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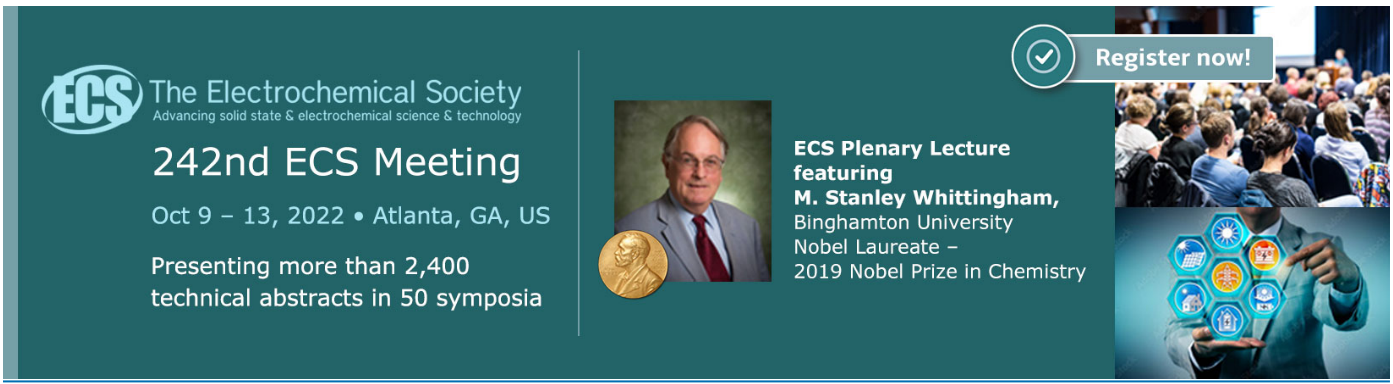

A numerical study of tidal run up and inundation impact using logical tool-less than equal

E Trihatmoko[1*], E S Pratiwi[2], Juhadi[3], T B Sanjoto[4], Sunarto[5], M A Marfai[6]

[1234]Department of Geography, Universitas Negeri Semarang;
[156]Department of Environmental Geography, Universitas Gadjah Mada
*edytrihatmoko@gmail.com

Abstract. Kendal Regency as Special Economic Zone and Industrial Park is stimulating the rapid coastal urban growth. This condition initiates the high risk of disaster in the northern Central Java. The research aims to model the tidal run-up and spatial inundation distribution using numerical calculation of logical tool-less than equal and to identify the land uses that are affected by the tidal run-up and inundation in the Kendal coastal area. This research conducted by the digital elevation model in 7 m spatial resolution and the highest high-water level (HHWL) data in the one-year analysis. Furthermore, the data processing was run using Less than equal tools. The result showed that the HHWL condition in 2018 reached up to 0.35 m. Considering the HHWL data, the eastern coastal area of the Kendal Regency is massively being affected by the tidal run-up and inundation. The furthest distance of the tidal run-up and inundation reached up to 3.7 km. There are six land uses affected, i.e., built-up area (0.04%), garden (2.01%), dry land (4.89%), grassland (5.09%), a fish pond (41.95%), and paddy field (4.24%).

Keywords: coastal area, tidal run up and inundation, spatial modelling

1. Introduction

Tidal floods, a condition where sea tides inundate a land area for a long time, can negatively affect life in coastal areas [1, 2, 3]. Seawater that pushes inland toward the drainage system in the settlement is likely to slow down the movement of wastewater, decreasing environmental quality. Soil degradation due to contamination by highly saline water continuously shrinks the agricultural land in coastal areas. Nearby communities also have to bear substantial economic losses as they have to allocate expenses for building embankments or raising the floor to prevent seawater flowing into the house [4, 5, 6].

Kendal Regency on the northern coast of Java Island is prone to tidal floods [7]. Its nearly level beach morphology is composed of alluvial fan deposits from several major rivers (i.e., Bodri, Kalikutho, Kendal, and Blorong), and it creates an environment where seawater can quickly enter the mainland during high tides. Damages to mangrove ecosystems due to abrasion and human intervention in coastal areas have erased the existence of natural barriers to tidal floods [8,9]. Coastal reclamation for expansion of the residential regions, special economic zones, and industrial parks also potentially change the direction of tides and broaden the inundated area landward.

Modeling the spatial distribution of tide propagation and inundation is an effort to reduce disaster risk in the future. Knowledge of inundated locations provides a basis for identifying at-risk objects. The next step includes calculating the amount of loss, which can be estimated by mapping the affected areas. Tide propagation and inundation in various regions on the north coast of Java Island have been modeled [10, 11], but for Kendal Regency, it has not been exposed in detail.

The rapid development of the geographic information system (GIS) technology offers many significant benefits, mainly for solving environmental and disaster-related problems [12, 13, 14]. Sources of elevation data with high resolution and records of highest tides are now available and sufficient for inputs to the modeling of tide propagation and seawater inundation with minimal errors. Many types of software are highly facilitative of running the mathematical process in inundation modeling. This study was designed to examine the areas affected by tide propagation and seawater inundation based on the outcome of the Logical Math tools with the Less Than Equal feature in ArcGIS. This method has faster and more straightforward steps to predict areas inundated by tidal floods. This method is also become a new method to be conducted to predict the inundation in Kendal coastal area.

2. Methods

Tidal run-up modeling was prepared with tidal data and Digital Elevation Model (DEM). The daily tidal information was obtained from the Ministry of Maritime Affairs and Fisheries (KKP). It consists of hourly records of sea level in one day for one month. The one-year tidal data analysis pinpointed the highest sea level, which was later used as the basis for tidal run-up modeling. The DEM data retrieved from the Geospatial Information Agency (BIG) has a 7x7m^2 resolution. It is created from various satellite images, such as IFSAR, TERRASAR, and ALOS PALSAR. There are several methods capable of estimating the propagation of tidal wave energy, including algorithms. In this case, a simple algorithm was employed to see and measure the propagation of high (+h) and low (-h) tides. The algorithm was determined using the Logical Math Tools-Less Than Equal in ArcGIS (Equation 1).

$$value \leq \pm h \quad (1)$$

The algorithm formulated in ArcMap was processed to produce a raster-based visual model of seawater propagation. This model was then analyzed and transformed into a thematic map of the highest tidal inundation in the coastal area of the Kendal Regency (Fig.1) automatically using ArcGIS software. The 2016 land use map acquired from BIG was overlaid with the tidal run-up map to identify the affected areas and their at-risk elements quantitatively.

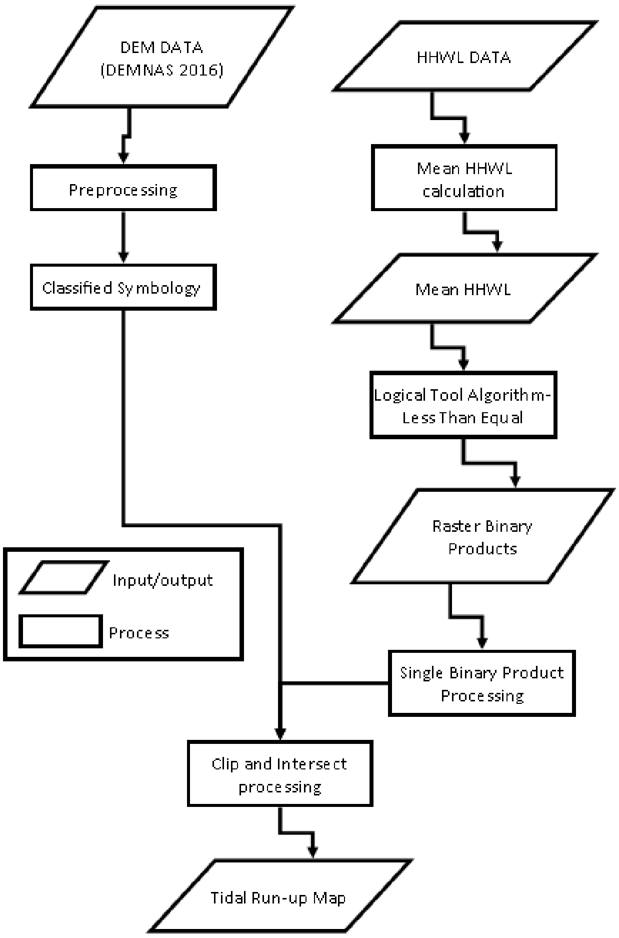

Figure 1. Research flow chart

2.1. Study Area

Kendal is a regency in Central Java Province that has been designed as a specific economic zone and industrial park according to the national development program. As stated in the local regulation [15], Kendal is a priority area for industrial activities, and the government has prepared 2,600 ha of land for this designation [16]. This program also takes into account the geographical position of Kendal, which is in the middle of the northern part of Java Island. Another consideration is its high accessibility through the North Coast Road, the most crowded land transportation lane in Indonesia [17].

3. Results and Discussion

Based on a simple algorithm in the Logical Math Tool-Less Than Equal, the modeling showed that tidal propagation and inundation harmed six land uses, most of which were in the north of the North Coast Road. The land uses were built-up area or building, plantation, dry agricultural land, grassland, pond, and paddy field, as shown in Table 1.

Table 1. Affected Land use Percentage (Limited by the North Coast Line toward the Shore)

No	Land use	- Area (m2)	Flooded Area (m2)	Flooded Area Percentage (%)
1	Building	29,184,049.80	12,684.28	0.04
2	Garden	2,039,142.61	40,911.18	2.01
3	Dry Field	9,317,652.11	455,249.50	4.89
4	Grassland	1,420,835.28	72,339.26	5.09

5	Fish Pond	34,688,776.19	14,550,961.30	41.95
6	Paddy Field	111,580,312.36	4,728,412.12	4.24

Source: Data calculation (raw data from BIG, 2016)

Referring to the area and the percentage of affected areas, ponds were the most widely affected land use. Tidal propagation and inundation deteriorate the land quality of the fish ponds and threaten their sustainability [18]. The other adverse impacts are as follows: (1) weakened pond embankments due to increased inundation, (2) decreased pond water quality due to the high supply of saline water from tidal propagation, (3) disrupted waste disposal from the ponds that eventually threatens their quality. Figure 2 compares the total area of land uses with the total area of land uses by tidal propagation and inundation on the coast of Kendal Regency, i.e., north of the North Coast Road on Java Island.

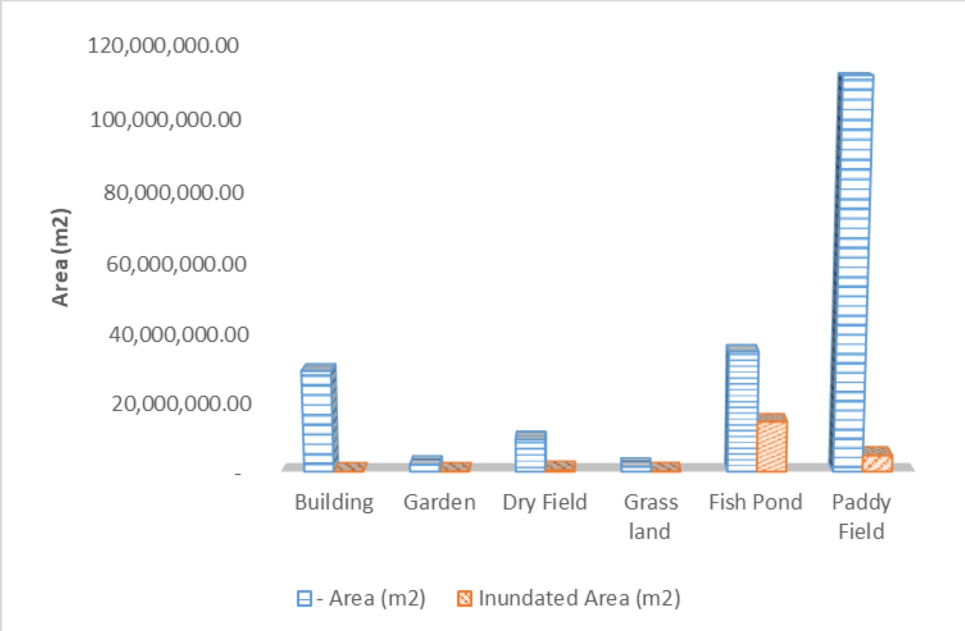

Figure 2. Graph of affected landuse compared to total landuse in nortern side of the north coast line

Table 1 and Figure 2 show that the built-up area, plantation, dry agricultural land, grassland, and paddy field are affected. Here, the built-up areas are not limited to settlements and public facilities but also buildings in general. The impact of tidal propagation and inundation on structures includes less optimal drainage system due to inundation—which decelerates the movement of wastewater, and subsequently, decreases environmental quality. Another impact is the environmental degradation of the built-up area—which damages properties, furniture, and other appliances [4, 6] and corrodes iron-based articles [19, 20, 21]. As for the cultivation area, the impact includes wilting and any disruptions to the growth stage that lead to plant death. Almost all terrestrial plants are intolerant of the high salinity in seawater [18].

The spatial distribution of tidal propagation and inundation in the Kendal Regency has reached a dangerous level. The model revealed that tides propagated 3.7 km inland and even put the Kendal Industrial Park, a local and national asset, at risk. This threat is shown in Figure 3. As a result, the management board of this estate needs to pile up a mass of land periodically to minimize the impact of tidal propagation and inundation.

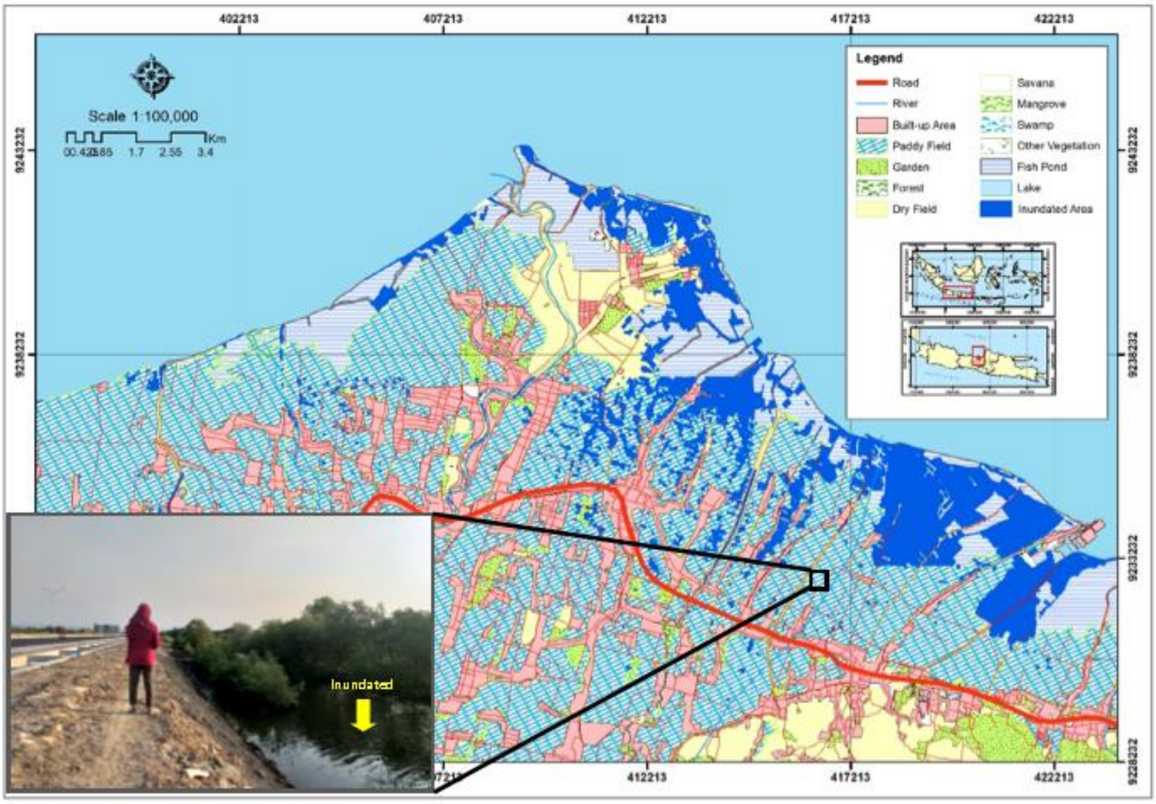

Figure 3. Spatial distribution of tidal run up and inundation map

The local government can use the tidal propagation and inundation modeled in this study as consideration for regional management. With a specific reference to tidal propagation and inundation events, the planned management can reduce the adversity that these disasters may cause.

4. Conclusion

The tidal propagation and inundation in Kendal Regency affected six land uses. In the north of the North Coast Road, the most significant percentage of the damaged areas (41.95%) was fish ponds and then followed by grassland (5.09%), dry agricultural land (4.89%), paddy field (4.24%), plantation (2.01%) and built-up area (0.04%). Records showed that the impact of these disasters was as far as 3.7 km inland. As such, a further study of regional management that takes tidal propagation and inundation into account becomes necessary, notably because these disasters do not cause a minor impact.

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