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RESEARCH PAPER

SPATIAL DISTRIBUTION OF WATER QUALITY IN WELANG, GEMBONG AND REJOSO RIVERS, PASURUAN, EAST JAVA, INDONESIA

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ABSTRACT. A river is a naturally formed freshwater stream that traverses land and eventually flows into a lake, sea, or another body of water. River provides fresh water for human activities such as irrigation for their paddy fields, aquaculture, industrial purposes, and many other purposes. At the same time, there exists an inherent disparity in the demand, availability, and quality of river water, often giving rise to significant challenges and issues. Environmental experts, commonly use a multivariate statistical method such as Principal Component Analysis (PCA), Storage and Retrieval (STORET), and cluster analysis for water quality analysis. However, those methods are numerical and limited in spatial visualization. Inverse Distance Weighting (IDW) interpolation, Voronoi, and Kriging were applied to obtain the spatial representation of water quality distribution Welang, Gembong, and Rejoso rivers in Pasuruan as study. The objectives are to locate on a map any river segments that experienced poor water quality throughout the observation period. We successively combined STORET with those spatial interpolation. The result shows that IDW interpolation, Voronoi, and Kriging can visualize and map river segments that had poor water quality during the observation time. However, due to the limited input data, the interpolation results exhibit variability. For instance, at a measured location with a STORET value of -28, IDW yielded -28, Voronoi -28, and Kriging -27. Beyond the measurement points, each interpolation method began to produce less accurate values. This study involves interpolating dynamic objects with limited measurements data in narrow channels, which differs from interpolating elevation in broader area, in terms of the accuracy of representation or visualization obtained from this spatial analysis still remain unresolved in this study.

KEYWORDS: interpolation, STORET, water quality, Pasuruan.

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INTRODUCTION

A river is a natural flow of freshwater that crosses land and goes into a sea, an ocean, a lake, etc. River has ecological functions such as habitat, conduit, filter, barrier, source, and sink (Wang and Pan 2011). On the other hand, rivers provide freshwater for human activities such as irrigation for their paddy fields, aquaculture, industrial purposes, etc. The demand, availability, and quality of river water are significant concerns. As the water quality of three rivers, Welang, Gembong, and Rejoso, in Pasuruan City and Pasuruan Regency, East Java, Indonesia (Figure 1) is deteriorating. They are crossing dense settlements, industrial clusters, and agricultural areas and end up in the Madura Strait. A previous study by Misnawati (2013) revealed that land use changes in the upper stream of the Welang River caused erosion, and the other problem was flooding (Arifin 2021).

The Welang River is located in a distinct watershed from the Gembong and Rejoso Rivers. Welang River is in the Welang watershed while Gembong and Rejoso Rivers are in the Rejoso watershed. The boundary of those two watersheds is adjacent and both have upstream in Bromo Mountain at the southern region of its watershed. The middle stream and the downstream Gembong River cross the City of Pasuruan with a high-density settlement and industrial area than the Welang and Rejoso rivers. As a result, theoretically, those three rivers will have different statuses and conditions.

Water quality analysis commonly uses multivariate statistical methods such as Principal Component Analysis (PCA) or cluster analysis as research by Ustaoğlu and Tepe

(2019), Muangthong and Shrestha (2015), Boyacioglu and Boyacioglu (2008). On the other hand, in Indonesia, there is a method called STORET (Storage and Retrieval), the United States Environmental Protection Agency (US EPA) based to determine the overall pollution rate implemented in a water quality study conducted by Sugiyarto et al. (2018), Yoviandianto et al. (2019), Aidi et al. (2021) and Mudjiardjo et al. (2021). This method is for general water quality assessment rather than for fishery purposes, and it lacks spatial visualization to show the areas of the river with a water quality concern. Therefore, this study is focused on spatial analysis to reflect water quality distribution in the Welang, Gembong, and Rejoso rivers. The aim is to identify areas of the river with water quality issues during the observation period and visualize them on the map.

MATERIALS AND METHODS

This study made use of a time series water quality dataset derived from three measurements taken at three different places along the Welang, Gembong, and Rejoso rivers (Figure 1). Meanwhile, the common factors to estimate pollution levels according to Tomar (1999) are temperature, color, BOD, suspended solid (TSS), pH, ammonia, phosphorus, and heavy metals. For this research, the dataset consists of physical and chemical variables of water such as temperature, pH, turbidity, DO, BOD, etc. STORET method works by comparing the water quality properties with the standard and giving them a certain score. The scoring calculation of the STORET method is represented in Table 1 and Table 2 which is from the Decree of the Indonesian Minister of the Environment Number 115 of 2003 concerning Guidelines for Determining the Status of Air Quality Status. For water quality standards, this study uses the Indonesian Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management.

According to Table 1, the STORET scoring required 3 components, maximum, minimum, and average. As a consequence, the data must be in series where at least obtained from three different measurements. In this research, the measurements were conducted in each river on 10 March 2021, 10 April 2021, and 29 April 2021 in the morning. The average time of measurements was between 08:00 am to 10:00 am and started from Station 1, Station 2, and Station 3 in sequence. Each river has three measurement stations as represented in Figure 1. We measured 12 water quality parameters in each river, those were temperature: TSS, turbidity, pH, DO, COD, nitrate, orthophosphate, Total Organic Matters (TOM), alkalinity, Cadmium, total nitrate, and total phosphate. To produce the visualization, spatial analysis used river network shapefiles received from the Indonesian Bureau of Geospatial (BIG) at a scale of 1: 25.000. Similar to Oke et al. (2013), the IDW (Inverse Distance Weighted) method in ArcGIS used in the mapping of water properties as obtained from the survey and laboratory analysis. IDW is also commonly used to predict the parameter in the field of hydrology science as research conducted by Rostami et al. (2019) and Yang et al. (2020). As continued, a raster data (grid) of water quality parameters resulted. As a comparison, we did interpolation with Voronoi and Kriging.

IDW takes on that the value at an unsampled location is a distance-weighted average of values sampled points within a defined neighbourhood surrounding the unsampled points (Tan and Xu 2014). Meanwhile, Kriging assumes that the weights are not only based on the distance between the measured points but also on the overall spatial arrangement of the measured points (Tan and Xu 2014). Kriging is a stochastic method similar to IDW (Wu and Hung 2016), and raster-based, so we are interested to compare it. On the other hand, Voronoi is vector based, and it is constructed from a series of polygons formed around the location of a sample point (ESRI 2016). It seems that Voronoi attempts to calculate a value based on the data points that are already known in an area. Moreover, the location of measurements in the field in this study is also very limited. It can be seen from Fig. 1, there were only 9 measurement locations spread over three rivers. Each measurement location or station in a river channel is also quite far apart. Theoretically, this is certainly less acceptable. However, a comparison of these three methods will be interesting to see.

In the step of processing, the river networks shapefile which was in polylines format converted to polygon by the buffering process. The reason was to make it able to clip the interpolated raster data resulting from the IDW, Voronoi, and Kriging method (interpolation) and as a representation of river boundary or boundary line of the river that separates with other land use. The boundary lines are virtual lines on the left and right river as a set of boundaries for river protection. According to Article No 9b, Government of Republic Indonesia Regulation Number 38 the Year 2011, river where at least 15 m (fifteen meters) from the edge left and right of the riverbed along the river channel, in case the river depth is more than 3 m (three meters) up to 20 m (twenty meters). Only the overlayed cells or grids with

Table 1. STORET Scoring for water quality assessment (source: Government of Republic Indonesia (2003))

Number of parameters	Value	Physical	Chemical	Biological
<10	Maximum Minimum Average	-1 -1 -3	-2 -2 -6	-3 -3 -9
>=10	Maximum Minimum Average	-2 -2 -6	-4 -4 -12	-6 -6 -18

Table 2. Water quality classification according to STORET Method (source: Government of Republic Indonesia (2003))

Class	Total Score	Name
A	0	Meet the water quality standard
B	-1 to -10	Lightly polluted
C	-11 to -30	Moderately polluted
D	>= -30	Highly polluted

the river networks remained the process and are used to depict the water quality variables of those rivers. The process was repeated to obtain spatial data for each water quality variable as well. The procedure for mapping water quality parameters is basically as seen in Fig. 2 for IDW and Kriging because both are in raster formats. In the meantime, Voronoi followed the same processes but in vector format.

For the spatial analysis, water quality grid data as the output of the process in Fig. 2 were vectorized to obtain vector data format. Finally, we dissolved it according to the water quality attributes to produce the final shapefile and layout it as a map displaying the spatial distribution of water quality. A detail of the spatial data processing is represented in Fig. 2.

RESULTS

The time series data collected from the Welang, Gembong, and Rejoso rivers were analyzed according to the STORET method. Table 3 provides an example of STORET scoring calculation based on water quality parameter measurements at Station 1 of the Welang River. Overall, the result of water quality was calculated with the STORET method for the Welang, Gembong, and Rejoso rivers represented in Table 4.

From Table 4, it clearly can be seen that water quality in both three rivers are at moderate to high pollution status. The only exception was the Welang River, which had moderate pollution at measuring Stations 1 and 2, but severe pollution at Station 3. It was discovered that two

Fig. 1.Research location in Pasuruan

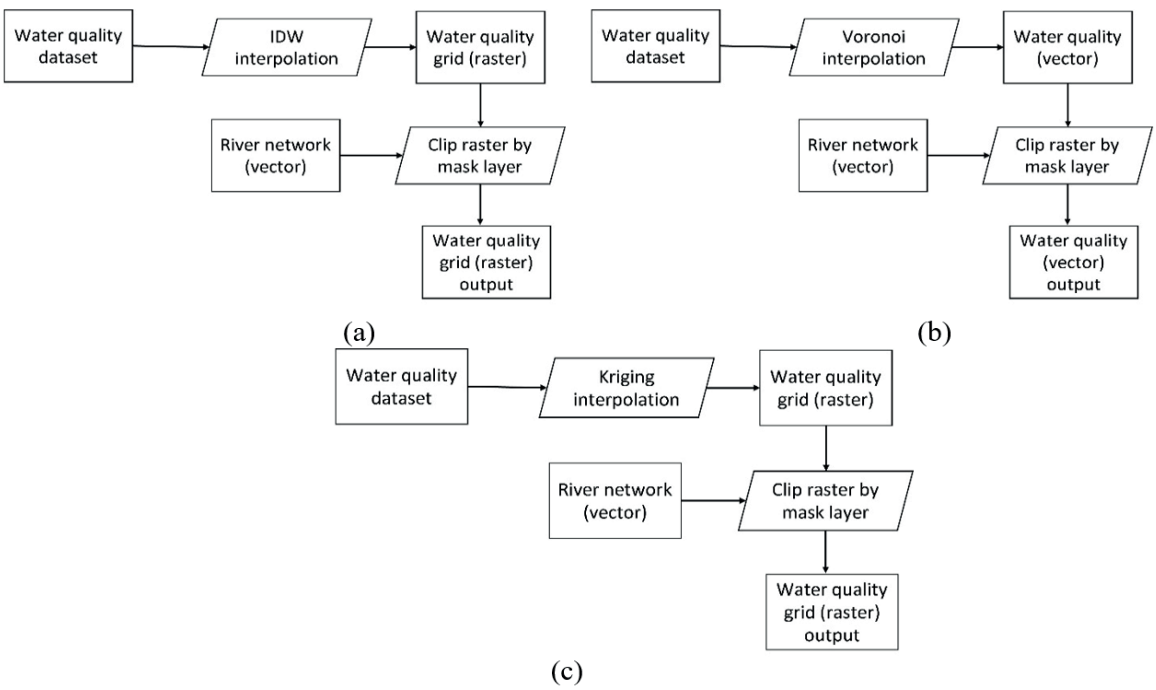

Fig. 2. Spatial data processing, (a) IDW, (b) Voronoi, and (c) Kriging Interpolation

parameters (TSS and alkalinity) caused pollution status to moderate at Station 1 by observing the calculation of the STORET score as shown in Table 3. TSS and alkalinity were above the water quality standard that was used for the analysis respectively. With the same principles, the calculation of the score was also conducted for the rest stations. When comparing the three rivers, the Gembong and Rejoso rivers were in worse condition than the Welang. For the Gembong River, it is understandable due to the river crossing city with a high density of settlements and industrial area where we found cadmium (Cd), Total P, pH, and temperature in each station that more than water quality standard.

Meanwhile, the Rejoso River although at the same water quality as the Gembong River had a bit different cause factor. In the Rejoso River total organic matter (TOM) was above the standard except for cadmium, Total P, pH, and temperature. According to TOM, water contains dissolved, suspended (particulate), and colloidal organic matter, implying that the Rejoso River was higher in this matter than the Welang and Gembong rivers. Meanwhile, Fig. 3 represents a visualization of water quality distribution based on STORET analysis for the Welang, Gembong, and Rejoso Rivers as well. The mapping procedure to obtain Fig. 3 was explained earlier in Fig. 2.

According to Fig. 3, it can be explained why TOM of the Rejoso River was high. It was high because the Rejoso River ran through the agricultural area. Furthermore, sediments spread through the end of the Rejoso River that linked with Madura Strait, and it was not in the same condition as the end of the Gembong River. We believe that part of the upper stream of the Rejoso River had faced degradation.

Table 3. Example of STORET Method calculation

Parameters		Units	Water quality standard	Station 1 - Welang River Calculation						Total Score
				Minimum	Score	Maximum	Score	Average	Score	
Physical	Temperature	°C	28-30	27.80	0	30.00	0	28.65	0	0
	TSS	mg/L	100	55.00	0	160.30	-2	132.3	-6	-8
	Turbidity	cm	200	8.90	0	35.00	0	15.58	0	0
Chemical	pH		6-9	7.68	0	8.60	0	8.05	0	0
	DO	mg/L	3	5.60	0	6.86	0	6.07	0	0
	COD	mg/L	40	16.60	0	21.70	0	19.65	0	0
	Nitrate	mg/L	20	0.28	0	0.94	0	0.76	0	0
	Orthophosphate	mg/L	1	0.100	0	0.147	0	0.123	0	0
	TOM	mg/L	30	8.01	0	21.50	0	11.46	0	0
	Alkalinity	mg/L	75	116.20	-4	244.00	-4	148.28	-12	-20
	Cd	mg/L	0.01	0.00	0	0.00	0	0.00	0	0
	Total N	mg/L	25	0.80	0	1.50	0	1.15	0	0
	Total P	mg/L	1	0.44	0	0.66	0	0.56	0	0
Total Score										-28

Table 4. STORET result of the Welang, Gembong and Rejoso rivers

Location	Station (ST)	Total Score	Pollution Status
Welang River	1	-28	Moderate
	2	-26	Moderate
	3	-46	High
Gembong River	1	-48	High
	2	-68	High
	3	-62	High
Rejoso River	1	-60	High
	2	-62	High
	3	-60	High

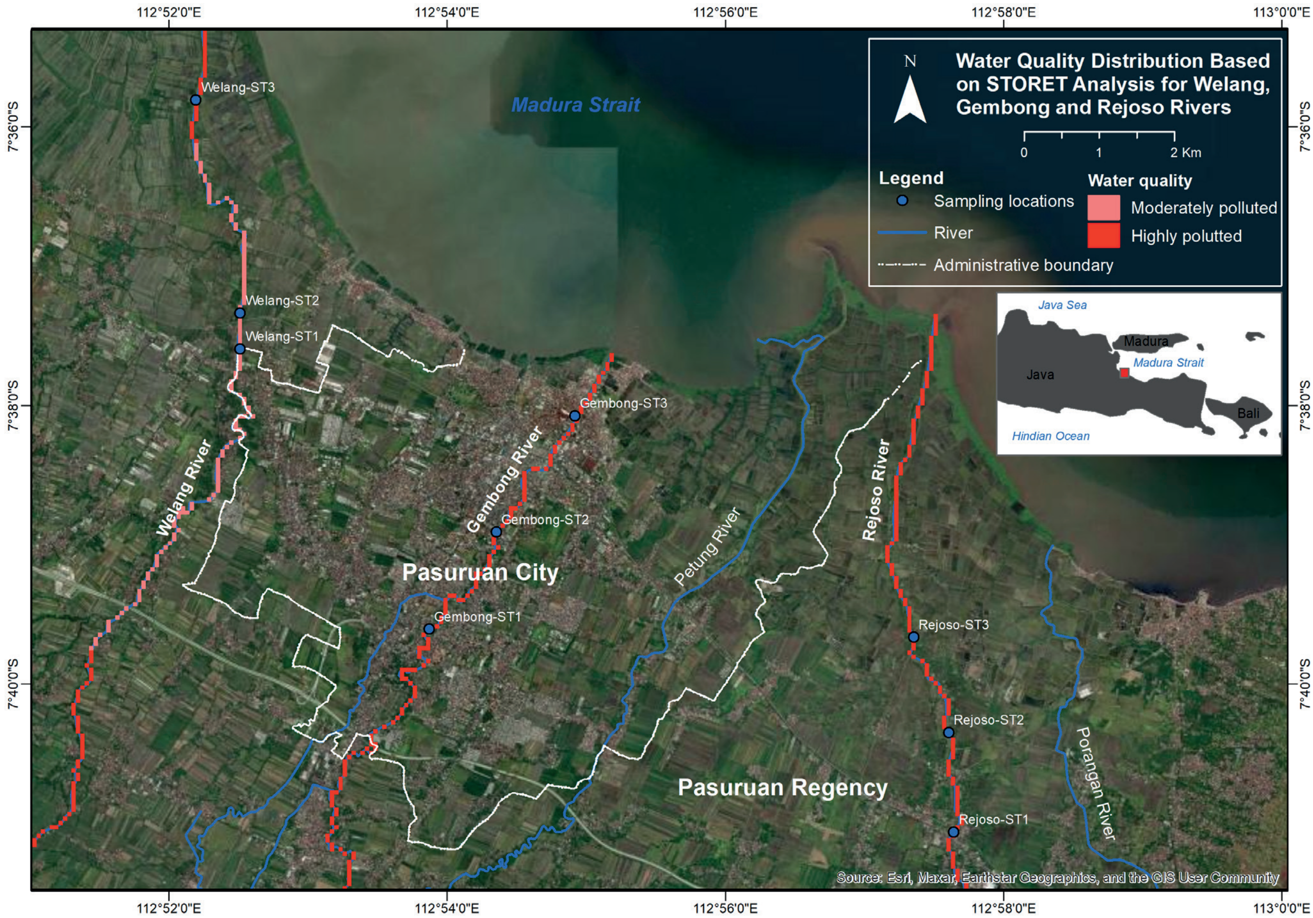

Fig. 3. Water Quality Distribution: Welang, Gembong, and Rejoso Rivers - STORET Method, visualized with IDW Interpolation in GIS

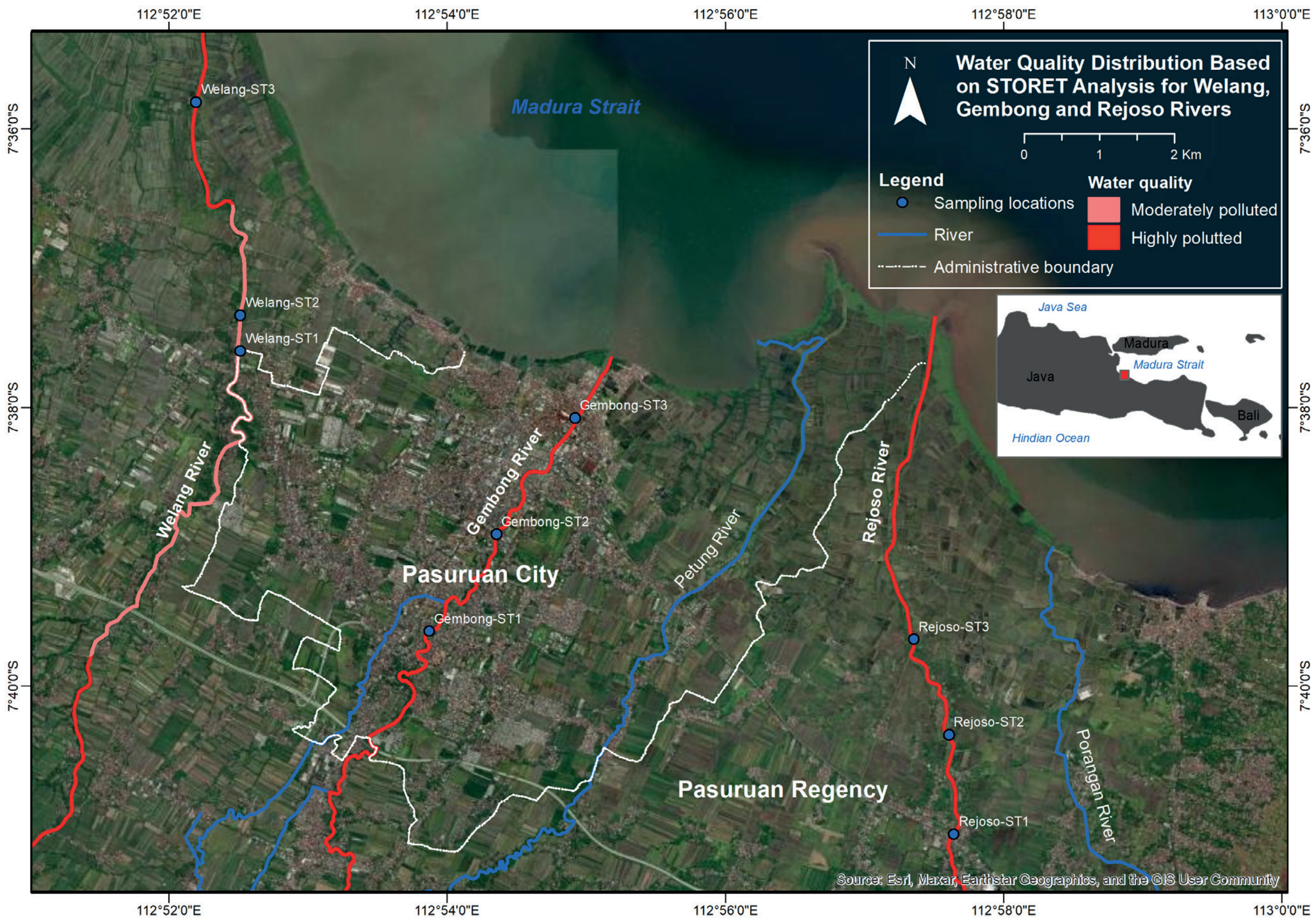

Fig. 4. Water Quality Distribution: Welang, Gembong, and Rejoso Rivers - STORET Method, visualized with Voronoi Interpolation in GIS

Fig. 5. WWater Quality Distribution: Welang, Gembong, and Rejoso Rivers - STORET Method, visualized with Kriging Interpolation in GIS

DISCUSSION

The IDW interpolation in this study is enabled to help in the visualization of the water quality variation as seen in Fig. 3. It was similar to Oke et al. (2013) that used the same method for the visualization of water parameters along the river course. But, due to limited measurement stations, the result from this study did not reach the detail of Oke et al. (2013). Meanwhile, Voronoi is not commonly to be applied for flowing water. Most researchers such as Dakowicz and Gold (2007) used Voronoi for terrain modeling, Daoud (2020) used Voronoi for surface groundwater modeling, Skamarock et al. (2012) – for the atmospheric model, and Hoffman et al. (2018) use Voronoi grids for earth system modeling. However, as shown in Fig. 4, the Voronoi diagram produced a good visualization of water quality variation. Similarly, Kriging interpolation is commonly used for terrain modeling or surface modeling, and this research also gives a good visualization as IDW and Voronoi (see Fig. 5). In general, those methods are spatial interpolation processes that use a set of point data to create surface data (Longley et al. 2005). With a limited number of stations to collect data for each river, the visualization of water quality (WQ) distribution will inevitably encounter challenges.

As we continue, there was an unexpected finding while studying the water quality (WQ) distribution that was visualized by those three various interpolation methods. In IDW interpolation, there were two water quality change borders. The first was a bit distance from Station 3, perhaps only separated approximately 0.5 Km, and the second was about 4 Km south of Station 1. Meanwhile, Voronoi interpolation resulted in an almost similar WQ change border at the southern site. But, on the north side which is close to Station 3, it was not the same. WQ change visually appears in the middle of Station 2 and Station 3. It was approximately 1.5 Km from Station 2 and 1,3 from Station 3 respectively. Then, the result from Kriging interpolation shows almost similar to IDW interpolation at the WQ change border near Station 3 and different at the south of Station 1. The WQ change border was approximately 2.5 Km distance from Station 1. Overall, with IDW interpolation, Voronoi had nearly the same WQ change border at the southern of Station 1. But, IDW interpolation and Kriging interpolation had similar WQ change border nearly the same at Station 3.

Furthermore, even if the distance between Station 1, Station 2, and Station 3 for the Welang River was not similar to the distance of stations on the Gembong and Rejoso rivers, the process can be completed through ArcGIS. Meanwhile, when looking back to the total score resulting from the STORET calculation for the Welang River, those scores scattered between -26 to -68 respectively. As an example, in the Welang River STORET score of 3 stations was -28, -26, and -46. The score at Station 1 and Station 2 was in the same range, but the score at Station 3 was far away. However, closer examination of the mapping result revealed a unique representation, as shown in Fig. 3, Fig. 4, and Fig. 5. There was a variation in the water quality change border as seen in Fig. 6. We did not examine the Gembong and Rejoso rivers in detail because the conditions were the same, all extremely polluted and depicted with the same visualization in Fig. 3, Fig. 4, and Fig. 5 from all interpolation methods.

From the GIS procedure, there are two main steps as the key to accurate visualization with GIS spatial analysis. The first is the number of points that represent the measurement station of water quality parameters at each river and the distance between those points as well. The second is the gap or distance between each point that represents locations of measurement water quality parameters itself. It occurred because, during the interpolation stage, IDW interpolation took into account the distance between points in the prediction. The IDW interpolation is fast, simple, and able to work on scattered data (Gentile et al. 2012). All of the points that filled in with the STORET score for this research only took a few seconds to complete in the interpolation process.

From a perspective of achieving smooth and clear visualization, the Voronoi result is indeed highly effective for representing the distribution of water quality due to its vector format. In contrast, IDW interpolation and Kriging methods are raster-based, meaning they operate on a grid-like structure, which can result in a different representation style compared to the Voronoi approach. In terms of the accuracy of the visualization resulting from the GIS analysis that has been conducted, we admit that still unable to address it due to limitations. As we are aware that water in the river flows away and it is dynamic from time to time, and it has just given the challenge to conduct real-time ground truth of the GIS analysis result as well. As an example, when observing in detail Fig. 7, the water quality change border that resulted from IDW interpolation, Voronoi and Kriging were not the same. IDW interpolation and Kriging interpolation WQ change border in the middle of land use ponds and aquaculture. Although it was looking the same, both were in different distance WQ change border if measured from Station 3. Meanwhile, Voronoi's result shows that WQ change the border located before the ponds and aquaculture areas.

Furthermore, readers may conclude from Fig. 7 that the transition of WQ in the midst of ponds and aquaculture is the accumulation of prior water flow, and it was growing worse over there based on IDW interpolation and Kriging interpolation. On the other hand, the change in WQ before entering the ponds and aquaculture region as a result of the Voronoi interpolation result may lead to a better understanding of how land use influences water quality. Misinterpretation risks arise if the dynamics of moving water features are not thoroughly comprehended. This is because, logically, water quality would typically not undergo significant changes simply upon entering a different land use, as illustrated in Fig 7-part Voronoi. As a result, the outcomes obtained from IDW interpolation and Kriging interpolation were found to be more logically consistent when compared to the Voronoi method, although it's worth considering that these differences might have arisen due to possible coincidental factors.

For a further detailed comparison between the three interpolation methods that are used for STORET visualization, we conduct detailed observation through the values. We randomly made points along the river channel to check the STORET values after the interpolation process. Fig. 8 shows the position of those points respectively. Meanwhile, Fig. 9 shows the plot of the value on the graph. We marked with box position numbers 5, 6, 8, 10, 11, 12, 14, 15, and 16 because those were locations where field measurements were conducted. Thus, STORET values from

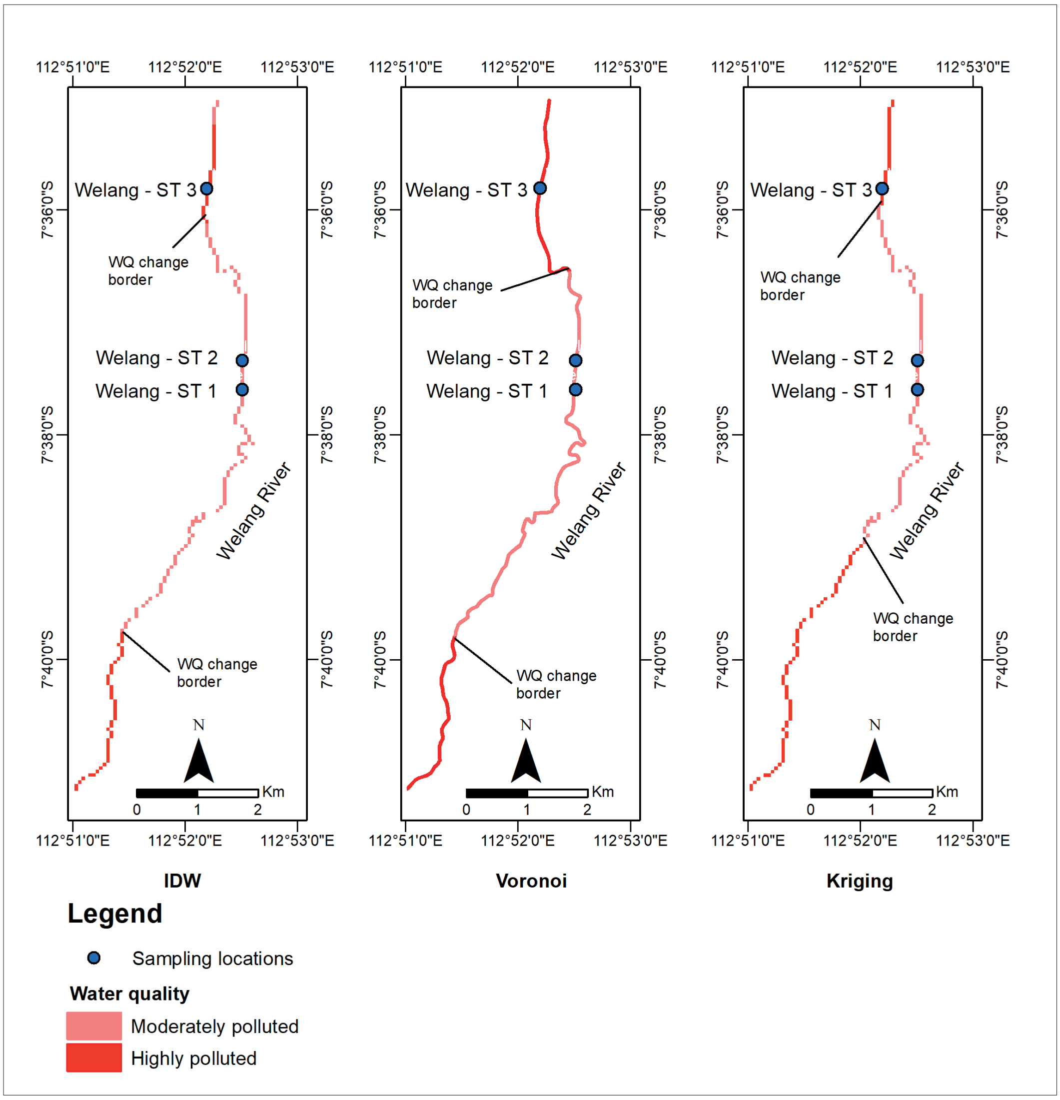

Fig. 6. omparison of water quality distribution in the Welang Rivers according to STORET method and visualized using IDW, Voronoi, and Kriging interpolation in GIS

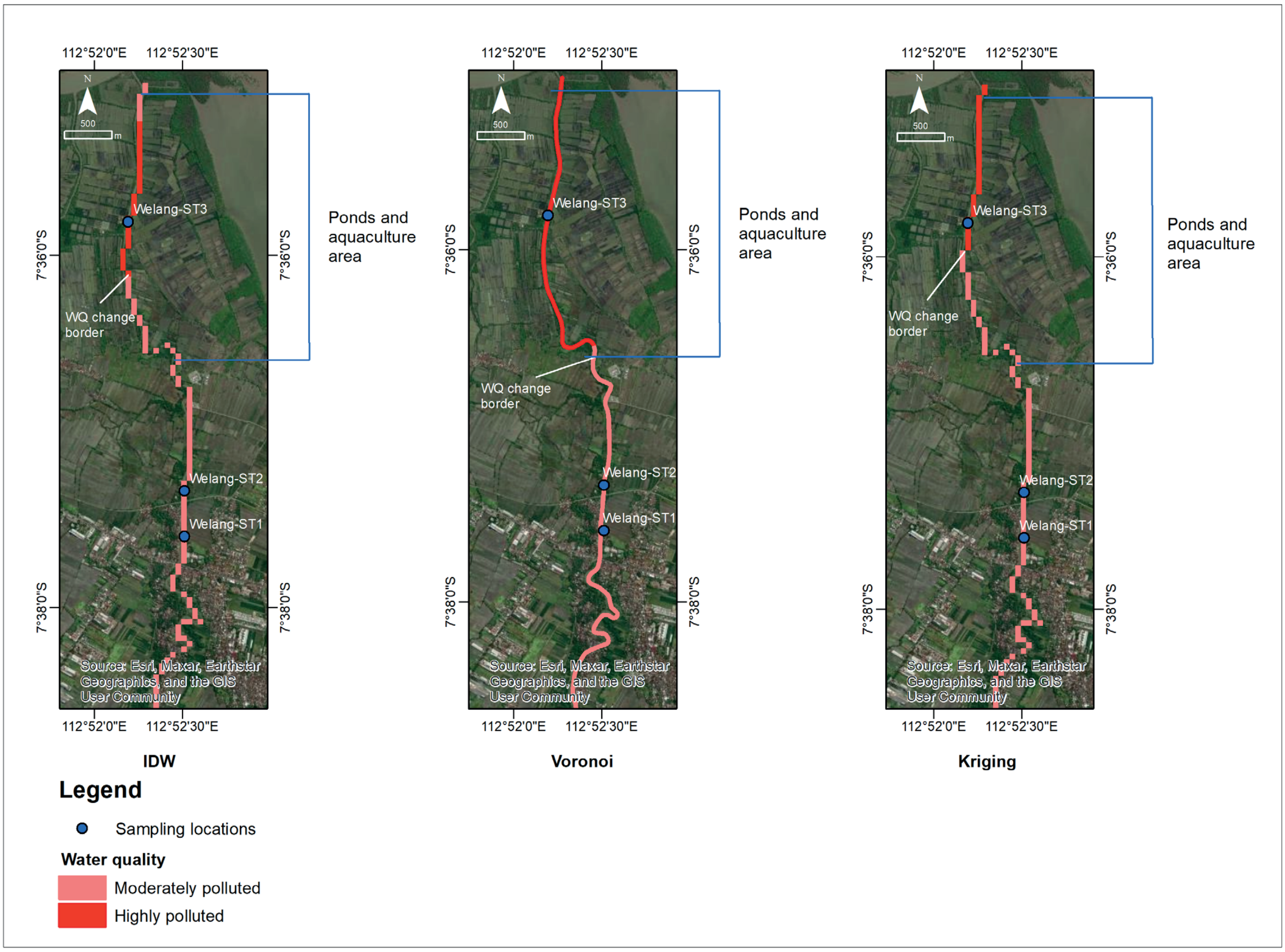

Fig. 7. Comparison of water quality transition border in the Welang rivers according to STORET method and visualized using IDW, Voronoi, and Kriging interpolation in GIS

those positions were results of calculation-based according to field measurement data and the others resulted from interpolation as well. As continue, Fig. 9 explains that the value resulted from three interpolation methods getting worse when it far from the field measurement positions. It means that a small number of samples or limited field measurements are not viable for those interpolation methods to gain accurate value. For example, at position 5, the STORET value = -28, IDW = -28, Voronoi = -28, Kriging = -27.79. Meanwhile, at position 4, IDW = -34, Voronoi = -28, Kriging = -38. When it outside the field measurement location, the interpolation gives contrast value. We admit that a limited number of field measurements that became the basis for the interpolation might be dangerous, gave inaccurate results, and produce the wrong visualization of the water quality distribution on the map. In the future, it is necessary to set more samples as a basis for interpolation in accordance to avoid imprecise results. We also admit that the appropriate distance between field measurement locations must be considered in order to be more representative.

Above all, interpolation is related to finding a set of discreet data based on measured data (Steffensen 2006) and it is based on the principle of spatial dependence (Childs 2004). This study involves interpolating dynamic objects in narrow channels, which differs from interpolating broader field elevation data with limited measurements. Consequently, there is a heightened potential for interpolation errors. Moreover, the study of water quality especially in lotic ecosystems such as a river that have two main zones, (1) rapids, and (2) pools (Reinbold 2018), will be more accurate if use bio-indicator such as micro-invertebrates that live in the bottom of waters such as research by B.T. Hart et al. (2001), Rizo-Patrón et al. (2013), Young et al. (2014) or with periphytons such as Kurteshi et al. (2008), Lili et al. (2010), Montuelle et al. (2010) rather than only rely on physical, chemical, and biological water properties. Thus, a combination of those approaches and GIS will be more accurate in representing the spatial distribution of water quality in the river.

Last but not least, despite this limitation, from the perspective of aquatic resource management, the spatial distribution of water quality represented on the map will be invaluable in supporting action planning to reduce river pollution. Utilizing methods such as STORET, PCA, Pollution Index, bio-indicators, or others would yield only numerical and descriptive information. However, incorporating GIS analysis as an additional step to visualize the results obtained from the previous methods elevates the information representation to the next level and enhances comprehension, particularly for individuals who tend to prefer visualized information over numerical data

CONCLUSIONS

The water quality study in the Welang, Gembong, and Rejoso rivers can be conducted properly, and the conclusions were as follows:

(1) The GIS for spatial analysis to represent water quality can help in the identification of river parts or river segments that face water quality problems during the period of observation and represent it on the map. Boundaries between different water quality conditions can be estimated and identified clearly through visualization. It

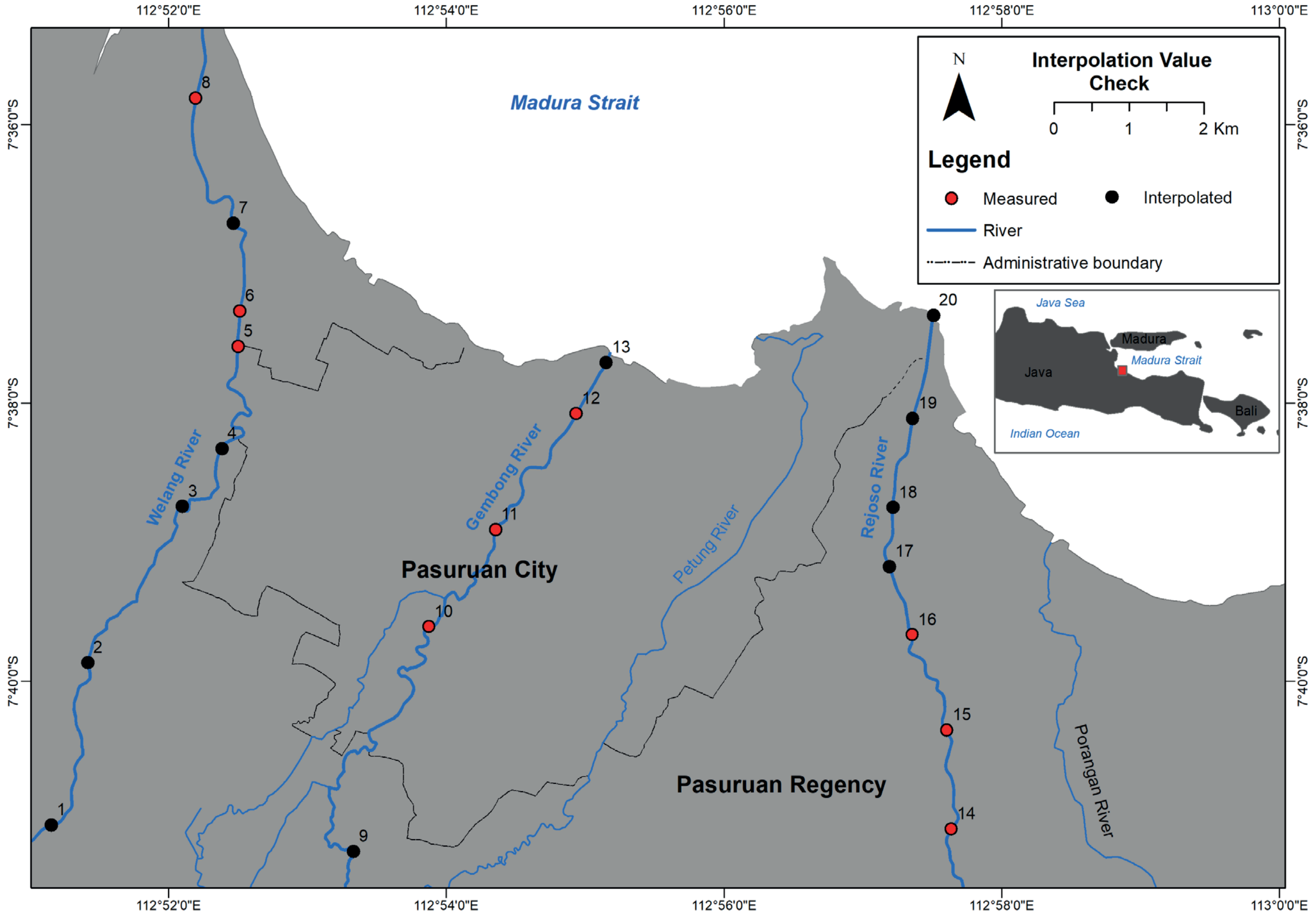

Fig. 8. Interpolation value check positions

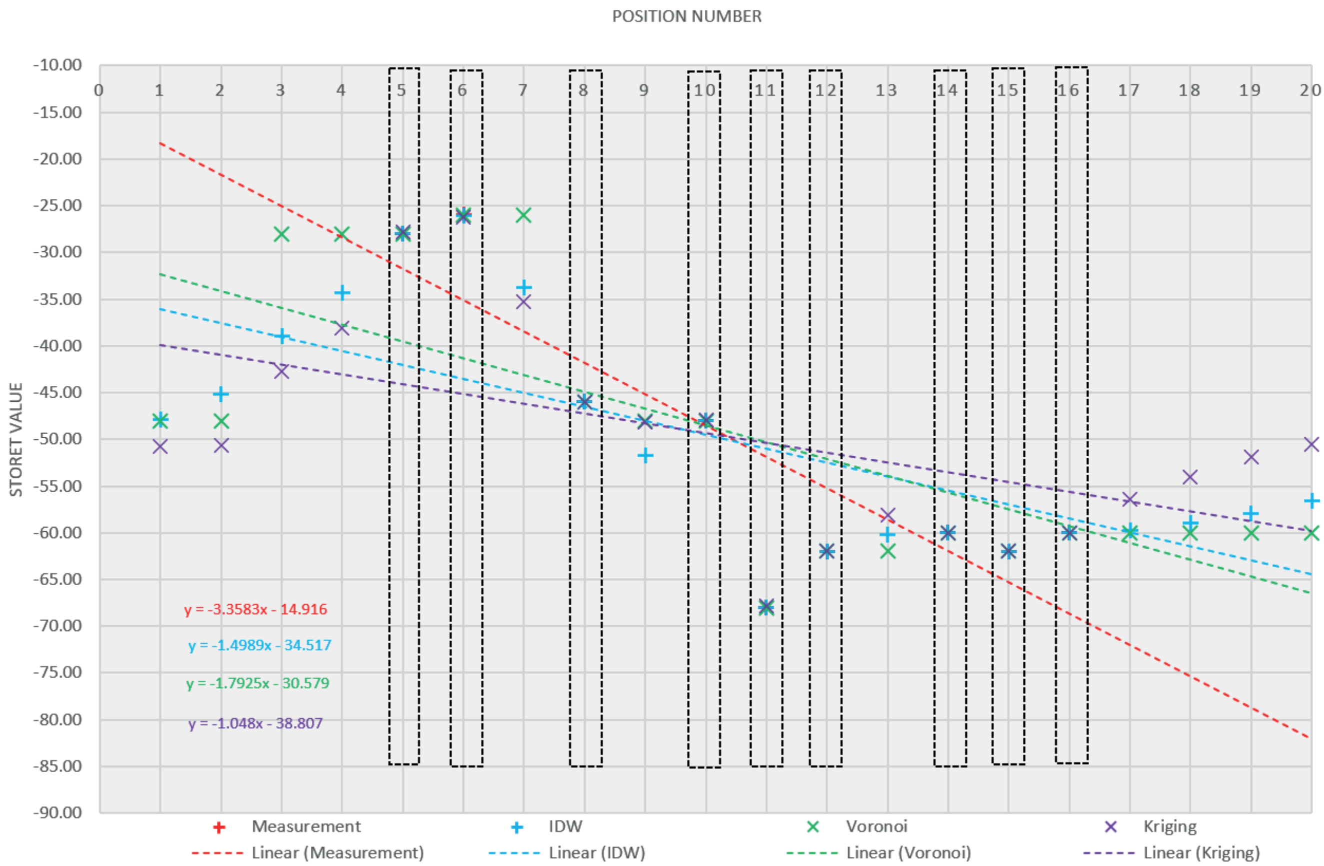

Fig. 9. Interpolation value plot

will be beneficial to support the activity of aquatic resource management, pollution reduction, or river management in general.

(2) The Small number of samples or limited field measurements are not viable for those interpolation methods to gain accurate value. The use of limited field measurements as the basis for interpolation may have adverse effects since it leads to inaccurate conclusions and the incorrect visualization of the water quality distribution on the map.

(3) Despite the several advantages, questions arise concerning the accuracy of representation or visualization derived from spatial analysis. Additionally, there is a significant challenge in conducting real-time ground truth verification of GIS analysis results. Further research is essential to address these concerns and provide a comprehensive answer.

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