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Coastal Inundation Model in the Coastal Area of Palopo City, South Sulawesi Province

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Abstract

The impact of sea-level rise is perceived by many archipelagic countries such as Indonesia. The higher the sea level rises every year, the larger the disaster threat in the coastal area. The current condition of most coastal areas indicates various pressures caused by city development, including the coastal area of Palopo City in South Sulawesi Province. The sea-level rise is suspected to be the cause of coastal inundation in Palopo City which, so far has not been identified. Therefore, this study aims to draw a coastal vulnerability map of sub-districts in Palopo caused by coastal inundation using GIS technology. Analysis of the areas affected by coastal inundation is carried out by processing spatial data. The sub-districts areas affected by coastal inundation are only those located in the coastal zones. The affected area in Bara, Wara Selatan, Wara Utara, Wara Timur, and Telluwana sub-districts are 160.64 ha, 21.41 ha, 73.55 ha, 87.56 ha, and 56.65 ha, respectively. In Bara Sub-district, the areas affected by coastal inundation are residential and mangrove conservation areas. The affected areas in Telluwana Sub-district are residential, production forest, coastal conservation, and mangrove conservation areas. The affected areas in Wara Selatan, Wara Timur, and Wara Utara Sub-districts are all residential areas. By using sea-level rise data of 27 years with its highest tide model, the coastal inundation in 2040 which is predicted to occur in Palopo City can be modeled properly.

Keywords: Sea Level Rise, Coastal Inundation, Palopo City, GIS

1. Background

Sea level rise is a global threat caused by global warming which engulfs the entire surface of the world. There are three causes of sea level rise, namely: melting of polar ice, extreme climatic events and land subsidence due to land compaction (Cahyadi *et al*., 2016). The impact of sea level rise is perceptible by many archipelagic countries, obviously including Indonesia. A report released by the Intergovernmental Panel on Climate Change (IPCC) revealed that global average surface temperature had increased by 0.3-0.6ºC since the end of the 19th century and is expected to rise 1.4-5.8ºC by 2100. The biggest threat from global warming is the rising of sea level which would heavily threaten human life and other ecosystems in coastal areas. Based on the Aeronautics and Space Administration (NASA) satellite data, sea level rise reaches 3.3 mm per year. The higher sea level rises every year will threaten life in the coastal area.

The coastal area is a vulnerable area that will be directly affected by environmental problems. Rich in potential biological and non-biological resources both on land and its waters, the coastal area provide many economic opportunities so that economic activity and pressure from people living in this area will directly influence the coastal environmental conditions. This makes the coastal area very vulnerable to environmental pressure, both coming from land and sea. Coastal areas are also very sensitive to natural phenomena related to environmental factors such as climate variability, climate change, and sea level rise. One of the pressures that will be examined in this paper is sea level rise which will threaten the sustainability of coastal areas in all parts of the world (Wirasatria *et al*., 2006 ; Hamuna *et al*., 2018).

Regarding the vulnerability of coastal areas in Indonesia, several studies have been conducted to assess the level of coastal vulnerability. One example is the vulnerability assessment in the coastal area of

Java Island. The results show that sea level rise at a rate of 2-8 mm/year in the next 100 years could inundate the coastal areas of Java which have a small angled and sloping beach morphology (Prabowo and Astjario, 2012). An analysis reported by Sakka *et al.* (2014) on the coastal vulnerability level of Makassar City, South Sulawesi Province indicates that the parameters which affect the coastal vulnerability are coastal slope and shoreline changes along Makassar City that has a high vulnerability especially on the coast of Tamalate Sub-District. Vulnerability on the northeast coast of Bali Province is caused by land conversion. The conversion carried out in this area was too close to the shoreline and significant high waves so that this area is categorized as a region with a high level of vulnerability (Putra *et al*., 2015).

Geographic Information System (GIS) is a technology that can be used for determining disaster vulnerability areas. This technology can be used to detect the vulnerability of disasters that occur on coastal areas such as shoreline changes (Natih *et al*., 2020), by utilizing spatial data processing in the form of maps, satellite remote sensing data and spatial modelling. The results of spatial data processing in GIS were used as the initial basis for determining the vulnerability level (Ilhami *et al*., 2014).

The coastal areas is currently facing various pressures caused by various city development, including development in the coastal area of Palopo City, South Sulawesi Province. The high dynamics of coastal areas will have implications on regional development, especially the development of coastal cities. Palopo City area that directly face the sea, with high activity of development and utilization should indirectly making the area vulnerable to disasters, including vulnerability due to global climate change. The sea level rise is suspected to be the cause of coastal inundation in Palopo City. Not many studies identified the coastal inundation areas in Palopo City, while in contrary, the Palopo City require information on areas prone to coastal inundation as a basis for determining disaster-prone areas. Therefore, this study aims to map the sub districts of Palopo that have coastal vulnerability caused by coastal inundation using GIS technology.

2. Methodology

2.1. Study Area and Data Source

Area of interest for this study is Palopo City, South Sulawesi Province. Geographically located between 2º 53' 15" to 3º 04' 08" South Latitude and 120º 03' 10" to 120º 14' 34" East Longitude (Figure 1).

This study used a quantitative approach with descriptive and associate types of analysis. Analysis of the areas affected by coastal inundation was carried out by processing spatial data.In the form of thematic maps, satellite data and spatial modelling. Spatial data modelling was conducted using cell-based spatial modelling, which is one of the spatial data processing techniques in raster-based GIS (Ilhami et. al., 2014).

Cell-based modeling uses a harmonic wave approach in the analysis process that can be employed to predict hourly sea level to obtain accurate results of the model (Glen, 1977). The results of the prediction of sea level can be further used in the process of predicting the potential for coastal inundation areas (Nugroho, 2013).

This study uses the average data model of increased sea level rise of 27 years (1993-2019). The inundation model in Palopo City in 2040 was processed by calculating the highest average annual tide data so that the inundation model formed would be the inundation occur at the highest tide and does not happen throughout the year. The analysis process also uses tide measurement data in Palopo City from January to December 2019. The tide measurement data were obtained from Indonesia Geospatial Information Agency (BIG). The other data used in this coastal inundation model study were DEMNAS BIG and Indonesia Topographic Map (RBI).

DEMNAS stands for Seamless Digital Elevation Model (DEM) Nasional owned by BIG, this data is an elevation data model which is a combination of several data sources such as IFSAR, TERASSAR-X and ALOS-PALSAR data by adding Masspoint data from stereo-plotting results. The spatial resolution for DEMNAS data is 0.27 arcsecond, using the EGM2008 datum and retrieved from http://tides.big.go.id/DEMNAS/. The average data of sea level rise is obtained from NASA, at which the data is processed using satellite data from satellites monitoring sea level rise. Satellite data used were data from Topex/Poseidon and Jason 1, 2 and 3.

The mean sea level (MSL) was calculated from tide measurement data with various observation intervals including daily, monthly and yearly. This analysis uses the daily MSL observation interval to predict mean MSL value resulting, a parameter to predict the highest mean value of tides. Tide data processing uses Admiralty calculations with the least square method approach to determine the harmonic component and tide forecasting, then it is used to determine the height of MSL (Khasanah, 2017). Data processing was carried out with the help of the worldtides2010 v1.2 application which was run with Matlab R2018a (Hasibuan, 2015).

The highest mean tide (MHWL) can be predicted with the average value of increasing sea level rise and harmonic constant value as a result of data processing from admiralty calculations, the mathematical equation used is as follows (Nugroho, 2013) :

$$MHWL_{predict} = MSL_{mean} + (M_2 + K_1 + O_1) \tag{1}$$

MHWL : Mean High Water Level
MSL : Mean Sea Level
M_2 : Amplitude of semidiurnal tide component caused by lunar gravity force
K_1 : Amplitude of diurnal tide component caused by lunar and sun gravity force
O_1 : Amplitude of diurnal tide component caused by lunar gravity force

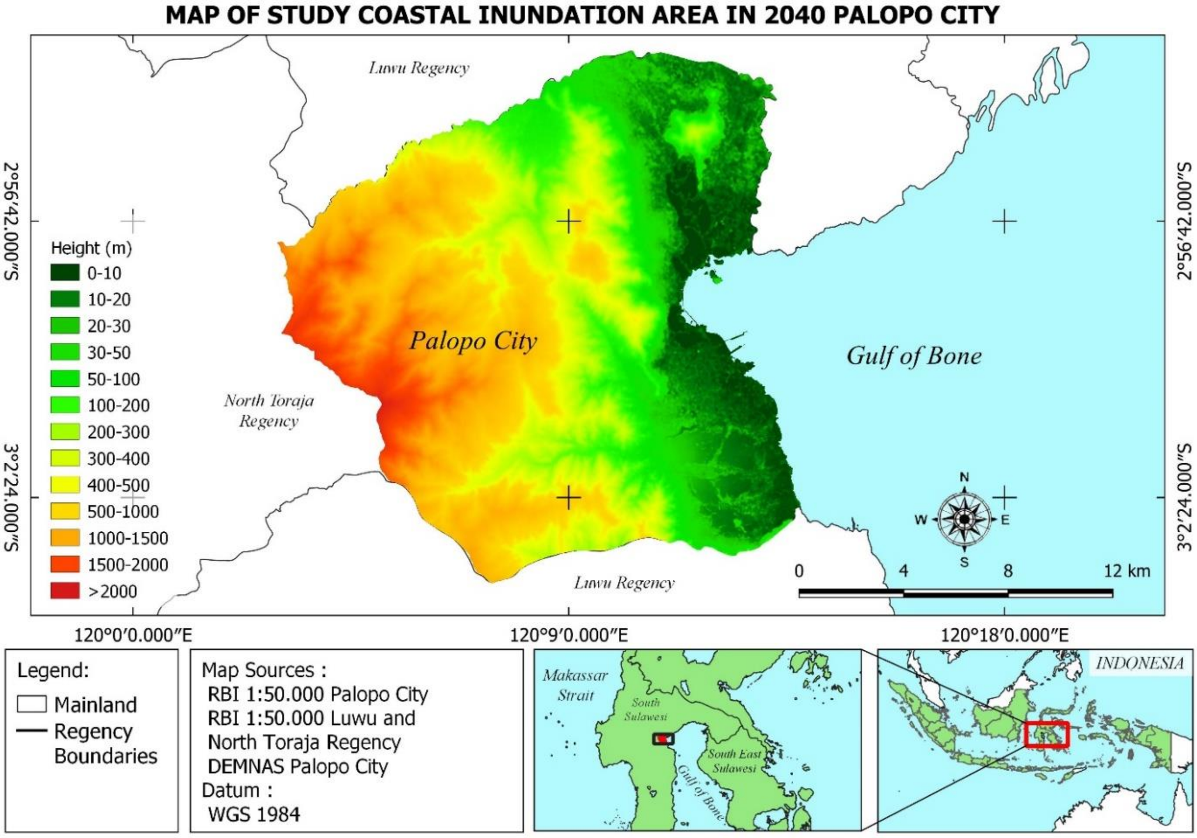

Figure 1. Map of Area Study

2.2. Spatial Analysis of Coastal Inundation

The spatial analysis of coastal inundation use model of tidal data in 2019 to predict coastal inundation in 2040. This analysis is based on the annual sea level increase (Sea Level Rise/SLR). SLR can affect the geographical conditions of the coastal area in the following year (KKP, 2014). In this analysis, the process was used to predict the potential impact of SLR in the span of 20 years, namely in 2040. The time span of 20 years indicates that sea level has increased significantly and changes the geographical conditions of coastal areas (Oktaviani, 2014). This analysis can also be used in predicting the potential of areas affected by sea level rise that may occur next year, although the results may not change significantly.

Determination of coastal inundation affected areas can be classified based on the DEM calculation for predicted tidal changes in 2040. This study uses a forecasting scenario, DEM only affected by changes MSL. The calculation process was carried out using QGIS v3.14 software, with the following equation (Nugroho, 2013):

$$Ri = DEM - (SLR\ (t1 - t0)) \qquad (2)$$

Ri	: The area affected by coastal inundation in the year-i
DEM	: Regional digital elevation model year 2019
SLR	: Coefficient sea level rise increase rate
t1	: The final year to be observed
t0	: Initial year observed

3. Result and Discussion

Palopo City divides into 9 sub-districts at which 5 sub-districts located in the coastal area. The five sub-districts located in the coastal area are Wara Selatan, Wara Timur, Wara Utara, Bara, and Telluwanua sub-districts. Meanwhile, the other four sub-districts that not in the coastal area are Sendana, Wara, Mungkajang dan Wara Barat. The area of each sub-districts can be seen in Table 1 (Badan Pusat Statistik Kota Palopo, 2019), the area sized located on the coastal area or adjacent to the coast is smaller (9,101 ha; Wara Selatan, Wara Timur, Wara Utara, Bara, and Telluwanua) compared to that of not located in coastal area (15,651 ha; Sendana, Wara, Mungkajang, and Wara Barat). The area affected by coastal inundation is only the sub-districts located in the coastal area and the sub-districts that do not attach to the coastal area are not affected at all. Therefore, planning of disaster mitigation can be carried out in a more effective way because the area is divided into sub-districts that allow easier activities to take care of.

The results of the sea level rise average data model of 27 years (1993-2019) is 3.3 mm/year and combined with the highest average annual tide and Digital Elevation Model (DEM) data. Those data are the main components to calculate the coastal inundation prediction model, the base model to predict coastal inundation in 2040. This coastal inundation model shows how far its affect on the land and it occurrence during the highest tide, so that the inundation type is temporarily inundation. This means that the affect will occur temporarily at the highest tide and not throughout the year. The results revealed that inundation prediction in 2040 affects all sub-districts that are located in the coastal area. They are Bara, Wara Selatan, Wara Utara, Wara Timur, and Telluwanua sub-districts (Figure 2).

Table 1. The Area of Palopo City Sub-Districts

No.	Sub-Districts	Total Area (Ha)
1	Sendana	3709
2	Wara Selatan	1066
3	Wara	1149
4	Mungkajang	5380
5	Wara Timur	1208
6	Wara Utara	1058
7	Bara	2335
8	Wara Barat	5413
9	Telluwanua	3434

The impact of this inundation is visualized in Figure 2. This figure shows the coastal inundation model that occurred in 2040. Increasing sea level rise through 2040 is the main factor to predict the coastal inundation. The impact area can be examine in Table 2, all sub-districts along the coastal line are affected. In Bara Sub-district the affected area is 160.64 ha, 21.41 ha in the Wara Selatan Sub-district, 73.55 ha in the Wara Utara Sub-district, and 87.56 ha and 56.65 ha, respectively in Wara Timur and Telluwana Sub-districts. Based on the data obtained from the Palopo City Spatial Plan (Kota Palopo, 2012), the coastal inundation will have an impact on the following areas: In Bara Sub-district, the areas affected by coastal inundation are residential and mangrove conservation areas. The affected areas in Telluwana Sub-district are residential, production forest, coastal conservation, and mangrove conservation areas. The affected areas in Wara Selatan, Wara Timur, and Wara Utara Sub-districts are residential areas.

Figure 3 illustrates the area affected by the coastal inundation in Telluwana and Bara Sub-districts. Coastal inundation that occured in the land area quite far from the coast. This is because the area is crossed by a river and the height of the land surface in the area has an elevation of less than 1.2 meters. Therefore, from the figure using the RGB satellite image visualization, part of the area has been used as a pond and residential area.

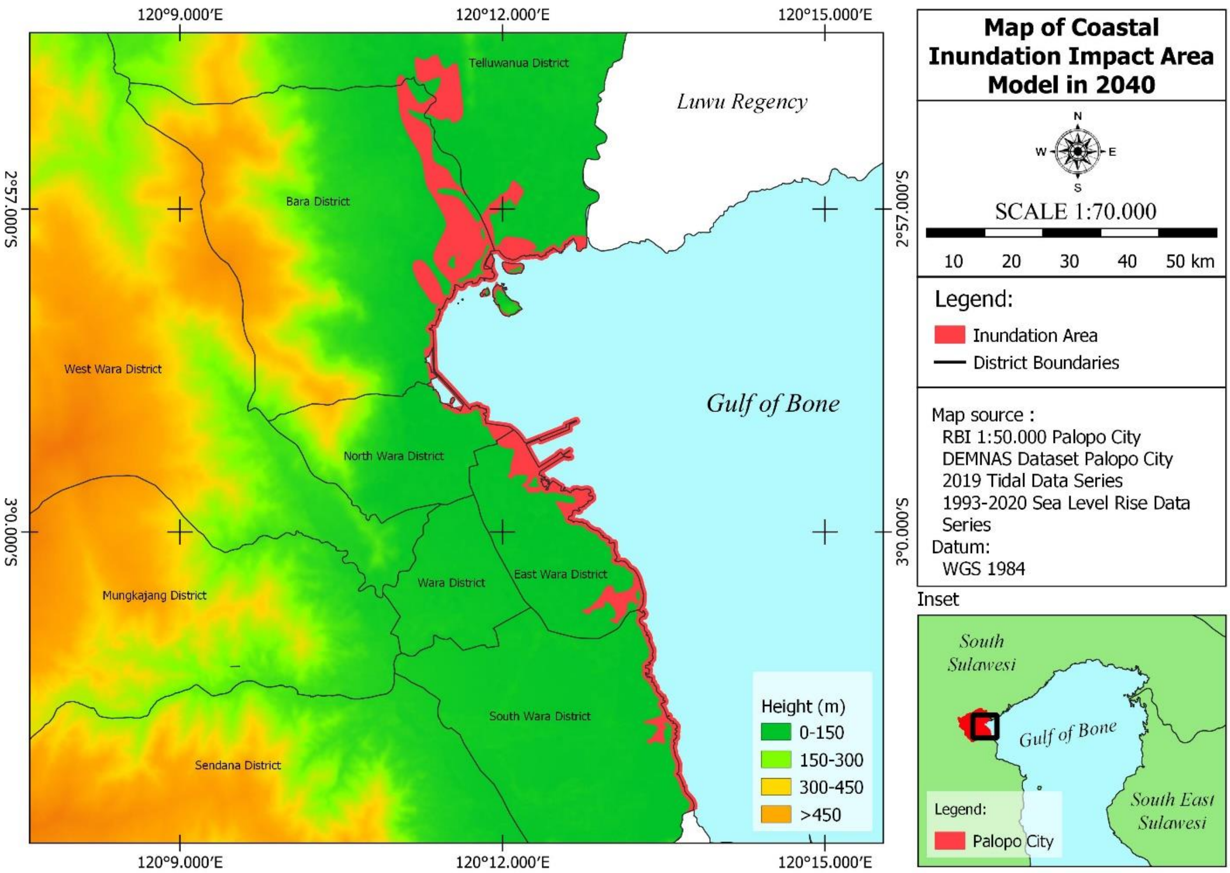

Figure 2. Palopo City Coastal Inundation Prediction in 2040

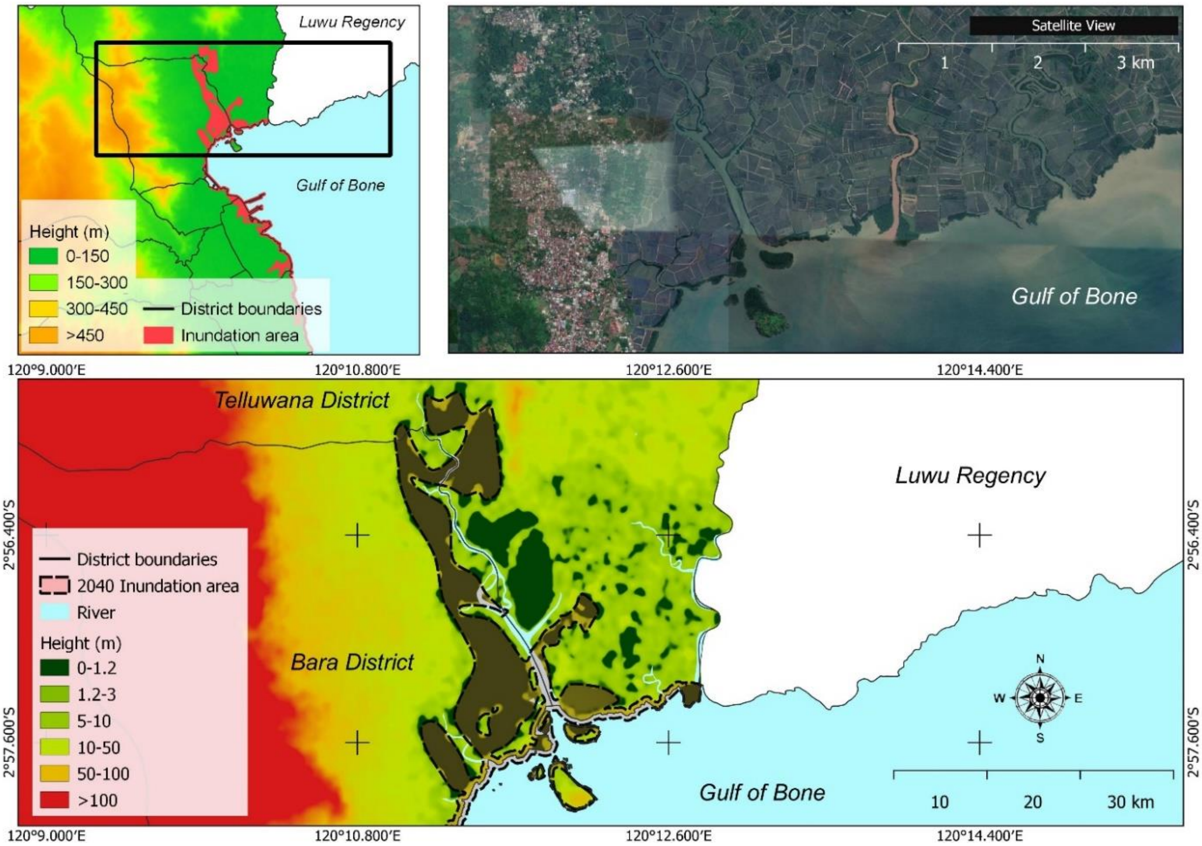

Figure 3. Coastal Inundation in Bara and Telluwana Districts

Table 2. The Affected Palopo City Area by Coastal Inundation in 2040

No.	Sub-Districts	Total Area (Ha)	Area Name
1	Wara Selatan	21.41	Residential Area
2	Wara Timur	87.56	Residential Area
3	Wara Utara	73.55	Residential Area
4	Bara	160.64	Residential Area and Mangrove Conservation Area
5	Telluwanua	56.65	Residential Area, Production Forest Area, Coastal Conservation Area, Mangrove Conservation Area

Through this model, the areas indicated to be affected by coastal inundation in Palopo City are obviously need plan for disaster mitigation. All five sub-districts located in coastal area have common condition at which residential areas are affected by the coastal inundation impact. This model suggests, that mitigation need to carry out in anticipating negative impact caused by such inundation. Without mitigation, the life of community at these areas are at risk. Some limitation, however has occurred from this research. The model requires additional data including the existing land use data, infrastructure data and land subsidence data. These data are important to increase the reliability of damage measurement caused by coastal inundation models in 2040. Important lesson learned from this study revealed that the results obtained are influenced by the quality of data. This coastal inundation model follows the trend of sea level rise which is modeled to occur at the highest tide, but for future research, inserting other relevant data is required to have a more accurate results and description of the model. Even so, this model has sufficiently described the possibility of coastal inundation along with the area affected that will occur in 2040 in each sub-district of Palopo City.

4. Conclusion

By using SLR data of 27 years and the highest tide model, the coastal inundation in 2040 which is predicted to occur in Palopo City can be modeled properly. All sub-districts along the coastline in Palopo City (Sub-districts of Bara, Wara Selatan, Wara Utara, Wara Timur dan Telluwanua) are affected by this coastal inundation with different areas and impacted areas. This model would be more accurate if the model is inserted with additional data on land subsidence and other relevant supporting data in Palopo City.

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