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Settlement suitability mapping based on the salinity index in the Banda Aceh City

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ABSTRACT

The availability of accurate land data is useful in planning, policymaking, regional development, and preserving the environment. Banda Aceh is the center of education and development in Aceh, Indonesia, which is located in the coastal area. The tsunami has had a significant impact on development and settlements in Banda Aceh. Currently, settlements in Banda Aceh rapidly grow also the need for land and water resources. Therefore, mapping the potential for residential land in Banda Aceh is required. This study examines land suitability in Banda Aceh based on the FAO salinity criteria and spatial data analysis by remote sensing methods. Based on the results, it is known that Banda Aceh has land suitable for settlement of around 85% or 2975 hectares. These areas are generally located close to watersheds and receive sufficient freshwater input. Meanwhile, areas far from rivers and close to the coast have brackish salinity. This area is not suitable as a residential area. There are about three sub-districts in Banda Aceh which are not suitable for settlement.

Introduction

The land is a natural resource that has a complete function in meeting various human needs. Land availability decreases along with population growth. Therefore, the land needs to be managed with the correct information. Since the 2004 tsunami disaster, residential areas in affected cities such as Banda Aceh are still a problem for the government. Several residential areas in Banda Aceh were destroyed by the earthquake and tsunami and are now in the direction and construction of new buildings (Syamsidik *et al.*, 2018).

Settlements are areas that are outside protected areas and are used as residences and for various community activities. A good settlement is significant in supporting the economy, socio-culture, community welfare, environmental sustainability, and climate (UU-RI, 2011). Aceh has a population of around 5 million people with a gross domestic product (GDP) in 2015 of 9.6 billion dollars,

increasing about 61% compared to 2004. The agriculture, plantation, and fisheries sectors contributed around 29% of Aceh's GDP, with 44.83 % of people make a living in this sector (Daly *et al.*, 2017). According to Achmad *et al.* (2015), population growth in the capital city of Aceh, namely Banda Aceh, is strongly influenced by social and economic factors. This population can continue to snowball and has the potential to create new social problems. Housing, access to work, and inadequate living are social problems that arise with rapid population growth. Therefore, a settlement or development integrated with the protection of social and environmental instruments is needed. This development can prevent future harmful and unsafe settlement crises. Mastrucci and Rao (2017) add that the criteria for proper settlement in each region vary. It depends on climatic conditions, building functions, construction materials, beauty or comfort, and community behavior.

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After the tsunami, the suitability of land or settlement in Banda Aceh has been assessed. Based on the study, it is known that the sectors that are recovering after the tsunami in the city of Banda Aceh are housing construction and rice farming (McLeod et al., 2010; Daly et al., 2017). However, Meilianda et al. (2019) revealed that the Banda Aceh coast (covering aquaculture ponds, buildings, and empty land) is still vulnerable to natural disasters such as the sea-level rise and land subsidence due to seismic or plate movements.

The latest technological developments from the Geographical Information System (GIS) allow the land suitability of Banda Aceh to be analyzed (Syamsidik et al., 2018). Land analysis can be done by combining GIS with information on permeability, slope, and land geology (Rusdi et al., 2015). One of the geological parameters that can be used to review land suitability is salinity.

In agriculture, salinity affects the growth and absorption of roots. According to Ivushkin et al. (2019), salinization at the soil surface has a detrimental effect on agriculture and aquaculture production. Excessive salt and ion accumulation in the roots can interfere with the osmosis process, plant nutrient balance, and poisoning in plants (Corwin and Yemoto, 2017). Salinity also affects soil degradation, such as increased soil dispersion, erosion, and engineering problems (Metternicht and Zinck, 2003).

Thus, salinity is required to assess land suitability and sustainable land resource management (Hardjowigeno and Widiatmaka, 2007). McLeod et al. (2010) revealed that the Aceh tsunami caused 37,500 ha of coastal areas to be inundated by seawater, which impacted soil salinity. Also, salinity trapped on the coast can reduce the productivity of Banda Aceh's agricultural land.

Soil salinity can be assessed by direct measurement with the soil electrical conductivity instrument method and salinity analysis (McLeod et al., 2010). Corwin and Yemoto (2017) reveal that measuring salinity on a laboratory scale can be done with three different approaches: measurement of Total Dissolved Solid (TDS), the electrical conductivity of groundwater, or the ratio of ions using spectrophotometry. For geospatial purposes, salinity can be assessed using remote sensing data such as Landsat-8 OLI, Sentinel-2A, and ASTER imagery. However, remote sensing data has limitations on data resolution and atmospheric effects.

This study examines the spatial distribution of salinity in Banda Aceh's city by using a combination of groundwater salinity measurements and spatial analysis with GIS. By knowing the geospatial salinity conditions, land suitability in Banda Aceh's city can be classified and mapped.

Materials and Method
Location and time

The study area is the city of Banda Aceh, Aceh province, Indonesia (5 36 '27 "N to 5 30" 58 "N and 95 16" 46 "E to 95 22" 40 "E). The study was based on a salinity survey in eight sub-districts in Banda Aceh, namely: Baiturrahman (1 point), Banda Raya (3 points), Jaya Baru (1 point), Kuta Alam (10 points), Kutaraja (2 points), Meuraksa (4 points), Syiah Kuala (9 points), and Ulee Kareng (2 points) (see Figures 1 and 2). The location of water sampling is on land (wells) and is 2936 meters (on average) from the coastline.
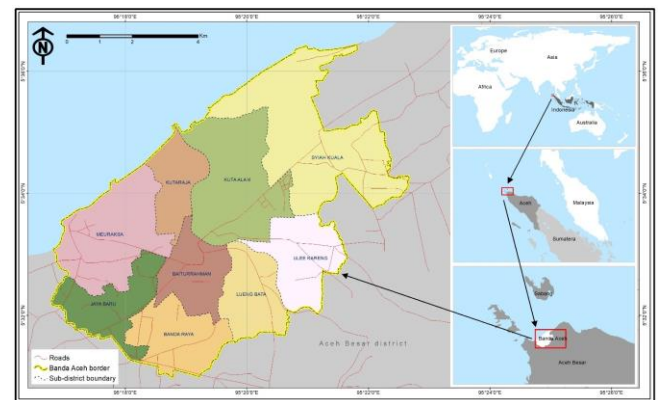

Figure 1. Research locations and thematic map of Banda Aceh sub-district, Indonesia.
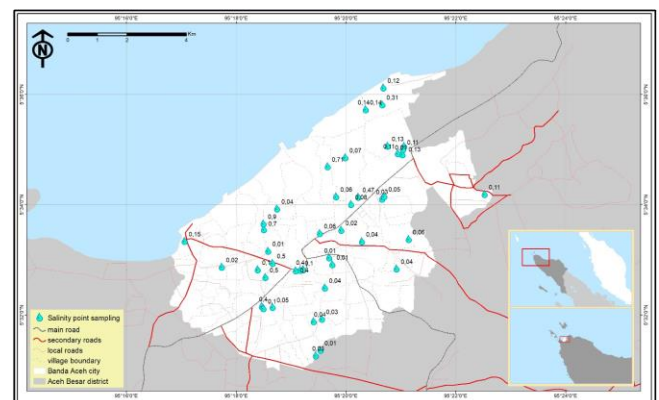

Figure 2. Salinity observation stations in the Banda Aceh area.

This research is an analysis of land suitability after a decade of the tsunami. Measurement of salinity in the field and data analysis in the laboratory took place from May to September 2014. According to Rizal et al. (2012), these months are the southwest monsoon period. Based on the Climate Hazards Group InfraRed Precipitation (CHRIPS) (Funk et al., 2015),

in the southwest monsoon, Banda Aceh's city is quite dry, the intensity of rainfall is below 5-7 mm/day. Therefore, in this study, the influence of the variable rainfall on salinity is limited.

Data analysis

The combination of the grid method and the systematic method is used for water sampling (well surface) (Puslitanak, 2004; Sufardi, 2012). Groundwater salinity was calculated using the Lutron PSA 311 Salt Meter instrument and calibrated with the ATAGO Hand-held Refractometer.

The results of the salinity measurement were then analyzed spatially with GIS. Spatial analysis is a mathematical and logical analysis technique, which finds patterns or relationships between geographic elements (Prahasta, 2009). In spatial analysis with GIS, variables and parameters are organized in several separate layers. Also, in the GIS module, several tools are used. GIS tools used in spatial salinity analysis or geospatial salinity consist of reclassification, interpolation, extraction, and overlay (Figure 3). Reclassification is the process of reclassifying or changing cell values into alternative values so that certain desired intervals can be obtained. This reclassification process applies to all domain zones. Furthermore, for salinity interpolation, the kriging technique is used, which refers to Prahasta (2009). Pramono (2008) concluded several advantages of the Kriging technique: its unbiased nature, small or minimum variation, and a linear combination of observations.

The following process is extraction in which a subset of raster data cells and their attributes are sampled. In this case, raster data is interpolated salinity data. The processed data is then overlaid or formed in a composite map to facilitate the identification of existing relationships. In this study, the land classification method based on salinity conditions refers to the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2007).

Results

The salinity obtained from several Banda Aceh stations is shown in Table 1 (in ppt or o / oo units). Based on Table 1, the average salinity at the measuring station is 0.0236 with a median of 0.0095. Meanwhile, the lower, middle and upper quartiles are 0.004, 0.0095, and 0.0288, respectively. These results indicate that the data's variation is high enough that it needs further analysis using spatial analysis techniques. The salinity values of 31 stations were analyzed using GIS tools and interpolated using the

Kriging technique. Kriging has advantages, including minimal variance in the results of data interpolation.
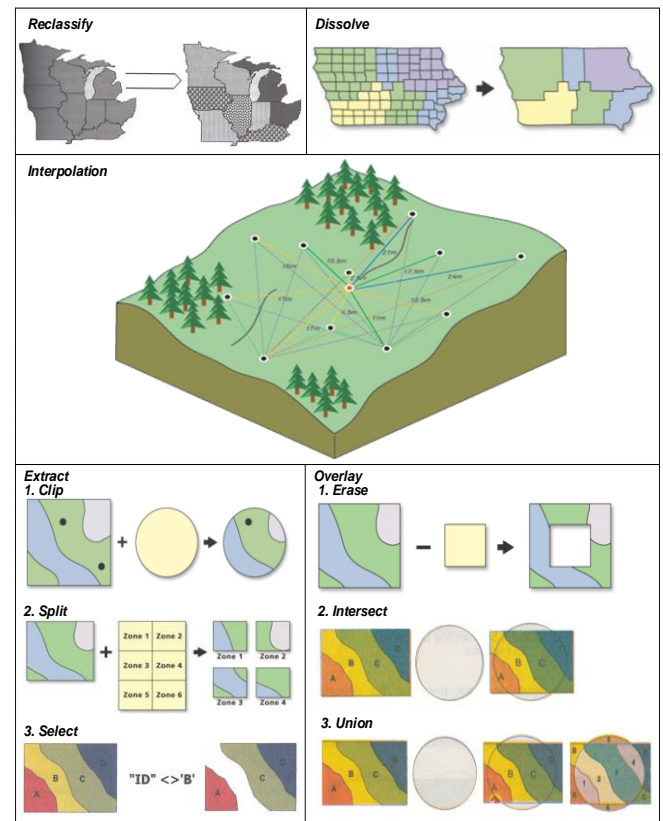

Figure 3. An illustration of spatial salinity data processing using GIS tools (modified from Prahasta, 2009; Indarto and Faisal, 2012; ESRI, 2013).

Figure 4 shows the results of salinity interpolation using the Kriging technique. Based on the analysis, the Banda Aceh area is classified into seven classes (see Figure 4). The highest salinity is near the coast, such as in Meuraxa, Kuta Raja, Jaya Baru, and a small part of Syiah Kuala. The rest, namely Banda Raya, Ulee Kareng, and Kuta Alam Districts, have low salinity.

Table 1. Water salinity at several measuring stations in Banda Aceh.

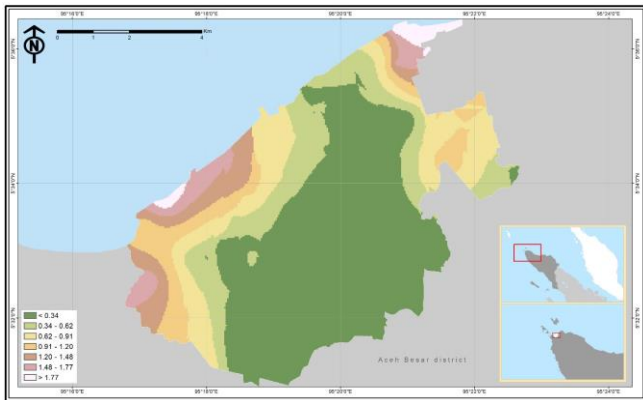| No	Districts	Salinity (⁰/oo)
1	Baiturrahman	0.146
2	Banda Raya	0.005; 0.004; 0.057
3	Jaya Baru	0.06
4	Kuta Alam	0.006; 0.003; 0.005; 0.004; 0.002; 0.007; 0.071; 0.006; 0.008; 0.047; 0.004
5	Kuta Raja	0.09
6	Meuraxa	0.002; 0.015; 0.001; 0.07
7	Syiah Kuala	0.011; 0.011; 0.013; 0.001; 0.011; 0.013; 0.031; 0.012; 0.028
8	Ulee Kareng	0.004; 0.006

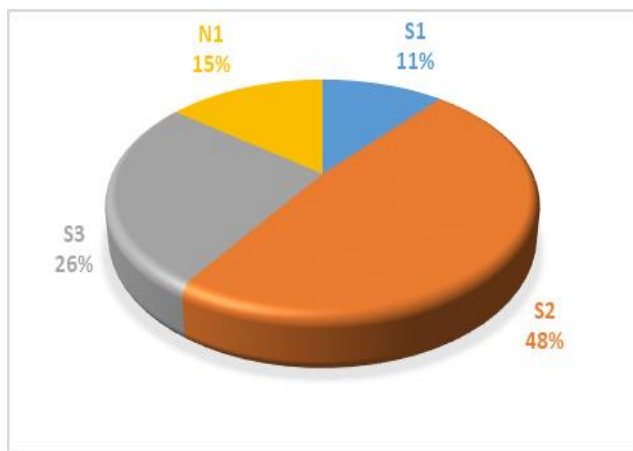Figure 4. Geospatial salinity in Banda Aceh based on the Kriging method.

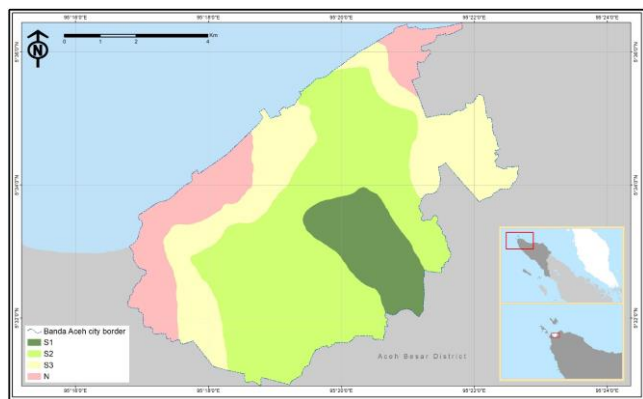Figure 5. Pie chart of land suitability based on salinity.

Figure 6. The cluster of residential based on salinity.

The land suitability is further classified based on FAO criteria (FAO, 2007). Table 2 displays land suitability based on salinity. Land suitability and salinity have a linear relationship, where the higher the salinity, the lower the level of settlement suitability. Clusters S1 and S2 indicate highly suitable and moderately suitable fields, respectively. Meanwhile, cluster S3 indicates marginally suitable land. Clusters N1 and N2 denote temporarily unsuitable and unsuitable fields over long periods, respectively. Thus, an area with freshwater

conditions is an area that is very suitable for settlement.

Table 2. Land clusters based on salinity.

Class	Salinity (^{o}/$_{oo}$)
S1	0
S2	0.01 – 0.05
S3	0.06 – 0.10
N1	0.11 – 0.15
N2	>0.16

Table 3. Land area based on salinity criteria.

Class	Hectare
S1	686
S2	2975
S3	1614
N1	888
Total	6136

Table 3 shows the land area suitable for settlement in the Banda Aceh area, while the percentage is shown in Figure 5. Based on the FAO cluster (FAO, 2007), land suitable for settlement in Banda Aceh can be seen in Figure 6. In general, based on salinity criteria, Banda Aceh has a reasonably good residential area (85%), which is dominated by cluster S2 or land sufficiently suitable for settlement (48% or 2975 hectares). Meanwhile, the land which is not suitable for settlement in Banda Aceh (N1) is relatively small, namely around 15% or 888 hectares. In general, areas that are not suitable for this are pond farming areas such as Kuta Raja, Meuraxa, and parts of Syiah Kuala. Also, the location is close to the beach, where it has received a heavy tsunami impact.

Meanwhile, areas suitable for settlement in Banda Aceh, such as the sub-districts of Ulee Kareng, Banda Raya, Lueng Bata, Kuta Raja, and Kuta Alam, are close to the Aceh River Basin. Areas adjacent to watersheds generally have lower salinity. It is because freshwater from upstream flows through the watershed and dilutes the salinity.

Discussion

The earthquake and tsunami in 2004 affected land conditions in Banda Aceh, such as changes in coastlines, erosion, land subsidence, soil and water contamination. Therefore, environmental studies such as land for settlement are needed. Salinity affects water resources quality, especially in coastal areas and small islands, where orographic rainfall is difficult and freshwater catchments are lacking. Also, the risk of seawater intrusion affects the quality of water resources. Most of the city of Banda Aceh is in coastal and lowland. Therefore, salinity is significant

for determining the direction of settlement development in the city of Banda Aceh.

According to Jiang and Rohendy (2018), although the supply of fresh water in Banda Aceh's city has been guaranteed, most people still depend on small industries that manage absorption water resources. Local people also use infiltration and river water for farming. This condition indicates the importance of water quality, such as salinity, for future management.

The spatial analysis results show that the coastal of Banda Aceh is not suitable for settlement. The threat of seawater intrusion into nearshore areas may influence this outcome, especially if the buffer zone near the coast has little or no mangrove vegetation. Kuta Jaya, Meuraxa, Jaya Baru, and Syiah Kuala can be used as a buffer zone but not suitable for residential development.

It follows Syamsidik et al. (2018), which states that the ponds and agriculture near the coast (such as in Meuraxa) are quite challenging to recover. Only about 80% of the agricultural land can be recovered while ponds are around 19%. It is difficult for these two sectors to recover due to irrigation or inadequate freshwater supply, closely related to salinity criteria. Also, changes in vegetation were affecting. The initial vegetation of Banda Aceh coastal was mangroves, but it turned into coastal forests (*Casuarina* sp.).

Globally, increased salinity in soils is an environmental threat. This difficulty is also a result of the drainage system's loss and inadequacy. According to Metternicht and Zinck (2003), in the world, there are approximately 955 million hectares of primary land and 77 million secondary lands that are affected by increased salinity (salinization), of which 85% is irrigated/drainage land.

Meanwhile, Ivushkin et al. (2019) found that 1 billion hectares of land (approx. 67-70% accuracy) were affected by salinization. According to Ivushkin et al. (2019), this process has a clear trend in the future. Metternicht and Zinck (2003) reported that about 20% of irrigated land in the world is affected by this salinization process, and the proportion continues to increase although relocation efforts have been made. In Aceh, after the tsunami, the high salinity can last up to three years even though washing by rain is relatively high (3000-7000 mm). McLeod et al. (2010) found a high correlation between poor rice farming productivity in Aceh and high soil salinization conditions. Therefore, based on spatial analysis, settlement development in Banda Aceh's city should be directed away from coastal areas such as Lueng Bata and Ulee Kareng.

Conclusion

Based on the salinity indicator, Banda Aceh City still has a high potential for residential areas, where 86% is cluster S (appropriate), and 14% is cluster N (unsuitable). The land area of cluster S1 (very suitable) is around 686 hectares or 11%, S2 (quite suitable) is around 2975 hectares or 48%, and S3 (according to marginal value) is around 1614 ha or 26%. Meanwhile, the land area that is not suitable or N1 (currently unsuitable) is around 888 hectares or 15%. Zones suitable for settlement are located relatively far from the coast and close to the watershed. When viewed from the salinity indicator, Ulee Kareng, Banda Raya, Kuta Alam, and Lueng Bata are several sub-districts used as residential areas in Banda Aceh.

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