m/km). The unevenness of the road surface is a picture of the longitudinal profile of the pavement which is an illustration of the comfort of driving on the highway (Umi et al., 2016; Yunus, Said, & Syarkawi, 2022). Currently there are several tools that can be used in IRI data collection, namely *Roughometer* NAASRA (Potter, 1978); Dipstick (Nasution et al., 1998); Rolling – Straight Edge; Merlin (Machine for Evaluating Roughness using Low-cost Instrumentation) (Jagadeesh Babu & Rahul, 2017); Profilographs (Anonymous, 2015); PARVID (Positioning Accurated Roughness with Video) (Sinurat, 2014); and Rouhgometer III (Mahardika et al., 2021). The IRI method is a widely used approach to assess road roughness. This method measures the roughness of the road surface by calculating the International Roughness Index value. The IRI value represents the vertical displacement of a standard measuring vehicle as it traverses the road. A higher IRI value indicates a rougher road surface (ASTM International, 1998).

Table 1. Criteria of Road Conditions Based on the IRI Values in Paved Surface Type

IRI Value	Category of Road Conditions
$IRI \leq 4$	Good
$4 < IRI \leq 8$	Fair
$8 < IRI \leq 12$	Slightly Damage
$IRI > 12$	Heavily Damaged

Source: (ASTM International, 1998)

2.2. PCI (Pavement Condition Index) Method

Pavement Condition Index (PCI) is a pavement condition assessment method developed by the U.S Army Cops of Engineers, expressed in a pavement condition index (Pavement Condition Index, PCI). The use of PCI for the evaluation of airport pavements, roads and parking lots has been widely used in America and has been published as the ASTM D 6433 standard (ASTM International, 1999). there are 19 (nineteen) types of damage to flexible pavement in the PCI method (Shahin, 1994). The PCI method is a standard method for evaluating pavement conditions. This method involves assessing various types of distress, such as cracks, potholes, and wheel path rutting, and assigning a numerical value that represents the overall condition of the pavement. The PCI value ranges from 0 (failed) to 100 (excellent), with higher values indicating better pavement conditions (ASTM International, 2007).

Table 2. Criteria of Road Conditions Based on the PCI Values in Paved Surface Type

PCI Value	Category of Road Conditions
0 - 10	Failed
10 - 25	Very Poor
25 - 40	Poor
40 - 55	Fair
55 - 70	Good
70 - 85	Very Good
85 - 100	Excellent

Source: (Shahin, 1994)

2.3. Bina Marga Method

In Indonesia, Bina Marga is the institution responsible for road infrastructure development (PUPR, 2016a). Bina Marga has developed a road condition assessment method used to measure the level of damages and wear on roads (Taufikkurrahman, 2021). This method involves visual observation of road surface conditions, such as damages, cracks, potholes, and deformations. Based on these observations, roads are classified according to their conditions, which can be used as references for road maintenance planning (Hapsari et al., 2018). The Bina Marga method is an assessment method developed by the Ministry of Public Works and Housing of Indonesia (Bina Marga) to evaluate road conditions. This method considers several factors, including surface distress, surface condition, and structural condition, to assess the overall road condition. The method provides a qualitative assessment of road conditions, categorizing them into various classes such as good, fair, or poor (Taufikkurrahman, 2021).

Table 3. Criteria of Road Conditions Based on the Bina Marga Values in Maintenance Program Type

Bina Marga Value	Category of Road Conditions
0 - 3	Road Improvement
4 - 6	Periodic Maintenance
7	Routine Maintenance

Source: (Direktorat Jenderal Bina Marga, 1990b)

2.4. Comparison of IRI, PCI and Bina Marga methods From Previous Research

From a theoretical perspective, the IRI, Bina Marga, and PCI methods are used for road condition assessment. The IRI method measures road roughness and is used to evaluate the ride quality of a road surface. However, it does not provide information on the types of road damage. The Bina Marga method is specific to Indonesia and identifies 6 types of road damage, including cracks, subsidence, surface roughness, potholes, ruts, and patches. The PCI method is used to evaluate the surface condition of a road and identifies 19 types of road damage, including cracking, rutting, and roughness (Shahin, 1994). These methods are important for making informed decisions regarding road repairs and maintenance.

From a practical perspective, the Bina Marga and PCI methods are used in Indonesia for road condition assessment and are subject to maintenance and procurement of road equipment. The Bina Marga method is easier and faster to use than the PCI method, but identifies fewer types of road damage. The PCI method is more specific in identifying types of road damage, but is more time-consuming to use. These methods are important for identifying road damage and making informed decisions regarding road repairs and maintenance.

Table 4. Comparison Result of IRI, PCI and Bina Marga Methods

Num	Road Damage Identification Methods	Type Survey	Comparison Result			Recommendation
			Bina Marga	PCI	IRI	
1	Bina Marga	Manuals	The Same	It's the same, but Bina Marga is easier and faster to use, while the PCI method is more detailed to use.	Relatively the same	PCI
2	PCI	Manuals	It's the same, but Bina Marga is easier and faster to use, while the PCI method is more detailed to use.	The Same	different	PCI
3	IRI	automatic	Relatively the same	different	The Same	PCI

Interpretation

PCI - IRI : the results of the comparison between the IRI and PCI methods depend on the specific context and purpose of the assessment (Melyar et al., 2021; Pratiwi, 2019). In general, the IRI method focuses more on measuring road surface roughness (Alinizzi et al., 2017; Hermawan et al., 2016; Yunusov et al., 2019), while the PCI method provides a more comprehensive assessment of overall road conditions (Yunus, Said, & Alifuddin, 2022). The IRI inspection is not sufficient to represent the actual field conditions; it is necessary to carry out a subjective functional examination by assessing the road, one of which is the Pavement Condition Index ASTM-D6433-99.001 (ASTM International, 1999). Therefore, the choice of method depends on the specific needs of the road management agency or other stakeholders involved in road maintenance and planning. In addition to differences in the rating scale, the IRI values obtained tend to be less close to field conditions. This is because the IRI value is derived from the magnitude of the ups and downs of the roughness sensor mounted on the axle of the survey vehicle, causing the sensor to only read the road surface through the car wheels (Hasibuan, 2019; Suwandi, 2016) besides that the PCI method is very dependent on the skills and subjectivity of the surveyor (Prasetyo et al., 2021). although the PCI method has been widely applied in several countries because it has many advantages. However, to carry out this examination requires a lot of money (Psalmen Hasibuan & Sejahtera Surbakti, 2019). there are differences in functional conditions between PCI and IRI but each shows a good correlation (Adeli et al., 2021).

PCI - Bina Marga : the results of a comparison between the PCI and Bina Marga methods turned out to produce relatively similar ratings (Faisal, 2020; Isradi et al., 2020; Salsabilla et al., 2020) but the Bina Marga method is easier and used quickly (Maulana et al., 2020), while the PCI method is more detailed and objective regarding all aspects of the damage (Faisal et al., 2021; Ramadhan et al., 2020). So it is recommended to use a maintenance program based on the results of the PCI method (Ayu et al., 2022).

IRI - Bina Marga : the results of a comparison between the IRI and Bina Marga methods yield relatively the same assessment (Zulmi et al., 2017).

2.5. Types Of Damage To Asphalt Roads Along With Their Causes

Types of damage to asphalt roads can be distinguished based on the type of pavement, namely flexible and rigid. The following are the types of damage to asphalt roads along with their causes:

1. Cracks, such as alligator cracks, edge cracks, shoulder joint cracks, reflection cracks, and shrinkage cracks. The causes include heavy vehicle traffic, differences in settlement between the shoulder and pavement structure, and vertical/horizontal movement under an additional layer.(Anonymous, 2023)
2. Distortion, such as shoving and transverse/vertical waves due to plastic deformation. The causes are heavy vehicle loads and an unstable pavement or foundation layer.(Anonymous, n.d.)
3. Surface defects (disintegration), such as polished aggregate and corrugation. The causes include heavy traffic, too fine asphalt, and too much fine aggregate.(Anonymous, 2017)
4. Bleeding, which is damage that occurs when high temperatures cause the asphalt to become soft and form a hump due to passing vehicles.(Anonymous, 2017)
5. Potholes, which are bowl-shaped road damage that vary in size from small to large. The causes include a non-functioning water absorption system or lack of drainage on the road, poor quality hotmix asphalt, and excess vehicle load.(Anonymous, n.d.)
6. Stripping, which is road damage that occurs on the surface of the road due to water or moisture entering the pavement layer.(Anonymous, n.d.)

3. METHODOLOGY

3.1. Location of Study

This study was conducted on the national road section of SP. Jambula - SP. Dufa-Dufa (from Jambula intersection to Dufa-Dufa intersection) in Ternate City, North Maluku Province, Indonesia. The location was chosen for research because the SP Jambula - SP Dufa road section is the longest national road in Ternate city, as seen in Figure 1, and it surrounds the city of Ternate, making it an important land transportation area in the city. This makes it a desirable location for identifying and analyzing road damage conditions.

This location was chosen to analyze the road deterioration of the longest road in Ternate City, North Maluku Province, Indonesia, with a length of 28.4 kilometers. The study focused on a road segment from STA 00+00 to STA 00+2000, which is equivalent to a length of 2 kilometers. Direct observation methods were used for data collection, including manual traffic counting, recording travel times, and measuring road geometry.

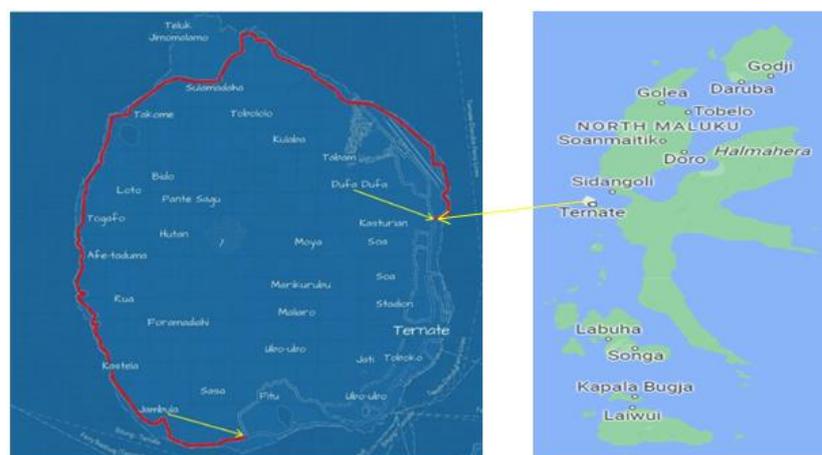


Figure 1. Test Site: Sp.Jambula – Sp.Dufa-Dufa Road, Ternate, North Maluku, Indonesia

The objective of this study is to gather data on road deterioration and traffic flow, which includes four types of vehicles: light vehicles, heavy vehicles, motorcycles, and non-motorized vehicles. Data were obtained directly through field observations and measurements. The observed road section has a 2/4D divided lane configuration. The observations were conducted in this road section because it is a busy and important area for land transportation in Ternate City, North Maluku Province, Indonesia.

3.1. Data Geometric

Primary data was obtained directly from surveys of geometric road conditions. This data includes road width, number of lanes, lane width, road shoulder width, and road type. Where the observed location is at the point of the road, namely the national road section of SP. Jambula - SP. Dufa-Dufa. The following is a description of the geometric conditions of the road (Table 5).

Table 5. Road Geometric Characteristics

Road Characteristics	Observation (Existing)
Road Type	Four-lane Split or Two-way Street
Type of Road Pavement	Asphalt
Road Lane Width	7 meters
Road Length	28.8 kilometers
Road Shoulder Width	1 meter

The data obtained from field observations will be processed and analyzed to generate valuable information regarding road damage from STA 00+000 to STA 00+2000 (twenty samples). The data from this research can assist decision-makers in road repair methods in Ternate City. Road maintenance needs to be improved to address minor damages such as small cracks or surface defects that affect road users' comfort.

3.2. Data Analysis

3.2.1. Research Procedure

The research planning phase involves setting the objective of the study, which is to assess road conditions and determine the extent of damage. Additionally, it includes selecting the specific road to be evaluated and gathering important information such as road length, width, and pavement layer type. It is crucial to ensure that the necessary equipment and instruments, such as an IRI measuring device, a camera for documenting road conditions, and historical road data, are readily available.

Next, the data collection phase begins with a visual survey to identify various types of road damage, including cracks, potholes, and deformations. The roughness of the road surface is measured using an IRI measuring device. To support the analysis, photographs or videos are taken to provide visual references.

The analysis phase involves employing the PCI method. This entails calculating the PCI index by combining the road damage scores based on established criteria within the PCI method. The PCI value is then determined using appropriate formulas or software, and the results are interpreted to evaluate the overall condition of the road pavement.

Similarly, the IRI method is utilized in the analysis stage. The data acquired from the IRI measuring device is used to calculate the IRI value using relevant formulas or software. The IRI value is then interpreted to assess the level of road surface roughness, and a comparison is made with standards outlined in guidelines or specifications to categorize the road's roughness.

Furthermore, the analysis incorporates the Bina Marga guidelines. These guidelines are reviewed to identify the specific types of road damage present. The evaluation of road conditions and determination of appropriate repair actions are based on the provided criteria within the guidelines. Adjustments may be made according to observed road conditions, and the necessary steps are determined in accordance with the guidelines.

Following the analysis, evaluation, and recommendation phase, the findings are assessed using the PCI, IRI, and Bina Marga guidelines to identify significant road damage that requires urgent repairs. Repair recommendations are formulated based on the analysis results and relevant guidelines. The final step involves presenting the comprehensive research report, including the analysis findings and recommendations, in written form.

In the implementation and follow-up stage, the research report is delivered to relevant parties, such as BP2JN Kota Ternate, the road management authority. Based on the repair recommendations, a budget is planned and allocated for the necessary repair actions. Ongoing monitoring and evaluation of the road repair implementation are conducted to ensure compliance with the recommendations.

3.2.2. IRI (International Roughness Index) Method

The results obtained from the pavement condition assessment on the Sp. Jambula-Sp Dufa road section, STA 00+00-2+00, using the International Roughness Index method, obtained from the PPK 2.4 North Maluku National Road Implementing Agency, can be seen in the following Table 12.

3.2.3. PCI (Pavement Condition Index) Method

Procedure for Pavement Condition Index (PCI) Method Data Analysis :

1. Determining the PCI (Pavement Condition Index) or road damage level based on damage parameters. To obtain the PCI value, the following formulas can be used:

- a.
$$\text{Density} = \frac{A_d}{A_s} \times 100\% \quad (1)$$

Or

- $$\text{Density} = \frac{L_d}{A_s} \times 100\% \quad (2)$$

For the type of distress "potholes," the density can be calculated using the following formula:

- $$\text{Density} = \frac{n}{A_s} \times 100\% \quad (3)$$

Where:

Ad: Total area of each distress level (m²)

As: Total area of the road segment (m²)

Ld: Total length of each distress level (m)

n : Number of potholes for each distress level This formula is used to determine the density of damage on the road surface.

- b.
$$\text{PCIs} = 100 - \text{CDV} \quad (4)$$

Where: PCIs: PCI for each sample unit or research unit, CDV: Corrected Deduct Value for each sample unit.

This formula is used to calculate the deduction value or CDV (Condition Deduct Value), which is obtained from the curve relationship between the total deduction value (TDV) and the deduction value (DV) by selecting the appropriate curve.

- c. The deduction value represents the influence of each damage on the pavement condition or performance.

2. The PCI value is based on the results of manual condition surveys. The PCI value can be calculated manually, and it is based on the deduction value (DV), which ranges from 0 to 100.

3. The CDV value is obtained from the curve relationship between the TDV value and the CDV value. Therefore, the PCI value for each unit can be determined using the formula: $\text{PCI} = 100 - \text{CDV}$. The CDV value can be obtained after obtaining the damage values from the survey results.

4. The calculation of the overall PCI value for a road segment can be determined using the following equation:

$$\text{PCIr} = \sum \frac{\text{PCIs}}{n} \quad (5)$$

Where:

PCIr: The average PCI Value of All Study Areas, Σ (PCIs): Sum of all individual PCIs for each sample unit, n: number of sample unit

3.2.4. Bina Marga Method

Procedure for Bina Marga Method Data Analysis :

1. Determine the road type and road class.
2. Calculate Load-carrying Capacity Reduction for the surveyed road and determine the road class using Table 1.
3. Tabulate the survey results and group the data according to the type of damage.
4. Calculate parameters for each type of damage and assess each type of damage based on Table 2.
5. Sum up the values for all types of damage and determine the road condition rating based on Table 3.
6. Calculate the priority value for road condition using the equation Priority Value

$$BM = 17 - (\text{LHR Class} + \text{Road Condition Value}) \quad (6)$$

Table 6. Load-carrying Capacity Reduction and Road classification value/road class rating

Load-carrying Capacity Reduction (Smp/Day)	Road Class Value
< 20	0
20 – 50	1
50 – 200	2
200 – 500	3
500 – 2000	4
2000 – 5000	5
5000 – 20000	6
20000 – 50000	7
> 50000	8

Source: (Direktorat Jenderal Bina Marga, 1990a)

Table 7. Load-carrying Capacity Reduction and Road classification value/road class rating

Type Of Cracks		Patch and Potholes	
Type Crack	Score	Area	Score
Alligator	5	> 30%	3
Random	4	20 – 30%	2
Across	3	10 -20%	1
Lengthwise	2	<10%	0
Nothing	1	Surface Roughness	
Crack Width		Type	Score
Indicator	Score	Desintegration	4
> 2 mm	3	Aggregate loss	3
1 – 2 mm	2	Rough (Hungry)	2
< 1 mm	1	Fatty	1
Nothing	0	Close Texture	0
Crack Quantity		Rutting	
Area	Score	Depth	Score
> 30%	3	> 5/100 m	4
10 – 30%	2	2 – 5/100 m	2
< 10%	1	0 – 2/100 m	1
Nothing	0	Nothing	0
Crack In The Form Of Ruts			
Depth		Score	
> 20 mm	7		
11 – 20 mm	5		

6 – 10 mm	3
0 – 5 mm	1
Nothing	0

Source: (Direktorat Jenderal Bina Marga, 1990a)

Table 8. Determination Of Road Condition Value Based on Total Damage

Total Damage Score	Road Condition Value
26 – 29	0
22 – 25	1
19 – 21	2
16 – 18	3
13 – 15	4
10 – 12	5
7 – 9	6
4 – 6	7
0 – 3	8

Source: (Direktorat Jenderal Bina Marga, 1990a)

4. RESULT AND DISCUSSION

4.1. Data Survey

4.1.1. PCI (Pavement Condition Index) Survey

The field data includes the type of damage, severity of damage, and quantity of damage, which are used to determine the PCI value that provides an assessment of the road pavement condition. The research data for determining the PCI value was collected on the road section from Sp. Jambula to Sp. Dufa (km 0 to km 2), consisting of 10 samples/segments, with each segment covering an area of 700 m². The field research results include data on flexible pavement damage for each sample/segment, measured in meters (m) and square meters (m²), for each type of damage. The following is a sample data obtained in the field, as shown in Figure 2.

Road Pavement Condition Survey Form										
Location		SP. Jambula – SP. Dufa		Station		+000 - 0+100		Number Sample		01
Date		Januari 22 - Mei 28, 2023		Area Size		700 m ²				
Types Of Damages										
1. Alligator Cracking (m ²)	10. Depression (m ²)			19. Flushing (m ²)		Sketsa				
2. Rutting (m ²)	11. Patching (m ²)					100 m				
3. Block Cracking (m ²)	12. Polished Aggregate (m ²)					← 7 m →				
4. Shoving & Depression (m)	13. Joint reflective cracking (m)									
5. Corrugation (m ²)	14. Drop-off (m)									
6. Raveling (m ²)	15. Longitudinal and transverse cracking (m)									
7. Edge Cracking (m)	16. Slippage cracking (m ²)									
8. Potholes (m ²)	17. Expansion (m ²)									
9. Ruts (m ²)	18. Weathering and raveling (m ²)									
Types, Area, and Quality of Damage										
Types	1	6	8	11	15					
Area and Quality	26 x 7 M	6 x 5 x 0,3 M	3 x 2 x 0,5 L	8 x 1,5 L	32 x 0,05 M					
Total Damage	L		3	L	12	L				
	M	182	M	9	M			1,6	M	
	H									
PCI Calculation										
Distress Type	Severity Level	Density (%)	Deduct Value	PCI = 100 - CDV						
1	M	26,00	59	34						
6	M	1,29	9							
8	L	0,43	44							
11	L	1,71	3							
15	M	0,23	2							
				Rating						
				POOR						
Total Deduct Value (TDV)				117						
Corrected Deduct Value (CDV)				66						

Figure 2. Form Survey PCI : Sp.Jambula – Sp.Dufa-Dufa Road, Ternate, North Maluku, Indonesia

4.2.2. Bina Marga Survey

From the field research results, the data on flexible pavement damage for each sample/segment is provided in meters (m) and square meters (m²) as the measurement units for each type of damage. The following is a sample data obtained in the field, as shown in Figure 3.

DETERMINATION OF SCORES FOR CRACK QUANTITY FORM							
Number	Stasioner (m)	Width (m)	Length (m)	< 10%	10 – 30%	> 30%	Total
1	0 + 000 - 0 + 100	7	100	1	2		3
2	0 + 100 - 0 + 200	7	100	1	-	3	4
3	0 + 200 - 0 + 300	7	100	1	-	-	1
4	0 + 300 - 0 + 400	7	100	-	2	-	2
5	0 + 400 - 0 + 500	7	100	-	-	3	3
6	0 + 500 - 0 + 600	7	100	1	-	-	1
7	0 + 600 - 0 + 700	7	100	1	-	-	1
8	0 + 700 - 0 + 800	7	100	1	-	-	1
9	0 + 800 - 0 + 900	7	100	-	2	-	2
10	0 + 900 - 1 + 0	7	100	-	2	-	2
11	1 + 0 - 1 + 100	7	100	-	-	-	0
12	1 + 100 - 1 + 200	7	100	1	-	-	1
13	1 + 200 - 1 + 300	7	100	-	-	-	0
14	1 + 300 - 1 + 400	7	100	-	-	-	0
15	1 + 400 - 1 + 500	7	100	1	-	-	1
16	1 + 500 - 1 + 600	7	100	-	-	-	0
17	1 + 600 - 1 + 700	7	100	-	-	-	0
18	1 + 700 - 1 + 800	7	100	-	-	-	0
19	1 + 800 - 1 + 900	7	100	-	-	-	0
20	1 + 900 - 2 + 000	7	100	-	-	-	0

Figure 3. Form Survey PCI : Sp.Jambula – Sp.Dufa-Dufa Road, Ternate, North Maluku, Indonesia

4.2.3. IRI (International Roughness Index) Survey

The survey results for the pavement condition on the road section Sp. Jambula-Sp Dufa STA 00+00-2+00 obtained from the Regional Road Implementing Agency (PPK) 2.4 North Maluku National Road can be seen in Figure 4.

STA (Km)	Kode	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
Condition	L2										
IRI/Score	L2										
Condition	L1	RR	RR	RR	RR	RR	B	B	B	S	S
IRI/Score	L1	8,2	10,1	8,2	12,1	10,4	3,5	2,0	3,8	6,4	4,9
Condition Lane N	LN	RR	RR	RR	RR	RR	B	B	B	S	S
IRI/Score Lane N	LN	8,2	10,1	8,2	12,1	10,4	3,5	2,0	3,8	6,4	4,9
Condition	R1	RR	RR	RR	RR	RR	B	B	B	S	S
IRI/Score	R1	8,4	10,1	8,2	12,1	10,4	4,0	1,2	3,8	5,8	7,0
Condition	R2										
IRI/Score	R2										
Condition Lane O	LO	RR	RR	S	RR	RR	B	B	B	S	S
IRI/Score Lane O	LO	8,4	10,1	7,8	10,4	10,4	4,0	1,2	3,8	5,8	7,0
Condition CL	CL	RR	RR	RR	RR	RR	B	B	B	S	S
IRI/Score CL	CL	8,3	10,1	8,1	11,7	10,4	3,8	1,6	3,8	6,1	6,0
Lane Type		2/2UD									
Surface		9-AC									
Road Width		7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
STA (Km)	Kode	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,0
Condition	L2										
IRI/Score	L2										
Condition	L1	RR	S	RR	B	S	RR	RR	RR	RR	RR
IRI/Score	L1	10,2	6,3	8,1	3,7	6,7	8,4	8,5	8,6	9,8	10,0
Condition Lane N	LN	RR	S	RR	B	S	RR	RR	RR	RR	RR
IRI/Score Lane N	LN	10,2	6,3	8,1	3,7	6,7	8,4	8,5	8,6	9,8	10,0
Condition	R1	S	S	S	B	S	RR	RR	RR	RR	RR
IRI/Score	R1	5,9	5,7	5,4	3,7	4,8	8,4	8,5	8,6	9,2	10,0
Condition	R2										
IRI/Score	R2										
Condition Lane O	LO	S	S	S	B	S	RR	S	RR	S	RR
IRI/Score Lane O	LO	5,9	5,7	5,4	4,0	4,8	8,3	6,3	8,6	6,2	10,0
Condition CL	CL	RR	S	S	B	S	RR	RR	RR	RR	RR
IRI/Score CL	CL	8,1	6,0	6,8	3,8	5,8	8,4	8,0	8,6	8,8	10,0
Lane Type		2/2UD									
Surface		9-AC									
Road Width		7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0

Figure 4. Form Survey IRI : Sp.Jambula – Sp.Dufa-Dufa Road, Ternate, North Maluku, Indonesia

4.2. Analysis Data

4.2.1. Result Data Analysis Using The Pavement Condition Index (PCI)

The determination of the most dominant type of damage on the pavement surface of the Sp.Jambula - Sp.Dufa road section in Ternate City, STA 0+00-2+00, can be seen in table 9, and the average PCI values can be seen in the following table 10.

TABLE 9. Summary Of Damage Level Values For Each Type Of Damage

Number/Damaged Type	Volume of Damage		Damaged Point
	m ²	percentase %	
1. Alligator Cracking (m ²)	1393	27,66	7
5. Corrugation (m ³)	292,6	5,81	5
6. Raveling (m ³)	111,45	2,21	5
8. Potholes (m ³)	15	0,30	5
10. Depression (m ²)	119	2,36	2
11.Patching (m ²)	42	0,83	2
15. Longitudinal and transverse cracking (m)	24,2	0,48	7
18. Weathering and raveling (m ²)	3038	60,33	11
	5035,25	100,00	44

Table 10. Summary Of PCI Category

No	Stasioner (m)	CDV	Nilai PCI	Rating Condition
1	0+000 - 0+100	66	34	POOR
2	0+100 - 0+200	84	16	VERY POOR
3	0+200 - 0+300	64	36	POOR
4	0+300 - 0+400	90	10	FAILED
5	0+400 - 0+500	83	17	VERY POOR
6	0+500 - 0+600	35	65	GOOD
7	0+600 - 0+700	12	88	EXCELLENT
8	0+700 - 0+800	28	72	VERY GOOD
9	0+800 - 0+900	55	45	FAIR
10	0+900 - 1+000	56	44	FAIR
11	1+000 - 1+100	72	28	POOR
12	1+100 - 1+200	47	53	GOOD
13	1+200 - 1+300	60	40	FAIR
14	1+300 - 1+400	41	59	GOOD
15	1+400 - 1+500	45	55	FAIR
16	1+500 - 1+600	65	35	POOR
17	1+600 - 1+700	62	38	POOR
18	1+700 - 1+800	61	39	POOR
19	1+800 - 1+900	74	26	POOR
20	1+900 - 2+000	76	24	VERY POOR
	AVERAGE		41.2	FAIR

The average PCI value for the pavement condition of the Sp.Jambula - Sp.Dufa road section (km 0 to km 2) is 41.2, based on the severity level and size of the damage in determining the Pavement Condition Index (PCI) and the Standard Rating Scale explained in table 2 of the Sp.Jambula - Sp.Dufa road section in Ternate City at STA 00+000-02+000. The condition is categorized as Fair, indicating the need for periodic maintenance on the road.

4.2.2. Result Data Analysis Using The Bina Marga Method

In the guideline book of the Directorate General of Highways No. 018/T/BNKT/1990, there are steps provided to determine the road condition value based on the type of damage.

1. Road Class Value

Based on the average daily traffic data (LHR) obtained from the Public Works, Spatial Planning, and Housing Agency of Ternate City, the LHR for this road section is 33,957 per day. Using Table 6, the road class value is determined to be 7 (20,000 - 50,000).

2. Road Damage Value

Based on the survey results of the surface layer damage condition on the road, numerical values are assigned for each type of damage. The road section consists of two directions, and the numerical values for road damage are determined based on Table 7. The group of cracks includes various types of cracks, crack width, and crack area. For patching, potholes, and surface roughness, the numerical values are assigned based on the type of damage. In the group of cracks, the highest numerical value is used among the different types of cracks present. For rutting, the numerical value is based on the depth of the rutting that occurs, while for depressions, the numerical value is based on the length of depressions per 100 meters. Once the numerical values are determined for each type of damage, the highest numerical value for each type is selected and summed to obtain the total numerical value representing the road damage condition, as shown in Table 8.

3. Road Condition Value

The road condition value is determined based on Table 8 for the Sp.Jambula - Sp.Dufa road section at STA 00+00-0+100. If the damage value is 15, then the road condition value is 4. The road condition value for each sample/segment is then used to calculate the road priority value in determining the type of road maintenance program. This allows for prioritization and allocation of resources based on the severity of the road condition to ensure effective road maintenance planning and implementation.

4. Road Priority Value

The priority value for each sample is calculated using Equation 6, and the priority values for each segment can be seen in Table 11.

Table 11. Summary Of Priority Bina Marga

Stasioner (m)	Total Damage	Bina Marga Value	Maintenance Program Type
0+000 - 0+100	4	6	Periodic Maintenance
0+100 - 0+200	6	4	Periodic Maintenance
0+200 - 0+300	3	7	Routine Maintenance
0+300 - 0+400	4	6	Periodic Maintenance
0+400 - 0+500	5	5	Periodic Maintenance
0+500 - 0+600	3	7	Routine Maintenance
0+600 - 0+700	3	7	Routine Maintenance
0+700 - 0+800	3	7	Routine Maintenance
0+800 - 0+900	5	5	Periodic Maintenance
0+900 - 1+000	5	5	Periodic Maintenance
1+000 - 1+100	2	8	Routine Maintenance
1+100 - 1+200	4	6	Periodic Maintenance
1+200 - 1+300	1	9	Routine Maintenance
1+300 - 1+400	1	9	Routine Maintenance
1+400 - 1+500	4	6	Periodic Maintenance
1+500 - 1+600	2	8	Routine Maintenance
1+600 - 1+700	2	8	Routine Maintenance
1+700 - 1+800	2	8	Routine Maintenance
1+800 - 1+900	2	8	Routine Maintenance
1+900 - 2+000	2	8	Routine Maintenance

Total	137	Periodic Maintenance
Average	6,85	

Based on the Bina Marga method, it can be concluded that the average priority value for the Sp.Jambula - Sp.Dufa road section is 6.85. This value is determined based on field survey results and according to Table 3, the recommended program for this road section is Periodic Maintenance. This program involves regular maintenance activities to preserve the condition of the road and ensure its long-term functionality and safety.

4.2.3. Result Data Analysis Using The IRI (International Roughness Index)

Table 12. Summary Of International Roughness Index (IRI)

Stasioner (m)	IRI Average	Rating Condition
0+000 - 0+100	8.3	Slightly Damage
0+100 - 0+200	10.1	Slightly Damage
0+200 - 0+300	8.1	Slightly Damage
0+300 - 0+400	11.7	Slightly Damage
0+400 - 0+500	10.4	Slightly Damage
0+500 - 0+600	3.8	Good
0+600 - 0+700	1.6	Good
0+700 - 0+800	3.8	Good
0+800 - 0+900	6.1	Fair
0+900 - 1+000	6.0	Fair
1+000 - 1+100	8.1	Slightly Damage
1+100 - 1+200	6.0	Fair
1+200 - 1+300	6.8	Fair
1+300 - 1+400	3.8	Good
1+400 - 1+500	5.8	Fair
1+500 - 1+600	8.4	Slightly Damage
1+600 - 1+700	8.0	Slightly Damage
1+700 - 1+800	8.6	Slightly Damage
1+800 - 1+900	8.8	Slightly Damage
1+900 - 2+000	10.0	Slightly Damage
Average	7.2	Fair

Overall, based on Table 3, it can be concluded that the average International Roughness Index (IRI) value for the pavement condition on the Sp.Jambula - Sp.Dufa road section is 7.2, which can be categorized as fair condition.

4.2.4. Comparison of IRI, PCI and Bina Marga Method

To compare the PCI (Pavement Condition Index) method, the Bina Marga method, and the IRI (International Roughness Index) method, several aspects need to be considered:

1. **Assessment Approach:** Each method has a different approach in evaluating the road pavement condition. The PCI method uses damage scores based on damage categories and category weights. The Bina Marga method classifies damages based on the type and severity of the damage. The IRI method measures road surface roughness using an international roughness index.
2. **Required Data:** Each method requires different data for analyzing the road pavement condition. The PCI method requires data on damages in various categories. The Bina Marga method requires data on damages and the type of road pavement. The IRI method requires data on road surface roughness measured using a Roughmeter or similar measuring device.
3. **Interpretation of Results:** Each method has a different interpretation scale for evaluating the road pavement condition. The interpretation scale may vary depending on the method used and the applicable standards or guidelines. And

4. Advantages and Limitations: Evaluating the advantages and limitations of each method is also important in comparing them. For example, the PCI method can provide more detailed information about road pavement damages, while the IRI method provides information about surface roughness that can affect the comfort of road users.

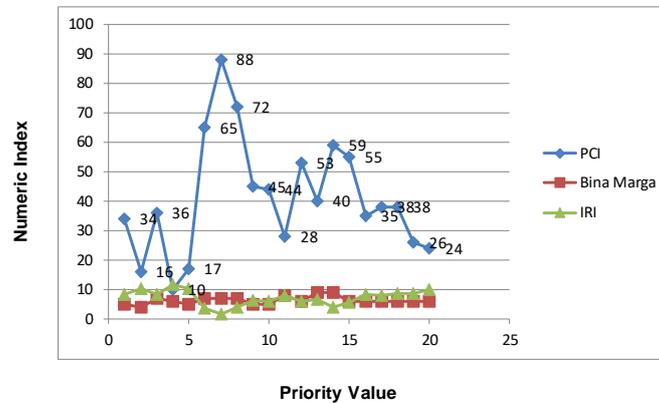


Figure 5. Relationship Graph of PCI, IRI, and Bina Marga Methods : Sp.Jambula – Sp.Dufa-Dufa Road, Ternate, North Maluku, Indonesia

Based on the identification results from Tables 10, 11, and 12, as well as Figure 5 of the three methods, namely IRI, PCI, and the Bina Marga method, several conclusions can be drawn that the road conditions vary from poor to good. From the graph results in Figure 5, it is evident that the Pavement Condition Index (PCI) method shows an inverse assessment pattern compared to the assessment graph of road conditions using the International Roughness Index (IRI) and Bina Marga methods. The International Roughness Index (IRI) provides an indication of the level of road surface roughness. The IRI results show that there are damaged sections of the road, both in the category of light and severe damage. However, the majority indicates that the road section falls into the moderate category. The Pavement Condition Index (PCI) provides an overall assessment of the road surface condition. The PCI values indicate that the majority of the road sections experience poor or fairly poor conditions, although there are some sections that show good or very good conditions. The Bina Marga method provides classification based on the level of road maintenance needs. In this case, the majority of the values require routine maintenance, with some values requiring periodic maintenance and road improvement.

It is important to consider other methods, such as the Bina Marga method and the PCI method, together with the IRI method to get a more complete picture of pavement conditions. For example, in STA 00+00-00+100, the PCI method calculates potholes with a density value of 0.43%, then the Bina Marga method calculates the value 0 because it is not included in the range ($10 > 30\%$). Of course, this is what makes the calculation difference between the analysis of the PCI method and the Highways.

Based on the identification results, although there are variations between the three methods, it can generally be concluded that the road conditions indicate the need for maintenance and improvement. In planning road maintenance, a combination of the three methods can provide a more comprehensive understanding and help in determining the priority of necessary repair actions. This is in line with the theory in sub chapter 2.4 Page 4 that the PCI, IRI, and Bina Marga methods complement each other. The IRI method is more suitable for measuring road surface roughness, while the PCI and Bina Marga methods are more suitable for assessing surface damage. Therefore, using multiple assessment methods can assist in making better decisions related to road repair and maintenance.

Based on research result, it is recommended to use a maintenance program based on the results of the Pavement Condition Index method because the PCI method has a more detailed and objective analysis regarding all aspects of the damage (Faisal et al., 2021; Ramadhan et al., 2020). In line with research (Ayu et

al., 2022) Although the PCI method is highly dependent on the skill and subjectivity of the surveyor (Prasetyo et al., 2021) The quality of manual surveys can be improved by not relying solely on human-based manual surveys, but must be improved gradually by using machine-based survey tools that can record road conditions exactly as they are, equipped with location detectors so as to create a continuous reference location (Hapsari et al., 2018) as an example of using the Hawkeye 2000 on the jl.ahmad yani section in East Kalimantan in 2021. There are only 4 Hawkeye in Indonesia and specifications most complete, there is only 1 (one) Hawkeye unit owned by the Ministry of Public Works (Setia, 2019) Sensor equipment includes Global Positioning System (GPS) and Differential GPS, Laser Profiler, Auto Crack Detection Profiler, Gipsitrec Geometry, Distance Measurement Instrument, and Asset Cameras. Apart from that, this vehicle is also supported by the Hawkeye Processing Toolkit Software (Samsuri et al., 2019; Surbakti et al., 2021).

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, despite the variation in interpretation and classification among the three methods, it can be generally concluded that the road conditions indicate the need for maintenance and improvement. In road maintenance planning, a combination of these three methods can provide a more comprehensive understanding and assist in determining the priority of necessary repair actions. By observing the patterns from the combined results of the road condition categories, it can be seen that the majority of road conditions tend to fall into the "Moderate" category. This pattern indicates that most roads experience a moderate level of damage but require attention in maintenance. Another pattern that can be observed is the presence of some roads classified as "Good". Although the number is not as high as the "Moderate" category, it still shows the existence of roads with relatively good conditions. Meanwhile, there are also some roads categorized as "Lightly Damaged", indicating more significant damage compared to the "Moderate" category. However, no roads fall into the "Severely Damaged" category. In terms of maintenance, the majority of roads require periodic maintenance, with only a few roads requiring routine maintenance. This indicates the need for regular maintenance to keep the road conditions optimal. The recommendation that can be given for further research is to add the SDI method to the method comparison. this needs to be done because the SDI value is influenced by the IRI value. Besides that, you can also add the IKP method and the RCI method.

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Mapping Socio-Economic Vulnerability to Rob Flood Hazards in Coastal Cities, North Pekalongan District, Pekalongan City

Denis Said Mukhtar¹, Ahmad Zuhdi²

^{1,2} School of Architecture Planning and Policy Development, Bandung Institute of Technology, Bandung, Indonesia
E-mail: ¹25421059 @mahasiswa.itb.ac.id, ²25421045 @mahasiswa.itb.ac.id

Abstract

Climate change brings danger to several areas, especially in coastal urban areas. One of them is the tidal flood which experienced inundation. Tidal floods pose a serious threat to the sustainability of social life and economic growth. Assessment of social and economic vulnerabilities is needed to overcome the risk of disaster hazards due to climate change in the form of coastal tidal floods in cities. This research is expected to be able to describe socio-economic vulnerability through the variables of population density, age, gender, occupation, and level of education to tidal floods that have occurred in 42% of the area. The research method used is quantitative analysis, scoring, and geographic information system modeling with village analysis units. The results showed that Panjang Baru Village was the most vulnerable area because of the high density and low-income levels of the people, most of whom were fishermen and farmers households. It also indicates the contribution of population density, level of education, and employment to the level of vulnerability. This study states that the socio-economic aspect is an important factor that must be considered for the sustainability of life and community adaptation to the threat of climate change, especially tidal floods.

Keywords

North Pekalongan District;
Urbanization of coastal
areas; Vulnerability
assessment.

1. INTRODUCTION

Coastal areas have a strategic role in Indonesia. Several main cities on Java Island are located in coastal areas, namely Jakarta, Semarang, and Surabaya (Ward et al., 2010; Cahyadi et al., 2013). The World Bank (2014) explains that in 2025, 68% of the population will live in Indonesian cities and it is predicted that this will continue to increase to 82% of the population in 2045. The phenomenon of climate-related hazards has become an urban development *issue*. the most challenging at the moment. Climate change brings danger to several areas, especially in coastal urban areas. This climate problem is exacerbated by various other problems such as the environment and ecological systems that continue to deteriorate. Along with the phenomenon of climate change, these coastal cities are becoming increasingly prone to disasters (Cahyadi et al., 2013).

One of the disasters that occur in coastal areas is flooding or what is also called rob (Blackett and Hume, 2006). Tidal floods are caused by sea level rise and/or land subsidence resulting in inundation (Handayani, 2020). Tidal floods can occur when the tide is in a position higher than the ground level which is then accompanied by a high volume of river flow from upstream (Harley, 2013). Climate change, in relation to coastal urban areas, has been shown to contribute to the socio-economic vulnerability of communities along with an increase in coastal urban populations (Kumar et al., 2010).

The phenomenon of climate change which has an impact on the dangers of tidal flooding has affected urban coastal areas with a higher risk when compared to non-urban coastal areas (Kumar et al., 2010). The danger of tidal flooding is also exacerbated by conditions of intensive subsidence in urban coastal areas due to the high intensity of development of built-up areas in urban coastal areas (Harley, 2013). Along with the phenomenon of climate change, these coastal cities in Indonesia are receiving quite serious threats to disaster hazards, especially tidal floods (Cahyadi et al., 2013). The threat of flood disasters in urban coastal areas is serious because it has an impact on physical, social, economic, and environmental damage (Blackett and Hume, 2006).

The impact of floods poses a serious threat to the sustainability of social life and economic growth in urban coastal areas (McGranahan et al., 2007).

Assessment of social and economic vulnerability is needed to overcome the risk of disaster hazards due to climate change in the form of tidal floods in coastal cities (Kumar et al., 2016). The phenomenon of urbanization will have an impact on increasing levels of social and economic vulnerability (Cutter et al, 2000). High socioeconomic vulnerability can occur if an area is dominated by high, low-income residents. In addition, socioeconomic vulnerability itself can be described as a benchmark related to the *socioeconomic characteristics* of the community in the process of facing and recovering from a disaster, so vulnerability will be a sign of socioeconomic conditions that can affect regional losses due to disasters caused by climate change. (Wang & Shaw, 2018).

Based on Presidential Decree Number 48 of 2014, the Pekalongan area is part of the *North Java Super Corridor as a center of economic growth, especially in the industrial sector* (Hudalah et al, 2020). North Pekalongan District in Pekalongan City is included in the northern coastal area which experienced tidal flooding. According to Cahyadi et al. (2013), the average flood height is 50 cm covering an area within 4 km of the Pekalongan coastline. Meanwhile, land subsidence ranges from 4.8 to 10.8 cm/year (BPBD Pekalongan, 2021). Based on data from the Central Java Pusdataru Service which was strengthened by Cahyono (2022), in 2020, it is known that the area of flood inundation in North Pekalongan will reach 618 hectares or the equivalent of 42% of the area of North Pekalongan. The population growth of North Pekalongan in the 2010-2022 period reached 10.44% from 73,159 people to 80,799 people (North Pekalongan in Figures 2010 and 2022). The city of Pekalongan is the center of the batik industry, especially in North Pekalongan District. In 2022, the number of batik craft industries is 161 units with a workforce absorption of 483 workers. Therefore, Pekalongan Utara District makes an important contribution to the growth of the creative economy due to the development of creative industries. This condition exacerbates the high intensity of urban activity and dense population which makes the environment worse. So, it is estimated that the number of areas that are socially and economically vulnerable to tidal flooding will continue to increase.

Table 1. Previous Research on the Vulnerability of Coastal Areas

Author, year Title	Research result	Research Methods and Differences
Flanagan, BE et al. 2011. <i>A Social Vulnerability Index for Disaster Management, Journal of Homeland Security and Emergency Management</i>	Social vulnerability refers to socio-economic and demographic factors that affect community resilience. This research shows that in a disaster context, socially vulnerable communities are more likely to be adversely affected, where they tend not to recover and find it difficult to adapt. Addressing social vulnerabilities effectively can help reduce human suffering and economic losses after a disaster. The location of this research is in the New Orleans area, which is the coastal area of the United States state of Louisiana. This study describes the development of a social vulnerability index from several variables including poverty, employment, income, education level, age, disability group, single parenting, ethnicity, housing structure, access to transportation, and population density.	<ul style="list-style-type: none"> Quantitative approach through scoring from the percentile ranking using the components of the SVI index In the previous research, the focus was on finding the potential value of the impact of the hurricane disaster to know which variables have the greatest influence on social vulnerability, while in this study it examines the spatial distribution of the level of socio-economic vulnerability. The previous research scale covered 1 city of New Orleans. Meanwhile, in this study, the focus was on the scale of the North Pekalongan sub-district.
Tate, E., 2012. <i>Social vulnerability indices: a comparative assessment</i>	This study focuses on the evaluation and comparison between social vulnerability indices through uncertainty and sensitivity analysis. The social vulnerability index is a	The focus of this research is to compare and validate the analysis of uncertainty and sensitivity in social vulnerability to all natural

using uncertainty and sensitivity analysis

tool used to assess the vulnerability of a community or population to various hazards or stresses by combining several social, economic, and demographic indicators to measure the vulnerability of a particular population. The findings of this study are that different social vulnerability indices can produce varying results (variability value index), changes in the weights and parameters assigned to the factors in the index can lead to different vulnerability ratings (sensitivity index), and special considerations of the study context emphasize that social vulnerability is context-specific and that a one-size-fits-all approach may not be appropriate.

Rufat, S., Tate, E., Burton, CG, & Maroof, AS 2015. *Social vulnerability to floods: Review of case studies and implications for measurement*

massive research aims to examine the concept of social vulnerability in the context of flooding in 67 cases during the 1997-2013 period worldwide. Social vulnerability refers to the vulnerability of individuals, communities or society to the adverse effects of flood hazards. Social, economic, and demographic characteristics, as well as institutional and governance aspects, are used in this study. The complexity of social vulnerability and the factors that contribute to different impacts on vulnerable communities (populations). There are challenges and limitations associated with measuring social vulnerability to flooding such as the dynamic nature of vulnerability, qualitative barriers, spatial and temporal variability of vulnerability, and the need for reliable and comprehensive data.

disaster hazards through a quantitative approach using deductive, hierarchical, and inductive methods in solving them. Meanwhile, in this study, the assessment focuses on assessing the level of vulnerability and spatial distribution of tidal floods

- The method used in previous research is content analysis with a qualitative approach which assesses the perspectives of several articles related to the most influential components from each country.
- This study focuses on identifying the main causes of social vulnerability to the effects of flooding, while this research does not only discuss the contribution of the socio-economic component but also identifies the spatial distribution of socio-economic vulnerability to the effects of tidal flooding in the Besir area.
- The scale of previous research includes a global scale.
- The method used is quantitative analysis through weighting and spatial multicriteria evaluation
- The scale in this study includes the city scale.
- In previous research, the focus was on assessing vulnerability evaluation from social and environmental aspects as well as adaptation based on the impacts of climate change. Whereas in this study the focus of research is not only on climate change but vulnerability to tidal floods.
- The method used is scoring, and weighting through the city-level FGD results.
- In previous research based on the type of city, where the research scale focused on

Kumar, P., Geneletti, D., Nagendra, H., 2016. *Spatial assessment of climate change vulnerability at city scale: a study in Bangalore, India*

This research in Metropolitan Bangalore aims to analyze and assess a comprehensive vulnerability to climate change at a city scale. This study adopts a spatial assessment approach and integrates multiple factors to evaluate vulnerability. This study shows that policymakers and urban planners can draw lessons from developing strategies that are effective in the context of climate change adaptation in Bangalore. Researchers considered many factors that contribute to vulnerability, such as socio-economic characteristics, land use patterns, and environmental conditions.

Handayani et al, 2017, *Vulnerability assessment: A comparison of three different city sizes in the coastal area*

Vulnerability assessment is a method that provides an opportunity to understand variables such as socioeconomic and infrastructure variables in playing a role in the discourse on the relationship between urbanization and climate change.

<p>area of Central Java, Indonesia</p>	<p>Vulnerability assessment can be carried out on a micro-scale. Comparative research on cities of different sizes shows that the larger the city, the more it has various levels of vulnerability among its smaller regional units (sub-units).</p>	<p>three coastal cities, while in this study the research focus was on the sub-district scale</p> <ul style="list-style-type: none"> • In previous studies, research focused on vulnerability to climate change in coastal areas, while this study involved a focus on vulnerability to tidal floods.
<p>Faniza, V, Pradoto, W 2019, <i>Socio-ecological vulnerability assessment and the results in spatial patterns: a case study of Semarang City</i></p>	<p>This research is aimed at examining socio-ecological vulnerability and the resulting spatial pattern on a city scale. Variables such as population density, education level, livelihood, income, and dependency ratio are needed to assess socio-economic aspects. In addition, in terms of environmental variables such as land use, topography, geology and climatology. This study analyzes the relationship between the vulnerability-resilience of socio-ecological systems and land cover patterns. Based on the case study, the findings show that almost 28% of the Semarang city area is socially-ecologically vulnerable. The characteristics of coastal cities provide results where the high vulnerability areas are located in the northern coastal area of Semarang City.</p>	<ul style="list-style-type: none"> • The method used is descriptive quantitative using scoring and spatial analysis • In previous research, it examined social and environmental resilience by involving land use, slope, and climatology variables. while in this study the focus is on the vulnerability variables from social and economic aspects. • The scale in the previous study was the city of Semarang, while in this study the focus was on the district scale
<p>Haryanti, V, G, & Yuliasuti, N. 2021. <i>Identification of the coastal inundation disaster and its effect on social vulnerability in north Semarang district, Semarang city</i></p>	<p>This research was conducted in North Semarang District. The variables used in this study were gender, education, income, special needs, vulnerable age and population density. high susceptibility value. high vulnerability is caused by the low role of women, educational conditions, income, and lack of inclusiveness for evacuation facilities for groups with disabilities.</p>	<ul style="list-style-type: none"> • The method used is a descriptive quantitative scoring technique and standardized z-score with data collection techniques through questionnaires • In the previous study, the object studied was 99 groups of families living on the coast of Semarang City, while in this study the object of research was the condition of the entire community which was described through the interpretation of census data in the coastal area of Pekalongan Utara District.

Previous research on socio-economic vulnerability usually discusses vulnerability at a macro scale and is associated with community adaptation to disasters/threats. Flanagan (2011) for example examines vulnerability in New Orleans which illustrates social vulnerability if managed effectively can help in social losses and economic losses for the community. Research by Kumar et al. (2016) in Bangalore shows that the description of socio-economic vulnerability conditions is one of the important considerations in formulating policies to create community resilience to the threat of disaster hazards due to the phenomenon of climate change. Faniza and Padoto (2019) conducted an environmental assessment and disaster risk assessment in Semarang which showed the socio-ecological level of community vulnerability. Handayani et al. (2020) argue that the process of mapping the level of vulnerability is an important tool in describing scenarios of spatial distribution in the local context which has been studied comparatively in Tegal City, Semarang City, and Lasem City. Based on the studies of researchers, it can be said that there are groups of people who tend to be vulnerable to the threat of disaster hazards. This is caused by the community's inability to deal with and recover from the hazards of the disaster (Adger et al., 2007, Cutter et al, 2000, Zhou et al., 2012).

This social-economic vulnerability mapping research in North Pekalongan departs from the assumption that creating community resilience to disasters is not entirely determined by physical intervention in the form of disaster management infrastructure development but can also be determined by the process of assessing the level of community vulnerability to disasters, especially those that are influenced by socio-economic conditions. Vulnerability caused by changes in socio-economic characteristics is a factor that determines the level of community adaptability to disasters (Sen, 1987). Pekalongan Utara District was chosen as the study area considering its status as one of the most vulnerable areas on the North Coast of Central Java. The city of Pekalongan has been hit by tidal floods since 2010 (Prihanto, 2012, Cahyono and Nugroho, 2022). This research will provide an overview regarding the level of socio-economic vulnerability of people in urban coastal areas that have not been widely discussed at the smallest delineation with the most possible data to obtain. This research will update research by Buchori (2015) regarding a vulnerability in the Pekalongan coast. This research departs from the question "**How is the distribution of social and economic vulnerability levels in North Pekalongan District?**". The purpose of this study is to map the level of socio-economic vulnerability through assessment and spatial distribution. This research wants to understand how the relatively even distribution of urban coastal areas can experience different levels of vulnerability. This research was conducted by identifying and spatial analysis related to the socio-economic vulnerability of the community in the coastal area of Pekalongan City. This research is expected to provide benefits for Pekalongan City development planning, especially in terms of disaster risk management through a socio-economic approach, so that urban development is carried out in a balanced way with improving the quality of society.

Table 2. Justification of Indicators for Socioeconomic Vulnerability Variables

<i>Research variable</i>	<i>Explanation</i>	<i>Indicator</i>	<i>Theory source</i>
Population density	High population concentration or population density in an area makes it difficult to evacuate from tidal floods	<ul style="list-style-type: none"> • Total population; • Village area; • Built-up Area; • Population Density Level. 	Johnson Jr and Zeigler, 1986; McMaster, 1988; McMaster, 1988
Age	The elderly and children are an age group that is very vulnerable to changes in conditions, in this case, tidal floods due to climate change	<ul style="list-style-type: none"> • Number of Population Under 14 Years of Age; • Number of Population Aged Over 65 Years. 	McMaster, 1988; O'Brien and Mileti, 199; Flanagan et al., 2011
	Children (<14 years) and the elderly (>65 years) have a high dependence on the help of others in dealing with exposure to the dangers of tidal floods		Cutter et al., 2000; Cutter et al., 2003
Gender	Women tend to have limited ability and physical strength in saving themselves compared to men	<ul style="list-style-type: none"> • Number of women • Number of men • <i>Sex ratio</i> 	Rufat et al., 2015; Morrow, 1999
	The recovery ability of the female sex tends to be more difficult than that of the male. <i>Specific sectoral</i> tendencies in terms of employment make it difficult for women to adapt to new situations		Cutter et al., 2003
Livelihood	The livelihood variable is considered to represent economic vulnerability. Jobs in the agricultural and fisheries sectors tend to have a more influential impact on changing conditions, especially the hazard of tidal floods	<ul style="list-style-type: none"> • Number of residents with livelihoods as farmers; • Number of residents with livelihoods as fishermen; • Number of residents with livelihoods as farmers; • The proportion of the total population livelihood fishermen at productive age. 	Cutter et al., 2003

Level of education	Communities with higher education levels tend to have access to disaster-related information	<ul style="list-style-type: none"> ● The number of the population graduated from elementary school ● Total Population Middle School Graduates ● Number of Population High School Graduates ● Number of College Graduates 	Cutter et al., 2003, Holland, 2011
	Regions with a high education level representation tend to influence access to decent jobs, resources, and income to assist in the recovery process.		Fatemi et al., 2017
Poor Residents	Low-income people or groups of poor people are one of the representatives of the economic vulnerability of an area due to limited resources and difficulties in recovering from the dangers of floods.	<ul style="list-style-type: none"> ● Number of poor people ● Number of poor families ● Number of pre-prosperous families 	Dasgupta, 1995; Cutter et al., 2000

1.1 Disaster, Hazard, and Vulnerability Concept

The paradigms of the concept of disaster (*disaster*), hazard (*hazards*), and vulnerability (*vulnerability*) are often related to the paradigm of disaster mitigation in the framework of disaster management (Wibowo, 2010). Disaster can be interpreted as an event or series of events that threaten and disrupt people's lives and livelihoods caused by natural factors and non-natural factors. In addition, human factors can also cause disasters, which can cause casualties, psychological impacts, property losses, and environmental damage (BNPB, 2013). Hazards *are* natural and man-made phenomena that have the potential to threaten human life, property loss, and natural damage (Wibowo, 2010).

Meanwhile, the IPCC (2007) defines vulnerability *as* a level in a system where the system is unable to deal with adverse impacts and is easily disrupted by global climate change, such as climate variability and extreme climates. The function of the system can also be seen from its sensitivity and adaptive capacity to global climate change. According to Wibowo (2010), vulnerability can be interpreted as a condition of a particular community that leads to or causes an inability to face the threat of danger. So vulnerability can be something that needs to be known before a disaster occurs because it relates to potential threats. Social vulnerability denotes social conditions concerning fragile resilience in the face of danger. The fragile social condition in a disaster situation can cause huge losses. While economic vulnerability shows the condition of the level of fragility of the economy is facing the threat of danger. At this stage, the economic conditions and social dynamics of the region will determine the level of community resilience in facing the challenges of climate change. The relationship between disaster, hazard, and vulnerability can be described as mutually exclusive. Vulnerable (fragile) socio-economic conditions will find it difficult to deal with disasters, even the threat of danger. Strong socio-economic conditions will reduce negative impacts due to hazards that occur in the social and economic context.

1.2 The threat of Rob Flood Hazards in Coastal Areas

Sea level rise due to global warming is one of the problems faced by coastal or island countries in the world (Kobayashi, 2003). Sea level rise in the world in 2100 will increase by around 18 cm to 59 cm (IPCC, 2007). Then sea level rise will range from 0.21 cm/year to 0.68 cm/year, or an average of around 0.44 cm/year. This phenomenon causes flooding in coastal areas (rob) which in the future has the potential to get bigger. The many phenomena of coastal flooding or what is commonly called tidal flood inundation, in the northern coastal area of Java Island at this time, is probably one result of changes in sea level due to global warming (Marfai, 2011). Global warming has a broad and serious impact on the bio-geophysical environment, such as sea level rise, increased rainfall, and floods, climate change, extinction of certain flora and fauna, migration of fauna and pests, and so on (IPCC, 2007).

Research on disaster focuses on influencing variables which include hazard or threat, vulnerability or sensitivity, and adaptability. Vulnerability is the tendency of a system to experience negative impacts which includes sensitivity to negative impacts and lack of adaptive capacity to deal with negative impacts. The vulnerability of a system to climate change is a function of its exposure, sensitivity, *and* adaptive capacity (IPCC, 2007). Cutter (1996) states that vulnerability is a basic concept of hazard mitigation. Hazard studies should start with a vulnerability assessment. Socio-economic vulnerability must be a central issue to research because of the causal effect of the level of vulnerability and the socio-economic characteristics of society, especially for many developing countries where coastal areas are usually the most densely populated areas and concentrations of poverty and which create more complex disaster mitigation problems. The impact of disasters on the continuity of social and economic activities of the community, such as disruption of the function of coastal areas and coastal cities, disruption of the function of urban infrastructure, disruption of the environment for settlement activities, reduced productivity of agricultural land to an increased risk of disease outbreaks (Klein et al., 2003). Vulnerability can be observed from several basic things, namely poverty, resources, ideology, economic system, dynamic pressure (local institutions, investment, local markets, macro forces, education, environmental degradation, training, soft skills, freedom of the press, population expansion, and urbanization), and physical environmental conditions: Hazardous locations, infrastructure and buildings, risky living, local economy, low-income levels, and public action (Winser et al, 2004).

2. METHOD

2.1 Description of Research Locations

Pekalongan City is one of the vulnerable cities on the north coast of Central Java. The most vulnerable area is Pekalongan Utara District, which consists of seven sub-districts (villages), namely: Bandengan Sub-District, Degayu Sub-District, Krapyak Sub-District, Kandang Panjang Sub-District, Padukuhan Kraton Sub-District, Long Baru Sub-District, Long Wetan Sub-District. The Pekalongan City BPBD stated that the area of the kelurahan which is prone to exposure to tidal floods is 1,057 hectares or around 23.36% of the total area. Tidal floods that were quite severe occurred from May to June 2022. The tidal floods inundated several areas in North, West and East Pekalongan Districts. Based on the results of online interviews with the Pekalongan City Public Works Office, in 2021 it is known that the pattern of distribution of inundation areas affected by tidal floods has changed after the construction of flood control infrastructure in the form of a 2-meter-high embankment that stretches from the Kandang Panjang sub-district to the Bandengan sub-district. In general, areas affected by tidal floods have tidal water levels reaching 30 cm to 80 cm with an average inundation period of 2 weeks. Based on the Pekalongan City BPBD disaster report document (2021) regarding the data for recording flood victims, it is known that 755 residents were victims of the flood incident in Pekalongan City.

The population of North Pekalongan District is 80,779 people with a population density of 5430 people/km². The population is dominated by male residents. Krapyak Village is the most populated area with a population of 18,490 people or 23% of the total population, while Bandengan Village has the least population with a population of 6158 people or 8% of the total population. In the context of education level, the population of North Pekalongan District is dominated by high school graduates. Based on statistical data for 2022, the sub-districts with the highest number of sub-district households are Krapyak Village with 3,698 households, and Kandang Panjang Village with 1,232 households.

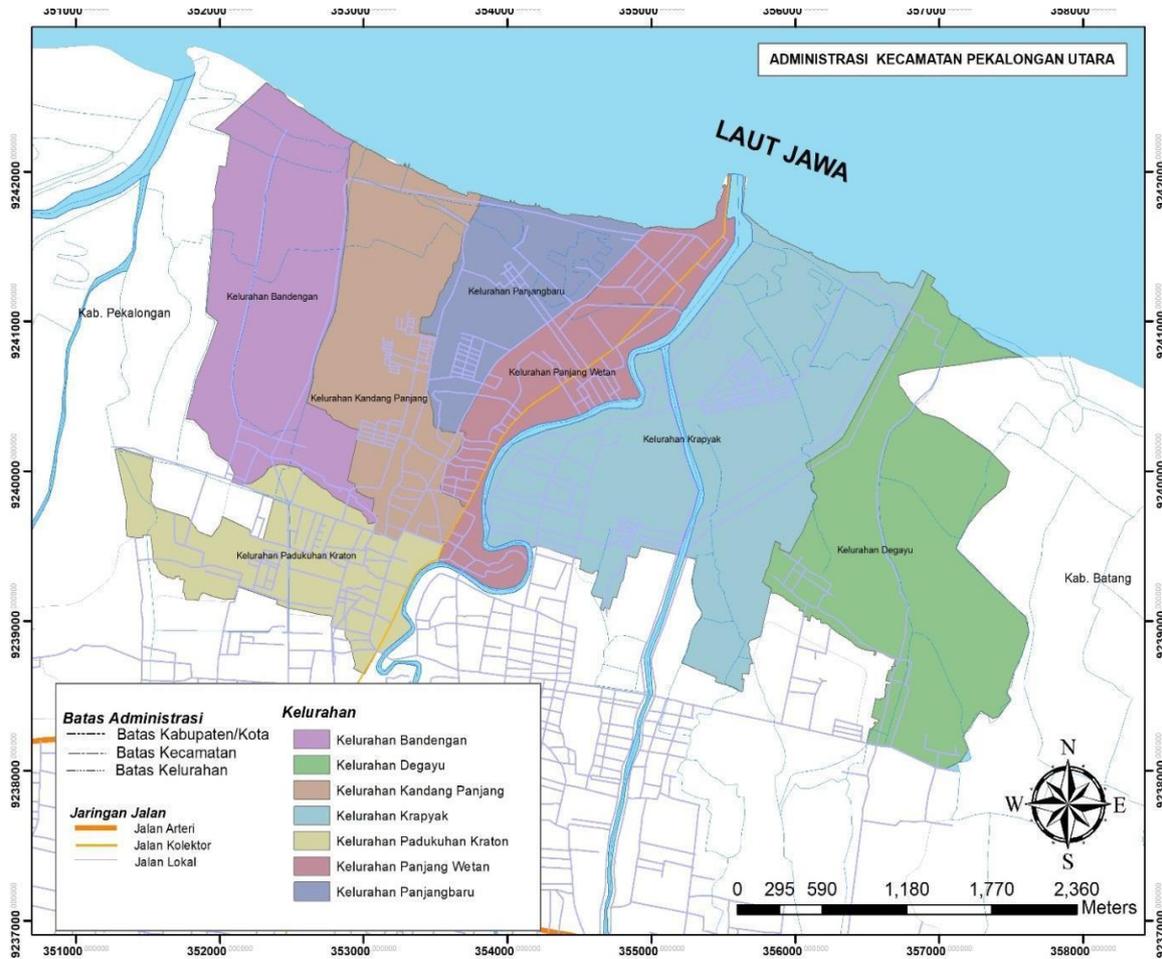


Figure 1. North Pekalongan District, Pekalongan, Central Java.

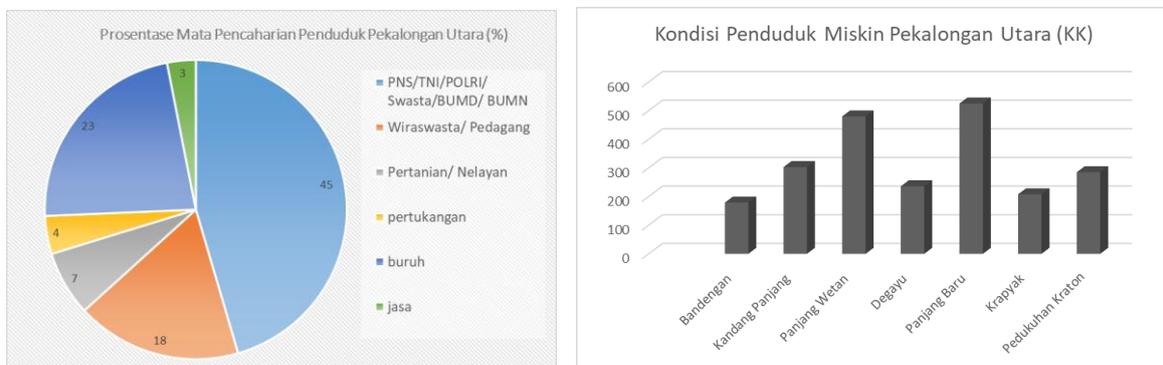


Figure 2. Livelihood Conditions and Poor Population in North Pekalongan District.

2.2 Statistical analysis

In this study, the method used is descriptive quantitative. The quantitative approach itself is an approach used by experts to collect, analyze and interpret data in the form of numbers (Creswell, 2009). Quantitative analysis in this study is used as an assessment technique that involves the process of calculating *the scoring* of each socio-economic vulnerability indicator. The scoring method is very important because it can represent the importance of each of the indicators applied. scoring itself is the most common calculation approach in measuring the level of vulnerability, especially in social contexts (Tate, 2012). Geographic information system (GIS) modeling based on indicators of socio-economic vulnerability can represent real conditions in the field. The collaboration of these two methods is an advantage in this research because the research results presented can be visualized in the form of a spatial distribution. Therefore, through quantitative analysis methods and

GIS modeling, it can be seen the spatial distribution related to socio-economic vulnerability based on predetermined variables. The data obtained from secondary sources comes from the government census documents of Pekalongan City. The level of socioeconomic vulnerability is assessed through the following steps, including:

1. Identifying and establishing indicators based on socio-economic vulnerability data: Socio-economic vulnerability indicators and data were obtained based on a literature review and then adjusted according to data availability and regional characteristics.
2. Calculating socio-economic vulnerability data: this data calculation stage aims to get the actual value of the data used. The calculation process is carried out using two methods, namely the ratio method and the scoring method. The ratio method requires dividing the value of each data with other matching data. For example, population density is the ratio between the total population of a sub-district and the area of the area. The scoring method is used for indicators which include indicators of population density, age, gender, livelihood, level of education, and poverty. Details of the method used for each data can be seen in Table 4.
3. Interpretation of spatial distribution patterns of vulnerability conditions based on variables using a geographic information system approach called GIS. The approach is carried out by combining the results of statistical analysis calculations into ArcMap to obtain the results of the distribution of spatial patterns of social and economic vulnerability in the Pekalongan Utara District.

2.3 Research variable

The research variables were obtained from the results of a literature review of several studies related to social and economic vulnerability. The results of the synthesis of the literature are represented in the elaboration of the synthesis of variables and indicators of social and economic vulnerability (Table 3.).

Table 3. Synthesis of Socio-economic Vulnerability Variables to theory according to Experts

Socioeconomic Vulnerability Index Variable	Source							Research variable
	Flanagan et al., 2011	Cutters 1995; 2000; 2003	Kumar et al., 2016	Birkman & Wiesner 2006	Wang & Shaw, 2018	Fatemi et al., 2017	Rufat et al., 2015	
Gender		✓	✓	✓	✓	✓	✓	1. Population Density 2. Gender/Gender 3. Age 4. Level of Education 5. Livelihoods/Job 6. Poor People
Age	✓	✓	✓	✓	✓	✓	✓	
Household composition/household structure	✓	✓				✓		
Population density	✓	✓			✓		✓	
special needs		✓		✓	✓			
Dependency ratio		✓		✓		✓		
Education	✓	✓	✓	✓		✓	✓	

Livelihoods/Income	✓	✓	✓	✓	✓	✓
Race/ethnicity and minorities	✓	✓				
Housing area	✓					
Transportation	✓					
Poor Residents		✓	✓		✓	✓

Adjustment of socio-economic vulnerability variables is adjusted to the availability of data and the study area in Pekalongan Utara District. This study uses 6 (six) main variables in measuring the level of socio-economic vulnerability in North Pekalongan District. The following is an explanation regarding the justification of research variables and their operational definitions:

1. Population density

Population distribution and density can be indicators of vulnerability. This indicates that a higher population concentration in an area reflects the density of the area, causing challenges and difficulties for residents in the evacuation process in the event of exposure to hazards (Johnson Jr and Zeigler, 1986; McMaster, 1988; Cova and Church, 1997).

2. Children and Seniors (Age)

Based on age, children and the elderly are vulnerable age groups. The condition of the vulnerable age group can be described by the condition of the unproductive age group, namely children (<15 years) and the elderly (>65 years). Children and the elderly in particular have difficulty moving and are more likely to have medical problems as a result of certain hazard exposure situations. (McMaster, 1988; O'Brien and Mileti, 1992; Flanagan et al., 2011).

3. Sex Ratio (Gender)

Gender can also be one of the more vulnerable social indicators of the population. sex comparisons indicate a vulnerable condition due to lack of access to resources and differential exposure (Liverman, 1990; Cutter, 1995; Fothergill, 1996; Enarson and Morrow, 1998). In particular, the female sex has a higher vulnerability than the male, this is due to their physiological and social disadvantages. (Morrow, 1999; Cutter, Boruff and Shirley, 2003).

4. Livelihood

Economic status determines a household's financial capacity to be able to bear losses resulting from exposure to hazards (Cutter, Boruff and Shirley, 2003; Hajra et al., 2017). Farmers and fishermen who work in the agricultural, fishery, mining and forestry sectors are considered as the main variables in viewing the condition of the vulnerability of types of livelihoods that are related to available natural resources. climate conditions will affect livelihoods that depend on natural conditions, as fishermen and farmers are more vulnerable to climate change.

5. Level of education

The level of education reflects a person's knowledge and skills and can significantly affect individual capabilities in reducing one's level of social vulnerability (Cutter, Boruff and Shirley, 2003; Holland, Lujala and Rod, 2011). The level of education consists of three levels, namely elementary, junior high and high

school. The level of education is largely determined by the level of educational graduates attained by residents in a Kelurahan.

6. Number of poor people

The poor are more vulnerable to certain hazards due to a lack of resources, poor housing quality, and an inability to recover quickly (Burton, Kates and White, 1993; Dasgupta, 1995). Wealthy households may experience greater material losses during hazard events, but such wealth allows them to be able to cope with large losses through insurance, social safety nets, and rights, and thus, recover more quickly from the effects of hazards (Cutter, Mitchell and Scott, 2000).

Table 4. Variables and Socioeconomic Vulnerability Scoring

No	Variable	Scoring			Explanation
		1	2	3	
1	Population density	Population Density 2,303 – 4,869 people/km ²	Population Density 4,870 – 7,435 people/km ²	Population Density 7,436 – 10,001 people/km ²	The population of the kelurahan is divided by the total area in km ²
2	Children and elderly (age)	Non-productive age ratio 0.265 – 0.287	Non-productive age ratio 0.288 – 0.310	Non-productive age ratio 0.311 – 0.332	Total ratio of non-productive age (children and the elderly) to the total population.
3	Sex Ratio (gender)	The ratio of the number of males and females >100	The ratio of the number of men and women = 100	The ratio of the number of males and females <100	Population ratio of the number of males and females (Males per 100 Females)
4	Livelihood	Proportion of farmers and fishermen in productive age 0.005 – 0.049	The proportion of farmers and fishermen in productive age is 0.500 – 0.093	The proportion of farmers and fishermen in productive age is 0.094 – 0.139	the ratio of the number of farmers and fishermen divided by the total productive age of the population
5	Level of education	Senior High School (SMA) is the highest level of education	Junior High School (SMP) is the highest level of education	Elementary school (SD) is the highest level of education	The level of education is determined by the majority of the level of education attained by the kelurahan population
6	Poor family	The proportion of the ratio of poor families is 0.045 – 0.098	The proportion of the ratio of poor families is 0.099 – 0.151	the ratio of poor families is 0.152 – 0.203	The total ratio of poor people based on city classification is divided by the total population.

The results of calculating the score are obtained from the highest total score and then classification of socioeconomic vulnerability is carried out which can be obtained using the formula:

$$\begin{aligned}
 \text{Class range} &= \frac{\text{Highest value} - \text{Lowest value}}{\text{number of class}} \\
 \text{Class range} &= \frac{14 - 9}{3} = 1 = 1
 \end{aligned}
 \tag{1}$$

Determination of socio-economic vulnerability class is done by calculating the highest score out of a total score of 14, the lowest score is 9, and the number of classes is divided into 3 classes. The total score results and class ranges are classified into 3 classes as shown in Table 5.

Table 5. Classification of Socio-Economic Vulnerability Classes

No	Classification of Socio-Economic Vulnerability Class	
	Vulnerability Level	Value Range
1	Low Vulnerability	9
2	Moderate Vulnerability	11-12
3	High Vulnerability	13-14

3. DISCUSSION AND DISCUSSION

Based on the scoring criteria in Table 4, the findings are then described for each variable of population density, the proportion of unproductive age (children and the elderly), sex ratio, level of education, livelihoods, and groups of poor people with the assumption that pre-prosperous families scattered in North Pekalongan District. The level of vulnerability of each variable can be seen in the following description.

3.1 Research result

The research results of this paper are in the form of a description of the level of vulnerability in 6 (six) variables. The discussion can be started with the Variable Distribution of Population Density and Productive Age Population in the seven kelurahan (village) as shown in Figure 3.

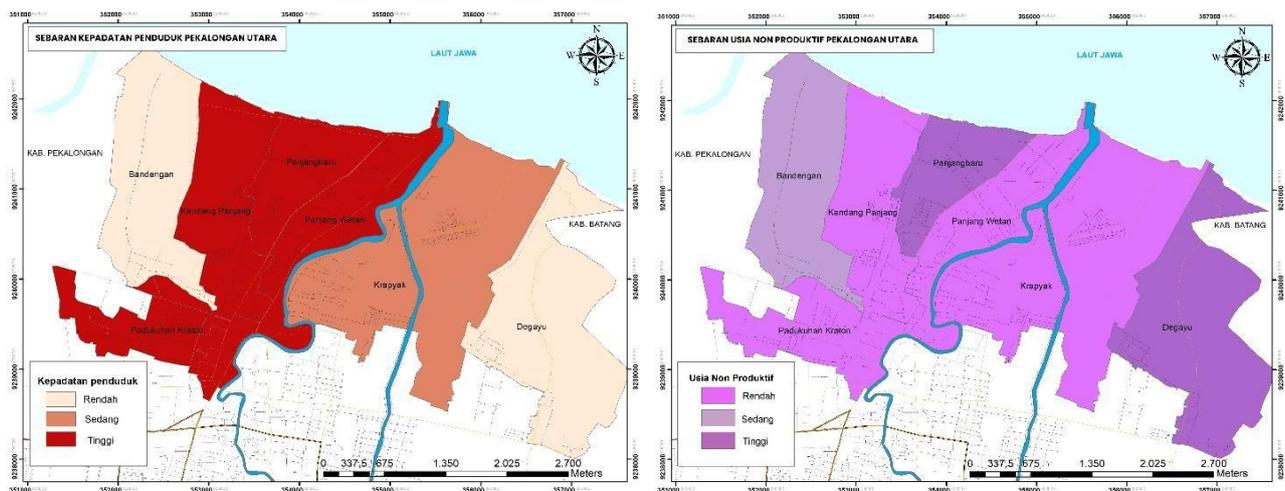


Figure 3. Spatial Pattern of Population Density and Vulnerable Communities (Children and Elderly)

Based on Figure 3, there are various patterns of distribution in terms of population density and vulnerable groups in society (children and the elderly). 4 (four) sub-districts have a high level of density, which are in the sub-districts of Panjang Wetan, Kandang Panjang, Panjang Baru and Padukuhan Kraton which are the most densely populated areas with a density of between 7,436-10,000 people/km². Meanwhile, Krapyak Village is at a moderate level with a density of between 4,870-7,435 people/km². It can be indicated that the Degayu and Bandengan sub-districts are less vulnerable to population density conditions, where the population density ranges from 2303-4869 people/km². Besides that, in Figure 3., it can be seen that there is an imbalance in the proportion of population density in the North Pekalongan District. This is indicated by the composition of the distribution of the population tends to be uneven so that it accumulates in one village. The high population density in an area will contribute value to a high level of social vulnerability in Pekalongan Utara District.

When looking at the variable of non-productive age, Degayu Sub-District together with Panjang Baru Sub-District are also areas of concentration of non-productive age. This kelurahan is included in the most vulnerable classification with a ratio of the proportion of unproductive age between the ratio values of 0.311 - 0.332.

Meanwhile, there is one sub-district that is included in the classification of moderate vulnerability with an unproductive age ratio, namely Bandengan Village. The proportion of the productive age ratio in Bandengan Village is in the range of 0.288 and 0.310. In this context, four sub-districts can be categorized as less vulnerable to the condition of the proportion of vulnerable ages, including Kelurahan Kandang Panjang, Panjang Wetan, Krapyak, and Padukuhan Keraton which have a low level of vulnerability with a proportion between 0.265 to 0.287.

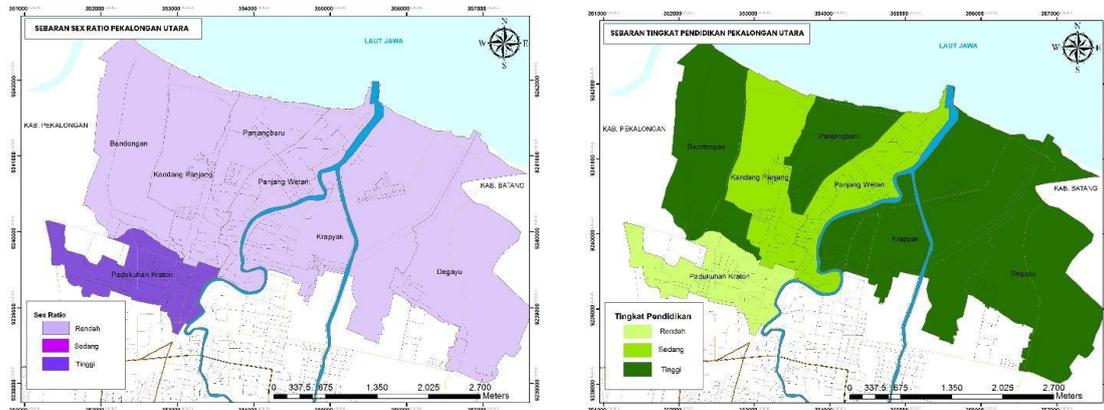


Figure 4. Spatial Pattern of Vulnerable Communities (Women) and Level of Education

This study also calculated the proportion of the ratio between the number of male populations to females. The approach taken is to count the number of males for every 100 females according to Table 4. above. From the available data, the Padukuhan Kraton Village has a larger proportion of women. Thus, the Padukuhan Kraton Village in this area is included in the high vulnerability category. Meanwhile, the other six sub-districts, Degayu, Krapyak, Kandang Baru, Kandang Panjang, Panjang Wetan, and Bandengan, are included in the low vulnerability category because they have a higher proportion of males than females.

In the context of education level, according to Table 4 regarding the scoring criteria, it can be stated that the lower the level of community education, the higher the level of vulnerability and vice versa. This is based on the argument that a high level of education will be directly proportional to the knowledge to survive and adapt. The ability to survive and adapt will reduce the level of vulnerability. From the available data above, it can be seen that Degayu, Krapyak, Panjang Baru, and Bandengan Villages have a high level of vulnerability because the population is dominated by elementary school graduates. While Kelurahan Panjang Wetan and Kandang Panjang are in the medium category because the population is dominated by junior high school graduates. Thus, only Padukuhan Kraton Village is in the low vulnerability category because most of the population has a high school education.

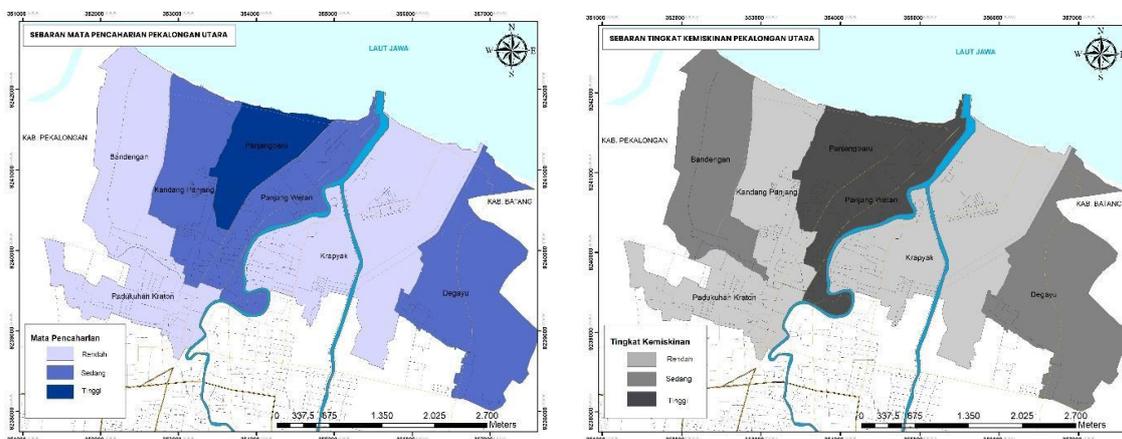


Figure 5. Spatial patterns of economic aspects (livelihood conditions and poverty levels)

Based on the vulnerability assessment from an economic perspective, another aspect studied related to vulnerability is livelihoods. The approach taken is through calculating the proportion of the number of farmers and fishermen to the total population of productive age. This is based on the assumption that the higher the proportion, the higher the level of vulnerability and vice versa. These livelihoods are sensitive to climate change stimuli as well as exposure to hazards that impact land productivity. Based on existing data and referring to Table 4, it is known that Kelurahan Kandang Panjang has a high level of vulnerability because the proportion is 0.940 to 1.170. While Bandengan and Panjang Wetan are included in the moderate vulnerability category because their proportions are between 0.710 -0.930. Thus other kelurahan are included in the low vulnerability category because the proportion of farmers and fishermen only ranges from 0.470 -0.70.

The last variable studied to determine the level of socio-economic vulnerability in the study area is the condition of poverty. The approach used in determining the poverty level is the ratio of the number of pre-prosperous families to the population. The lower the proportion, the better the level of social welfare and the lower the level of vulnerability. Vice versa. Based on the calculations carried out, it can be seen that the Panjang Wetan and Panjang Baru sub-districts are in the high vulnerability category because they have a proportion ratio of poor families between 0.152-0.203 while the Degayu Kelurahan which has a proportion ratio of poor families between 0.099-0.151 is categorized as moderate vulnerability. Thus, three sub-districts fall into the low vulnerability category, namely Kandang Panjang, Krapyak and Padukuhan Kraton because they have a proportion between 0.045-0.098.

Table 6. Socioeconomic Vulnerability Scoring Results

No	Kelurahan (Village)	Variable					
		Population Density (Person/Km ²)	Children and elderly (index)	Sex Ratio (gender)	Level of education	Livelihoods (index)	Poor families (index)
1	New Length	9,327 (Tall)	0.332 (Tall)	103.4 (Low)	Elementary Domination (High)	0.139 (High)	0.203 (High)
2	Wetan Length	10,001 (Tall)	0.265 (Low)	105.62 (Low)	Middle School Domination (Medium)	0.050 (Medium)	0.155 (High)
3	Long Cage	8,657 (Tall)	0.282 (Low)	101.85 (Low)	Middle School Domination (Medium)	0.029 (Medium)	0.093 (Low)
4	Degayu	2,303 (Low)	0.322 (Tall)	103.08 (Low)	Elementary Domination (High)	0.046 (Medium)	0.121 (Medium)
5	Krapyak	4,879 (Currently)	0.275 (Low)	103.08 (Low)	Elementary Domination (High)	0.043 (Low)	0.045 (Low)
6	Banding	2,786 (Low)	0.293 (Currently)	104.65 (Low)	Elementary Domination (High)	0.029 (Medium)	0.116 (Medium)
7	The Kraton Paddock	7,653 (Tall)	0.273 (Low)	98.87 (High)	SMA Domination (Low)	0.005 (Low)	0.090 (Low)

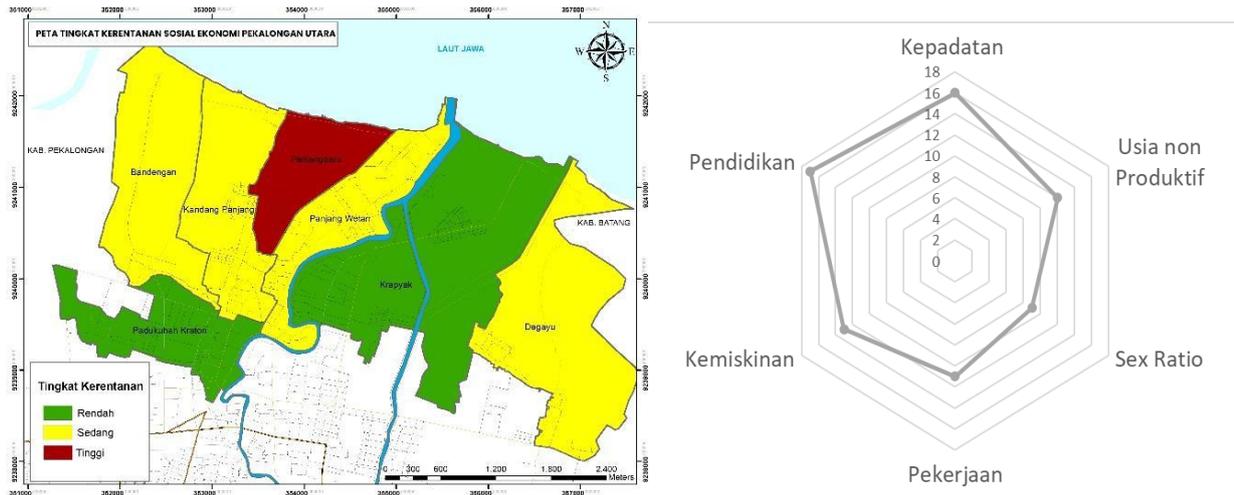


Figure 6. Radar Chart of Vulnerability Variable Scoring and Spatial Patterns of Socioeconomic Vulnerability

Based on the diagram above, it can be concluded that there are 6 (six) indicators or variables that can explain the condition of the level of socio-economic vulnerability in Pekalongan Utara District. The education level indicator is the indicator that contributes the most to the vulnerability score. In addition, indicators of population density, poverty or poverty and non-productive age make a significant contribution in assessing socio-economic vulnerability. When referring to the condition of the level of education, this shows that there are still very few people in North Pekalongan District who are highly educated. These conditions will have an indirect effect on other variables, especially the ability of the community to adapt to the dangers of exposure to tidal floods in North Pekalongan District. The condition of the level of education will have an influence on the economic condition of the community, especially the poor who are the most vulnerable to external factors.

Furthermore, high population density contributes a fairly high value to the level of vulnerability in Pekalongan Utara District. Areas that have a high density in areas prone to tidal flooding will experience difficulties in evacuating. In addition, areas with high density will be synonymous with slum settlements. The slums themselves will be interconnected with disturbances in the regional supporting infrastructure systems such as roads, drainage, and sanitation. This condition will have an impact on public health in Pekalongan Utara District.

Furthermore, several indicators have relatively low contribution values among other variables such as *sex ratio*, vulnerable age (elderly and children), and livelihoods. The proportion of sex or gender in North Pekalongan Sub-District experienced a difference from previous years, where the proportion of the male sex was higher than that of the female sex. This condition causes the value contribution given to tend to be low because the proportion of male sex is higher, it can be concluded that community resilience will be better against exposure to tidal flood hazards. This also applies to the non-productive age which contributes a low value, because the proportion of non-productive age tends to be low. The low proportion of vulnerable age will affect the value of vulnerability so that regional responsibility for vulnerable age groups becomes lighter. Meanwhile, in the context of the sex ratio concerning education, the majority of primary and junior high school graduates are women. This fact shows another problem, namely gender equality in education. Although not revealed in this study, social norms that consider education less important for women need to be changed.

Classification is carried out into 3 vulnerability classes spread across 7 (seven) Sub-Districts. Based on the results of the analysis calculation, it is known that those included in the high vulnerability level classification are in Panjang Baru Village, then those included in the moderate level of vulnerability are in Bandengan Village, Kandang Panjang Village, Panjang Wetan Village, Degayu Village, and lastly, those that enter the level low vulnerability, namely Krapyak Village and Padukuhan Kraton Village. The results of the analysis have been supported by validation through field observations, where the new Long Village has a high level of

vulnerability because the area is a densely populated residential area and there are still slums in it. Sub-districts with a low level of vulnerability (Krapyak and Padukuhan Kraton) have the potential for strong community social capital because the majority of the population has graduated from higher education and the majority of the population works outside the agricultural and fishing sectors. This shows that the economic conditions in Krapyak Village and Padukuhan Kraton have a good indication of adapting to tidal flood hazard conditions.

3.2 Discussion

Socio-economic vulnerability research in the context of urban development presents a process for identifying, categorizing, calculating, ranking vulnerabilities, and mapping the distribution of vulnerabilities in an area. Based on the data presented in this study, previous work has considered the social, economic, and other supporting aspects as the main variables and indicators. Based on the research results, it is known that there are three classifications of vulnerability levels in Pekalongan Utara District. The educational level variable contributes a strong value in assessing the level of socio-economic vulnerability. Meanwhile, the gender variable through the gender ratio contributes a low value in determining the value of the socio-economic vulnerability level. The new Kelurahan Panjang area has the highest vulnerability value among the other five kelurahan, where the kelurahan has a high population density, the community is dominated by low levels of education, the number of fishermen and farmers is high which affects the high number of poor families.

Adger et al (2007) argue that the livelihoods of people in vulnerable areas are an important aspect in assessing vulnerability and need to be elaborated further because it relates to food insecurity in coastal areas. In line with that, Ahsan and Warner (2014) again stated that community livelihoods and capacity are important challenges that must be faced in balancing the ability to recover from changing conditions and pressures, especially tidal floods due to climate change. In addition, Flanagan et al (2011) argue that regional recovery which tends to be slow is influenced by education level, age, poverty, and population density, this will have an impact on the capacity and capability to recover from the threat of disaster. the vulnerability of the social group concerned depends on their resilience capacity (Malakar and Mishra, 2016). The capacity of individuals and social groups when facing pressure from changing environmental conditions will most likely affect their livelihoods.

Based on some of the results of this perspective, it provides two main implications. First, it has implications for community resilience. Seeing the tendency for coastal urban areas in Java Island to have the same characteristic issues, the use of data from the results of socio-economic vulnerability assessments can assist in formulating policy decisions. The capacity and capability of the community will affect the implications of community resilience in recovering and adapting to the threat of disaster hazards to changes in environmental conditions. then the second implication is that the results of this study have implications for urbanization and sustainability. Handayani et al (2017) stated that the phenomenon of massive urbanization in the northern coastal region of Central Java should diversify livelihoods. This will help them create resilience and sustainability from a socio-economic standpoint. In addition, Faniza and Pradoto (2019) argue that developing coastal areas have great social vulnerability seen in the case of Semarang City, this again shows that the increasingly developing north coast of Java puts pressure on the social aspects of society. In line with this research, North Pekalongan is a coastal area affected by tidal floods, which has an overview of the distribution of social and economic vulnerability which is dominated by moderate to high vulnerability. Therefore, resource allocation must consider important factors in reducing vulnerability in tidal flood prone areas.

Research on social and economic vulnerability often discusses regional vulnerability at a macro scale (cities with more than a million inhabitants) concerning urbanization (Handayani, et al, 2017). Livelihoods from fishermen to other sectors are an indication of changes in coastal areas that are undergoing urbanization (Handayani and Kumalasari, 2015). Meanwhile, Jabareen (2006) argues that population density is an aspect that determines urban survival. North Pekalongan is a sub-district located in a medium-scale city with growing coastal characteristics. Vulnerability research on this micro-scale can be a lesson about social and economic vulnerability, especially in coastal areas affected by tidal floods.

Future study studies will explore how this socio-economic vulnerability assessment can be used as part of the equation regarding preparedness in disaster hazard mitigation. In addition, according to Flagnan et al (2011) this social vulnerability assessment can assist again in targeting disaster management interventions, especially from the socio-economic aspect. presentation of the results of the assessment through mapping of socio-economic vulnerability provides an overview of the spatial distribution in areas that are prone to the threat of flood disasters. The description of the spatial distribution also helps in the process of formulating policies so that the planning program that is carried out does not run partially and completely. The process of assessing the level of vulnerability uses measuring tools that are common, flexible and easy to understand to enable other researchers to be able to provide easily accessible data in various conditions and research areas.

However, using a socio-economic vulnerability assessment has several limitations in seeing the condition of people in vulnerable areas. One limitation is the composition of some small populations which can change rapidly in subsequent years. This limitation can be triggered by government programs related to the control of slum areas which have an impact on the relocation of several communities in the area. therefore it is necessary to make similar research adjustments in response to the possibility of urban regeneration in Pekalongan City. In addition, the use of secondary data in this study is a limitation in exploiting social conditions from the direct perspective of the people in North Pekalongan sub-district. the perspectives of people in vulnerable areas such as community perceptions to social capital are the next important discussion to be studied in more depth.

4. CONCLUSION

This research study uses several combinations of data and information through institutional secondary data that are adjusted to the characteristics of the research area to assess socio-economic vulnerability to tidal flood hazards. Vulnerability assessment is carried out using a quantitative process, namely using the scoring method and normalizing the value of each variable. The vulnerability assessment method provides an opportunity to understand how socio-economic variables can play a role in determining the relationship between the phenomenon of urbanization and the hazard of tidal floods due to climate change.

Based on the findings, it was found that the level of social and economic vulnerability to the tidal flood hazard in Pekalongan Utara District was divided into three vulnerability categorization classes. The new Panjang Sub-district received the highest vulnerability score, the Padukuhan Kraton Sub-district received the lowest vulnerability score, and four other sub-districts such as Panjang Wetan Sub-District, Bandengan Sub-District, Kandang Panjang Sub-District and Degayu Sub-District were included in the moderate vulnerability category. In addition, the value contribution that most influences the value of socio-economic vulnerability is education, population density, and poor families. Judging from the results of the assessment, the Panjang Baru sub-district has the highest level of vulnerability because the sub-district has a low level of education, a high population density, a high number of poor people and a high proportion of pond farmers and fishermen among the 6 other sub-districts.

Therefore, the findings provide evidence that gives a broad meaning related to the socio-economic conditions of coastal communities that can have implications for the readiness of an area in creating community resilience in areas prone to tidal floods. In addition, resource allocation and regional growth are also important for maintaining the environment and socio-economic balance of the people of Pekalongan Utara District. Therefore, the most important thing is how to reduce vulnerability due to tidal flood hazards. limitations in this study are the use of secondary data and the composition of the small population. The involvement of primary data needs to be continued in further research, especially to find out community perceptions regarding social capital, capacity, and capability in depth at the same scope scale so that future researchers get a real picture of the community in North Pekalongan District. Thus, this research provides the data needed to make new efforts to overcome and mitigate the dangers of tidal floods due to climate change from a socio-economic perspective, especially in the northern coastal cities of Java Island.

5. ACKNOWLEDGMENTS

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Experimental Study of Precast Beam Joints Using Steel Plates in Beam-Column Joints Due to Cyclic Loading

Hanafi Ashad¹

¹Department of Civil Engineering, Universitas Muslim Indonesia Makassar, South Sulawesi, Indonesia
E-mail: ¹hanafi.ashad@umi.ac.id

Abstract

In seismic design, reinforced concrete structures must perform well under heavy load conditions. To withstand large lateral loads without severe damage, structures require strength and energy dissipation capacity. It is generally not economical to design reinforced concrete structures to the greatest possible ground motions without damage. Therefore, the need for ductility must be weighed against economic constraints. This research is focused on dry joints where the joints are on beams in the plastic hinge area and modeled using steel plates, this modeling will be compared with the hysteresis and ductility curves in three types of specimens namely BU-1 without using plate joints, BU-2 using plate joints measuring 300mm x 400mm, BU-3 plate joints measuring 200mm x 400mm, with the same thickness and quality, namely 8mm thick and Fu 370 MPa. To strengthen the use of the plate connection, A325 bolts with a diameter of 12 mm and Fu 620 MPa are used. The results show that the pinching effect is found in the hysteresis curve of the BU-2 and BU-3 specimens. Meanwhile, for the ductility test at peak load, namely the seventh ductility for BU-1, the value is still better than BU-2 and BU-3. These results can still be improved with several variations of plate thickness, for this reason, further studies are recommended to develop and increase recommendations for several variations of plate joints, because precast joints, especially dry joints, are still the focus of research, especially in Indonesia.

Keywords

beam-column joint; precast concrete; cyclic loading; steel plate.

1. INTRODUCTION

The use of precast systems for buildings has experienced very rapid development in the world, including in Indonesia in the last decade. Its use is growing rapidly based on several advantages, such as saving processing time, resulting in relatively better efficiency and quality (Elliot, 2016; Wahjudi et al., 2019).

In seismic design, reinforced concrete structures must perform well under heavy load conditions. To withstand large lateral loads without severe damage, structures require strength and energy dissipation capacity. In general, it is not economical to design reinforced concrete structures to the greatest possible ground motion without damage. Therefore, the need for strength and ductility must be weighed against economic constraints. Ductility is an important property of structures that respond inelastically during earthquakes. Ductility is defined as the ability of sections, members, and structures to deform inelastically without excessive degradation of stiffness or strength (KR & GS, 2012).

Joints play an important role in providing structural integrity. Lack of understanding, poor connection design, and neglecting the actual response of joints in structural analysis can lead to inadequate structural design and consequently disaster (Hashim & Agarwal, 2018). This requirement becomes critical in precast construction systems where strength is largely governed by joint capacity. Ellingwood (2007) explained that realistic continuity of load paths between elements through joints can improve structural integrity and stiffness and limit collapse rates.

Beam-column joints are an important element of reinforced concrete structures, especially in earthquake areas. During an earthquake, the beam-column joints are subjected to axial, vertical and horizontal shear stresses through seismic forces, their behavior has a significant influence on the earthquake response of the building causing cyclic motions (Ravikuram & Kothandaraman, 2022; Ahmad et al., 2022; Moehle & Mahin, 1991). Kassem et al. (2022) explained that the lateral forces induced by shear stresses cause diagonal cracks in the joints, resulting in shear failure of the joints. Initially, the beam reinforcement yielded due to

the earthquake force, then the reinforcement in the joint area yielded and bond slip caused a decrease in the strength of the connection.

The ductile properties of a structure can be achieved by considering the stability of the structure during an earthquake. The plastic hinges within a building structure can only occur at the ends of the beams and the column base, and shear walls (Park, 1995; Paulay et al., 1978). Strong connection system can behave elastically in the event of fatigue or collapse outside the joint. Meanwhile, the ductile connection system can experience inelastic deformation. This ductile joint can reduce residual displacement due to drift damage and prevent inelastic deformation (Priestley, 1997; Hawkins & Ghosh, 2000).

Within the elastic boundary where the formation of a plastic hinge will occur in the beam, it is due to its natural ductile behavior. Also, it does not cause global or partial mechanism formation. However, when the plastic hinge is developed in front of the column or the end of the beam, directly related to the joint, it will experience an inelastic joint (Council, 2009). Therefore, the plastic hinge formation should ideally be away from the joint's surface. This is impossible unless special measures are taken to ensure this, making precast systems challenging to develop and inefficient. This efficiency affects the behavior of the joint system, which will transfer the force carried by one part of a structure to another so that the entire construction will bear external force treatment by the behavior of each element. Thus, precast concrete combined with various types of joints must be ductile to lateral and vertical loads (Shariatmadar & ZAMANI, 2014) and to overcome building failure requires the addition of diagonal and straight reinforcement as well as the use of reinforcing thread (Lu et al., 2012; Fernandes et al., 2013) where damage to the common area can be prevented. The earthquake-resistant building regulations of various countries to date still maintain the ductility requirement. Furthermore, beam-column joint reinforcement detail depends on the aspect of detail, strength, and serviceability.

Many experimental and numerical studies were carried out to understand the behavior of beam-column joints due to seismic forces and affect the strength parameters of the joints. Hanson and Connor (Hanson et al., 1967) were pioneers in understanding the behavior of beam-column joints. The experimental results are defined as the horizontal joint shear. Park and Paulay (Park and Paulay, 1973; Park & Paulay, 1991) describe a joint shear retaining system with two mechanisms namely the strut mechanism is the shear force supported by the diagonal section of the concrete to resist the joint shear and the truss mechanism is the shear force supported by vertical and horizontal reinforcement through the bond between the concrete and the reinforcement. after the crack occurred. Other studies have also proposed this mechanism system in predicting joint shear strength and beam column joint behavior (Kim & LaFave, 2008; Yu & Tan, 2014).

In recent decades, several studies have focused on understanding how beam-column joints respond to seismic action (Aycardi et al., 1994; Bracci et al., 1995; Melo et al., 2022). In addition, some earthquake codes have undergone repeated improvements to their implementation. ACI recommended beam-column connection design (ACI-ASCE, 1976) takes inelastic deformation into account. Connection design procedures, detailed proposals for resistance to gravity loads, seismic loads, and the interaction of forces in all directions at the joints of the frame structure. Cyclical behavior and deformation capacity, attachment, and length of reinforcement in beam-column joints.

The precast system at the member connections must be designed in such a way as to have the desired behavior. Structural elements are affected by joints where the connection will transmit the force carried by one part of the structure to another so that the entire construction will be subjected to external force treatment in accordance with the behavior of each element. Then the construction of the connection will occur a complex behavior (Hasan, 2011). So precast concrete which is combined with various types of joints must be ductile against lateral and vertical loads.

Steel plate connection system in several studies, among others. Dessouki et al. (2013) configuration of joint behavior with the ANSYS program in his research identified the effect of plate thickness, bolt diameter, beam height then produced yield line analysis to propose an equation for plate bending capacity. Van-Long et al. (2013) in his test using a circular profile using a steel plate connection to predict the strength of the connection by bending test compared to the results of finite element analysis. Mohamadi-Shoore et al. (2013) the use of hollow profiles with connection modeling using steel plates in his research on the investigation of geometrical characteristics by finite element analysis then produces moment and rotation relationships.

The above research concentrated on steel construction. While research on precast concrete using plate joints including Zhisheng (2013) implementation of precast concrete using plate joints with flexural strength testing and exterior joints the results of his research on cracking, stiffness analysis, energy dissipation. Cheng et al. (2015) applied plate joints to beam-column reinforcement, the results of his research on cracking, hysteresis behavior and ductility analysis.

From the above review, it was concluded that congested areas of reinforcement always create difficulties during erection. In addition, beam-column joints are prone to earthquakes due to bending moments and reverse shear forces. The shear forces induced in the joint area are usually five times the column shear forces (Lin & Restrepo 2002). On the other hand, in frame structures that only adopt beam-column joints, precast components can be very heavy and difficult to transport due to their larger dimensions. With a complete frame configuration of beam-column joints, dense reinforcement details are fabricated. Reinforcement continuity will further enhance integrity and prevent failure (premature failure). Most importantly, the condition where the location of the plastic hinge coincides with the critical joint area can be avoided by requiring joint strength.

This research is focused on dry joints where the joints are on beams in the plastic hinge area and are modeled using steel plates. The principle of stress distribution in beams using steel plate joints has similarities with conventional beams, the force received on the beam, namely the upper reinforcement when compressive loading will be transmitted to the connection through the steel plate. The steel plate will receive force while the shear force is transmitted to the bolt. In the connection the role of the main reinforcement such as a conventional specimen will be replaced by using a steel plate connection, where the plate dimensions are higher than the cross section being joined, the bolt installation is higher, so that the moment-resisting force arm is greater than the moment arm load on the cross-sectional flange plate (Yu & Tan, 2014; Melo et al., 2022). As illustrated in Figure 1. Based on this hypothesis, the behavior of precast concrete beams is expected to be like conventional beams.



Figure 1. Steel plate joint model

The advantages of using this plate connection, are: (1) Can be machined quickly and safely, significantly increasing the efficiency of the structure; (2) Can optimize the performance of the structure and can be used in the repair of the structure, because the construction and direction of force is clear and simple.

2. EXPERIMENTAL PROGRAMME

2.1 Specimen Design

In this study, the prototype structure was taken from a plane frame structure, the height per floor was 4.0 m, and the distance between columns was 4.0 m. for more details, illustrated in Figure 2.

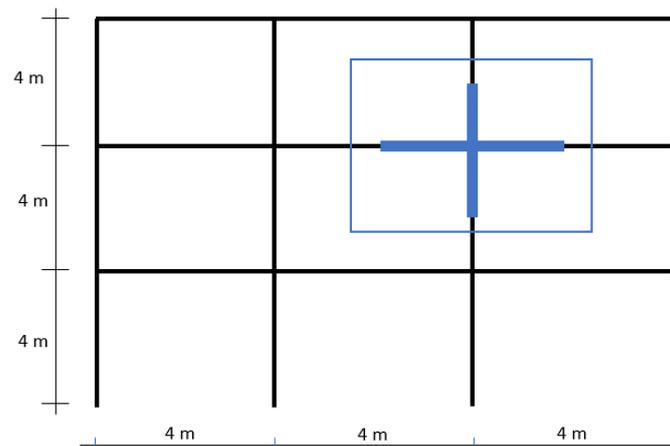


Figure 2. Representation of specimen

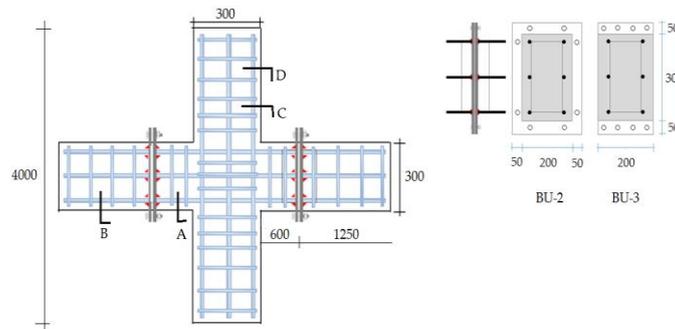


Figure 3. Beam-column dimension and steel plate connection models (BN-2 and BN-3)

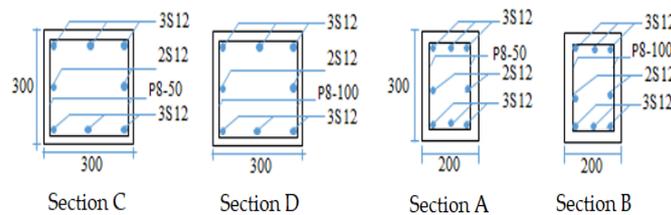


Figure 4. Beam and column reinforcement

The design parameters in figure 3, 4 use three types of test objects, namely BU-1 without using plate joints, BU-2 using plate joints measuring 300 mm x 400 mm, BU-3 plate joints measuring 200 mm x 400 mm, with the same thickness and quality, namely thickness 8mm and $F_u = 370$ MPa. To strengthen the use of the plate connection, A325 bolts with a diameter of 12 mm and $F_u = 620$ MPa are used.

2.2 The Specimen Manufacturing Process

In general, the manufacturing process is fully carried out at the Structural Laboratory of Hasanuddin University, Faculty of Engineering, Department of Civil Engineering, Gowa, South Sulawesi - Indonesia. The manufacturing process, as illustrated in Figure 5.

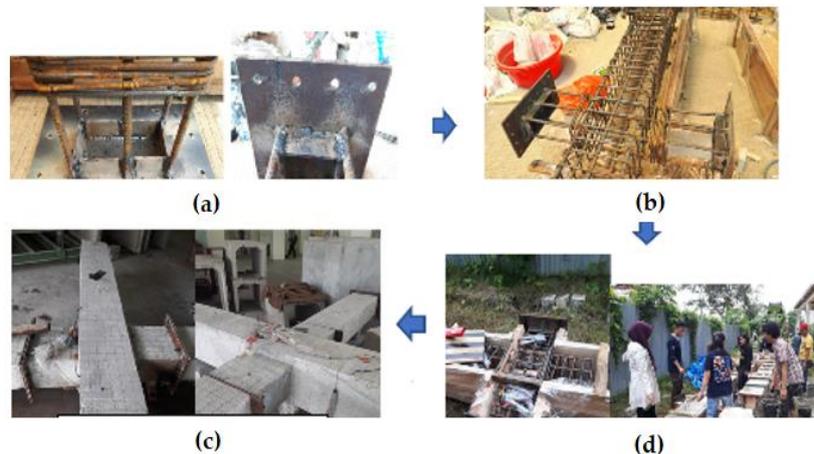


Figure 5. Specimen manufacturing process

Figure 5. explains, a) the steel plate assembly stage, b) the plate is welded with reinforcement before casting, c) the casting stage, and d) the connection to connect precast using bolts.

2.3 Mechanical Properties of Concrete

The mechanical properties of concrete on compressive strength and modulus of elasticity on cylindrical specimens at the age of 28 days can be seen in Tables 1 and 2 as follows.

Table 1. Concrete compressive strength

Description	Plan (MPa)	Result (MPa)
Normal concrete	25	27.40
Grouting concrete		47.19

Table 2. Modulus of elasticity of concrete

Description	Load (N)	Stress (MPa)	Strain
Normal concrete	211760	26.98	$4,57 \times 10^{-4}$
Grouting concrete	289120	36.83	$5,82 \times 10^{-4}$

Table 1. Shows that normal concrete quality meets the planned criteria, while grouting concrete is used in joint areas. For Table 2, comparison of the value of stress to strain at the level of 40% concrete compressive strength, the modulus of elasticity for normal concrete is 22780.54 MPa and for grouted concrete is 24638.52 MPa.

3. METHOD AND TEST SETUP

3.1 Method

The test method is based on ECCS (1986), this method describes the procedure system applied, for example, if it is called a complete test procedure (requires three specimens, two for a monotonic test and one for a cyclic test), if it is called a short test procedure (requires only one specimen for cyclic test). For economic reasons, the second procedure is preferred.

Assuming that there is a lack of initial references regarding elastic load (F_{y+} ; F_{y-}) and elastic displacement (δ_{y+} ; δ_{y-}) it is necessary that the displacement step is small enough to ensure that at least four levels of displacement are applied before the elastic displacement is reached. In this procedure the elastic load is defined as the intersection of the modulus tangent (E_{t+} ; E_{t-}) on the initial force transfer curve evaluated from the first cycle and the tangent to the envelope curve of the cycle with a slope of 10% from the initial modulus tangent as illustrated in Figure 6.

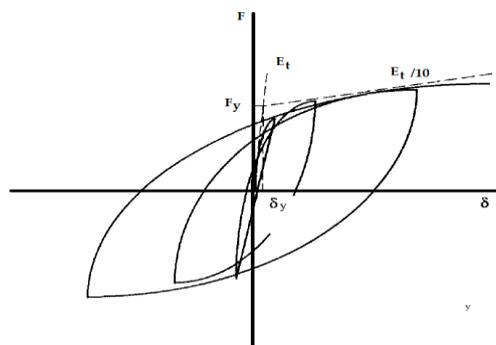


Figure 6. Yield limit reference (ACI Committee, 2005)

The test object is said to perform well if it is fulfilled in both directions of response (ACI Committee, 2005):

- The specimen must achieve a minimum lateral resistance of (E_n) before its 2% drift ratio exceeds a value consistent with the allowable deviation ratio of applicable seismic regulations.
- The maximum lateral resistance (E_{max}) recorded in the test should not exceed the value (λE_n), where λ is the required overstrength of the test column.
- For cyclic loads at the maximum deviation level that must be achieved as a reference for acceptance of test results, where the value cannot be less than 0.035, the third full cycle characteristic at the deviation level must comply, as follows:
 1. The peak force in the direction of the applied load must not be less than 0.75 (Maximum) in the direction of the same load (figure 7a);
 2. Energy dissipation shall not be less than 1/8 (figure 7b);

3. The secant stiffness of the line connecting the drift ratio -0.0035 to $+0.0035$ drift ratio must be not less than 0.05 times the initial stiffness (figure 7c).

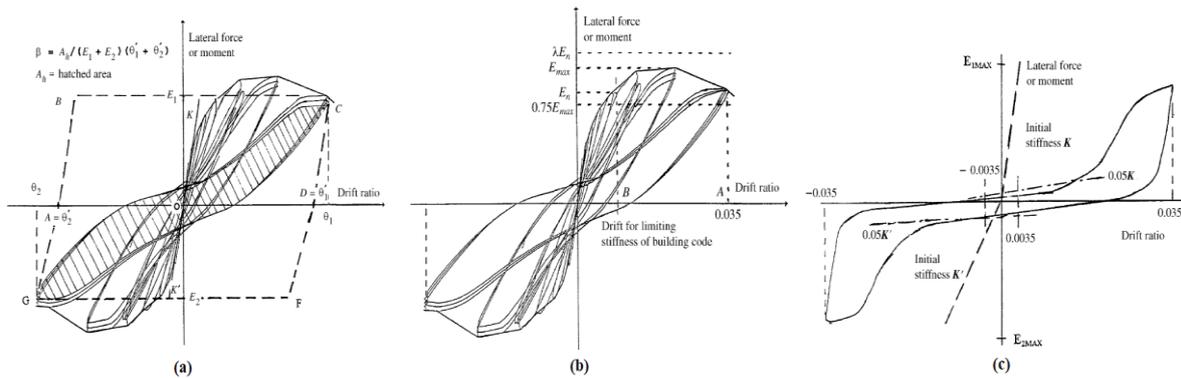


Figure 7. Performance response

3.2 Test Setup

In the ECCS recommendation (1986), which was explained above, if the procedure is simplified, the displacement value (δy) is predicted by the analytical model. Cyclic testing is designed to have a loading pattern as displacement control, as follows:

- One cycle at intervals $\delta y^+/4$ and $\delta y^-/4$
- One cycle at intervals $2\delta y^+/4$ and $2\delta y^-/4$
- One cycle at intervals $3\delta y^+/4$ and $3\delta y^-/4$
- One cycle at intervals δy^+ and δy^-
- Three cycles at intervals $2\delta y^+$ and $2\delta y^-$
- Three cycles at interval $(2+2n) \delta y^+$ and $(2+2n) \delta y^-$ ($n=1,2,..etc$)

Then, cycles and intervals are added based on the needs.

The above description explains that the increase in the next cycle is $\delta y/4$, $2 \delta y/4$, $3 \delta y/4$, $(2+2n)\delta y$, where $n=1,2,3$, etc. While $2\delta y(2+2n)\delta y$ is planned with short procedure, as illustrated in Figure 8. The ECCS concept is prepared for full cycle loading with tensile and compressive forces as well as positive and negative displacements. The negative displacement of the component under test is outside the accuracy of the transducer. The minimum displacement value is taken as zero, $\delta y = 0$. The compressive force in the next cycle returns the specimen to zero displacement after reaching its elastic limit.

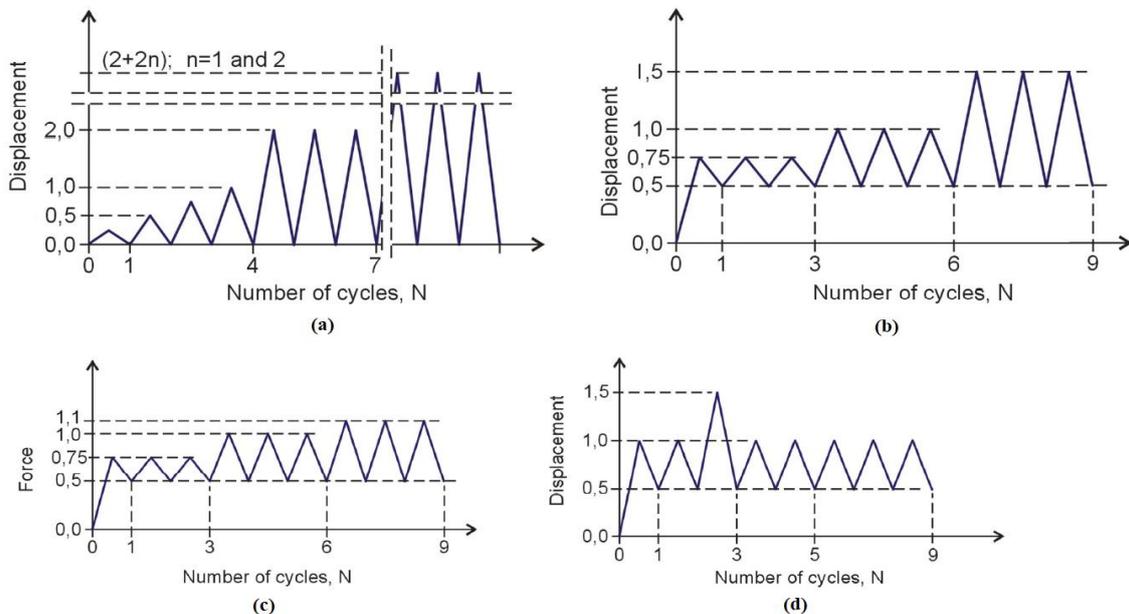


Figure 8. Illustration of a loading pattern (ECCS, 1986; Budziński & Ślęczka, 2020), (a) Loading pattern as recommended by ECCS, (b) Repeated with displacement control, (c) Repeated with load control, (d) Repeated with excess load in the third cycle.

Figure 8(a) it is explained that the record contains several cycles in the elastic range, followed by a group of three cycles of increasing amplitude, with unloading to a zero value with a displacement control pattern. As a reference level, a displacement value corresponding to a characteristic one turn of the screw is accepted. Displacement references obtained during monotonic loads in each group of specimens tested. Furthermore, it is assumed that the load recording is repetitive, with groups of three cycles whose amplitude increases, with un-loading up to a certain level (not equal to zero). In the case of the record in figure 8(b) loading is controlled by displacement and the degree of unloading is equal to 0.5 at displacement. In the case of the records of figure 8(c) loading is controlled by force and the degree of unloading is equal to 0.5 at displacement, characteristic of the group of specimens under consideration. This load scenario is supposed to simulate a typical load record, where the maximum value of the load is derived from the sum of the permanent and variable actions. The final loading record in figure 8(d) simulates the joint overload in the third cycle outside the elastic range and after that repeated loads with smaller amplitudes.

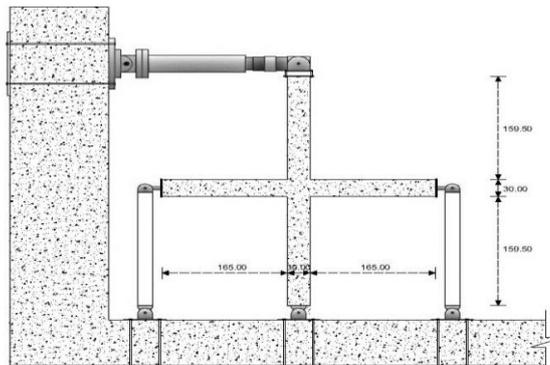


Figure 9. Schematic view (dimensions in mm)



Figure 10. Specimen photo display

Figure 10 can be explained as follows:

- Actuators; used to measure level loads or cyclic horizontal shear forces
- Strain gauges; strain gauges, either installed in reinforcement (Type FLA 6-11) or in concrete (Type PL 60-11)
- LVDT; displacement transducer
- Load cells; force meter circuit
- Logger data; Observe and record the load that occurs

In ECCS [34] divided ductility, calculated by the following equation.

Partial Ductility:

$$\mu_{oi}^+ = \frac{e_i^+}{e_v^+} \quad (1)$$

$$\mu_{oi}^- = \frac{e_i^-}{e_v^-} \quad (2)$$

Full Ductility:

$$\mu_i^+ = \frac{\Delta e_i^+}{e_v^+} \quad (3)$$

$$\mu_i^- = \frac{\Delta e_i^-}{e_v^-} \quad (4)$$

where:

e_i^-, e_i^+ is limit deviation.

$\Delta e_i^-, \Delta e_i^+$ is total of limit deviation.

e_v^-, e_v^+ is deviation in the yield condition.

The above equation can be represented in the form of a curve, as illustrated in Figure 11 below.

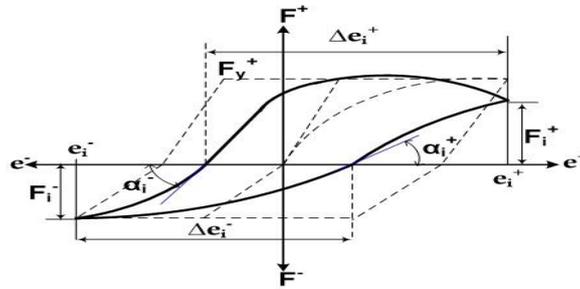


Figure 11. Value of the characteristic moment-displacement curve

4. RESULTS AND DISCUSSION

4.1 Hysteresis Curve

The hysteresis curve, which is illustrated in Figure 12. The x axis represents displacement, and the y axis represents loading. The peak line of the first cycle on the hysteresis curve per cycle of load is the skeleton curve.

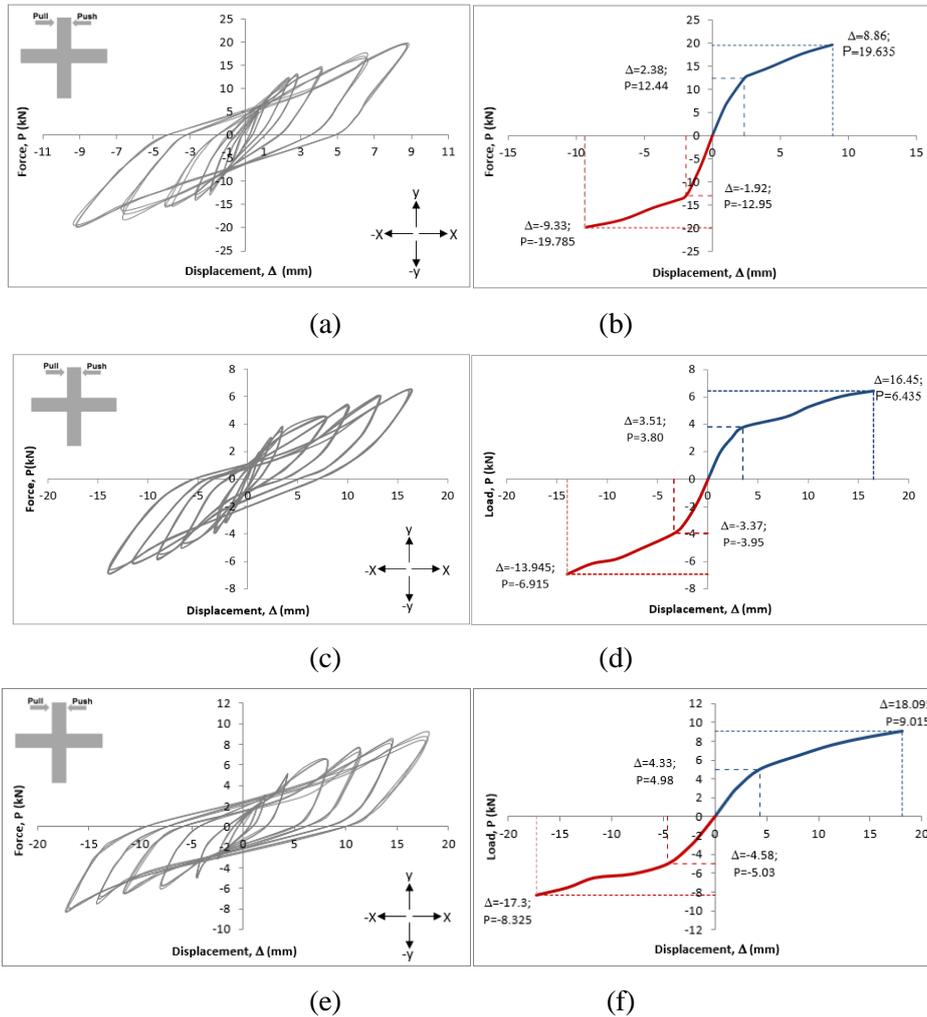


Figure 12. Hysteresis curve; (a) Hysteresis curve for BU-1; (b) Skeleton curve for BU-1; (c) Hysteresis curve for BU-2; (d) Skeleton curve for BU-2; (e) Hysteresis curve for BU-3; (f) Skeleton curve for BU-3.

Based on the hysteresis curve in Figure 12. Shows a significant difference compared to the test object (BU-1). In addition, the pinching effect on the two specimens (BU-2 and BU-3) where the greater the deformation, the smaller the ability to withstand loads, as well as the ability of the specimens (BU-2 and BU-3) to carry loads on the plastic condition is smaller when compared to the test object (BU-1). This is not in accordance with the plans and hypotheses that have been made. The precast specimen does not behave like a monolithic structure which can be deformed collectively. The dominant behavior that occurs is the movement of the beam against the joint on the surface of the steel plate, when a horizontal force is applied to the column, the behavior of the movement of the steel plate joint on the beam forms a rotational deformation.

4.2 Ductility for Beam-Column Joints Test

Ductility is the ability of a structure to undergo repeated alternating inelastic deformations beyond its first yield point, while retaining a large amount of its load-bearing capacity. Data analysis refers to the ECCS standard.

From equations 1 and 2, the partial ductility results are presented in tabular form, as follows.

Table 3. Partial Ductility for BU-1

Ductility number	Push			Pull			$m_{average}$
	e_i^+ (mm)	e_y^+ (mm)	m_{oi}^+	e_i^- (mm)	e_y^- (mm)	m_{oi}^-	
1	0.72		0.30	-0.70		0.36	0.33
2	1.17		0.49	-1.20		0.62	0.56
3	2.38		1.00	-1.92		1.00	1.00
4	2.84	2.36	1.19	-2.73	-1.92	1.42	1.31
5	4.16		1.75	-4.37		2.28	2.01
6	6.64		2.80	-6.65		3.46	3.13
7	8.86		3.73	-9.33		4.86	4.29

Table 4. Partial Ductility for BU-2

Ductility number	Push			Pull			$m_{average}$
	e_i^+ (mm)	e_y^+ (mm)	m_{oi}^+	e_i^- (mm)	e_y^- (mm)	m_{oi}^-	
1	1.18		0.33	-1.02		0.30	0.32
2	2.34		0.34	-2.29		0.68	0.67
3	3.51		1.00	-3.37		1.00	1.00
4	7.76	3.51	2.13	-6.64	-3.37	1.97	2.09
5	10.14		2.89	-9.09		2.97	2.79
6	13.30		3.79	-		3.42	3.61
7	16.45		4.69	-		4.14	4.42

Table 5. Partial Ductility for BU-3

Ductility number	Push			Pull			$m_{average}$
	e_i^+ (mm)	e_y^+ (mm)	m_{oi}^+	e_i^- (mm)	e_y^- (mm)	m_{oi}^-	
1	1.34		0.31	-1.46		0.32	0.31
2	2.15		0.49	-2.49		0.54	0.52
3	4.33		1.00	-4.58		1.00	1.00
4	8.20	4.33	1.89	-8.04	-4.58	1.76	1.82
5	11.40		2.63	-		2.55	2.59
6	14.59		3.37	-		3.12	3.24
7	18.10		4.18	-		3.78	3.98

The partial ductility above, specimen of BU-1, BU-2 and BU-3, gives an upward graph, starting from the 1st to the 7th ductility. The largest value was given to BU-2 which gave a yield of 4.42, compared to BU-1 which was 4.29, while BU-3 experienced a decrease in value of 3.98.

The full ductility test is given in the following table.

Table 6. Full Ductility for BU-1

Ductility number	Push			Pull			$m_{average}$
	D_{ei}^+	e_y^+	m_i^+	D_{ei}^-	e_y^-	m_i^-	
	mm	mm		mm	mm		
1	0.73		0.30	-0.86		0.44	0.38
2	1.45		0.61	-1.87		0.82	0.71
3	2.83		1.19	-2.63		1.37	1.28
4	3.67	2.38	1.54	-3.37	-	1.95	1.75
5	5.65		2.38	-5.81	1.92	3.03	2.70
6	9.74		4.10	-		5.25	4.68
7	13.00		5.47	-		7.30	6.39

Table 7. Full Ductility for BU-2

Ductility number	Push			Pull			$m_{average}$
	D_{ei}^+	e_y^+	m_i^+	D_{ei}^-	e_y^-	m_i^-	
	mm	mm		mm	mm		
1	1.32		0.38	-1.37		0.40	0.39
2	2.64		0.75	-2.83		0.89	0.80
3	4.36		1.24	-4.52		1.34	1.29
4	9.83	3.51	2.80	-8.87	-	2.63	2.72
5	13.44		3.83	-	3.37	3.77	3.80
6	17.40		4.96	-		4.96	4.96
7	21.77		6.21	-		6.25	6.23

Table 8. Full Ductility for BU-3

Ductility number	Push			Pull			$m_{average}$
	D_{ei}^+	e_y^+	m_i^+	D_{ei}^-	e_y^-	m_i^-	
	mm	mm		mm	mm		
1	1.79		0.41	-2.08		0.45	0.43
2	3.01		0.69	-3.47		0.76	0.73
3	5.85		1.35	-6.79		1.48	1.42
4	12.40	4.33	2.86	-	-	2.90	2.88
5	17.12		3.95	-	4.58	3.91	3.93
6	21.82		5.04	-		4.95	4.99
7	27.40		6.33	-		6.00	6.16

Full ductility as shown in table 6, 7, and 8 increases in each loading cycle from cycle 4 to cycle 6, while in cycle 7 there is a decrease.

From the two data and curves above, it can be concluded that even though there is a pinching effect and there is movement at the plate joints which results in rotational deformation, they are still able to maintain their bearing capacity. Based on FEMA 356 table 6.6 (FEMA, 2000), the maximum value for displacement ductility is $\mu > 4$, so fall into the category of High Ductility demand.

5. CONCLUSION

Based on the results of the analysis and discussion, it is concluded as follows:

1. The hysteresis curve of the load-displacement relationship on the precast test object using the resulting plate shows a very significant difference to the monolith test object (BU-1), where the maximum load BU-1 produced is an average of 19.71 kN, the test object precast (BU-2) of 6.68 kN, while precast specimen (BU-2) of 8.67 kN.
2. The occurrence of a pinching effect causes degradation of strength and stiffness due to the large displacement mechanism, namely BU-1 the average displacement is 9.10 mm, BU-2 is 15.20 mm, while BU-3 is 17.70 mm, this indicates that the load capacity can be withheld very small as described in point 1.
3. At the level of partial ductility for BU-1 the average yield obtained is $\mu = 4.29$, BU-2 is $\mu = 4.42$, and BU-3 is $\mu = 3.98$.
4. At full ductility level for BN-1 the average results obtained are $\mu = 6.39$, BU-2 is $\mu = 6.23$, and BU-3 is $\mu = 6/16$.

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Flood Disaster Risk Reduction Strategies in Urban Area, Bulukumba Regency

Andi Idham Asman¹, Harry Hardian Sakti¹, Dzulqarnain Aras¹, Nurul Wahyuni¹, Farhan Aldiansyah¹

¹ Urban and Regional Planning, Faculty of Engineering, University of Muhammadiyah Bulukumba
Email : andiidhamasman@umbulukumba.ac.id

Abstract

Flood is a disaster that often occurs in big cities in Indonesia, caused by the high density of buildings and the unpreparedness of infrastructure to adapt. Urban Areas of Bulukumba Regency (UABR) is one of the centers of urban areas that has experienced flooding in recent years. The urban area of Bulukumba Regency is a downstream area of the Bialo Watershed whose upstream area is also in the Bantaeng Regency area. Rapid urban development has resulted in a change in land cover to become built-up land so that catchment areas are narrower in the middle and downstream zones, as well as changes in vegetation in the upstream zone which has received land conversion from forest areas to plantation areas. In addition to the potential for flooding due to river flow, the urban area of Bulukumba also has the potential for flooding due to sea tides or tidal floods. The high level of hazard flood potential has not been followed up with sustainable flood management based on disaster risk reduction in the UABR. Based on this, it is necessary to study the level of risk of flooding in the Urban Area of Bulukumba Regency and an appropriate strategy to reduce the risk of flooding in the Urban Area of Bulukumba. The aim of this research is; (1) identify the level of risk of flooding in the UABR; and (2) formulate an appropriate strategy as an effort to reduce the risk of flood disaster in the UABR. The research approach used is the mixed method, with the analytical method used for data processing in the form of risk analysis, spatial analysis namely overlay analysis using GIS software and qualitative descriptive in formulating strategies. The results of this study are a map of the level of flood disaster risk and recommendations for flood risk reduction strategies in the UABR.

Keywords:

Floods; Disaster Risk Reduction; Climate Change.

1. INTRODUCTION

Based on Law No. 26 of 2007, flooding is an event or condition where an area or land is submerged due to an increased volume of water. A flood is a type of natural occurrence that happens when there is an excess of water that cannot be handled by the area's drainage system due to heavy rainfall. This issue affects the formation of puddles in the area, which could be harmful to the neighborhood (Rahmat, 2014). The relatively high rainfall in a certain time unit, which is better known as rainfall intensity, is one of the main factors causing flooding. Rainfall intensity is the amount of rainfall that occurs in a time period where the water is concentrated (Loebis, 1992).

Flood disaster is a disaster that often occurs in big cities caused by the increase in human population and climate change. Flood risk is particularly severe in urban areas (Chen et al., 2015). The complexity of urban areas with various economic activities and as the center of population concentration also has a major contribution to climate change. The impact of climate change can increase the potential for disasters, especially hydrometeorological disasters. PVMBG (Hermon, 2012), defines hydrometeorological disasters as events or series of events of floods, landslides, ecosystem damage, land degradation, cyclones and droughts that threaten and disturb people's lives and livelihoods caused by both natural and human factors. resulting in property losses, human casualties, environmental damage, and psychological impacts. In Indonesia, hydrometeorological disasters such as floods and tidal waves are disasters with the most frequent and routine occurrences every year (DIBI BNPB, 2022).

The Urban Area of Bulukumba Regency (UABR) is one of the centers of urban areas where floods have occurred in recent years. Based on data in the BPBD on Disaster Risk Book for Bulukumba Regency, there

are 30 flood points in Bulukumba Regency and 11 points are in the UABR. The UABR is a downstream area of the Bialo watershed whose upstream is also within the Bantaeng Regency area. Rapid urban development has resulted in changes in land cover from open field into built-up land so that the catchment area becomes narrower in the middle and downstream zones, as well as changes in vegetation in the upstream zone which undergo land conversion from forest areas to plantation areas. River silting is also a factor causing flooding and levees which still have little impact on the high risk of flooding in the Watershed (DAS). In addition to the potential for flooding due to river flow, the Bulukumba Urban area also has the potential for flooding due to high tides or tidal flooding. The flood event caused losses in the form of damage to public facilities, the emergence of casualties, environmental damage, loss of property, and inundation of productive land to residential residents.

The UABR is one of the centers of urban areas where floods have occurred in recent years. The urban area of Bulukumba Regency is a downstream area of the Bialo watershed whose upstream is also within the Bantaeng Regency area. Rapid urban development has resulted in changes in land cover from open field into built-up land so that the catchment area becomes narrower in the middle and downstream zones, as well as changes in vegetation in the upstream zone which undergo land conversion from forest areas to plantation areas. River silting is also a factor causing flooding and levees which still have little impact on the high risk of flooding in the Watershed (DAS). In addition to the potential for flooding due to river flow, the Bulukumba Urban area also has the potential for flooding due to high tides or tidal flooding. The flood event caused losses in the form of damage to public facilities, the emergence of casualties, environmental damage, loss of property, and inundation of productive land to residential residents.

Based on this, it is important to study the level of flood risk and an appropriate strategy is needed to reduce the risk of flooding in the UABR. The aim of this research is; (1) identify the level of flood disaster risk in the UABR; and (2) formulate the right strategy as an effort to reduce flood risk in the UABR.

2. METHODS

Method data collection used in the study are field observation/survey, interview, and study literature. The method analysis used for interest data processing is in the form of risk analysis, spatial analysis and descriptive qualitative. Qualitative method conducted to describe the interpretation of cluster risk flood disaster in UABR as well as formulation of the right strategy as effort flood disaster risk reduction.

2.1 Analysis Risk

To understand risk in terms of vulnerability analysis in certain threat situations, you can use the PAR (Pressure and Release) model approach. The Pressure and Release model (PAR model) was introduced as a simple way of how disasters occur when the threat of a disaster impacts the affected community. The basis of this PAR model is that a disaster event is a meeting of two opposing forces (these forces produce processes that produce vulnerabilities on the one hand, and hazards on the other).

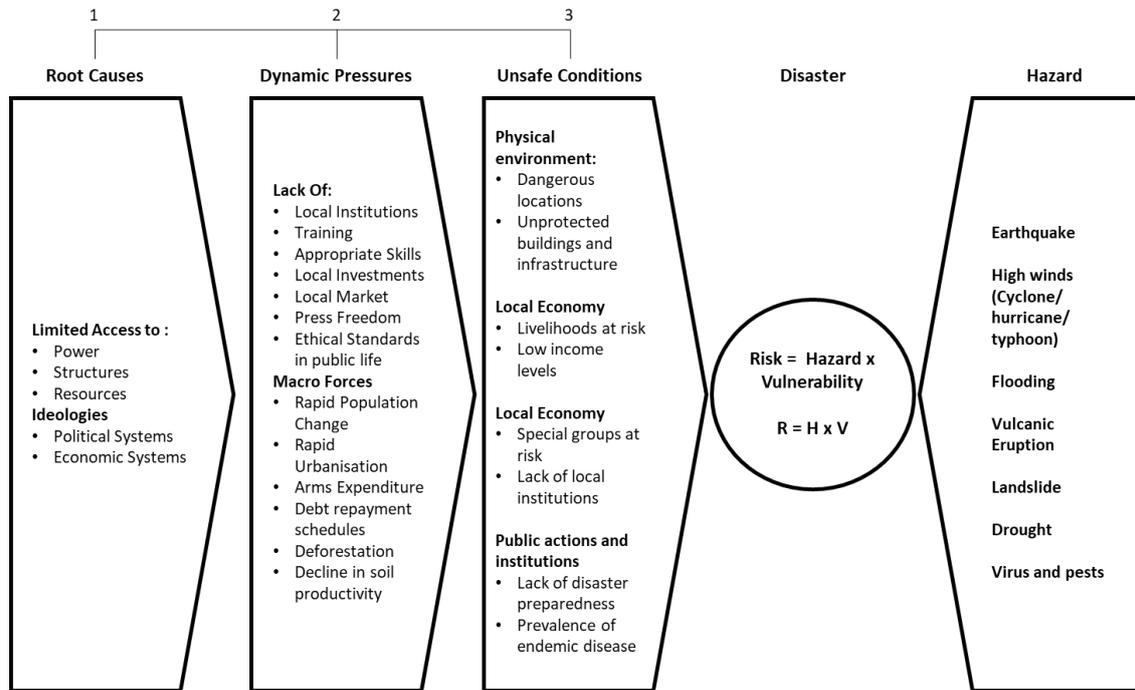


Figure 1. Pressure and Release model: the progression of vulnerability.

the concept of risk analysis is the calculation of the hazard with the affected vulnerability. Analysis risk conducted based on draft risk in change climate, then calculation risk in climate change could be conducted (Esmail *et al.* 2022; Gao *et al.* 2023) with formulas:

$$R = H \times V, \text{ with} \quad (II.1)$$

$$V = f(E, S, C,) \quad (II.2)$$

- Description :
- R = Risk
 - H = Hazard
 - V = Vulnerability
 - E = Exposure
 - S = Sensitivity
 - AC = Adaptive Capacity

Table 1. Disaster Risk Matrix Flood

Risk level		Vulnerability index		
		Low	Medium	High
Hazard index	Low			
	Medium			
	High			

Source : Modification form BNPB Perka No 2 (2012); Jibhakate *et al* (2023)

2.2 Analysis Spatial

Analysis spatial is a method analysis performed with to do analysis based on available spatial data. The technique used in the analysis study is technique overlays, that is merging various thematic maps (has specific information/database). The overlay technique is used to determine the potency flood hazard in the Bialo watershed based on the area function parameters that have been set and overlay results tabulation cross Among hazard and vulnerability to determine risk.

The assessment parameters are used for knowing the existence potency of flood disaster in the form of rainfall data, slope, texture soil and land cover. Details assessment are show in Table 2 below.

Table 2. Parameter Determination Level of Flood Hazard

No	Parameter	Score	Score	Information	Weight
1	Rainfall Intensity	1	Very low (<127 mm/ mo)	3	
		2	Low (127-182 mm/ month)		
		3	Medium (183-291 mm/ month)		
		4	Height (292-346 mm/ month)		
		5	Very high (>346 mm/ month)		
2	Land Cover	1	Vegetation	3	
		2	Water Body		
		3	Open space		
		4	Rice fields / Grass		
		5	Settlement		
3	Soil Texture	1	Sand	2	
		2	Sand argillaceous		
		3	Clay		
4	Slope	1	Convex (>3%)	2	
		2	Flat (0-3%)		
		3	Concave (<0%)		

Source : Haryani, 2017; Aziza *et al.* 2021; Li *et al.* 2023; Jibhakate *et al* (2023)

2.3 Analysis Descriptive Qualitative

Analysis descriptive qualitative is an analysis performed to describe the condition or the situation that happened in the field, where data and information couldn't be analyzed quantitatively, so needs explanation through discussion. Qualitative descriptive in this study is used from the synthesis process of various literature studies and condition of field studies on flood risk. The result of the synthesis than become the basis for preparation of appropriate strategies for reducing flood risk in UABR.

2.4 Variable Study

Variables used in flood disaster risk in urban areas of Bulukumba Regency are as follows:

Table 3. Variable study and details technique

No	Aspect	Variable	Sub Variable	Analysis Method
1	Flood Hazard Index	Determination Parameters flood hazard	- Rainfall Intensity - Land Cover - Texture soil - Slope	<i>Overlays</i> analysis
2	Flood Vulnerability Index	Exposure	- Density population (ratio) - Density building (Ratio)	- Analysis Quantity - Analysis Scoring and Weighting
		Sensitivity	- Poverty rate (Ratio) - Community Development Index (Index)	- Analysis Quantity - Scoring and Weighting Analysis
		Adaptive capacity	- Income per capita (Rupiah) - Green Open Space Area (Percentage)	- Analysis Quantitative - Scoring and Weighting Analysis
3	Flood Risk Index	Hazard Analysis Vulnerability Analysis	- Hazard Index - Vulnerability Index	- Cross Tabulation and <i>Overlay</i> Analysis

No	Aspect	Variable	Sub Variable	Analysis Method
4	Disaster Risk Reduction Strategy	Disaster Risk Analysis (Disaster Risk Index)	- Prevention and Mitigation - Preparedness - Emergency response	- Qualitative Descriptive Analysis

Source: Analysis Results, 2022

3. RESULTS AND DISCUSSION

Ujung Bulu District is one of the districts in Bulukumba Regency which is the capital of Bulukumba Regency with an area of 14.44 km² which is administrative consists of 9 sub-districts. By astronomical Ujung Bulu district is located between 5° 31'S-5° 35'S and 120° 10'E-120° 15'E. Administrative boundaries in Ujung Bulu District are as follows.

- a. North : Gantarang District
- b. South : Flores Sea
- c. East : Ujung Loe District
- d. West : Gantarang District

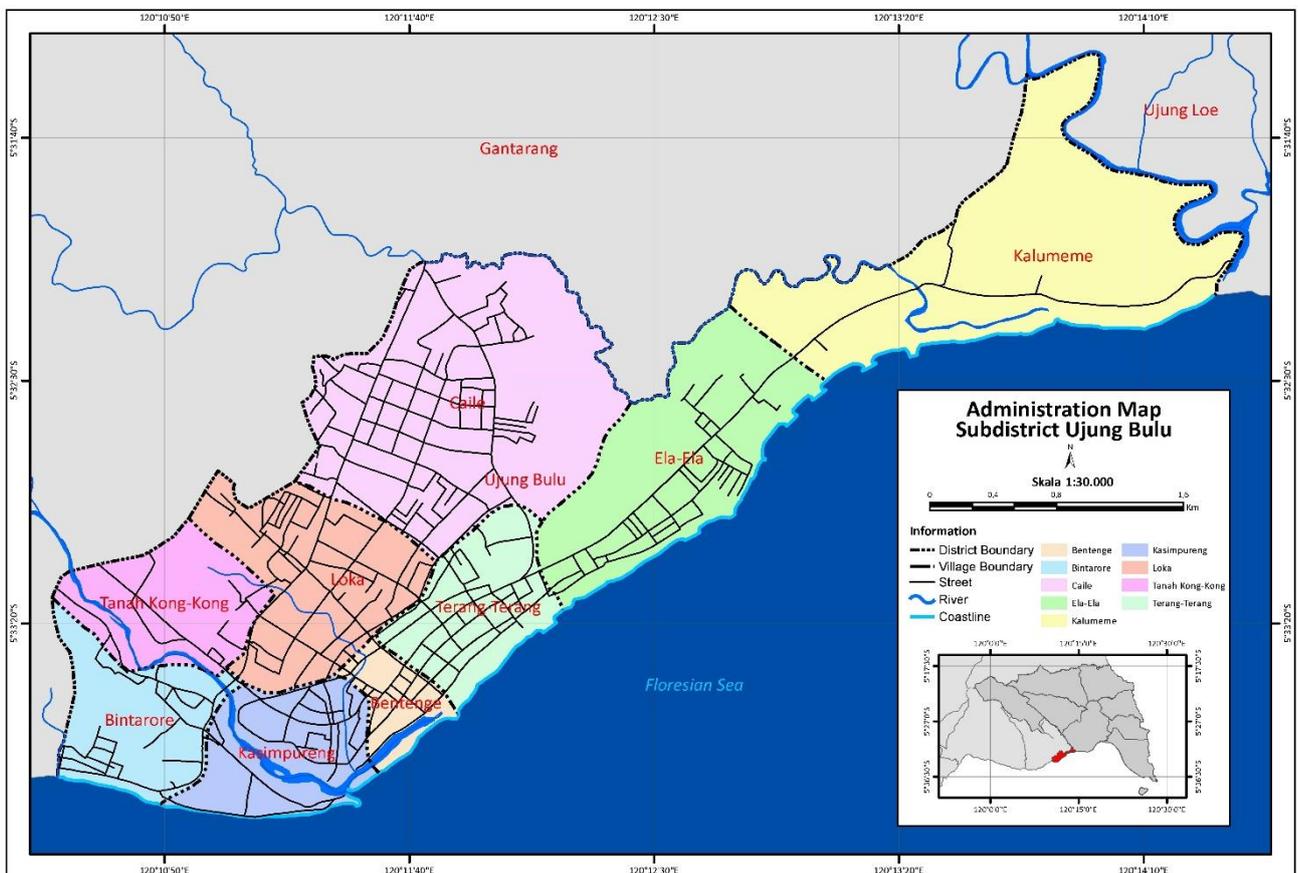


Figure 2. Administration Map

Source: Spatial Plan Bulukumba Regency 2012-2032

Based on the spatial plan of Bulukumba Regency From 2012-2032, Ujung Bulu District entered into the strategic area of the economy which includes area tourism, area trade and area strategic coast with the development of urban with waterfront city concept so that many developments around beach done. Besides that, according to the spatial plan of Bulukumba Regency, the Watershed has the potential to raise flood hazard in UABR. the downstream area of the Bialo watershed with a length of 191.26 km and the Kirasa watershed with a length of 26.50 km is a UABR district that often experiences flooding. (RBI Scale 1:25,000 in 2012 and Interpretation of Spot Imagery 6 in 2016, Bulukumba Regency).

Local Disaster Management Organisation (BPBD) Bulukumba put forward there are 30 points of disaster flood. Based on the survey data amount point disaster flood the most occurred in Ujung Bulu District (UABR) i.e there are 9 dots of incident flood. Besides potency flood consequences Genre River, an urban area of Bulukumba Regency also has potency flood due to tides or tidal floods. The reality indicates that UABR is an area that has the threat of flood disaster.

3.1 Hazard

Hazard is something condition or action or possible potential that raises loss of people, property or environment. Hazard is a source or a hazardous situation and potency for accident or disease in humans, damage to equipment and damage environment. Hazard is all of something including a situation or potential action for raises accident or human injury, damage or other disturbance (Ramli, 2010:57). Potency or threat alone could be grouped into 2, i.e potency main hazard and potency collateral hazard.

The level of hazard is based on the possibility happening disaster and the resulting impact of consequence disaster (BNPB No. 2 of 2012). Hazard follow to flood disaster flood rated very high in urban areas. For example, UABR (Ujung Bulu District) which is the centre of activity society, will impact more disaster-critical an area around. As for parameters used to determine flood hazard in the UABR with method overlays with GIS where combine intensity rain, land cover, texture land, and slope.

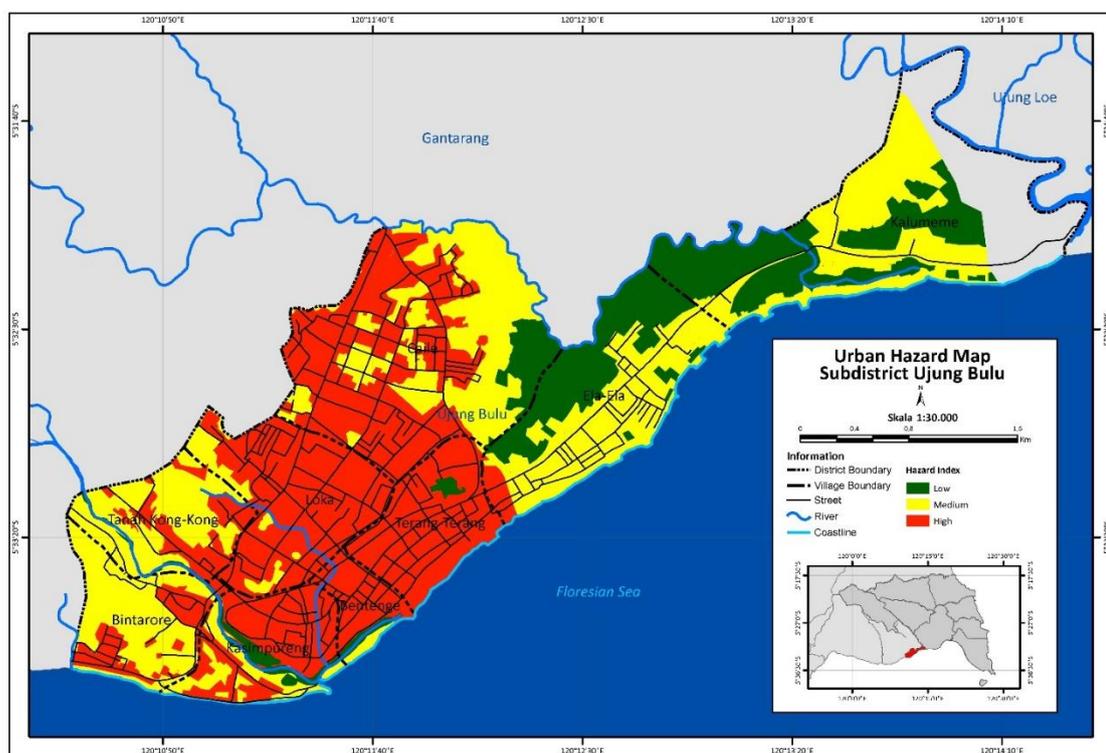


Figure 3. Flood Hazard Map
Source: Analysis Results, 2022

Analysis results overlay hazard flooding in UABR, showing that the level of hazard in the UABR consists of three hazard zones that are high, medium, and low.

3.2 Vulnerability

According to Minister of Environment and Forestry Law Number P.7/Menlhk/Setjen/Kum.1/2/2018, vulnerability is a trend system for impact negative includes sensitivity to impact negative and lacking the adaptive capacity for resolve negative impact. vulnerability of climate change could be studied from three components vulnerability that is exposure, sensitivity, and adaptive capacity. Analysis of vulnerability to potency hydrometeorology hazard (flood) as a consequence of impact climate change, so indicator vulnerability needs consider potency disaster affected. Indicators of vulnerability to disasters due to climate

change are dynamic. vulnerability of flood determined by the parameters of exposure, sensitivity, and adaptive capacity. Indicator vulnerability of this research is served in Table 4.

Table 4. Indicator vulnerability

No	Vulnerability	Indicator
1	Exposure	Density Population
2		Density Building
3	Sensitivity	Human Development Index
4		Poverty level
5	Adaptive capacity	Income per capita
6		Green Open Space Area

Source: Analysis Results, 2022

3.2.1 Exposure

Exposure is a trend for climate change in the future and potential hazard related based on the climate change model, and in some cases, based on records of the meteorological pattern. Exposure was analyzed with method scoring. Assessment parameters in exposure in UABR in the form of density population and density building. Development sector economics in urban areas of Bulukumba Regency is dominated by sector trade, triggering urbanization from village to city. The reality makes the level of density of residents in UABR considered susceptible to flood disaster. Besides that, residents naturally need lodging and buildings like trading area buildings, offices, and other facilities. The existence of more building density is considered susceptible to hydrometeorology hazard (flood) in an area. Data and rate exposure in UABR are served in Table 5.

Table 5. Index exposure

Indicator	Data	Score	Index
Population Density (people /km)	3,397	3	high
Building Density (Ratio)	44.92 %	2	medium
Index exposure		2,5	high

Source: Analysis Results, 2022

The results of the analysis obtained show that the level of exposure in UABR is a population density have 3,397 people/km² with a score of 3 categories high and building density has a ratio of 44.92% with a score of 2 categories medium.

3.2.2 Sensitivity

Sensitivity is how much a system will be affected or responsive to climate stimuli but can be changed through socio-economic changes. Sensitivity is the extent to which various social systems and economic sectors are impacted by the relevant climate risk. Parameters that determine the level of community sensitivity include the poverty level and the community development index. The higher the sensitivity level of the community, the higher the level of flood vulnerability will be. Disaster events, including hydrometeorological disasters, can reduce the value of the human development index and increase poverty which will have an impact on the city's economic sector. The sensitivity index is obtained by multiplying the weight and score of each indicator. Data and sensitivity level of UABR are presented in Table 6.

Table 6. Index Sensitivity

Indicator	Data	Score	Index
Poverty Rate (Ratio)	7.43%	1	Low
Community Development Index (Index)	69.26	2	Medium
Index Sensitivity		1.5	Low

Source: Analysis Results, 2022

The results of the analysis show that the sensitivity value in the UABR is the poverty rate of 7.43% with a score of 1 being in the low category and the community development index being 69.26% with a score of 2 being in the medium category.

3.2.3 Capacity Adaptive (Adaptive Capacity)

Adaptive capacity is the potential or ability of a system to adapt to climate change, including climate variability and extreme climates, so that potential damage can be reduced/prevented. In order to reduce the possible effects of climate change hazards, individuals, families, communities, businesses, or institutions must act individually or collectively. Parameters that determine the level of adaptive capacity include per capita income and the percentage of green open space. Per capita income is the average income of people in the UABR. The higher the level of per capita income, the higher the community's ability to adapt to the economic sector when a hydrometeorological disaster (flood) occurs. The data and level of adaptive capacity of the UABR are presented in Table 7.

Table 7. Index Adaptive Capacity

Indicator	Data	Score	Index
Income Per Capita (Rupiah)	33.80 million	2	medium
Green Open Space Area (percentage)	10.56	3	high
Index Adaptive Capacity		2,5	high

Source: Analysis Results, 2022

The results of the analysis show that the adaptive capacity in the UABR is 33.80 million incomes per capita with a score of 2 in the medium category and the presentation of green open space area of 10.65 % with a score of 2 in the medium category.

The results of the analysis of the parameters of exposure, sensitivity, and adaptive capacity. From the index value of each aspect, the vulnerability index is determined using a matrix. The impact index is carried out by connecting the exposure and sensitivity aspects described as presented in Table 8 below.

Table 8. Matrix Index Impact

Index Impact		Exposure		
		Low	Medium	High
Sensitivity	Low			V
	Medium			
	High			

Source: Analysis Results, 2022

The impact index in Table 8 is high. Furthermore, the results of the impact index matrix are then connected with the adaptive capacity aspect to determine the vulnerability index. The higher the adaptive capacity it has, the lower the vulnerability index will be. The vulnerability index is presented in the following table 9.

Table 9. Matrix Index Vulnerability

Index Impact		Exposure		
		Low	Medium	High
Capacity Adaptive	Low			
	Medium			
	High		V	

Source: Analysis Results, 2022

Based on Table 9, the vulnerability index in the UABR to hydrometeorological disasters is on high level.

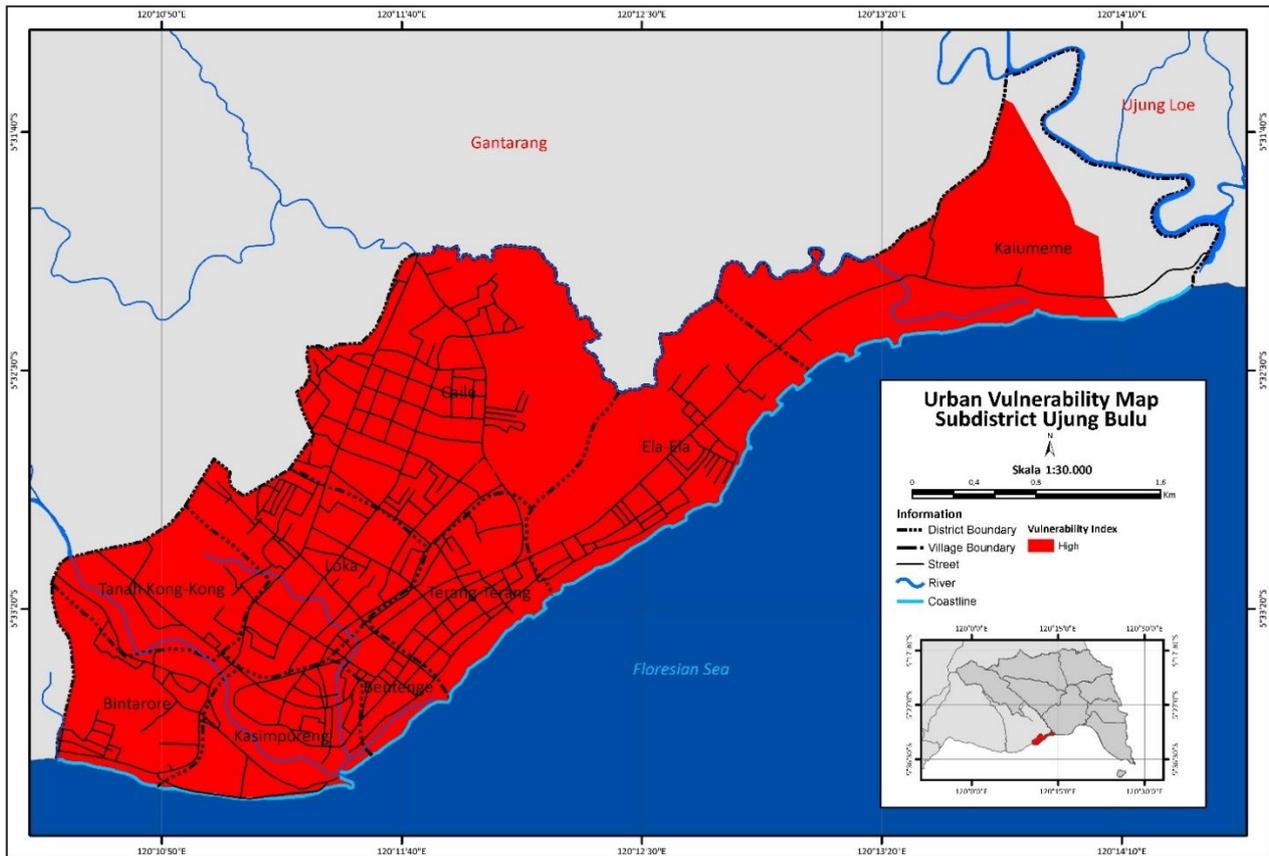


Figure 4. Vulnerability Map Flood
 Source: Analysis Results, 2022

3.3 Risk

Regulation of the Head of the National Disaster Management Agency No. 2 of 2012 concerning General Guidelines for Disaster Risk Assessment explains that the level of disaster risk is determined by combining the level of hazard and the level of vulnerability. The assessment of the level of flood risk in the UABR is based on the results of the cross-tabulation between the level of hazard and the level of vulnerability. The results of the analysis of the flood risk level in the UABR are presented in Figure 10 below.

Table 10. Disaster Risk Index Floods in UABR

No	Risk Index	Area(Ha)
1	Medium	186.83
2	High	878.45
Amount		1065.28

Source: Analysis Results, 2022

- a. Structural Mitigation
 - Increasing the drainage capacity is one of the countermeasures to deal with future hazards (Rahayu, 2019).
 - Protect and retrofit critical infrastructure, such as the construction of reservoirs and dams as flood control which have benefits for power generation, irrigation of agricultural land, tourism attraction and so on (Asman, 2019)
- b. Non-Structural Mitigation
 - Disaster Risk Reduction is included in the RTRW or RPJMD (Asman, 2019)
 - Implementing river zonation (Rahayu, 2021)

3.4.3 Long Term

- a. It is crucial to involve local populations in disaster risk reduction initiatives and to build their resilience to better prepare them for prospective disaster situations (Furqon, 2018)
- b. Revitalising Informal Settlements and Their Environments (RISE) program (Wolff. E, 2021)
- c. There is a SOP emergency response
- d. Preparation of basic needs during the emergency response

4. CONCLUSION

The urban area of Bulukumba Regency (UABR) has high, medium, and low flood hazard potentials. This potential can cause harm to humans, property, or the environment. The level of flood vulnerability in the UABR is in the high category with exposure, sensitivity and high adaptive capacity. The results of the overlay analysis and the results of the cross-tabulation between the level of hazard and the level of vulnerability in the UABR, show that the hydrometeorological (flood) level of risk of the UABR consists of two zones, namely high and medium risk. This condition further emphasizes the need for disaster mitigation efforts as early as possible to minimize the impact of the risks that occur.

The handling strategy carried out to reduce the risk of flooding is through efforts in the pre-disaster phase (prevention and mitigation, as well as preparedness) and post-disaster (emergency response). Strategies of flood disaster risk reduction in the UABR is divided into three terms; short-term strategy are emergency response and recovery capabilities; mid-term strategy are structural and non-structural mitigation such as increasing the drainage capacity, protect and retrofit critical infrastruktur, Disaster Risk Reduction are included in the RTRW or RPJMD and river zonation; and long-term strategy is prepared communities to adapt potential disaster in the future and RISE Program.

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Engineering Faculty, Universitas Andi Djemma, Jl. Tandipau No. 5 Palopo
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