Salinity of paddy field in main landforms in Indramayu Regency, West Java

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Abstract. One of the main problems of paddy field in Indramayu is the high level of salinity. Paddy fields in Indramayu Regency are located around the North Coast. This area is dominated by the alluvial, fluvio-marine, and marine landforms groups. This study aims to examine the relationship between soil salinity and the type of landform. A total of 102 soil samples on paddy soils were taken and analyzed in the laboratory to obtain soil salinity data. The average of soil salinity value in each landform was compared with one another. Several litho-sequent transects were constructed to observe the pattern of salinity distribution and two soil profiles were observed to confirm the soil forming material. The soils in the marine landform group had the highest salinity, followed by the fluvio-marine and alluvial group, with a mean value was 390.6 mg L⁻¹, 141.0 mg L⁻¹, and 61.9 mg L⁻¹, respectively. The salinity of soils developed from marine deposit is higher than alluvium deposit. The closer distance to coastline makes the possibility of higher sea water intrusion, causing higher soil salinity. The landform approach in estimating soil salinity level is very useful, making it easier to find effective land management to reduce negative impacts on paddy field.

1. Introduction
Rice is the main food commodity and staple foods of Indonesian people. Most of the rice in Indonesia is grown on paddy fields. Nationwide, rice production in Indonesia in 2019 reached 54,604,033.34 t. This amount is less than rice production at 2018 that reached 59,200,533.72 t [1].

The total area of rice fields is stipulated in the Decree of the Minister of ATR/Head of BPN No. 686/SK-PG.03.03/XII/2019 dated 17 December 2019 concerning the Determination of the National Rice Field Area for 2019. This information becomes the basis for calculating the area of rice harvest. This number is much larger than the dry land paddy fields. This shows that the wetland is very important as producer of main food staple in Indonesia. According to the Decree of the Minister of ATR/Head of BPN, Indonesia's rice field area is 7,463,948 ha. Java Island dominates the ownership of the largest area of rice fields. East Java is the province with the largest rice field area in Indonesia. This province has rice field area of 1.2 million ha. Central Java and West Java have rice field area of 1,049,661 ha and 928,218 ha, respectively. The most productive rice fields are located in the northern part of Java Island (Pantura area). This area is positioned extending from the west to the eastern region of Java Island.

One of the problems with lowland soils in Pantura area is the high level of salinity, especially in areas close to the coastline. Saline soil is soil that has a high salt content. Salinity indicates the level of chemical compounds dissolved in the soil. Saline soil is soil that contains inorganic compounds such as Na⁺, Mg²⁺, K⁺, Cl, SO₄²⁻, HCO₃⁻, and CO₃²⁻ in a solution, thereby reducing soil productivity. High soil salinity will damage soil fertility, because it will kill soil fertilizing organisms such as bacteria and
earthworms. In developed agricultural areas, efforts are made to make earthworms alive through environmental engineering, so as to restore soil fertility [2]. Salinity will affect the physical and chemical properties of soil, namely: increased osmotic pressure, increased ionization potential, deteriorating soil infiltration, disruption of soil structure, poor soil permeability and decreased conductivity [3].

Salinity occurs not only due to less dissolving and less rainfall salt wash, but also because evaporation (evaporation) which rapidly cause salt accumulation in the soil [4]. Sources of salinity in the soil can come from materials in situ or from other places through saltwater runoff due to tidal flooding, high tides or through seawater intrusion. The process of entering sea water into groundwater flows is the definition of sea water intrusion [5]. The continuous exploitation of water and increasing volume from time to time causes the formation of empty space in the aquifer layer so that the empty space on the land is then filled with sea water [6].

Lands in the surrounding coastal area is generally lowland and have different landform. Landform is defined as the form of land on Earth's surface, particularly on the mainland, which occur due to certain geomorphic processes and through a series of specific evolution. In general, the landform in the coastal area in Indramayu is classified into the marine, fluviatile-marine, or alluvial group, which depends on the process of soil formation. Marine landforms are formed by marine processes, both constructive (deposition) and destructive (abrasion). Fluviatile-marine landform is formed by a combination of fluvial and marine processes. The existence of this landform can be formed in the marine environment (delta) or in the mouth of a river which is directly affected by sea water activity. Meanwhile, alluvial landform is formed from ancient lake activity, fluviatile process (river activity), colluvial (due to gravitational force) or a combination of fluviatile and colluvial processes.

The nature of fertile land in coastal areas has caused a lot of land in the area to be used as a place for agricultural cultivation, including the development of rice fields. However, in some places these lands have high salinity and have the potential to threaten agricultural cultivation, so that efforts are needed to overcome these problems. Failure to overcome these constraints can lead to unproductive land or crop failure.

The tolerance of each plant to high soil salinity varies. Some plants can survive high salinity in the soil, while others cannot. Rice is not a salt resistant crop [7]. Salinity can be a major problem in the growth of rice plants, especially in dry and coastal areas [8]. The magnitude of the effect on the growth of rice plants depends on the salinity value. Symptoms of salt poisoning in rice plants include shorter plants, reduced tillers, whitish leaf tips and often chlorinated parts of the leaves. Conditions like this, if allowed to continue, will cause plants death. In saline soil, the content of saline solution in the soil can inhibit germination, nutrient absorption and plant growth [9]. Research [10] regarding the test of rice tolerance to salinity proved that salinity greatly affects rice plants, especially at the germination stage of the seeds that will grow. Salinity causes plants to dry out, and prevents the roots from performing osmosis where water and nutrients move from areas of low concentration to high concentration. Therefore, water and nutrients cannot move to the plant roots. The higher the soil salinity level, the higher the pressure on germination. High salinity can lead to nutrient poisoning and water stress in plants, causing disruption of the activity of cell membranes, enzymes, and elements that are important in the photosynthetic process. The response given by these plants is to collect important metabolic elements in the cytoplasm to overcome the problem of water stress [11]. The impact of salinity on rice depends on several factors, namely stress intensity, climatology, and the resistance value of each plant [12]. In addition, salinity can affect the accumulation of elemental ammonium and reduce chlorophyll in leaves [13]. For agricultural cultivation to be successful in this area, proper land management is needed to reduce soil salinity or the impact of high soil salinity.

This study aims to examine the relationship between soil salinity and landform. The landform approach in estimating salinity levels is expected to facilitate people or farmers in seeing the potential hazards of soil salinity for agricultural cultivation, so that it will make it easier to find solutions to solve their problems.
2. Materials and methods
This research was conducted in the paddy fields in northern part of Indramayu Regency, West Java. A total of 102 soil samples distributed in the marine (M), fluvio marine (B) and alluvial (A) landform groups were taken from the field. The landform information in Indramayu Regency is taken based on the semi-detailed soil map at a scale of 1: 50,000 [14] which refers to Indonesian landform classification guidelines for soil mapping [15]. Soil samples were taken from the surface from the soil to a depth of 1 to 10 cm. The soil sampling was carried out between August and October 2014, when the weather conditions were during the dry season. Soil samples was taken from field proportionally according landform area, Soil samples from the alluvial landform group were 37 observations, the fluvio marine group were 40 observations, and the marine group were 15 observations. The position of the soil sampling was marked using GPS. Measurement of the distance to the observation position from a salt water source, namely the coastline or salty river, was carried out through maps. The soil samples were analyzed in the laboratory to obtain salinity data. The salinity properties of the soils are measured using a conductometer. The average of soil salinity value in each landform was compared among one another.

Some of the properties of soil salinity in several consecutive observations based on topo-litho sequent transects were observed to see the pattern of salinity levels based on the landform. In addition, observations and sampling were made of two soil profiles that represent the main soil-forming materials, namely marine sediment and river sediment. Several soil properties, namely soil texture, soil pH, salinity, and exchangeable bases of Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$ were analyzed in laboratory. The resulting data were interpreted to determine the type of soil parent material.

3. Results and discussion
Indramayu Regency is divided into various landform, namely marine, fluvio marine, alluvial, tectonic and volcanic landform. The marine, fluvio marin, and alluvial landforms are found in the northern part, generally in the form of wetlands which have flat to slightly flat relief with a slope of 0 to 3%. Of the three landform groups, the alluvial landform group was the largest area of 87,945 ha, followed by fluvio marine area of 40,412 ha, and marine landform covering 15,830 ha. Tectonic and volcanic landforms are located in the Southern part. These landforms are dry land with a higher slope and elevation than the landforms in wetlands. These tectonic and volcanic landform areas are 57,529 ha and 1,756 ha, respectively.

The rice fields in Indramayu district are generally located in the northern part, in the marine, fluvio marine, and alluvial landform. The spatial distribution of these landform is presented in figure 1. The marine landform group is generally closer to the coastline, followed by the fluvio marine and alluvial groups. Paddy soils in the marine landform group generally had the highest salinity level, followed by the fluvio marine group and the alluvial group. The average salinity in the marine landform group was 390.6 mg L$^{-1}$, followed by the fluvio marine landform with a mean value of 141.0 mg L$^{-1}$, and the alluvial landform with average value of 61.9 mg L$^{-1}$ (figure 2). The distance from coastal line is the one of main factors that cause high soil salinity. The closer distance to the sea makes the possibility of higher sea water intrusion, causing higher soil salinity. The average distance of observation on marine landform from coastal line is higher than the average observation distance on fluvio marine and alluvial landform. The average distance of observation from coastal line according landform type is shown in figure 3. Distance from coastal line can affect soil salinity level, especially related to the possibility of intrusion or exposure to sea water runoff. The closer the distance, the higher the probability of high salinity.

The distribution pattern of soil salinity clearly shown in the distribution of salinity based on the topo-litho sequent transect (figure 4). On the three observation transects, it appears that the soil salinity level in each landform has the same trend in which marine landform has the highest soil salinity level, followed by the fluvio marine group, and then the alluvial group with the lowest salinity value. However, the salinity values on each of these transects are varied. In transect 1 (t-1), the difference in soil salinity levels in each landform is not too high, while in transect 2 (t-2) and transect 3 (t-3), the soil salinity value in the marine landform is much higher than those in the fluvio marine and alluvial landform.
The soils in the marine landform group are developed from marine sediment materials. These marine sediment materials generally have a high salt content as a result of the accumulation of materials originating from the upstream area. Meanwhile, the alluvial landform group develops from river bed materials so that the soil salinity is lower. Table 1 shows the characteristics of the two soil profiles located in the marine and alluvial landform. Both soil types are classified as Vertic Endoaquept according to the Soil Taxonomy classification system. Soil in profile P01 is located in Marine landform while P02 is located in alluvial. Both of these soils have a fine texture (clay) throughout their horizons. In P01, the soil reaction conditions were slightly alkaline in all layers with a pH value (H₂O) > 6.0. The levels of Na, Mg and Ca-exchangeable in the soil absorption complex are quite high and dominant. Exchangeable Na has the highest amount followed by Mg and Ca. Meanwhile, K⁺ has the lowest number. P02 has a slightly acidic soil reaction at the surface of the soil, while the layers below the surface are classified as alkaline with a pH value (H₂O) > 7.0. Ions Ca and Mg are quite high and
dominant in the soil absorption complex, where Ca has the highest amount followed by Mg. K and Na ions are found in low numbers, where Na ions have the lowest number.

In P01, the number of Mg is higher than Ca, in contrast to the P02 that the number of Ca ions is higher than Mg. This shows that P01 soil developed from marine sediment, while P02 soil developed from river sediment. The dominance of Mg ions is a good indicator of soil parent material derived from marine sediments, whereas the dominance of Ca ions is a good indicator of soil parent material derived from fluvial sediments [16]. This confirms that P01, which are in the marine landform developed, from marine sediment, while the P02, which lies on alluvial landform, developed from alluvium sediment. The salinity value of P01 developed from this marine material in all soil layers was much greater than P02 developed from alluvium sediment.

![Figure 4](image4.png)

**Figure 4.** Soil salinity values on 3 transect lithosequent (a) transect 1, (b) transect 2, and (c) transect 3.
Soils developed from marine materials have higher soil salinity properties than soils developed from alluvium. In P01, the number of Mg ions is higher than Ca ions, on the contrary in P02, the number of Ca ions is higher than Mg ions. This shows that P01 soil developed from marine sediment, while P02 soil developed from river sediment. The presence of Mg ions is a good indicator of soil parent material derived from marine sediments, while the dominance of Ca ions is a good indicator of soil parent material derived from fluvial sediments [17]. This confirms that P01 that is located in the marine landform developed from marine sediment, while P02 that is located in alluvial landform developed from alluvial sediment. The soil salinity value of P01 developed from marine material was much greater than P02 which developed from alluvium sediment in all soil layers.

Soils in marine landform are formed by processes of seawater activity, both constructive (deposition) and destructive (abrasion). The deposition of materials from the sea which contain high salts causes this material to play an important role in the high level of salinity in marine landform compared to soils in fluvial marine and alluvial landform. Soils in alluvial landform have the lowest salinity levels because the soil-forming material is a sediment from upstream materials with lower salinity. Meanwhile, the fluvio-marine landform whose formation process is influenced by sea and river water activities has the salinity between the two previous landforms.

Table 1. Some physical and chemical properties of the soil profiles in lowland rice fields in Indramayu.

| No Hor | boundary | Texture | pH H2O | pH KCl | Salinity | Cation exchangeable (NH4Acetat 1N, pH7) |
|-------|----------|---------|--------|--------|----------|-----------------------------------------|
|       | cm       | sand    | silt   | clay   | (mg L⁻¹) | Ca          | Mg         | K   | Na         |
| P01   | I        | 0-18    | 3      | 18     | 79       | 6.8         | 6.3        | 464.00 | 13.96      | 16.38 | 0.68       | 23.03 |
|       | II       | 18-48   | 3      | 26     | 71       | 7.7         | 6.9        | 217.00 | 11.71      | 16.29 | 0.78       | 17.01 |
|       | III      | 48-75   | 4      | 28     | 68       | 7.5         | 6.7        | 203.00 | 10.03      | 13.22 | 0.90       | 16.89 |
|       | IV       | 75-115  | 2      | 24     | 74       | 7.8         | 7.1        | 293.00 | 11.32      | 15.27 | 1.08       | 21.69 |
|       | V        | 115-150 | 2      | 22     | 76       | 7.7         | 7.0        | 264.00 | 9.68       | 13.25 | 1.04       | 19.89 |
| P02   | I        | 0-15    | 1      | 24     | 75       | 5.2         | 4.2        | 31.40  | 13.01      | 9.13  | 0.17       | 1.88  |
|       | II       | 15-38   | 6      | 24     | 70       | 7.4         | 6.4        | 27.20  | 19.41      | 11.12 | 0.24       | 2.70  |
|       | III      | 38-67   | 6      | 21     | 73       | 8.0         | 6.9        | 36.00  | 24.25      | 12.65 | 0.25       | 3.22  |
|       | IV       | 67-112  | 3      | 54     | 43       | 8.5         | 7.3        | 37.90  | 21.84      | 11.85 | 0.22       | 3.29  |
|       | V        | 112-150 | 8      | 29     | 63       | 8.0         | 6.9        | 38.70  | 15.49      | 10.17 | 0.12       | 2.73  |

In addition to the soil parent material factor, salinity can be caused by the intrusion of sea water. Intrusion occurs due to the hydrostatic imbalance of freshwater and salt water. The water system pattern includes aspects of quality, volume, and water discharge which greatly affect salt water intrusion. Reduced river water discharge for irrigation purposes can change the salinity and water circulation patterns in coastal waters such as estuarine areas. If the river water discharge decreases, the salt intrusion reaches further upstream of the river. This not only affects the coastal waters ecosystem, but also the land ecosystem around these waters. When the hydrostatic pressure of fresh water decreases, salt water intrusion occurs and it increases the salt level in the aquifer. The relative position factor of salt water sources is important, the closer distance to the sea makes the possibility of sea water intrusion higher, thus making the possibility of increasing soil salinity. The measurement results show that paddy soils located in the marine landform group which are closer to the coastline generally have the highest salinity level, followed by paddy soils in the fluvio marine and alluvial landform groups. This result is in line with the results of previous studies [18, 19] on the mapping of sea water intrusion and soil salinity which shows that the northern part of Indramayu is relatively higher in salinity than that in the southern part of Indramayu.
The landform approach is useful in estimating the nature of soil salinity in general so that land management can be easier to reduce the negative impact of salinity on rice fields. Several approaches can be taken in the management of rice fields that have high soil salinity, including using rice varieties that are tolerant of high salinity, applying crop rotation and planting time management, washing the salts using irrigation water to reduce salinity levels and using suitable soil ameliorant.

Reducing soil salinity levels can be done by rinsing the land several times so that the salt is wasted through the surface water flow. This method can be very effective at lowering soil salinity if adequate freshwater, irrigation and drainage are available. A functioning drainage channel can remove salts from agricultural land, allowing it to be replanted [20].

One type of soil ameliorant that can be used is gypsum. Gypsum application to saline soil can improve the physical and chemical properties of soil such as CEC (cation exchange capacity), increase water holding capacity, increase Ca and S content, can function as soil stabilizer, and can reduce soil pH [21]. Gypsum can replace sodium ions in the soil with calcium, so it can automatically remove sodium and increase soil percolation. The use of salt-tolerant varieties is necessary to overcome the growth and production of rice plants which are generally sensitive to salt stress. Dendang rice variety is one of the varieties that is tolerant of salinity with a potential yield of 5.0 t ha$^{-1}$ [22]. Several other rice varieties that are tolerant to salinity have been released by Agency for Agricultural Research and Development Indonesia, namely Lambur, Siak Raya, Inpari 34 Salin Agritan, Inpari 35 Salin Agritan, Inpari Unsoed 79 Agitan, Inpari 42 Agritan GSR, Inpari 43 Agritan GSR, Inpari 44 Agritan [23].

4. Conclusions
The following conclusions can be drawn from the study results:
- The paddy soil in the marine landform group had the highest salinity level, followed by the fluvo-marine group and then the alluvial group, with a mean value was 390.6 mg L$^{-1}$, 141.0 mg L$^{-1}$, and 61.9 mg L$^{-1}$, respectively.
- The parent soil-forming factor influences the difference in salinity levels in these landforms. The parent material in the form of marine sediment causes the soil in the marine landform to have a higher salinity level than the soil in the alluvial landform formed from river sediment. Meanwhile, the land in the fluvo marine landforms is in the middle of the two previous landforms. Distance from sea water is also a major factor in the high salinity of the soil, especially related to the possibility of seawater intrusion or exposure to sea water runoff. The closer the distance to the coastline, the higher the probability of high salinity will be.
- The landform approach is very useful in estimating the level of soil salinity, making it easier to find suitable types of soil management to reduce negative impacts on paddy field. Some efforts that can be made to reduce the impact of high salinity on paddy soil include using rice varieties that are tolerant of high salinity, implementing crop rotation management and planting time, washing salt using irrigation water and using suitable soil ameliorants.

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