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Research Article
Multivariate Analysis of Physical and Chemical Parameters of Marine Water Quality in the Straits of Johor, Malaysia

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Abstract

Objective: The purposes of this study was to determine the main parameters that affect the ecological conditions in marine water and to identify the similarity of the areas with respect to the water quality status. **Materials and Methods:** This is a quantitative study which focuses on multivariate statistics on time series data of six marine parameters from 12 monitoring stations in the Straits of Johor, Malaysia. **Results:** Principal component analysis revealed that there are three main factors involved in determining the distribution of parameters, namely physicochemical, chemical and organic contaminants with the variation proportions of 37, 20 and 18%, respectively. Cluster analysis showed that all stations can be categorized into 2 clusters with distinct characteristics in terms of water quality parameters. **Conclusion:** There are three main factors that characterize the marine waters. The clusters connect similar sampling stations in terms of parameters and pollution levels with comparable environmental activities. Three factors representing three different processes are related to the physicochemical pollution factor, the chemical pollution factor caused by decomposition of aquatic life and the organic contaminant factor. Both of the physical parameters (Temperature and conductivity) as well as the chemical parameter (TSS) were found to the most influential, in physicochemical pollution factor. The pH and Dissolve Oxygen (DO) are parameters in the chemical pollution factor. Oil and grease involved only in the organic contaminant factor. Stations, which are located at the border between Johor Bahru city and Singapore produce organic pollution and affect the DO level of aquatic life. Three monitoring stations located in different areas of the border are exposed to high values of TSS and pH. This shows that both the Western and Eastern parts of the Straits of Johor are highly exposed to chemical pollution. Weather conditions and timing changes are the constraints of this study.

Key words: Multivariate statistical analysis, principal component analysis, cluster analysis, water quality

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Changes in water quality can pose a hazard to marine ecosystems and sensitive endangered species[1]. Changes in the quality of marine waters used for recreation, fisheries and industry may also pose a threat to humans. Thus, it is clear that protection of these valuable resources requires strong regulatory intervention and such intervention can be trusted to make the decisions necessary to establish the condition of the ecosystem[2].

Substances that can be observed in marine waters include persistent toxins (heavy metals, polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDTs), etc.), suspended solids, harmful pathogens, oils, wastewater compounds, visible pollutants, such as plastics and other rubbish. Aquatic organisms as well as human health and resources can be affected by marine pollution[3]. Such pollution may contribute to the death of aquatic organisms or lead to their mutation, resulting in potential sterility or other adverse effects on the ecosystem. Additionally, high levels of toxins in aquatic species due to water pollution may affect human health and so preventive actions should be taken.

Assessing a complex data structure requires a suitable statistical technique. For example, non-parametric regression has been used to determine smooth trends in physical parameters in marine water and pseudo-likelihood test provides the significance of the trend[4,5]. Multivariate statistical techniques for environmental data have been used extensively to characterize and evaluate water quality, since they allow better interpretation of complex data structures[6-8]. For example, they can be used to determine the existence of spatial variations of water quality caused by environmental and human factors[9-16] and spatial variation of a large number of water parameters in river basin[17]. Similar technique for environmental study has been used to characterize geographical distribution of soil since they allow better interpretation of regional patterns of manganese and nickel bioavailability[18]. Besides, it is very important for Malaysia to have a data analysis of water quality parameters to identifying the level and sources of pollution contaminating the marine water. Multivariate analysis using Principal Component Analysis (PCA) and Cluster Analysis (CA) was selected because this method able to calculate and analyze more than 2 variable equations. Even the other alternative method, such as graph pattern, univariate and bivariate can provide some information, these selected techniques help to achieve the research objectives, which involves many variables. In addition, this technique will produce accurate results and easy to handle.

The PCA and CA are multivariate statistical techniques that have widely been used to provide information about water quality[7,19-25]. Such techniques allow better interpretation of large and complex data matrices[20]. The PCA is a powerful technique for reducing a large number of data parameters without losing much information from the actual observations[26,27]. The technique has been used in a number of environmental studies[28] since it yields valuable insight into environmental management and protection[29]. The PCA is used for the evaluation of ground water monitoring wells and hydrographs, examination of spatial and temporal patterns of surface water quality, identification of chemical species related to hydrological conditions and assessment of environmental quality indicators[7,30-35]. The use of PCA in water quality assessment has increased over the last few years due to the need to achieve substantial data reduction for decision making[36-41]. Similar method has been used to investigate the spatial variation in the composition of wastewater[42]. It is used with physical, chemical and biological data for the purpose of extracting the factors related to changes in water quality[19,16,43,44,]. In this study, PCA works to create a new component or group based on all the 6 parameters studied. Through this method, each new group has produced its own effect on the pollution in the study area. Elements of the parameters contained in each group are linear to each other. Therefore, control of pollution can be focused by selecting the largest group, the next option is limited to experiments can be carried out.

The CA enables the grouping of object clusters on the basis of similarities within a cluster and dissimilarities between clusters. The use of cluster analysis as a data mining technique has been widely adopted in a number of fields. The CA has also been used in marine studies for identifying sampling zones for different degrees of contamination[45], distinguishing the spatial variation of biogeochemical cycles of nutrients and carbon[21], differentiating mangrove and open sea stations from other areas by considering distinctive physico-chemical characteristics[46] and the characterization of separate stations with high anthropogenic influence[47]. The technique is useful for the assessment of water quality[48-51]. In this study, the data of water quality parameters from 12 monitoring stations and date of sampling are grouped according to specific cluster using CA. From that, each profile parameters that were studied can be determined. Through these profiles, information on pollution levels and concentrations of pollutants that contaminate the marine water in the Straits of Johor will be ensured. So, it will transform and provided detailed information on the sources

of pollution contributed by the marine water activities, development and natural conditions of environmental context.

The importance of marine parameters in the characterization of ecological features in the ocean has stimulated interest in the spatial variation of physical and chemical parameters in water. Hence, the objectives in this study are two-fold: (1) To determine the main parameters that contribute to changes in ecological conditions of marine waters and (2) To identify similarities in the areas studied in terms of water quality status. However, this study is limited to, weather factor. Knowing that water samples taken had the effect of both tide and low tide, the weather conditions will change when there is a lot of rain or output into the stream. This will cause the dilution of sea level and will disrupt both of the ambient conditions and the results of the study. Second, this study had conducted a field base experiment of which is influenced by timing changes. The results will be influenced by tides and the resulting variation caused by marine activities such as shipping and boating.

MATERIALS AND METHODS

Study area and monitoring sites: The study area is the Straits of Johor, a relatively narrow and shallowbody of water located between the Southern edge of Johor state in Peninsular Malaysia and Singapore (Fig. 1). The width of the Johor Straits varies between 500 m and 6 km (at the entrance to the Strait of Malacca). The depth varies between 5-25 m deep. Key activities include fisheries and shipping[24].

Seawater speed of a few knots used to flow through the strait, which connects the continental shelf in the South China Sea to the East with the Strait of Malacca to the West. The beaches on both sides of the straits in Malaysia and Singapore are used as tourist attractions and a means for stimulating the economy. To ease the flow of people and commercial goods, highway and railway causeways were built in 1924. Increasing urbanization and settlement in Johor Bahru city and Singapore have contributed to the growing pollution load in the straits, which is made worse by the presence of the causeway which affects the free flow of water on both sides[44].

Straits of Johor were chosen as the study site because it is the site of a clash between the 2, namely Malacca Strait and the South China Sea, which occurred under semi-confined water body condition. From that, the study will see the natural phenomena in between the coastal way of East and West. If the study conducted in any location of marine water, which does not have a clash between the 2 straits, the results of water quality arising due to these natural phenomena will not be obtained and identified. Second, the site selection study is intended to find effects resulting from collisions in between the 2 countries, namely Malaysia and Singapore. The main specialty is the impact of shipping activities and waste water discharge. From this factor, it will identify whether both of storm water and waste water discharge from the 2 countries have the potential to adversely affect water quality. Twelve water quality monitoring stations were established to cover a wide range of pollutant parameters along the straits, which may reasonably represent the water quality of the marine system in the Straits of Johor.

Data preparation: Six water quality parameters from the 12 monitoring stations (Fig. 1) were monitored every month

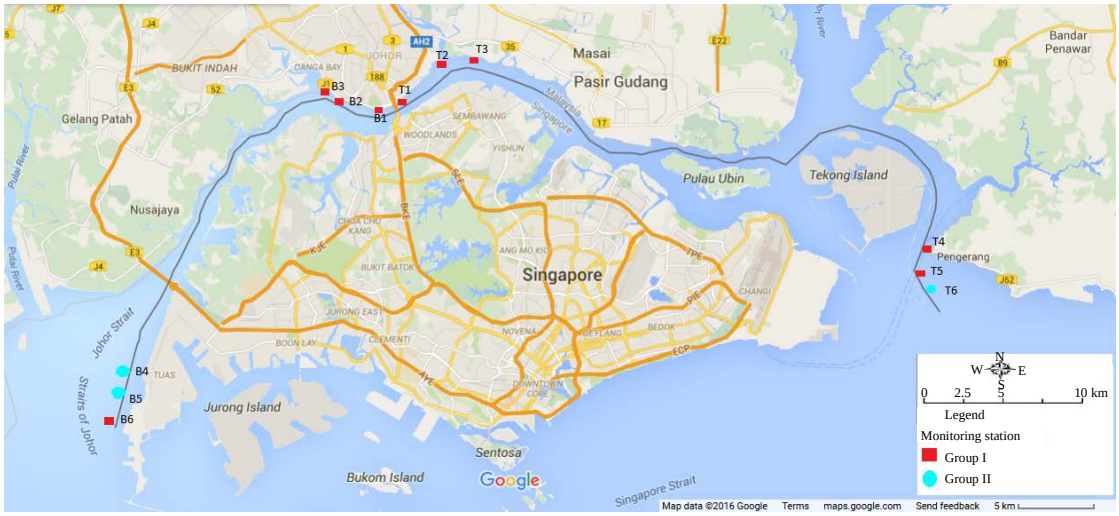

Fig. 1: Location of the study area and water quality monitoring station

from 2003-2013. Recent data are not reviewed because of the development activities taking place in some locations of sampling, starting in 2014. If the present data are adopted, it is probable that final decision on the effects of marine pollution will be affected by external factors. Therefore, the study only focused on similar stations in between 2003-2013. The parameters monitored were a temperature, Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), Total Suspended Solids (TSS), oil and grease (OG). The data were supplied by the Institute of Climate Change (ICC) at the National University of Malaysia (UKM). Each parameter selected in this study has the individual function towards the results of water quality. Physical parameters are temperature and EC, chemical parameters included pH, DO, TSS and organic contaminant of oil and grease. The pH is a measure of acidity or basic quality of marine water and is an important chemical factor in marine life. The most important basic requirement of environmental quality for aquatic life is the DO level, which refers to the amount of oxygen dissolved in the water. Oxygen enters the marine water from the surrounding air through the photosynthesis process from aquatic plants. High levels of DO are considered a healthy ecosystem (greater than 7 mg L^{-1}) since it has the ability to support a better diversity of marine organisms. The TSS is an indication of all of the particles suspended in water that cannot cross pass through a filter. Large volume of suspended sediment causes interference and reduces light penetration and the production of photosynthesis process for marine life will be reduced. Last but not least, oil and grease analysis was performed to verify the uncertainty caused by indiscriminate dumping of waste oil and poor oil management within the sites.

Multivariate statistical methods

Principal Component Analysis (PCA): The PCA is a statistical technique that linearly transforms an original set of variables into a substantially smaller set of uncorrelated variables without losing the information contained in the original set of variables[52]. The PCA is a statistical measure of multivariate data used to reduce the complexity of a large number of input variables to allow better interpretation of the original variables[6,29,53,54]. Each of the principal components have high correlations with the original variables[52]. This is particularly advantageous since a set of data from many variables can be combined into a two-dimensional subspace (plane) which represents the principal components. Hence, the data can be illustrated with respect to 2 dimensions of the principal components[55] and thus provide a straightforward visual representation of what the data look like, instead of appearing as a large mass of numbers. The original data can also be visualized in a three-dimensional subspace which corresponds to 3 principal components. Thompson[22] noted that PCA is the default method in many statistical programs since it is commonly used in Exploratory Factor Analysis (EFA). Gorsuch[56] indicated that PCA is recommended when there is no prior theory about the data. Pett *et al.*[57] suggested using PCA in establishing preliminary solutions in EFA. Dunteman[52] indicated that PCA has a similar goal to factor analysis in that both techniques enable the explanation of the variation in a set of observed variables on the basis of a few underlying dimensions. It is also stated that PCA has no underlying statistical model of the observed variables on the basis of maximum variance properties of the principal component. The variable weights in the linear combination are derived on the basis of maximizing a certain statistical property. Dunteman[52] further indicated that PCA is sometimes used prior to factor analysis to determine the dimensionality of the common factor space. According to Latif *et al.*[58] PCA can be used to extract significant factors (principal components, PCs) so as to analyze the relationships between the observed variables[59]. Principal components are the linear combinations of the original variables and the eigenvectors[25].

Mathematically, PCA is derived as follows:

- Encoding the variables X_1, X_2, ⋯, X_p to have zero mean and a unit variance
- Calculating the correlation matrix, R
- Finding the eigen value λ_1, λ_2, ⋯, λ_p and the corresponding eigen vectors a_1, a_2, ⋯, a_p by solving Eq. 1:

$$|R\text{-}I\lambda| = 0 \quad (1)$$

- Removing any components which only account for a fraction of the changes in the data set
- Developing loading factors and running the varimax rotation matrix to the loading factor matrix to deduce the main parameters

Cluster Analysis (CA): The CA is a mathematical approach that can be used to determine the similarity of variables. In particular, CA allows the sorting of variables with the same descriptions into the same cluster, it is often illustrated in dendrogram form. Hierarchical cluster analysis with squared euclidean distance is used to determine multivariate equations in marine water quality[60,61]. Squared Euclidean distance (D^2) between locations I and II is calculated from the uniform value of the location as defined in Eq. 2:

$$D^2 = (Z_{DO\ I}-Z_{DO\ II})^2+(Z_{TSS\ I}-Z_{TSS\ II})^2+... \quad (2)$$

where, $Z_{DO\ I}$ and $Z_{DO\ II}$ are constant values for a particular parameter at locations I and II. The squared euclidean distance between two locations or cases is defined as a coefficient. The first 2 combined cases have the smallest distance or high uniformity. The hierarchical clustering allows a distinct display of the relationships of the stations in terms of the water quality parameters as compared to non-hierarchical clustering. The euclidean distance enables the calculation of normal magnitude between stations with respect to the water quality parameters.

RESULTS AND DISCUSSION

Principal Component Analysis (PCA): Principal component analysis was conducted on the raw data set. Three components (Eigen value >1) accounted for 37.213, 20.486 and 17.597% of the total variance (Table 1). From the results in the Table 1, the 1st principal component (PC1) had high contributions from temperature, conductivity and total suspended solids (0.818) with a strong and positive correlation of 0.890, 0.827 and 0.818, respectively. The three parameters can be categorized as physicochemical parameters[62]. Even meet the standard requirements of the Malaysian government, the temperature and EC parameters are the largest contributor towards the marine water quality. Water temperature is a degree of the heat present in the marine water and it gives a great control towards aquatic communities. Water temperature changes consequence in controlling the proportion of metabolic activities and life cycles. The variation of water temperature is normally affected by the surrounding temperature, groundwater inflows, storm water runoff, turbidity and contact with sunlight. Stable water temperature plays an important role in the quality of water because most of physical, chemical and marine biology properties are directly affected by the temperature of marine water. Both conductivity and TSS would be affected by temperature[63]. Higher conductivity would represent the warmer water body[15], causing increases in conductivity value from 2-3% per degree celsius. High TSS can also cause an increase in surface water temperature[64], because the suspended particles absorb heat from sunlight. Therefore, changes in temperature definitely can affect the solubility of solids, including heavy metals[65] and can make some compounds more toxic. Variations in TSS occurred due to floating fine silt and detritus carried by rainwater from catchment, deforestation and sand mining activities[66]. According to Avvannavar and Shrihari[67], a large amount of suspended sediments would be harmful to fish and aquatic life, disturbing and reducing light penetration. On the other hand, discharge to the stream is able to alter conductivity. Poor sewage systems typically produce chloride, phosphate and nitrate, which would increase conductivity[68] and oil spills would reduce conductivity[45]. Low tidal influences tend to result in higher values than high tide due to the decrease in the water level during sampling and because of the large amount of settle able solids and sedimentation at the bottom of the marine water.

Table 1: Weight of three principal components of seawater quality parameters with eigen values of greater than 1.0

	Principal component		
Parameters	1	2	3
Temperature	0.890	-0.067	0.123
Conductivity	0.827	0.127	0.181
Total suspended solids	0.818	0.264	-0.237
Dissolved oxygen	0.275	0.670	-0.143
pH	-0.062	0.831	0.144
Oil and grease	0.085	0.021	0.954
Eigen values	2.233	1.229	1.056
Total variance (%)	37.213	20.486	17.597
The percentage of cumulative variance (%)	37.213	57.699	75.296

The 2nd principal component (PC2) explained 20.486% of the total variance attributed to dissolved oxygen (DO) and pH, with a positive correlation of 0.670 and 0.831, respectively. This component can be categorized as a decomposition factor of aquatic life[33]. This accounted for the positive correlation between pH and DO, where low DO represented an acidic pH condition due to the decomposition process[69]. When the marine water is too acidic or basic, it will harm and kill the organisms through disruption of marine organism's biochemical reaction. The most important environmental quality criterion for aquatic life is the DO level, which refers to the amount of oxygen dissolved in the water[70,71]. Oxygen enters marine water from the surrounding air through the photosynthesis process from aquatic plants. The DO levels drop if the water body contains large quantities of dead and decomposing matter[72]. The amount of oxygen consumed by microorganisms through the decomposition of organic material increases the amount of dissolved carbon dioxide[70] due to the enhanced photosynthetic process. The presence of carbon dioxide (CO_2) tends to make water become more acidic[73].

The 3rd component explains just 17.597% of the total variance and the parameters involved are oil and grease only, which can be categorized as hydrocarbon factors. Oil and grease analysis was performed to verify the uncertainty caused by indiscriminate dumping of waste oil and poor oil management of port areas. The main sources of oil and grease

in Malaysian coastal areas result from vessel leakage and disposal of engine oil from boats and ship operators[74]. In addition, the combination of smaller oil spills and grease leakage from vessels into the water during the loading and unloading of containers increased the oil and grease values[34].

The above results indicate that the water properties were mainly influenced by the physicochemical parameters (temperature, EC and TSS), followed by the chemical parameters (pH and DO) and finally by oil and grease. Additionally, the ecological condition in the in the Straits of Johor is affected primarily by water temperature, conductivity and total suspended solids.

Cluster analysis (CA): The results of CA are shown in Fig. 2 in which the 12 monitoring stations are classified into 2 groups. Cluster 1 consists of stations T1, T2, T3, T4, T5, B1, B2, B3 and B6, while the remainder T6, B4 and B5 belong to cluster 2.

There are nine monitoring stations in cluster 1 near the Johor mainland with similar features. All the parameters meet the department of environment (DOE) standards and the chance of contamination in the marine water of these stations is low. However, the temperature, oil and grease parameters are the highest recorded, while the DO is the lowest in this cluster. Said *et al.*[75] described how more oxygen is available in cooler water temperatures. This is because hot water tends to have a lower DO saturation level than cold water[37]. Similar sources of pollution at this cluster resulted from the environmental context, for example construction, land use, population density and economic activity. Johor Bahru is the second largest city in Malaysia[41] after Kuala Lumpur. The area is rapidly developing to accommodate the large population. In addition, most of the sampling sites at cluster 1 are located on the border between Johor and Singapore. Pasir Gudang Port is known to be the 16th busiest port in the world[50]. The Port of Singapore, one of the busiest free ports is also a source of pollution caused by oil spills from ships[39]. A combination of smaller oil spills and grease leakage from vessels during the loading and unloading of containers increased the oil and grease value. Plus, there are many cruise ships in the territorial waters between Johor and Singapore and is one of the factors of oil contamination. When a cruise ship is traveling at a period of time, a lot of production in the form of waste was produced. Both solid and liquid wastes will be discharged into the sea without being treated first. Other than that, ballast water is one of waste from the ship. Ballast water is used on to control a ship's stability by modifying the ship's center of gravity as cargo is unloaded and when the ship is under loaded. Ballast water is then discharged during loading, which leads to a transfer of marine species from one part of the earth to another and the overall mixing of water from many ports.

Stations B4 and B5 in cluster 2 are located at the western end of the Straits of Johor and are closer to the shipping routes. Therefore, the level of water at the two stations is similar and the possibility of the occurrence of pollution is high. Although, within the stated DOE requirements, all stations in cluster 2 recorded higher readings for pH, DO and TSS compared to cluster 1, but the readings for temperature, conductivity and oil and grease are the lowest. Station B5 recorded the highest and lowest values for all stated parameters. In addition, station T6 is vulnerable due to its location on the national border, which is prone to marine water pollution caused by the tide. Moreover, the station is located in the Johor Straits waterway out of the South China Sea.

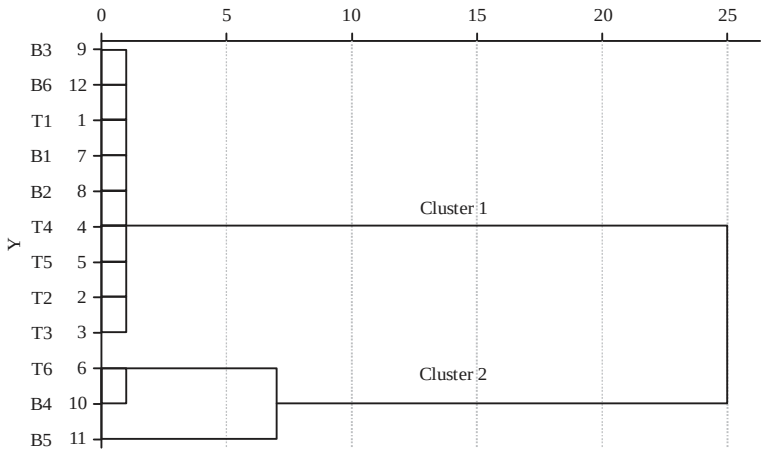

Fig. 2: Minimum variance for ward dendrogram

CONCLUSION

The study of physical, chemical and organic contaminant parameters of marine water quality in the Straits of Johor has achieved its purposes. Marine water quality was analyzed by using DOE standard and was found that, water quality is significantly improved during high tide and much better rather than during low tide. It is due to the water level increase from mixing of storm water and seawater that resulting dilution during high tide, which leads to a decreased concentration of particulate matter in the water. During low tide, water quality much worst due to the pollutants settle at the bottom of the marine water. There are 3 factors representing 3 different processes are related to the physicochemical pollution factor, the chemical pollution factor and the organic contaminant factor. Nine monitoring stations namely stations T1, T2, T3, T4, T5, B1, B2, B3 and B6 had higher values of oil and grease, along with lowest temperature and DO. Stations T1, T2, T3, B1, B2 and B3 which are located at the border between Johor Bahru city and Singapore produce organic pollution and affect the DO level of aquatic life. Three monitoring stations namely stations B4, B5 and T6 are exposed to high values of TSS and pH. However, the information gathered does not reflect the overall water quality conditions. Information of organic pollutants and heavy metals are not identified due to the absence of these parameters. Therefore, extensive study into the organic contaminants and heavy metals should be assessed. Emphasis on noise, air and water pollution should be emphasized and combined. Through a comprehensive observation of all aspects of parameters, better follow-up action can be obtained to improve the existing specificity, while preserving the quality of the straits of Johor in general.

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