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A Preliminary Study on the Water Quality from two Estuaries in Madura Island, East Java, Indonesia

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ABSTRACT

The water quality in the western part of Madura Island is currently faced with a severe threat due to pollution. Therefore, this study aimed to investigate the water quality from Bancaran and Kwanyar estuaries, Madura Island, using the physicochemical approaches. A total of eight physiochemical parameters such as salinity, temperature, pH, DO, CO_2, BOD, Pb, and Cd were investigated at three sampling stations of each estuary on 15 June 2022 and 19 December 2022 to identify the potential environmental factors controlling the water quality for effective monitoring and management of these estuaries. The results showed that temperature (25–29.5ºC), pH (7.47–7.8), DO (2.45–4.57 ppm), CO_2 (0.5–10.4 ppm), BOD (1.86–9.99 $mg.L^{-1}$) and Pb (–0.55 to –0.31 $mg.L^{-1}$) differed significantly ($P < 0.01$), while salinity (0.2–2.90‰) and Cd (0.02–0.05 $mg.L^{-1}$) did not exhibit significant differences ($P > 0.05$). Pearson's correlation indicated significant positive correlations between salinity and Pb, as well as Cd and Pb. According to the principal component analysis (PCA), salinity and BOD were related to the Kwanyar estuary, while the other parameters were associated with the Bancaran estuary. This preliminary investigation showed a decline in the water quality of these estuaries, specifically from DO measurement. Although low DO levels occur naturally, the continuous occurrence will affect the living organisms in the water that plays an important role in the aquatic environment. Therefore, continuous monitoring of these estuaries is needed to provide better information and for protection as well as sustainable use of water resources.

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INTRODUCTION

The estuarine ecosystem is highly productive and plays an essential role in determining the growth and development of human communities, as well as generating economic income. However, human activities such as transportation, fishing, agriculture and aquaculture, tourism, as well as waste from houses, communities, and industries have contributed to water pollution (Zou et al., 2007). These activities that cause high pressure or environmental stress also have significant negative impacts on water quality and ecosystem status. Consequently, the condition of the environment deteriorates, potentially leading to the degradation of the water quality, living organisms, and the local community (Herrera-Silveira and Morales-Ojeda, 2009; Srivastava et al., 2022). To achieve a better understanding and appreciation of water quality on a spatial and temporal scale, there is a need to regularly prevent and control water pollution (Simeonov et al., 2003; Singh et al., 2004). This can be accomplished through the implementation of regular

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water assessment and monitoring, consideration of typical biochemical or physiochemical factors, as well as the reduction of pollution levels. Due to spatial and temporal variation in water quality, it is imperative to conduct extensive, continuous, and effective water monitoring (Satheeshkumar and Khan, 2012; Dirican, 2015; Rahman et al., 2021).

Several methods or assessments have been applied to measure water quality and pollution, such as descriptive, multivariate statistical analysis (Satheeshkumar and Khan, 2012; Huang et al., 2011), fuzzy comprehensive assessment, comprehensive water quality identification index (CWQII) (Fu et al., 2014) and a combination of seven methods (Ji et al., 2016). Furthermore, physical, chemical, and biological variables must be evaluated during water assessment (USEPA, 2002; Kachroud et al., 2019; Soben et al., 2021). These factors influence the presence, distribution, and composition of living organisms, and reflect the condition of the environment (Ajith Kumar et al., 2006; Saravanakumar et al., 2008).

Madura Island is an isolated island separated from the Java mainland by the Madura strait and connected by the Suramadu Bridge (Surabaya-Madura). The quality of the coastal and estuarine waters in the western region has become a serious concern due to pollution from anthropogenic activities, industries, and port wastewater that have affected the condition in local communities, specifically for fisheries and agriculture (Delphine et al., 2022). The two closest areas, namely Bancaran and Kwanyar are threatened by the impact of pollution. Bancaran estuary is located in the Bangkalan District and is very close to the pollution resources at the western Madura. The local communities also contribute to pollution through household wastes, as well as organic and non-organic materials. Preliminary investigations have shown that the water condition around this estuary fluctuated from low to moderate pollution based on cadmium, biochemical and chemical oxygen demand, as well as total organic matter (Ulfah et al., 2019; Putri and Triajie, 2021). Meanwhile, the Kwanyar estuary is located opposite (eastern part) of the Bancaran estuary and the water quality is polluted by Cd, Cu, Pb, and Hg (Nugraha, 2009). The water quality at these estuaries zone constantly fluctuates due to environmental and natural processes. This makes it necessary to provide further information about the water quality to obtain more advantages regarding the condition of the water, specifically for the local communities. Therefore, this study aims to investigate the water quality from Bancaran and Kwanyar estuaries, Madura Island, using physicochemical approaches, such as BOD, DO, CO_2, salinity, temperature, pH, Cd, and Pb. The results are expected to be used as further data about water conditions in these estuaries and contribute to the development of agricultural, and national economy by ensuring environmental sustainability.

MATERIALS AND METHODS

Study site

Bancaran estuary (7°0.591'S, 112°45.355'E) is located in Bancaran village, Bangkalan District, Madura Island, East Java, Indonesia. Furthermore, it is a common coastal estuary, influenced by both seawater from the Java Sea and freshwater from the Bancaran River. The depth of the water in this estuary constantly fluctuates with the tide, ranging from zero or dry during the low tide to 2 or 3 meters during the high tide. This estuary is surrounded by mangrove trees, such as *Sonneratia* sp., *Rhizophora* sp., and *Nypa* sp. The mangrove zonation is also accompanied by salt marsh vegetation, aquatic trees, shrubs, and thickets. Meanwhile, Kwanyar estuary (7°9.879'S, 112°52.155'E) is located southeast of Bancaran village and is surrounded by the true mangroves, *Avicenia* sp., *Rhizophora* sp., *Sonneratia* sp., shrimp, and prawn. The Kwanyar estuary is also influenced by the seawater from Madura Strait and the Java Sea. The local people have used these estuaries as fisheries resources, such as fish, crabs, prawns, and mollusks. The accumulation of boat/ship anchors, including household and aquaculture wastes in the rivers can affect the water condition in these estuaries.

Data collection

A total of three sampling sites were selected to examine the water quality of the Bancaran estuary on 15 June 2022 and Kwanyar estuary on 19 December 2022. Station 1 was located at the inner estuary (local settlement) (7°0.747'S, 112°45.588'E; 7°9.721'S, 112°52.196'E), Station 2 was at the mouth of the estuary (mangrove recreational zone or ponds) (7°0.604'S, 112°45.394'E; 7°9.772'S, 112°52.154'E), and Station 3 was at the outer part of the mouth (7°0.393'S, 112°45.179'E; 7°9.853'S, 112°52.165'E) (Figure 1).

The surface water of each station was collected using sample bottles, with three replications. Subsequently, several variables were evaluated to determine water quality, such as salinity, temperature, water acidity (pH), dissolved oxygen (DO), biological oxygen demand (BOD), carbon dioxide (CO_2), lead (Pb), and cadmium (Cd). Salinity, pH, temperature, and DO were measured directly during the sampling session (in-situ). The salinity was measured using a hand refractometer (Atago, Japan), a pH56 meter (Milwaukee, Romania) was used to measure pH and temperature, while DO was determined using a Mi 605 Dissolved Oxygen Meter (Milwaukee, Romania). Meanwhile, BOD and CO_2 were measured using Winklers' method, Pb and Cd were measured at the Surabaya State University laboratory, Indonesia (ex-situ), using Atomic Absorption Spectrophotometry (AAS). All the collected samples were transferred to the laboratory for analysis.

Data analysis

The mean and standard error of each variable were calculated descriptively. Before conducting any test, all data were assessed for normality and homogeneity of variance using the Shapiro-Wilk and Levene's tests, respectively. Since the data were not normally distributed, the Mann-Whitney U test was performed to assess the significant difference of each measured water variable of the Bancaran and Kwanyar estuaries. Pearson's correlation was used to measure the correlation or relationship between each variable (Helsel and Hirsch, 2002; Quinn and Keough, 2002). Furthermore, principal component analysis (PCA) was performed to extract the most

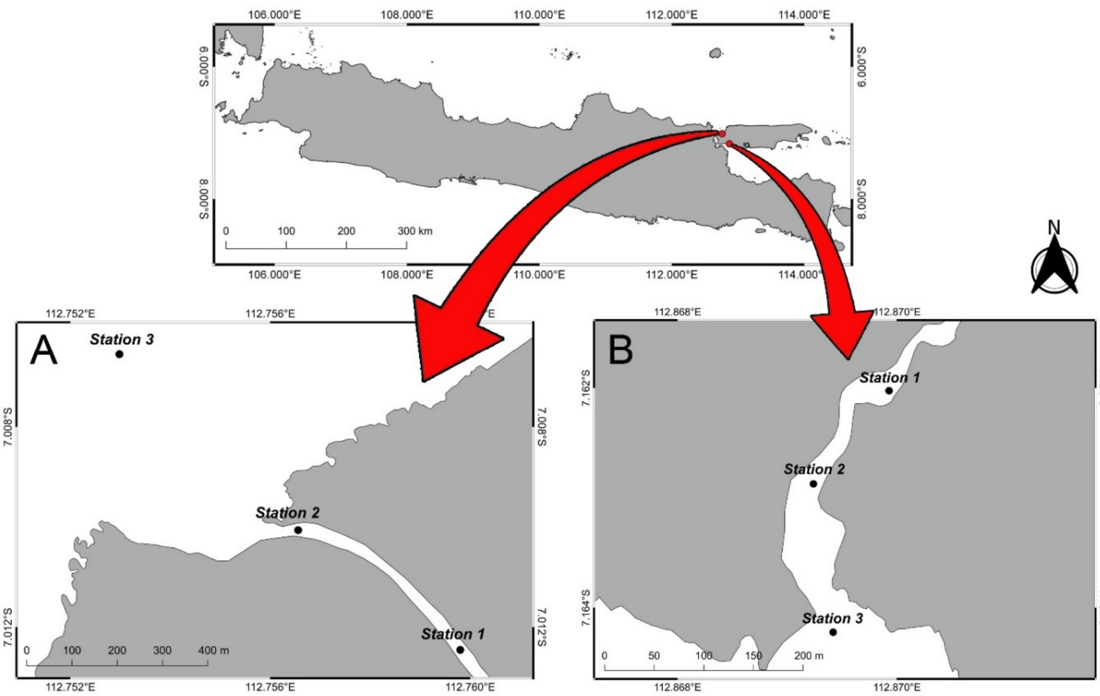

Fig. 1. The map showing three sampling stations at (A) Bancaran estuary and (B) Kwanyar estuary, Madura Island, Indonesia.

meaningful latent parameters from a complex dataset through data reduction with minimal information loss. This technique is a powerful pattern recognition tool that attempts to explain the variance of a large dataset of intercorrelated variables with a smaller set of independent variables. PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which represent linear combinations of the original variables. These components align with the directions of maximum variance (Vega et al., 1998; Liu et al., 2003; Singh et al., 2004). Statistical packages PAST version 3.18 and IBM SPSS version 23 were used to analyze all the data.

RESULT AND DISCUSSION

Physicochemical water properties

The measurement of the water variables in the Bancaran estuary showed that salinity ranged from 0.2–2.90‰ (mean: 1.18 ± 0.42‰), temperature 29–29.5ºC (mean: 29.29 ± 0.06ºC), water acidity (pH) ranged 7.5–7.8 (mean: 7.63 ± 0.04), Dissolved Oxygen (DO) 3.63–4.57 ppm (mean: 4.02 ± 0.13 ppm), carbon dioxide (CO_2) 2–10.4 ppm (mean: 5.99 ± 1.01 ppm), Biochemical Oxygen Demand (BOD) 1.86–3.33 mg/l (mean: 2.81 ± 0.23 mg/l), cadmium (Cd) 0.03–0.04 mg/l (mean: 0.04 ± 0.002 mg/l) and lead (Pb) ranged from –0.55 to –0.31mg/l (mean: –0.43 ± 0.03 mg/l).

In the Kwanyar estuary, salinity ranged from 1.0–2.20‰ (mean: 1.72 ± 0.18 ‰), the temperature was constant at 25ºC, water acidity (pH) 7.47–7.53 (mean: 7.5 ± 0.01), Dissolved Oxygen (DO) 2.45–3.02 ppm (mean: 2.71 ± 0.06 ppm), carbon dioxide (CO_2) 0.5–1.4 ppm (mean: 1.04 ± 0.1 ppm), Biochemical Oxygen Demand (BOD) 5.26–9.99 mg/l (mean: 6.85 ± 0.52 mg/l), cadmium (Cd) 0.02–0.05 mg/l (mean: 0.03 ± 0.004 mg/l), and lead (Pb) 0.11–0.17 mg/l (mean: 0.14 ± 0.007 mg/l). Moreover, detailed measured water variables was presented in Table 1.

Table 1. Physicochemical measured water variables from Bancaran and Kwanyar estuaries, Madura.

Estuary	Site & replicate	Salinity (‰)	Temp. (°C)	pH	DO (ppm)	CO_2 (ppm)	BOD (mg/l)	Pb (mg/l)	Cd (mg/l)
Bancaran	Station 1.1	0.2	29.4	7.58	4.01	6	3.25	0.305	0.032
	Station 1.2	0.2	29.1	7.59	3.8	3	3.33	0.364	0.029
	Station 1.3	0.3	29	7.56	3.76	4	3.17	0.405	0.029
	Station 2.1	0.4	29.4	7.52	4.57	10.4	1.86	0.347	0.041
	Station 2.2	0.5	29.5	7.52	4.49	9	1.95	0.42	0.041
	Station 2.3	0.5	29.3	7.5	4.47	9.5	1.89	0.443	0.040
	Station 3.1	2.9	29.3	7.78	3.76	6	3.27	0.524	0.041
	Station 3.2	2.8	29.1	7.78	3.72	4	3.29	0.512	0.041
	Station 3.3	2.8	29.5	7.8	3.63	2	3.26	0.547	0.041
Kwanyar	Station 1.1	2.00	25	7.53	2.72	0.50	6.41	0.113	0.027
	Station 1.2	2.00	25	7.49	2.45	0.90	6.02	0.119	0.031
	Station 1.3	2.00	25	7.47	2.88	1.30	7.04	0.116	0.029
	Station 2.1	1.00	25	7.52	2.68	1.40	8.71	0.122	0.019
	Station 2.2	1.00	25	7.53	3.02	1.00	9.99	0.131	0.021
	Station 2.3	1.00	25	7.50	2.57	1.00	6.35	0.126	0.024
	Station 3.1	2.10	25	7.48	2.60	0.80	6.44	0.166	0.050
	Station 3.2	2.20	25	7.49	2.83	1.40	5.41	0.152	0.047
	Station 3.3	2.20	25	7.47	2.65	1.10	5.26	0.160	0.044

In the Java Sea, the sea surface salinity ranged from 30 to 35‰ (Wyrtki, 1956; Petit et al., 1996; Nontji, 2005; Bahiyah et al., 2019) but significantly decreased reaching zero at the mangrove ecosystem, including those in the East Java (Gita et al., 2015; Sholoqin et al., 2021; Febriansyah et al., 2022; Salma et al., 2022; Wiraatmaja et al., 2022). Moreover, this study also showed a similar trend to previous reports. Salinity variation in the mangrove estuary was mostly influenced by the tidal movement, resulting in three well-known categories, namely oligohaline, mesohaline, and polyhaline, with values of 0.5-5 ppt, 5-18 ppt, and 18-30 ppt. The input of freshwater runoff from the terrestrial zone/mainland also determined the salinity fluctuation, specifically during the rainy season. Furthermore, the morphology of the river (large or small) cannot be neglected, as small water channels tended to be oligohaline or freshwater in condition (Ng and Sivasothi, 2001; Barik et al., 2018).

The sea surface temperature of Indonesian seawater is commonly warm, ranging from ~ 27°C to ~ 31°C (Nontji, 2005; Kusuma et al., 2017; Yunita and Zikra, 2017). These values can be slightly lower or higher sometimes, as observed in East Java (Gita et al., 2015; Sholoqin et al., 2021; Febriansyah et al., 2022; Salma et al., 2022; Wiraatmaja et al., 2022). Moreover, the results of this study aligned with the general conditions in Indonesia. According to Iskandar et al. (2020), the combination of heat transport and horizontal heat flow from the Pacific Ocean to the Indian Ocean, including Indonesia might contribute to the warming of the sea. Water temperature was one of the important variables in the estuary ecosystem because it determined the status of DO, species distribution, photosynthesis, metabolism of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, as well as diseases (USEPA, 1997; 2006).

Water acidity (pH) is among the main variables in the estuary, with values ranging from 7.6 to 8.3 in Indonesian water (Putri et al., 2015), including East Java (Gita et al., 2015; Febriansyah et al., 2022; Salma et al., 2022; Wiraatmaja et al., 2022). Generally, the pH of water is influenced by various factors such as the accumulation of minerals in the water, soil, dust from the air and household as well as waste materials from other living organisms. Short-term or long-term water acidity in the waterbody is mostly affected by human activities. For example, the accumulation of overloading nutrients will cause the blooming of algae and change the pH condition in a short time. Water acidity lower than 5.0 or above 9.0 may affect the survival of plants and animals. The solubility of iron and copper will also become difficult in the waterbody when the pH value changes. Therefore, the toxicity will remain in the estuary water as the pH decreases (USEPA, 1997; 2006).

The level of DO in the estuary is characterized by significant fluctuations influenced by depth and temperature. Generally, higher temperatures lead to decreased DO concentration while lower values tend to promote DO levels. The difference between surfaces and the bottom layer (vertical stratification) also influences the DO and mostly, where the upper layer has a higher value. A minimum of 5 $mg.L^{-1}$ is considered ideal to support living organisms, where slightly lower values ranging from 3 to 5 $mg.L^{-1}$ causes stress, and < 3 $mg.L^{-1}$ leads to the worst condition such as death (USEPA, 1997; 2006). In this study, the DO level in the Bancaran and Kwanyar estuaries are not in good condition, thereby causing stress to organisms. Similarly, the DO level close to the Bancaran estuary ranged from 3 to 4.6 $mg.L^{-1}$ (Badriani, 2017; Maharani et al., 2019). According to USEPA (2006), water pollution is the main key to reducing the oxygen level, however, low oxygen conditions may also naturally occur in estuaries relatively unaffected by humans. The severity and duration of low DO conditions in these areas are less extreme.

Carbon exists in both the atmosphere and water. Alkalinity, acidity, carbon dioxide (CO_2), pH, total inorganic carbon, and hardness were interconnected components of the inorganic carbon complex. These parameters influenced photosynthesis by aquatic plants and water acidity. Based on previous reports, it was recommended that the amount of carbon dioxide (CO_2) in the water should not exceed 15 mg/l (USEPA, 1997; 2006). Meanwhile, this study showed that the CO_2 concentration was still in good condition (< 15).

The amount of BOD was mostly correlated with DO concentration in the estuaries, where an increase in BOD level caused a decrease in oxygen concentration. In most cases, the significant BOD level for unpolluted or natural water was < 5 $mg.L^{-1}$. This indicated that the impact of higher BOD concentration was similar to the low DO concentration, causing stress to living organisms, and ultimately leading to death (USEPA, 1997; 2006). In this study, the BOD level in the Bancaran and Kwanyar estuaries was in good condition. This was similar to the results from the area around the Bancaran estuary (Badriani, 2017; Yusnita and Triajie, 2021), however, there was little pollution in the Kwanyar estuary.

The occurrence and concentration level of toxic substances such as lead (Pb) and cadmium (Cd) in the estuaries recently showed a significant increase. This condition affected the community structure and populations, specifically human health and other living creatures. Aquatic living resources such as fishes, crabs, prawns, and mollusks that were very abundant in the estuary were consumed by humans. However, toxic substances including Pb and Cd accumulated in the tissues of the animals, making consumption risky (USEPA, 1997; 2006). This made it necessary to monitor the water quality by assessing the level of Pb and Cd in the water and the animals. This monitoring was important due to the impact of toxic substances on the ecosystem and human health (Bakary et al., 2015; Mehrgan et al., 2019; Lee et al., 2021).

Significant differences ($p < 0.05$) were observed in the measured water variables from both estuaries, including temperature, pH, dissolved oxygen (DO), carbon dioxide (CO_2), biochemical oxygen demand (BOD), and lead (Pb). Meanwhile, salinity (Mann-Whitney $U = 27$, $p = 0.23$) and cadmium (Cd) (Mann-Whitney $U = 30$, $p = 0.35$) did not show a significant difference, as presented in Figure 2. This indicated that the variables were still in normal condition or did not vary significantly at both estuaries. However, temperature, pH, DO, CO_2, BOD, and Pb exhibited significant differences, indicating variations between Bancaran and Kwanyar estuaries. These results were related to the location, water circulation, and natural processes. Although the difference was only 4ºC (temperature) and very little variation in water acidity (pH), both variables were different statistically. The difference in temperature and pH in the Bancaran estuary compared to the Kwanyar estuary was related to the heat from the industrial activities, shipping at the port, and the impact of global warming. According to Los Huertos (2020), industrial was one of the sources of thermal pollution that caused a decrease in water quality due to changes in the ambient water temperature. Additionally, sea surface temperature

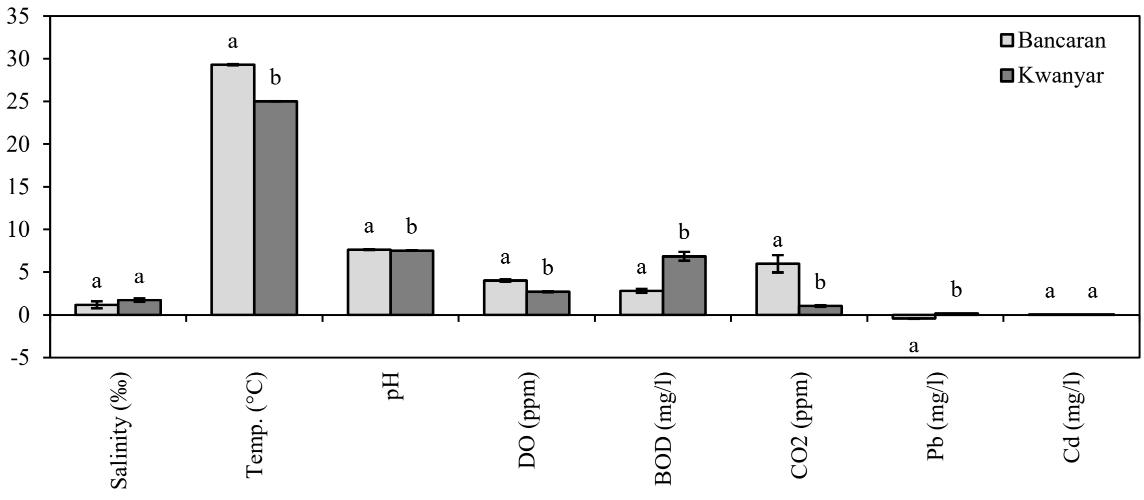

Fig. 2. Mean value (±SE) of the measured water variables from Bancaran and Kwanyar estuaries, Madura Island. Similar superscripts indicate no significant differences and different superscript indicate significant differences.

had changed greatly due to global warming (USEPA, 2022). The significant difference in DO, CO_2, BOD, and Pb was related to the different localities, water current and circulation, decomposition of organic matter, convection, mixing, and the input of other materials into the water (Kress, 2003; Abowei, 2010; Kress et al., 2014; Coppola et al., 2018; Mavropoulou et al., 2020; Chen et al., 2022).

Correlation of water quality variables

The results on the Pearson's correlation from the Bancaran estuary showed that salinity had a positive correlation with temperature, pH, BOD, and Pb (r = 0.08–0.95), but negatively correlated with DO, CO_2, Cd (r = –0.89 to –0.42). Furthermore, the temperature had positive correlations with DO, CO_2, and Pb, but negatively correlated with pH, BOD, and Cd. Water acidity (pH) had positive correlations with BOD, Pb, and salinity, while there were negative correlations between temperature, DO, CO_2, and Cd. In the Bancaran estuary, 50% of the correlation was positive and the remaining was negative, with significant positive correlations observed between salinity and pH, BOD, and pH, as well as DO and CO_2. Significant negative correlations were observed between salinity and Cd, pH and DO, pH and Cd, DO and BOD, as well as CO_2 and BOD. In the estuary, salinity had positive correlations with Cd and Pb, but negative correlations with pH, DO, CO_2 and BOD (r = –0.75 to –0.16). However, the temperature did not show any correlation due to its constant value. Water acidity (pH) had positive correlations with DO and BOD but negatively correlated with salinity, CO_2, Cd, and Pb. Based on the results, a 43% positive and 57% negative correlation was observed in the Kwanyar estuary, with significant positive correlations found between salinity and Pb, Cd, and Pb. Tables 2 and 3 showed that there were negative correlations between salinity and BOD, pH and Pb, as well as Pb and BOD. Generally, lower a pH value increased the salinity and

Table 2. Correlation coefficients of each water variable from Bancaran estuary. Asterisks and bold values indicate significant differences at level $p < 0.05$ (*) and $p < 0.01$ (**).

	Salinity	Temp	pH	DO	CO_2	BOD	Cd	Pb
Salinity	1							
Temp	0.081	1						
pH	**0.947****	–0.030	1					
DO	–0.572	0.453	**–0.777***	1				
CO_2	–0.425	0.413	–0.659	**0.950****	1			
BOD	0.439	–0.441	**0.689***	**–0.962****	**–0.907****	1		
Cd	**– 0.898****	–0.039	**–0.779***	0.456	0.358	–0.244	1	
Pb	0.579	0.586	0.320	0.331	0.421	–0.456	–0.591	1

Table 3. Correlation coefficients of each water variable from Kwanyar estuary. Asterisks and bold values indicate significant differences at level $p < 0.05$ (*) and $p < 0.01$ (**).

	Salinity	Temp	pH	DO	CO_2	BOD	Cd	Pb
Salinity	1							
Temp	0.[a]	0.[a]						
pH	–0.628	0.[a]	1					
DO	–0.178	0.[a]	0.280	1				
CO_2	–0.161	0.[a]	–0.303	0.299	1			
BOD	**–0.759***	0.[a]	0.645	0.554	0.123	1		
Cd	0.395	0.[a]	–0.488	–0.062	0.110	–0.360	1	
Pb	**0.792***	0.[a]	**–0.677***	–0.191	–0.003	**–0.695***	**0.849****	1

Note: [a] cannot be computed due to constant value.

affected the living organisms in the water body, especially the invertebrates (Zalizniak et al., 2009). Satheeshkumar and Khan (2012) also reported that there was a significant correlation between pH values and water salinity. However, natural conditions varied and fluctuated every single second (USEPA, 2006). For example, Rugebregt and Nurhati (2019) observed a negative correlation between pH, salinity, and temperature in Ohoililir, Southeast Maluku, Indonesia.

Principal Component Analysis

PCA was applied to the datasets of the two main estuaries to compare the composition and identify the influencing factor on water quality. Based on the eigenvalue greater-than-one rule, four principal components accounting for 97% of the total variation were retained. The first two principal components explained 60.35% and 22.93% of the variance, respectively. The third and fourth principal components were considerably less important, explaining only 12.27% and 1.28% of the variance, respectively. The principal component 1 (PC1) was positively influenced by temperature, pH, DO, CO_2, Pb, and Cd, while salinity and BOD had a negative impact on the component. PC2 was positively affected by salinity, pH, BOD, Pb, and Cd, while negative correlations were observed among temperature, DO, and CO_2, as presented in Figure 3. Scatter plots of the extracted PCs from the PCA showed clustering and relationship among the

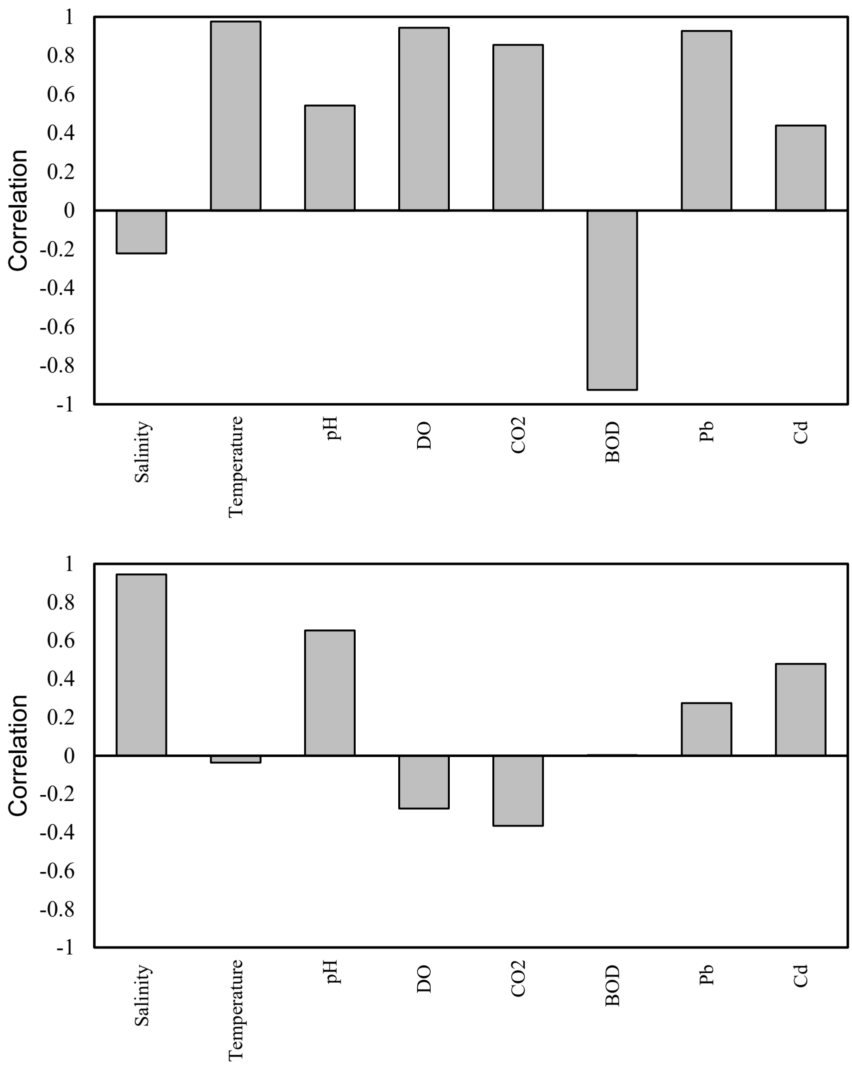

Fig. 3. Principle component 1 (PC1) (top) and principle component 2 (PC2) (bottom) of the PCA from two estuaries (Bancaran and Kwanyar estuaries), Madura Island.

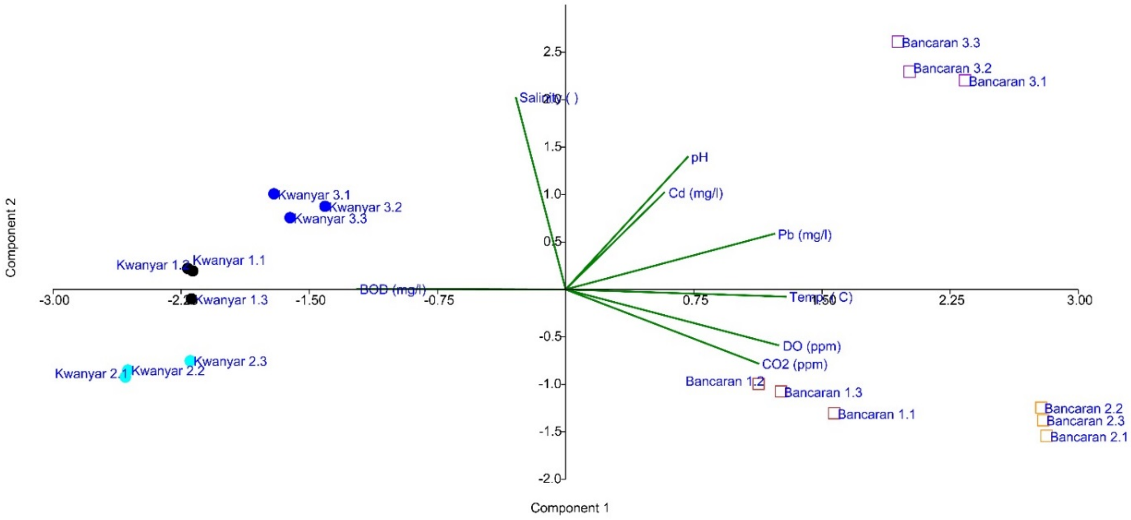

Fig. 4. Principle Component Analysis (PCA) bi-plot ordination of the water quality in Bancaran and Kwanyar estuaries, Madura Island.

variables from both estuaries. Kwanyar estuary was characterized by salinity and BOD, while the Bancaran estuary was influenced by temperature, pH, DO, CO_2, Pb, and Cd, as illustrated in Figure 4.

The high differences in salinity and BOD from both estuaries indicated that there was a significant influence on the freshwater loading from the river channel due to the rain factor. Domestic waste and nutrients also affected the BOD in the water body (USEPA, 1997; 2006). The water quality in the Bancaran estuary indicated an abnormal condition, as shown by the DO and BOD presented in Table 1, which showed that pollution occurred in this estuary.

In this preliminary study, a total of eight physicochemical water variables were measured. However, more water variables measurements were needed to obtain more information regarding the water quality at these estuaries, such as nitrogen (NO_2^-; NO_3^-; NO_4^-), phosphate (PO_4^{3-}), total suspended solids (TSS), total dissolved solids (TDS), and nutrients followed by continuous observation weekly, monthly, seasonally, or yearly.

CONCLUSION

In conclusion, significant differences were observed in the measurements of temperature, pH, DO, CO_2, BOD, and Pb between the Bancaran and Kwanyar estuaries, as determined by the Mann-Whitney U test. However, there was no significant difference observed in the levels of salinity and Cd. The correlations also varied for each measured water variable from both estuaries using Pearson's correlation. Principal component analysis and plotting of the PCs in scatter diagrams identified the latent parameters controlling the water chemistry of the estuary temporarily. The results showed that the DO condition required immediate attention from those two estuaries. This condition occurred due to the impact of waste materials from households, industries, and anthropogenic activities that affected the living organisms responsible for oxygen production, such as green algae and green plants.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. Furthermore, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this study.

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