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Preliminary Study of Tsunami Impact on Soil Salinity for Agriculture Based on Geophysical Data, a Case Study of Aceh Besar, Indonesia

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Abstract: The Tsunami, (natural phenomenon) that occurred in Aceh Province in 2004, not only caused severe damage to the infrastructure and human casualties but also altered the conditions of the soil. The change in soil condition led to economic loss (productivity and activity) in certain areas that were affected by the Tsunami. Studies show that the land inundated with Tsunami flood and sedimentation caused the land to become unproductive since the salinity level increased. The geophysical method was used to delineate the level of soil salinity in areas affected by Tsunami. A total of four measurement lines ranging in length from 160 to 210 meters were constructed specifically in Aceh Besar region. In the Blang Krueng District, three measuring lines (K1, K2, and K3) were positioned slightly away from the shoreline and one measurement line was conducted in the Blang Bintang (B1) region to validate the difference between the conductivity values of land polluted with tsunami sediment and seawater intrusion. Results show that the areas affected by Tsunami sedimentation had a greater conductivity value than unaffected areas classified by the conductivity value of 0.06 – 2 S/m and 0 – 0.05 S/m for Blang Krueng and Blang Bintang areas respectively.

Keywords: *Tsunami, soil salinity, geophysical method, conductivity*

1. Introduction

Aceh Province is located in the northernmost and westernmost parts of Indonesia and it is renowned as a province with a high level of natural disasters. Based on geological conditions, Aceh lies on the confluence of two tectonic plates; Eurasian and Indo-Australian. Therefore, geologically induced conditions of plate activities are quite frequent (Syukri et al., 2019; 2020), such as the Tsunami phenomenon. The impact of the 2004 Tsunami not only caused severe damage to the economy, infrastructure, and human casualties (Rusydy et al., 2020; Suppasri et al., 2019; Azmeri et al., 2017) but also affected the change in soil conditions. This change in soil conditions could lead to decreased economic activity and production, especially in agriculture. Due to changes in soil structure and qualities produced by the deposition of Tsunami sediments, the area once used as agricultural land is thought to be unproductive because Tsunami sediments covered the subgrade surface (Niino, 2008; Tinning G., 2011; Marohn et al., 2012). 92.81% of Aceh's economic activities rely on agriculture (farming, forestry, and fishing). In order to assess the level of efficacy of land usage for agricultural purposes, particularly in the Aceh Besar region, a comprehensive study of post-tsunami soil conditions is necessary. Using observations on a limited scale, such as in the laboratory, soil structure can be determined by incorporating more sophisticated imaging capabilities. (Helliwell et al., 2013; Schlüter et al., 2014). Nevertheless, Romero et al; (2018) state that there is presently large-scale method of measuring the whole soil structure using the geophysical method. Therefore, this study aims at using the geophysical method capacity to determine soil salinity for agricultural purposes by mapping the soil conditions. In addition, the geophysical approach can describe the subsurface structure across a vast area. Moreover, the implementation of the 2-D geoelectric approach is regarded as the most appropriate technique because it can explain various elements crucial for plant development (Johnson et al., 2001; Kravchenko et al., 2002)

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Tsunami Impact on Soil Characteristics

The magnitude 9.1 Sumatra-Andaman earthquake, which occurred on December 26, 2004, produced the most catastrophic Tsunami in recorded history (Lay et al., 2005). The Tsunami submerged up to 29,000 hectares of agriculture in Aceh Province, causing damage to the farms. The agricultural area is contaminated due to seawater's entrance and mud deposition. The entrance of seawater and mud accumulation increased the inundated farmland's salinity. As the salinity level rises, the osmotic potential of the soil falls, and it is anticipated that saltwater and debris-inundated fields could limit plant growth. As a result, the plant's roots would have trouble absorbing the water, as it is strongly bound to the soil particles, resulting in physiological dryness. Hereinafter, the high level of salinity could also lead the protoplast to be wrinkled as a result of cell damage

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and sodium poisoning. The decrease in plant growth activity is caused not only by the inability of plant roots to obtain water but also by the tendency of the plant's water content to discharge the surrounding high salt concentration. Hereinafter, the high level of salinity could also lead the protoplast to be wrinkled as a result of cell damage.

Soil Salinity and pH

The presence of the primary inorganic solutes dissolved in water constitutes soil salinity. The salt concentration of the soil is considered detrimental to plant growth. The salt content in the soil alters a soil's ability to absorb water. As the salt content of the soil rises, the fluctuation of ions within plants impedes the natural passage of water from the soil to the plant roots. This also causes the water absorbed by plant roots to be sucked back into the soil, leaving plants dehydrated. In addition, an increase in the concentration of dissolved salts in the soil will increase the osmotic pressure; thus, inhibiting the absorption of nutrients and water absorption, resulting in a decrease in the amount of water entering the roots and a depletion of the water supply in plants (Muliawan et al., 2016).

According to Aizat et al; (2014), soil pH is related to soil electrical conductivity (EC). Soil pH is one of the most informative characteristics of soil about its state. The measured properties are the concentration of hydrogen ions in the soil. Additionally, it defines the presence of fertilizers and soil solubility. Since it determines the soil's toxicity and nutrient deficiency, pH at a certain level can be harmful to plants. Aizat et al (2014b), also stated that the amount of soluble salt in alkaline soil makes it to drop. It indicates that soil with a high salt level can be detected by its high EC and low pH levels. Table 1 present the tier of soil salinity level based on soil electrical conductivity.

Table 1. Classification of Soil Salinity and Soil EC (Rhoades et al., 1989).

No.	Salinity Level	Soil EC (S/m)	Class of Salinity
1	Non-Saline	0 – 0.2	0
2	Low	0.2 – 0.4	1
3	Moderate	0.4 – 0.8	2
4	High	0.8 – 1.6	3
5	Very High	>1.6	4

2. Study Area

Aceh Besar Regency is an administrative city surrounding the provincial capital of Aceh. Physio- graphically, Aceh Besar consists of an undulating alluvium that stretches from northwest to southeast. This area's alluvium is predominantly composed of gravelly sand, gravel, sandy clay, sandy silt, clayey silt, silty clay, and sediment originating from a wetland (Syukri et al., 2020b). The Aceh Besar Regency is divided into two distinct regions based on geological and geomorphological features. A mountainous region dominates the first section with modest hills and undulating terrain. Plain lands dominate the second section of Aceh Besar, and the majority of the suburbs are situated near the coast (Figure 1).

The research areas are situated in two distinct Aceh Besar districts. The first research area is located in the district of Blang Krueng and comprises a total of three measuring lines (Figure 2). Based on geological setting, this area is dominated by alluvium which has a type of sand, gravel, and mud (Bennet, et al., 1981). The selection of the study region is because the 2004 tsunami severely damaged Blang Krueng due to its proximity to the coast. Despite its proximity to the coast, most of the inhabitants of Blang Krueng are farmers. This issue prompted the author to study whether land contaminated with tsunami sedimentation is still efficient for agriculture.

The second study area is subsequently separated from the first study region (Figure 3). The research area is determined based on its morphology and topography, which classify it as a hilly region. Geologically, this area is formed by breccia, Agglomerate, Andesite, Dacite, Tuff, dan volcanic ash from Lam Teuba Volcano (Bennet, et al., 1981b). Two measured lines were undertaken to determine the difference in conductivity values between Tsunami sediment-contaminated and uncontaminated ground.

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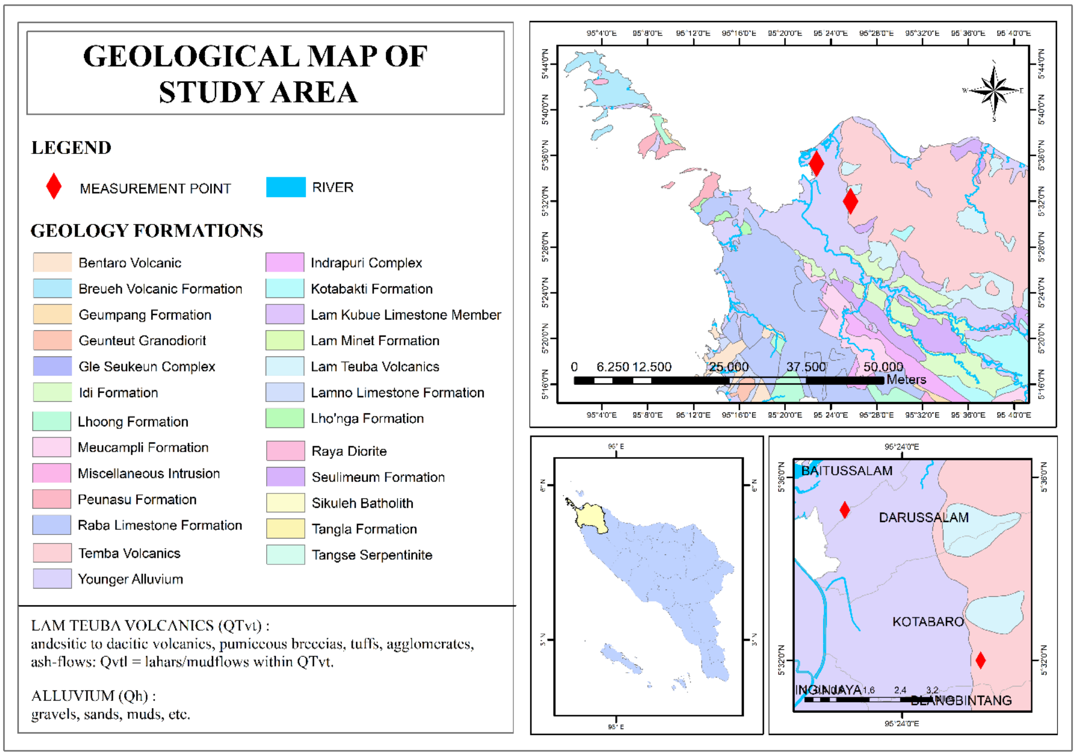

Figure 1. Geological Map of Aceh Besar Regency (Bennett et al., 1981c)

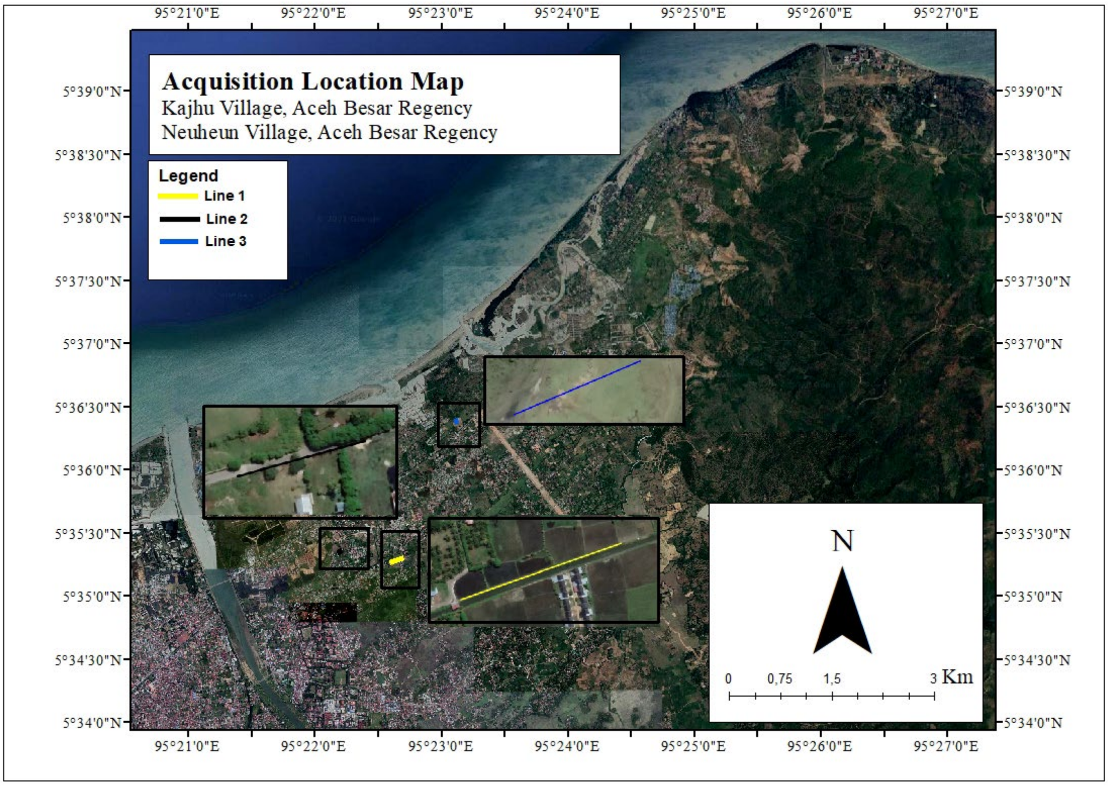

Figure 2. Study area of Blang Krueng District with three 2-D geoelectric measurement lines

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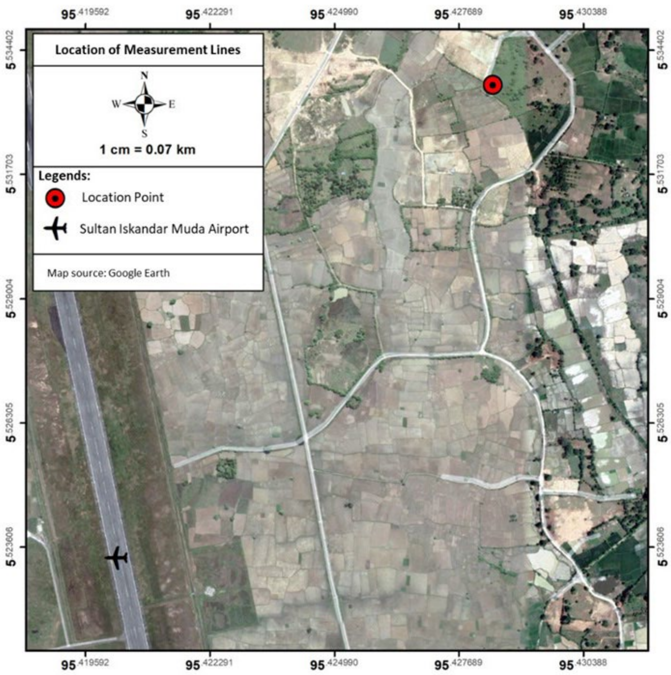

Figure 3. Study area of Blang Bintang District with 2-D geoelectric measurement lines

3. Methodology

2-D geoelectric approach and field measurements were conducted at two separate sites. The 2-D Geoelectric approach was utilized due to the correlation between soil salinity and electrical current propagation below the surface. According to (Raja eta al., 2009), anthropogenic activities, such as the inefficient management of land and water resources and the weathering of parent materials, have resulted in the pervasive salinization of soils. Nonetheless, large-scale tsunamis also contribute to the salinization of soil conditions. The 2-D geoelectrical method is an active geophysical technique that involves delivering a regulated direct current (dc) into the subsurface via an iron electrode rod. Subsurface information is classified by calculating the apparent resistivity (a) from the recorded resultant electrical potential at a certain point/depth. Since the conductivity data are the inversion of the resistivity data, they were obtained automatically. Using software inversion, the tomography/pseudo-section approach is also used to depict the detail of the subsurface via tomography/pseudo-section model yield (Pierce et al., 2012).

In order to determine the amount of soil salinity in Aceh Besar, a total of four measurement lines ranging in length from 160 to 210 meters were constructed. In the Blang Krueng District, three measuring lines (K1, K2, and K3) were positioned slightly away from the shoreline, as illustrated in Figure 2. In addition to observing the variation of soil electrical conductivity in relation to soil salinity induced by tsunami sedimentation, the objective of line geometry was to explain the soil salinity level based on saltwater intrusion. In addition, one measurement line was conducted in the Blang Bintang (B1) region to validate the difference between the conductivity values of land polluted with tsunami sediment and seawater intrusion and without intrusion.

4. Result and Discussion

The result of measuring the geoelectric field in two dimensions along the lines K1, K2, K3, and B4 is represented in Figures 4, 5, 6, and 7. The pseudo-sections have revealed conductivity values ranging from 0 to 15 S/m at depths ranging from 20 to 40 meters. In general, the pseudo-section is divided into two primary zones based on the depth of plant roots. Based on observation and field data, the author concludes that the initial zone of lines K1, K2, and K3 in the Blang Krueng district, which has a thickness of < 5 m, is interpreted as a tsunami sediment-contaminated layer.

Figure 4 depicts the result of the Blang Krueng district's lines K1, K2, and K3. The results indicate that the area is categorized as conductive. It is demonstrated by the conductivity of up to 10 S/m. The first zone of lines K1, K2, and K3 have a conductivity value of between 0.06 and 2 S/m. The zones are regarded as a sandy clay-dominated alluvium layer with a thickness of ± 5 m. The second zone of lines K1, K2, and K3 is then characterized as having a conductivity value between 2 and 10 S/m and a depth of > 5 m. The high conductivity value of the second zone is thought to be the result of sea-derived sedimentation.

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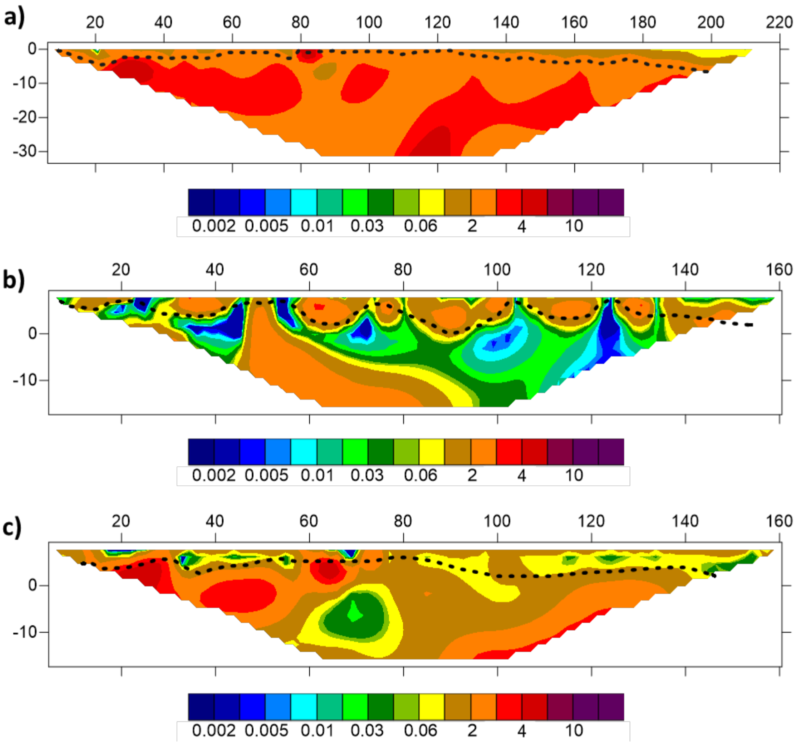

Figure 4. Conductivity inversion models of Blang Krueng district; a) K1, b) K2, c), and K3

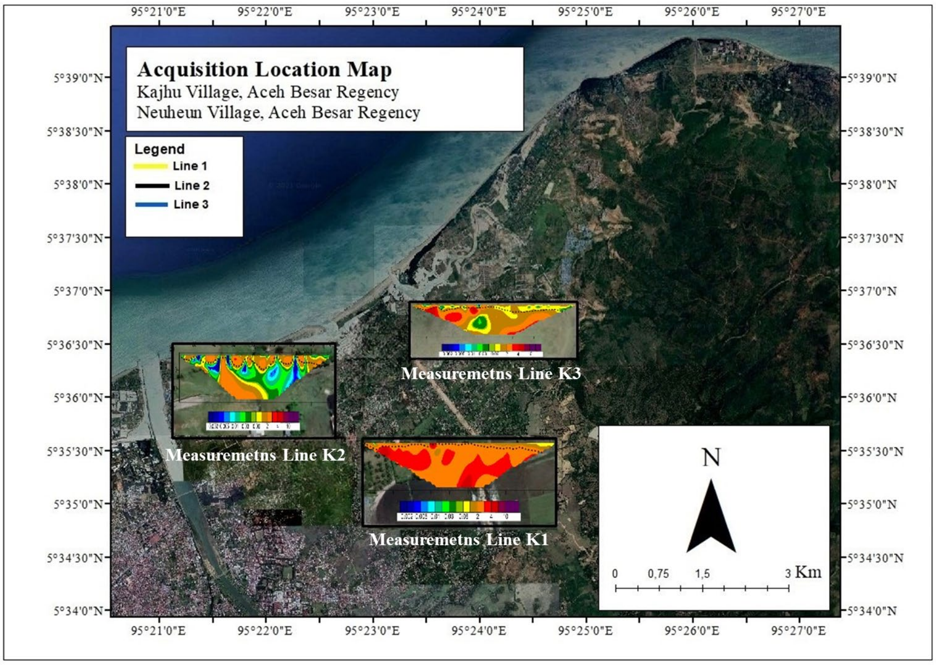

Figure 5. Conductivity inversion model based on location of measurement lines at Blang Krueng district.

Figure 6 shows the pseudo-section of line B1 in the Blang Bintang region. The observed value of conductivity is less than 1 S/m. With a depth of 40 meters, the distribution of conductivity values is typically between 0 and 0.08 S/m. The pseudo-section is also divided into two major zones, with the first zone having conductivity values of between 0 and 0.005 S/m understood to be the first layer, which is dominated by clay and has a thickness of < 5 m. In contrast, the second zone is understood as a layer of tuff and andesite. The zone is characterized by a conductivity value of > 0.05 S/m and a depth of > 5 meters.

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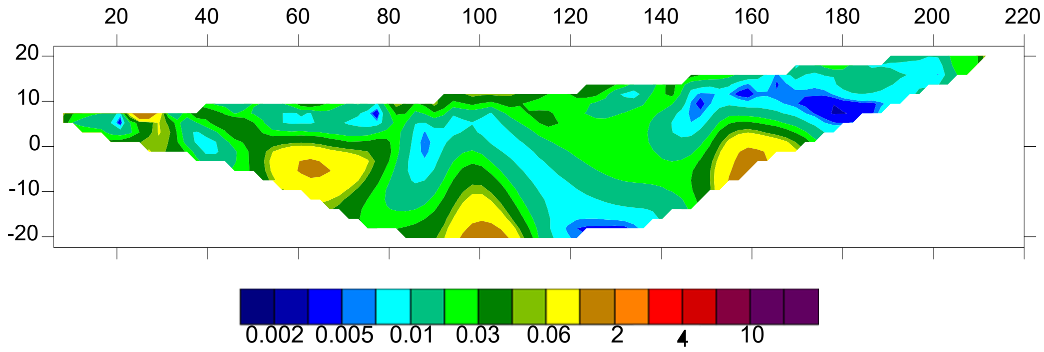

Figure 6. Conductivity inversion models of Blang Bintang district; measurement line of B1

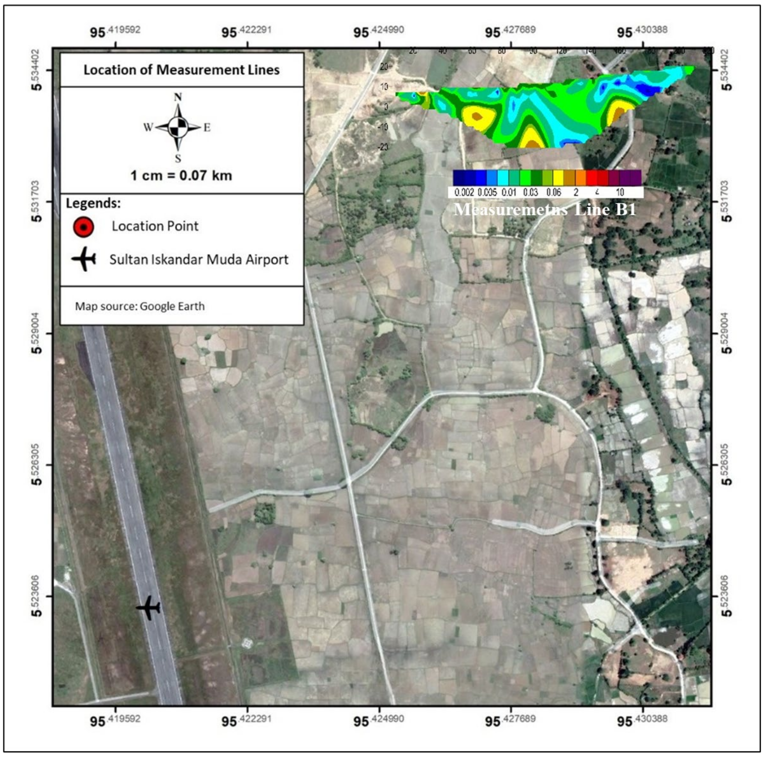

Figure 7. Conductivity inversion model based on location of measurement lines at Blang Bintang district

In addition, the result of soil pH reveals that the area covered by Tsunami sediment deposition (Blang Krueng) has a lower pH range than the Blang Bintang region. In the Blang Krueng region, the measured pH ranges from 5.0 to 6.4; however, in the Blang Bintang region, the pH range is significantly greater, ranging from 6.7 to 7.2.

Based on observation and interpretation of field measurements, it was determined that the soil condition of the region contaminated with depositional tsunami sediment in 2004 (Blang Krueng) differs significantly from that of the unaffected area. With a thickness of 5 m, it has a wide range of conductivity values between two regions, 0.06 – 2 S/m and 0 – 0.05 S/m respectively. The obtained result indicates that the salinity level in the tsunami-contaminated Blang Krueng region is significantly greater than in the Blang Bintang region. It is also collaborated by the fact that the Blang Bintang region is located far from the shoreline; hence the 2004 tsunami did not touch the region.

In addition, it was discovered that the Blang Krueng the studied area, which was a tsunami-affected location in 2004, had undertaken a mitigation effort in the form of land reclamation (Yusya' et al., 2008). This suggests that even though the Agency for the Rehabilitation and Reconstruction of Aceh and Nias, United Nations, and Non-Governmental Organizations have completed the mitigation stage of sediment removal from severely damaged land, the sustainability effects produced by the tsunami sediment still affects the soil in the region. According to Roy et al (2014), although the rehabilitation of agricultural land productivity has been conducted, it has not been fully accomplished due to different phenomena stemming from the physicochemical and biological status of topsoil under long-term natural conditions.

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5. Conclusion

Based on the research findings, it can be stated that locations damaged by tsunami sedimentation in 2004 had a greater conductivity value than unaffected areas. The measurement findings showed a conductivity value of > 2 S/m at a depth of 5 m in the category of extremely high salinity. In addition, the measurement results suggest that the measurement of land salinity for agricultural purposes may be described in detail with a broad range of geophysical measures, particularly the 2-D geoelectric method used in this study.

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