Spatial Distributional of Irrigation Water Quality in Peaty Paddy Field of Paser Regency, East Kalimantan Province, Indonesia

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Abstract. Paddy is one of the main food-crop commodities in Indonesia. The main problem in paddy cultivation in Paser Regency is good water quality for plants. Water is the main requirement for paddy plants to grow and develop. Water quality to meet the needs of paddy plants is a very important factor. pH H_2O, TDS (Total Dissolve Solid) and EC (Electrical Conductivity) are some of the water parameters used as a reference in determining land suitability for paddy plants. The purpose of this research is to spatially analyse the water parameters (pH H_2O, TDS and EC) for the water needs of paddy plants in Paser Regency. Determination of sample points using stratified random sampling method and parameter measurements are carried out directly in the field in the irrigation area. Interpolation analysis used the IDW (Inverse Distance Weighted) method with a power weight of 2. RMSE values from the interpolation results for pH H_2O 0.0001, TDS 0.1695 and EC 0.0003. The results of the interpolation of several parameters are then analysed by overlay to determine the spatial relationship between parameters. The results of the analysis show that the average values in Paser Regency are pH H_2O 6.13, TDS 478.64 ppm and EC 0.82 mS/cm. The area of pH H_2O (6.5-8.4) suitable for paddy plants is 391447.87 ha, TDS (<2000 ppm) 1067265.23 ha and EC (<3 mS/cm) 1066907.37 ha. Most of the pH H_2O suitable for paddy plants is in the northern region, while the TDS and EC are better in the northern region although most of them are still suitable for paddy plants. Each parameter has a spatial relationship, where the value of each parameter influences each other. Overall, the northern area in Paser Regency is more suitable for paddy cultivation according to water parameters, namely pH H_2O, TDS and EC.

1 Introduction

Paddy is a food crop that requires a lot of water. Water is one of the main needs for plants to support optimal growth and development. Most of the water needs of paddy plants are supplied from rainwater and irrigation. Some parameters of irrigation water to meet the needs of paddy plants are the quantity and quality of water. Problems that often arise in irrigation water are related to water quality [4]. In addition, water quality is also rarely considered by farmers. Poor management related to irrigation water quality management by farmers is one of the causes of low irrigation water quality [9].

Several parameters that are generally used to measure the level of irrigation water quality for plants are pH H_2O, TDS (Total Dissolve Solid) and EC (Electrical Conductivity) [10]. The pH of H_2O is the level of acidity in water which is indicated by a value of 0 to 14. The pH of H_2O that is good for paddy plants ranges from pH 6.5 to pH 8.4 [11]. TDS is the total dissolved solids contained in irrigation water. The TDS value is shown in ppm and the TDS value suitable for paddy plant growth is less than 2000 ppm [12]. A high TDS value indicates a higher level of turbidity in irrigation water. EC is a parameter to determine the number of ions in water that transmit electricity. The EC value is generally expressed in the form of mS/cm and a good EC value for paddy plants is less than 3 mS/cm [5].

Analysis of water quality parameters is carried out spatially using the Geographic Information System (GIS). Spatial analysis aims to determine the distribution in a spatial context and determine the spatial relationship between parameters. The spatial variability of each parameter needs to be known using available techniques which are often called spatial interpolation. One spatial interpolation technique is Inverse Distance Weighted (IDW). By inverse weighting of sample distance, the IDW method predicts unsampled values based on values from surrounding samples. The IDW method generally assumes that the closer the interpolation distance is to the sample, the interpolated results tend to have values that are almost similar to the values from adjacent samples [6]. This method is suitable to be used to determine the variability of each water quality parameter which has similarities according to irrigation flow [13].

From previous research, it is clear that studying the variability of water quality namely pH H_2O, TDS and EC is a significant endeavour as it will likely help in site-specific management of irrigation water resources in paddy crops. This research uses the IDW

interpolation method to explore the spatial variability of pH H_2O, TDS and EC in irrigation water for paddy planting in Paser Regency, East Kalimantan Province, Indonesia. If spatial patterns of these parameters are discovered, these can be used for site-specific water resource management [14]. The purpose of this research is to spatially analyze the spatial distribution of water quality parameters i.e. pH H_2O, TDS and EC in the peaty paddy field. Determination of sample points using stratified random sampling method and parameter measurements were carried out directly in the field around the irrigation area.

2 Material and methods

The research was conducted from August 2023 to September 2023. The research location was in Paser District, East Kalimantan Province, Indonesia. The area of the research area is 1070115.85 ha or 10701.16 km2. The location of the research area starts from 346130.7329-455235.9485 (East) and 9733687.4763-9892759.7449 (Northing) with reference EPSG: 32750-WGS 84. The projection is Universal Transverse Mercator (UTM) with 50S zone. The material used in this research was an administrative map of Paser Regency at a scale of 1:50,000. The research tools used were pH meter, TDS meter, EC Meter, Garmin GPS, computer and Qgis 3.28 software.

Determination of sample points using stratified random sampling method based on the irrigation network area. The number of sample points in this study was 9 sampling locations. The coordinates of the sample points are determined using the Global Positioning System (GPS). Water quality parameters, namely pH H2O, TDS and EC, are measured directly on the land using a pH meter, TDS meter and EC meter. Measurements of each parameter were carried out at each point of the irrigation canal sample location, each sample measurement location was carried out three times and then the results were averaged. The results of the pH H2O, TDS and EC measurements were then input into Qgis software for spatial analysis. The value of each parameter has been input into the GIS software, then analyzed for spatial autocorrelation using the Moran's Index and P-value. Then interpolation is carried out to get the distribution of values for each parameter using the IDW interpolation method.

Initially the Moran index was used to determine the spatial pattern of a data using the formula below [2]:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} wij(x_i-\bar{x})(x_j-\bar{x})}{z_x^2\sum_{i=1}^{n}\sum_{i=1}^{n} wij} \quad (1)$$

Where: I = Moran's Index; n = number of samples; xi = value in sample I; xj = value in sample y; ¯x = average number of variables or values; wij = weighting element between sample i and sample y; = Sample percentage variance.

The interpolation method used is Inverse Distance Weighted (IDW). The calculation of the IDW method uses the following formula [1]:

$$F(i) = \sum_{i=1}^{m} W_i Z(r_i) = \frac{\sum_{i=1}^{m} Z(r_i)/|r-r_i|^p}{\sum_{j=1}^{m} 1/|r-r_i|^p} \quad (2)$$

Where: P = parameter; m = the number of neighbouring points taken into account at a certain cutting distance. The interpolated values are compared with the true values via one-cross validation of the omitted points.

Several tests were carried out to find a low Root Mean Square Error (RMSE) value on interpolation using the formula below [2]:

$$RMSE = \sqrt{\sum_{i=1}^{n}(p_i - a_i)^2} \quad (3)$$

Where: P_i = primary simulation result value of the observation variable; a_i = true value of the observed variable; n = number of observations

The RMSE calculation aims to measure the level of interpolation results that have been carried out. The lower or closer to zero the RMSE value, indicates the higher the level of accuracy of the interpolation. RMSE values from interpolation results for pH H_2O 0.0001, TDS 0.1695 and EC 0.0003. The interpolated data is then classified based on the category of each parameter. Classification results are presented in the form of distribution maps of pH H_2O, TDS and EC in scale. Then the maps are overlay analyzed by combining several maps. The results of the overlay analysis are presented in the form of an irrigation water quality map. The map of the research area is shown in Figure 1.

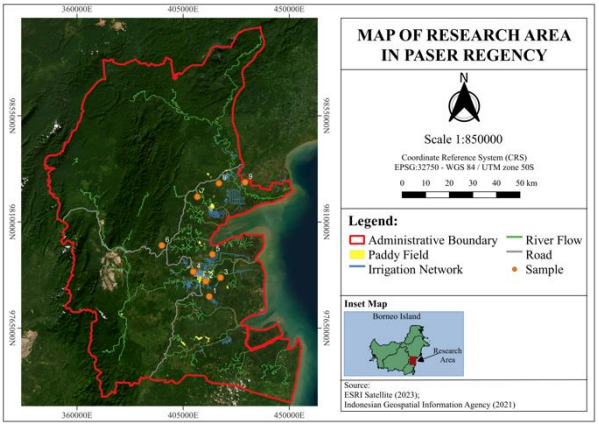

Fig. 1. Map of Research Area

3 Result and discussion

Table 1 shows the quality values of each parameter in the study area. The pH value of H_2O ranged from pH 4-9.2, TDS ranged from 10-3580 ppm and EC ranged from 0.02-5.7 mS/cm. In general, the value of each parameter has a different range of values. This could be due to differences in location and irrigation networks in sampling.

Table 1. The Value of Water Quality Parameters

Parameter	Min	Max	Mean	Median
pH H_2O	4	9,2	6,37	6,1
TDS (ppm)	10	3580	514,44	100

EC (mS/cm)	0,02	5,7	0,87	0,15

3.1 Spatial Distributional of pH Water (pH H_2O)

Figure 2 shows the grouping analysis of water pH (pH H2O). Moran's index of 0.793 (positive) indicates that there is a grouping pattern. The data show some similarities in values in some parts of the study area. Apart from that, the existence of grouping is also supported by a P-value of 0.01, although in some small parts there are values that are more random. This is also supported by previous research, that a Moran's index that is close to +1 or -1 and a P-value <0.05 indicates that there is spatial autocorrelation and the data distribution is more clustered [15]

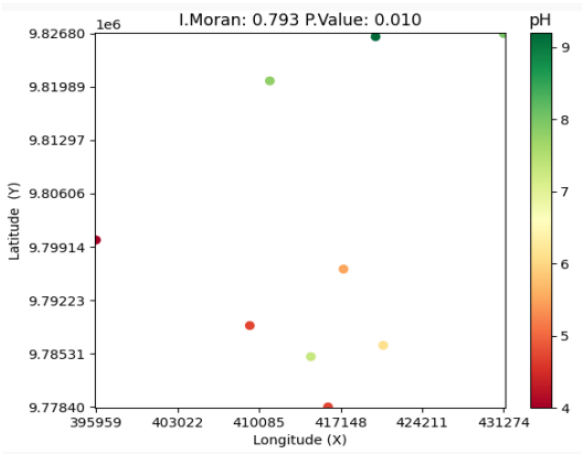

Fig. 2. Moran Index of pH Water

Figure 3 shows the distribution of water pH values (H_2O) in the study area. The distribution of water pH values in the study area is divided into three categories, namely acid, neutral and alkaline. The red color on the map shows the water pH value <6.5, the yellow color on the map shows the water pH value 6.5 -8.4 and the blue color on the map shows the water pH value >8.4. As can be seen in Table 2, 62.33% of the research area is included in the Acid pH category with an area of 666989.76 ha and 36.58% is included in the Neutral pH category with an area of 391447.87 ha. Conversely, a small portion of the study area is included in the category of alkaline pH with a percentage of 1.09% with an area of 11678.22 ha.

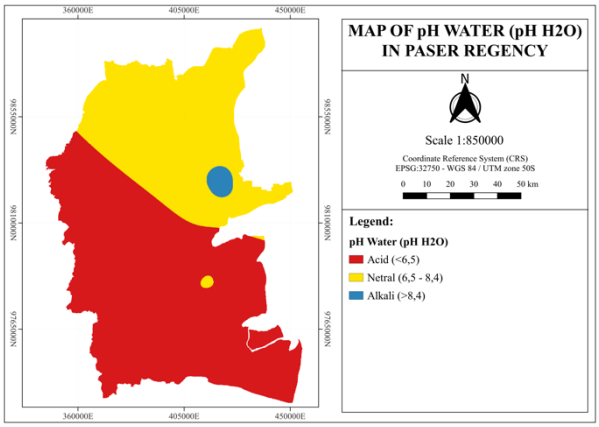

Fig. 3. Distribution Map of pH Water in Paser Regency.

Table 2. The Distribution of Area for Criteria of pH Water

Color	pH H_2O	Criteria	Area (ha)	Percentage (%)
Red	<6,5	Acid	666989,76	62,33
Yellow	6,5 – 8,4	Netral	391447,87	36,58
Blue	>8,4	Alkali	11678,22	1,09
Amount			**1070115,85**	**100**

Referring to Figure 3, pH water with the acid category is clustered in the southern research area and pH water with the neutral category is clustered in the northern research area. In contrast, pH with the alkaline category is only found in a small part of the study area. The northern part of the research area with neutral water pH is more suitable for paddy cultivation. In addition, pH water with a neutral category is one of the conditions for growing paddy plants [7]. On the other hand, the southern region, which is dominated by pH water, is in the acid category, which is not suitable for paddy cultivation. This can cause toxicity in plants such as aluminium toxicity which can inhibit the growth and development of paddy plants and can reduce productivity. [17]. However, it is possible that this area can be cultivated for paddy plants with the condition that there is a need for good management of irrigation water, such as adding lime and biochar before planting [18]. The same thing is also found in some research areas with pH water that is in the alkaline category. pH water in the alkaline category contains quite high levels of cations, so it has the potential to cause paddy plants to become poisoned [3]. However, in this area it will be more difficult to manage irrigation water than pH water in the acid category [19]. Thus, in this area it is not suitable for cultivating paddy plants when viewed from the pH of the water.

3.2 Spatial Distributional of TDS

Figure 4 shows the TDS grouping analysis in the research area. Referring to the Moran Index value, namely 0.182, it shows that the distribution of values is not clustered, but is more random. However, if we refer to the P-value of 0.085, it shows that several small parts experiences grouping. This might happen because the properties of TDS are very location specific and influenced by many factors. This is also supported by previous research, that the Moran's index which is close to 0 and the P-value >0.05 indicates there is no spatial autocorrelation and the data distribution is more random [16].

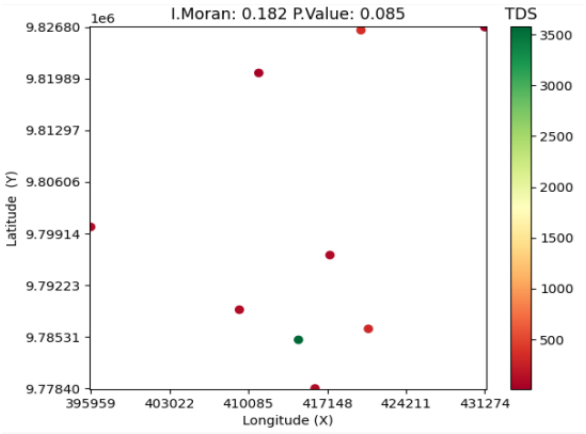

Fig. 4. Moran Index of TDS Water

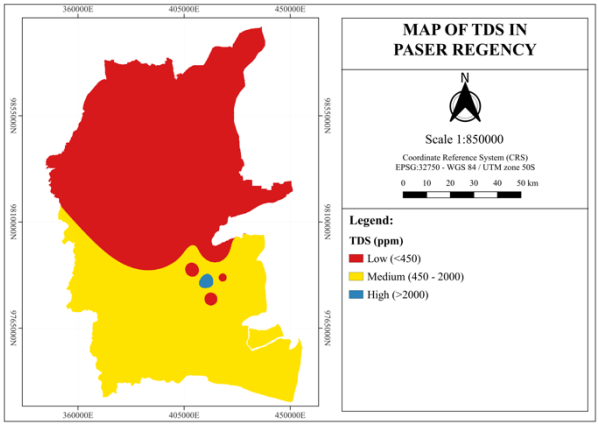

Fig. 5. Distribution Map of TDS in Paser Regency

Figure 5 shows the distribution pattern of TDS (ppm) values in the research area. The distribution of TDS values from the interpolation results is divided into three categories, namely low, medium and high. As can be seen in Figure 5, the low category (red on the map) has a value of <450 ppm, the medium category (yellow on the map) has a value of 450-2000 ppm and the high category (blue on the map) has a value of >2000 ppm. Most of the area is dominated by the low category with a percentage of 57.35% (613667.49 ha), while for the medium category the percentage is 42.39% (453597.74 ha) and the high category is 0.27% (2850.61 ha), For more details, see Table 3.

Table 3. The Distribution of Area for Criteria of TDS

Color	TDS (ppm)	Criteria	Area (ha)	Percentage (%)
Red	<450	Low	613667,49	57,35
Yellow	450 - 2000	Medium	453597,74	42,39
Blue	>2000	High	2850,62	0,27
Amount			**1070115,85**	**100**

Referring to Figure 5, TDS with a low category is grouped in the northern region, the moderate category is clustered in the southern region and the high category is in a small portion of the region. One of the requirements for growing paddy plants is to have a TDS value below 2000 ppm [20]. This shows that most of the research area is still suitable for cultivating paddy, if we refer to the TDS value. However, in the medium category it is necessary to check the TDS value periodically because it can potentially become a high category in certain circumstances. The high TDS value in areas with the high category is most likely caused by household and industrial waste as indicated by the population density spread across the area [8]. Apart from that, it is very likely that this is also caused by agricultural waste such as fertilizer waste, pesticides and plant residues [21].

3.3 Spatial Distributional of EC

Figure 6 shows the grouping pattern of EC values in the research area. The Moran Index with a value of 0.164 indicates that the EC value in the study area is more random. However, if we refer to the P-value of 0.043, in some small parts there are clustered values. This is also similar to the incident with the TDS value.

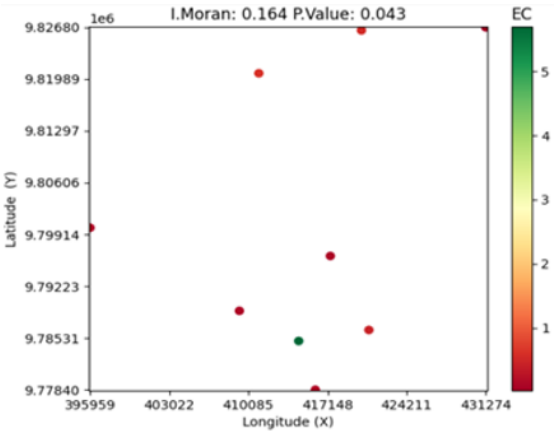

Fig. 6. Moran Index of EC Water

Figure 7 shows the distribution of EC values in the study area. As seen in Figure 7 there are three categories namely low, medium and high. The red color on the map shows an EC value of <0.7 mS/cm, the yellow color on the map shows a value of 0.7-3 mS/cm and the blue color shows a value > 3 mS/cm. As shown in Table 4, the medium category was more dominant in the study area with a percentage of 57.41% (614331.73 ha), then continued with the low category with a percentage of 42.29% (452575.64 ha) and the high category with a percentage of 0. 3 % (3208.48 ha).

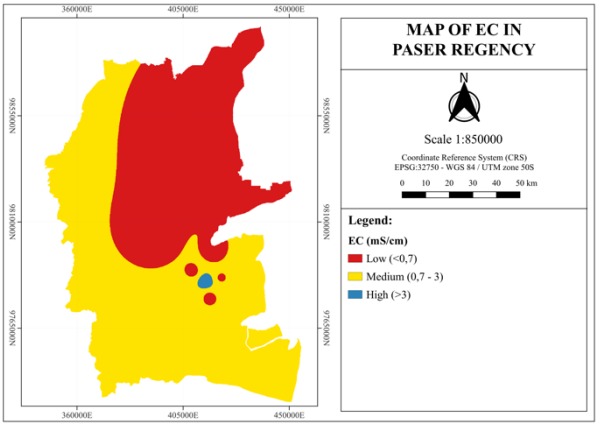

Fig. 7. Distribution Map of EC in Paser Regency

Table 4. The Distribution of Area for Criteria of EC

Color	EC (mS/cm)	Criteria	Area (ha)	Percentage (%)
Red	<0,7	Low	452575,64	42,29
Yellow	0,7 - 3	Medium	614331,73	57,41
Blue	>3	High	3208,48	0,30
Amount			**1070115,85**	**100**

Referring to Figure 7, the distribution of EC values in the low category is clustered in the north area, while the medium category is grouped in the south and east areas. Conversely, the high category is only found in a small number of areas. This is most likely caused by domestic waste in residential areas [24]. Broadly speaking, the distribution of EC values is not much different from the distribution of TDS values and pH. This is because the EC value with the TDS dan pH value has a fairly close relationship [22]. Apart from that, the high EC value in water is also caused by several factors such as salt content [23]. In areas close to the sea, EC values are higher. Waste from human activities such as agricultural, industrial, mining waste and so on also has quite a large potential for increasing the EC value of water [25].

Overall, the water quality area, namely pH H2O (6.5-8.4) which is suitable for paddy plants, is 391447,87 ha, TDS (<2000 ppm) 1067265,23 ha and EC (<3 mS/cm) 1066907,37 ha [26]. The pH of H_2O which is suitable for paddy plants is mostly in the northern region, while the TDS and EC are better in the northern region although most of it is still suitable for paddy plants. The northern region of Paser Regency is more suitable for paddy cultivation in terms of quality parameters, namely pH H_2O, TDS and EC.

3.4 Spatial Distributional of Irrigation Water Quality

Figure 8 shows the spatial distribution of irrigation water quality in Paser Regency. As seen in Figure 8, there are three categories of irrigation water quality, namely less good (red color on the map), quite good (yellow color on the map) and very good (blue color on the map). The red color on the map indicates less good irrigation water quality criteria with pH values <6.5 and >8.4, TDS >2000 ppm and EC values >3 mS/cm. Yellow color on the map shows the criteria of quite good irrigation water quality with pH value 6.5-8.4, TDS 450-2000 ppm and EC 0.7-3 mS/cm. Blue color on the map indicates very good irrigation water quality criteria with pH values of 6.5-8.4, TDS < 450 ppm and EC < 0.7. As seen in Table 5, most of the study area is in the less good criteria with a percentage of 69.26%, followed by very good criteria with a percentage of 30.69% and quite good criteria with a percentage of 0.05%.

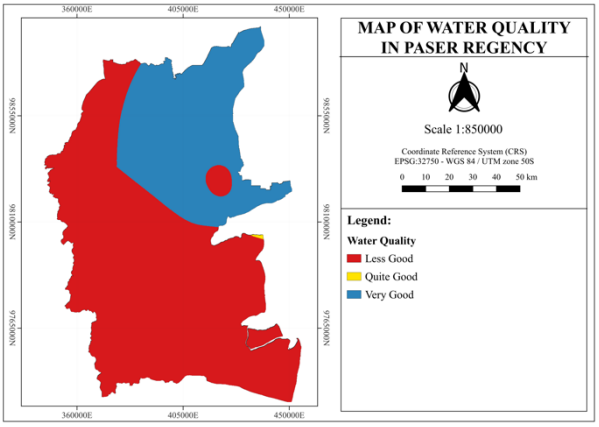

Fig. 8. Map of Irrigation Water Quality in Paser Regency

Table 5. The Distribution of Area for Criteria of EC

Color	Criteria	Area (ha)	Percentage (%)
Red	Less Good	741111,67	69,26
Yellow	Quite Good	551,23	0,05
Blue	Very Good	328452,96	30,69
Amount		**1070115,85**	**100**

Referring to Figure 8, most of the study area is in the less good irrigation water quality criteria. In this area, good irrigation water management is needed for paddy cultivation. Waste management and the use of fertilizers according to the recommended dosage can minimize the contamination of harmful chemical elements in irrigation water [27]. In addition, the use of mulch and the addition of biochar to the soil can also minimize toxicity to paddy plants [30]. This is very important to do to minimize toxicity in paddy plants [28]. In the criteria of very good irrigation water quality is in the northern region. This area is very suitable to support paddy cultivation. In the criteria quite good also needs to be considered related to the management of irrigation water, although this criteria is only found in a small part of the research area. This is because poor management of irrigation water in this area will potentially reduce the quality of irrigation water, so that the quality of irrigation water becomes less good [29].

4 Conclusion

Spatial distributional parameters of water quality for paddy plants, namely pH H_2O, TDS and EC are relevant parameters for site-specific management of irrigation areas. The results of this research prove that the northern part of the research area is more suitable for cultivating paddy. Likewise, the results of this study confirm that each irrigation water quality parameter is spatially related.

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