Malaysian Journal of Sustainable Environment
Vol.9.No.2 (2022) 257-278
doi: 10.24191/myse.v9i2.18838

ASSESSMENT OF SURFACE WATER QUALITY IN A MALAYSIAN PORT VIA MULTIVARIATE STATISTICAL ANALYSIS

Wan Nur Fazlina Abdol Jani[1*], Firdaus M.H2, Fatihah Suja[2], Shahrom Md Zain[2] & M. Abdullah[1]
***Corresponding author**
*[*1]College of Engineering, UiTM Cawangan Johor, Kampus Pasir Gudang, 81750 Masai, Johor, Malaysia*
[2]Faculty of Engineering and Built Environment, 43600 UKM Bangi, Selangor, Malaysia

*wanfazlina@uitm.edu.my,fir@ukm.edu.my
fati@ukm.edu.my, smz@eng.ukm.my
moham3767@uitm.edu.my
Received: 14 April 2022
Accepted: 6 June 2022
Published: 31 August 2022

ABSTRACT

Maritime transport has become an important method of comprehensive connectivity for imports and exports for major centers of economic activity all over the world. However, transport and port activities have grown without addressing their pollution impact on the environment. Marine water samples in a port in Malaysia were collected to find the similarities and differences in the physicochemical aspect. The principal component analysis concluded that 87.0% of the variance was explained by the four components at high tide, each accounted for 33.6% (physicochemical), 26.9% (correlation between pH and organic matter), 14.1% (trace metals), and 12.4% of the total variance (the concentration of Copper). Then, 94.5% of the total variance of the five components contributed 37.9% (turbidity, pH, organic parameters, and suspended solids), 19.6% (parameter Zn), 17.4% (parameter Ni), 11.7% (average of organic pollutants) and 7.7% of the total variance (DO and physical factors associated with TSS), each at low tide have been identified. Hierarchical cluster analysis grouped eight sampling stations into four clusters of similar water quality characteristics at both tides. Therefore, water quality monitoring and the control of untreated *metal and organic waste discharge into marine waters are indispensable.*

Keywords*: Marine water quality, Environmental impact, Spearman's Coefficient Correlation analysis, Principal Component analysis, Cluster analysis,*

INTRODUCTION

A port is an important national asset that needs to be carefully protected. Ports should be maintained to preserve both public health and the natural environment (Jani et al., 2021). Maritime transport is considered the most cost-effective way of moving goods and materials, with data showing that more than 90% of the world's trade is carried by sea (IMO, 2018). However, transport and port activities have grown without addressing their pollution impact on the environment. Based on a study by AAPMA (2001), shipping and port operations contributed to approximately 12% of the total marine pollution. According to a study by Jo O'Brien (2002) and Diane et al. (2004), port operations, including ship waste, oil spills, runoff, dredging, port development, and other entities, have been sources of marine pollution. Major sources of oil spills include marine terminals, pipe leaks in harbours, offshore drilling leaks, destruction of oil tankers and barges, and the washout of oil into storm drains (Ford et al., 2008; Soe, 1996).

In addition to operating as a trade route for cargo vessels, the ocean has an important role as a buffering agent. The ocean acts as a thermal buffer, balancing the greenhouse gas carbon dioxide and pollutants in the earth's climate, thus protecting people from sudden changes in the Earth's increasing temperature as a result of modernization. However, marine pollution is rapidly spreading globally, which could affect this buffer. According to Derraik (2002), marine pollution occurs when there is an inappropriate change in the ocean's composition, condition, colour, and quality, making the water unusable. Contamination may occur in terms of biology, chemistry, and/or physics. Although pollutants might not be seen by the naked eye, impacts can and do occur as a result of human arrogance, which is continually destroying the oceans. Besides, sustainability of the coastal water areas is important to be maintained due to the benefits they have towards economic and ecological roles (Kamaruddin et al., 2020). Sustainability development and management such as protection, conservation, and prevention of marine pollution allow future generations to appreciate marine resources and utilized them for better use (Kamaruddin et al., 2018).

Water quality assessment encompasses monitoring, data evaluation, reporting, and dissemination of the condition of the aquatic environment (Wu et al., 2015). A growing number of marine water monitoring programs is crucial to collect huge datasets. Huge datasets are important to obtain a better understanding of how anthropogenic activities influence the marine water environment. The application of different multivariate approaches (cluster analysis (CA) and principal components analysis (PCA)) for the interpretation of these complex data matrices offer a better understanding of the water quality and ecological status of the studied systems (Li et al., 2018; Rehman et al., 2018). This method of analysis has been used in many investigations to classify and characterize surface or groundwater quality data at a range of spatial and temporal scales (Gulgundi & Shetty 2018; Machiwal & Singh, 2015; Masoud, 2013). Plus, these methods can be applied in water studies for in-depth knowledge of water quality conditions, and they can be used as practical tools for water resource management (Kazi et al., 2009). According to previous studies, the integrated use of various multivariable approaches is preferable for mutual verification of the results obtained (Su et al., 2011).

Water quality degradation can make it unusable for human needs, and it has a negative impact on the environment. Therefore, evaluation of water quality is necessary (Masoud & Amir, 2016). Because of that, the purpose of this study was to apply multivariate techniques of Spearman's Rank Correlation Coefficient (SRCC), PCA, and Hierarchical Cluster Analysis (HCA) to find the similarities and differences in the physicochemical composition of the water in one of the ports located in Peninsular Malaysia. Moreover, this analysis sought to examine the relationship among the various parameters of marine water quality.

METHODOLOGY

Sampling Location

Studies of marine pollution in Malaysia were conducted in a port located in Peninsular Malaysia. This port is one of the largest multi-purpose ports in South Asia and is capable of handling up to 60% of the country's trade activities. Water samples were taken from eight different sampling sites with tidal influences, representing the context of the marine ecosystem in a Malaysian port. Figure 1 shows the location of the program plan in 8 sampling stations consisting of areas with environmental context and different port activities. The location, date, and description of the sampling sites are shown in Table 1.

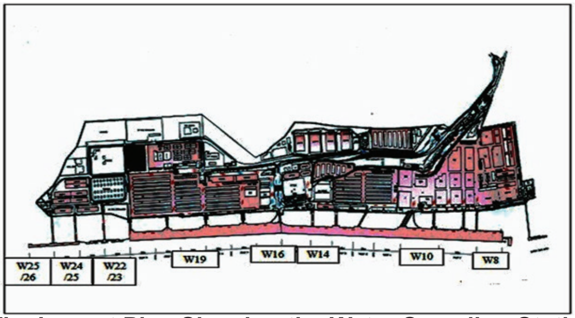

Figure 1. The Layout Plan Showing the Water Sampling Stations at a Malaysian Port

Table 1. Information and Description of Sampling Stations

No.	Pier (Wraft)	Distance from Pier 1 (m)	Water Depth (m)	Description of Cargo
1	W8	120	11.0	Container from Asia and Europe
2	W10	755	13.2	Container from Asia and Europe
3	W14	1560	15.0	Container from Asia and Europe
4	W16	1840	12.7	Container handling kernel oil
5	W19	2585	13.0	Container from coastal areas
6	W22/23	3355	11.7	Containers of liquid petroleum gas (LPG)
7	W24/25	3800	11.7	Container handling fine particles

8	W25/26	3985	12.0	Container handling fine particles

Source: Author

Sampling Operation

Samples from eight different pier locations were taken from 0-5 cm below the surface of the water by using a water sampler (Model 110, Australia). Sampling was carried out under two different water conditions, at low tide (1300 hours to 1500 hours) and high tide (1930 hours to 2100 hours). Water samples were collected from 5 different dates in duplicate for both high tide and low tide (volume of approximately 1500 ml). Samples were stored in clean polyethylene bottles using the standard method APHA 4500-P. Then, the samples were stored in a refrigerator at 4°C prior to laboratory analysis to maintain quality.

Parameter Measurements

The samples involved in this study were characterized by their physical properties, chemical properties, organic pollutants, and trace metals according to interim marine water quality standard (IMWQS). Physical analysis included two parameters, namely the temperature and turbidity. The chemical analysis consisted of dissolved oxygen (DO), pH, total suspended solids (TSS), and ammonia nitrogen (NH3-N). Finally, the concentration of organic contaminants in marine waters was measured using the following parameters: biochemical oxygen demand (BOD), oil and grease (O&G), chemical oxygen demand (COD), and trace metal concentrations of Aluminum (Al), Chromium (Cr), Copper (Cu), Iron (Fe), Zinc (Zn) and Nickel (Ni). All samples were run in triplicate to determine the average and the accuracy. The reading was acquired from many different points to represent the location where the water samples were collected.

The results of physical and chemical parameters, the concentration of organic contaminants, and the concentrations of NH3-N in the eight sampling stations for both the high and low tides in the studied harbour are shown in Table 2. The overall trace metal concentrations in the harbour are shown in Table 3.

Table 2. Physical Parameters, Chemical Parameters, Organic Pollutant Concentrations, and the Concentration of NH3-N

Station	Tidal	Temp (°C)	pH	DO (mg/L)	Turbidity (NTU)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	O&G (mg/L)	NH3-N (mg/L)
W8	High	28.6 ± 2.0	8.1 ± 0.6	7.91 ± 0.45	25.47± 24.53	112 ± 43	5.2 ± 2.9	5.2 ± 2.9	40.20 ± 12.30	1.49 ± 0.05
	Low	30.3 ± 2.6	8.2 ± 1.0	7.63 ± 0.41	66.20 ± 110.4	170 ± 218	6.6 ± 1.1	6.6 ± 1.1	25.30 ± 12.70	2.40 ± 0.05
W10	High	28.2 ± 1.7	8.3 ± 1.1	7.87 ± 0.52	19.40 ± 30.60	105 ± 52	3.6 ± 2.3	3.6 ± 2.3	72.40 ± 151.60	3.71 ± 0.01
	Low	29.7 ± 2.4	8.2 ± 0.9	7.71 ± 0.67	122.80 ± 187.20	189 ± 194	6.1 ± 4.4	6.1 ± 4.4	51.50 ± 91.00	1.57 ± 0.03
W14	High	28.6 ± 0.9	8.2 ± 1.0	7.89 ± 0.39	16.00 ± 6.00	96 ± 46	3.9 ± 4.7	3.9 ± 4.7	123.90 ± 370.10	2.37 ± 0.01
	Low	29.5 ± 2.6	8.1 ± 0.9	7.65 ± 0.62	146.60 ± 276.73	178 ± 205	4.2 ± 6.3	4.2 ± 6.3	18.10 ± 5.10	2.12 ± 0.03
W16	High	28.5 ± 1.0	8.4 ± 0.9	7.80 ± 0.37	18.93 ± 4.07	97 ± 52	3.8 ± 1.5	3.8 ± 1.5	153.50 ± 88.00	3.72 ± 0.03
	Low	29.5 ± 2.6	8.2 ± 1.0	7.70 ± 0.85	135.67 ± 227.66	186 ± 192	3.0 ± 2.9	3.0 ± 2.9	13.00 ± 7.00	2.70 ± 0.04
W19	High	28.5 ± 0.8	8.3 ± 1.1	7.84 ± 0.37	23.87 ± 21.13	100 ± 93	3.2 ± 1.8	3.2 ± 1.8	153.30 ± 307.70	1.79 ± 0.01
	Low	29.4 ± 2.5	8.3 ± 1.2	7.69 ± 0.71	137.53 ± 189.14	205 ± 308	6.0 ± 4.2	6.0 ± 4.2	195.90 ± 483.60	4.10 ± 0.02
W22/ 23	High	28.5 ± 1.0	8.34± 0.8	7.86 ± 0.42	23.27 ± 15.73	93 ± 64	3.5 ± 2.1	3.5 ± 2.1	136.00 ± 372.50	2.48 ± 0.01
	Low	29.3 ± 2.9	8.06± 0.7	7.69 ± 0.53	112.40 ± 190.93	213 ± 537	3.2 ± 2.4	3.2 ± 2.4	140.60 ± 396.40	2.10 ± 0.02
W24/ 25	High	28.7 ± 0.2	8.2 ± 1.0	7.80 ± 0.37	22.73 ± 12.06	111 ± 60	3.7 ± 1.3	3.7 ± 1.3	161.50 ± 474.00	0.46 ± 0.03
	Low	29.4 ± 2.7	7.9 ± 0.6	7.73 ± 0.49	73.27 ± 206.72	145 ± 324	4.0 ± 1.0	4.0 ± 1.0	27.40 ± 49.60	1.89 ± 0.05
W25/ 26	High	28.6 ± 0.5	8.2 ± 1.0	7.82 ± 0.26	24.80 ± 20.20	99 ± 116	4.3 ± 3.1	4.3 ± 3.1	99.10 ± 168.40	1.65 ± 0.03
	Low	29.4 ± 2.8	7.9 ± 0.6	7.74 ± 0.65	39.05 ± 80.95	127 ± 249	3.6 ± 2.3	3.6 ± 2.3	44.10 ± 98.90	1.65 ± 0.04

Source: Author

Table 3. The Total Value of the Concentration of Trace Metals

Station	Tidal	Al (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Ni (mg/L)	Zn (mg/L)
W8	High	0.008 ± 0.022	0.004 ± 0.005	0.075 ± 0.051	0.331 ± 0.309	0.028 ± 0.009	0.018 ± 0.029
	Low	0.002 ± 0.002	0.004 ± 0.004	0.050 ± 0.049	0.066 ± 0.063	0.016 ± 0.014	0.016 ± 0.015
W10	High	0.007 ± 0.016	0.003 ± 0.006	0.086 ± 0.062	0.277 ± 0.263	0.022 ± 0.004	0.017 ± 0.039
	Low	0.002 ± 0.000	0.004 ± 0.010	0.081 ± 0.080	0.065 ± 0.062	0.017 ± 0.015	0.018 ± 0.021
W14	High	0.005 ± 0.008	0.004 ± 0.004	0.085 ± 0.071	0.255 ± 0.235	0.025 ± 0.005	0.018 ± 0.025
	Low	0.002 ± 0.003	0.004 ± 0.006	0.059 ± 0.058	0.147 ± 0.343	0.016 ± 0.014	0.013 ± 0.020
W16	High	0.017 ± 0.049	0.007 ± 0.000	0.080 ± 0.069	0.403 ± 0.427	0.026 ± 0.004	0.017 ± 0.043
	Low	0.002 ± 0.003	0.004 ± 0.012	0.057 ± 0.037	0.069 ± 0.067	0.021 ± 0.020	0.018 ± 0.030
W19	High	0.012 ± 0.028	0.007 ± 0.023	0.084 ± 0.074	0.270 ± 0.220	0.029 ± 0.005	0.017 ± 0.038
	Low	0.002 ± 0.005	0.003 ± 0.006	0.062 ± 0.043	0.079 ± 0.077	0.017 ± 0.017	0.016 ± 0.031
W22/23	High	0.007 ± 0.009	0.011 ± 0.037	0.085 ± 0.076	0.268 ± 0.212	0.029 ± 0.005	0.029 ± 0.034
	Low	0.002 ± 0.005	0.002 ± 0.005	0.062 ± 0.061	0.085 ± 0.083	0.017 ± 0.016	0.014 ± 0.030
W24/25	High	0.014 ± 0.040	0.009 ± 0.031	0.087 ± 0.079	0.263 ± 0.197	0.033 ± 0.004	0.030 ± 0.038
	Low	0.004 ± 0.008	0.003 ± 0.006	0.066 ± 0.065	0.082 ± 0.080	0.017 ± 0.017	0.015 ± 0.026
W25/26	High	0.020 ± 0.019	0.011 ± 0.029	0.090 ± 0.036	0.227 ± 0.163	0.026 ± 0.012	0.002 ± 0.005
	Low	0.004 ± 0.004	0.002 ± 0.003	0.069 ± 0.068	0.088 ± 0.086	0.017 ± 0.017	0.016 ± 0.029

Source: Author

r

Multivariate Analysis

The IMWQS provided by the Department of the Environment (DOE, 2019) was used as a reference for the analysis of each parameter in this study. These standards are used to identify the status and classification of marine waters for a port in Malaysia. The results of the statistical analysis obtained will be represented using SPSS.

Statistical methods of multivariate analysis; SRCC, PCA, and HCA analysis were used to analyze the data. SRCC was used in this study specifically to determine the relationship between two parameters, related either directly or inversely. It is important to identify high-risk parameters contributing to the quality of other parameters and vice versa. Through this analysis, the resulting high-risk parameters need to be monitored in more detail to ensure that the marine water quality in the study area is preserved. PCA analysis is used in this study to create new components or groups based on all the 15 parameters studied. Through this method, each new batch produced has its own impact on the pollution in the study area. Elements of parameters in each cluster are linear with each other. Therefore, pollution control efforts can be focused by selecting the largest groups, and a limited number of experiments can be conducted. Finally, HCA was carried out to detect the behaviour and similarities among the sampling stations. This analysis is important because the studies were conducted in eight locations with different site conditions, as well as different shipping and port activities. With HCA analysis, the study will determine the parameters of the major contributor to marine pollution at each location.

RESULTS AND ANALYSIS

Correlation Evaluation on Parameter using Spearman's Rank Correlation Coefficient (SRCC)

Table 4 and Table 5 show the SRCC analysis of the physical parameters, chemical parameters, organic pollutants, and heavy metal concentrations. Based on the analysis, it was found that the DO parameter is directly proportional to COD (rs = 0.719), but inversely proportional to the concentration of O&G (rs = -0.802) and metallic Al (rs = -0.771) for each tide. This shows that the high COD is not due to low BOD, since that would cause low DO; instead, the high COD is believed to be caused by the high concentration of Al compounds from W24/25 and W25/26 (container handling fine particles). However, there was insufficient evidence from the previous study to support that statement.

DO also tends to be inversely proportional to dissolved heavy metals, such as Al (rs = -0.760) and Cu (rs = -0.783) at the low tide. The oily and liquid petroleum runoff then dissolved into the ocean, lowering the DO. Furthermore, the DO content decreased due to the usage of rusted tools on the port's shoreline, as well as small particles that release contaminants like Al into the water during loading and unloading activities at the bulk material wharves W24/25 and W25/26.

In high tide conditions, the pH is directly proportional to the NH3-N (rs = 0.758) and inversely proportional to the temperature of marine water (rs = -0.826). Obviously, an increase in the concentration of NH3-N directly increases the pH level. The high pH resulted from runoff caused by busy port activities with cargo, private vehicles, and untreated sewage by using toilets that are drained directly into marine water containing high ammonia levels. Besides, increased runoff also lowers the temperature of marine water.

Based on the SRCC analysis, although the concentration of Al metal is proportional to the COD (rs = 0.756), it is inversely proportional to pH (rs = -0.760), DO (rs = -0.760) and TSS (rs = -0.756) at the low tide. This result is due to the decrease in water level at low tide, increasing the total suspended solids and particles in the water. The enhancement of Fe and Al will also directly increase the concentration of COD due to carbon-containing Fe and Al compounds.

Principal Component Analysis (PCA)

Techniques for producing new variables that are linear combinations of the original variables can be obtained through PCA. Through this technique, the new variables that result will not correlate (Liu et al., 2003).

Table 4. Spearman Correlation Analysis on the State of the Tide on the Physical, Chemical, Organic Pollutants, and Heavy Metal Concentrations. N = 8

	Temp	pH	DO	Turbidity	TSS	BOD	COD	O&G	NH_3-N	Al	Cr	Cu	Fe	Ni	Zn
Temp	1	-0.826*	-0.024	0.452	0.452	0.500	-0.548	0.048	-0.932**	0.263	0.279	0.168	-0.452	0.518	0.393
pH		1	-0.325	-0.443	-0.647	- 0.635	0.132	0.419	0.758*	-0.018	0.098	-0.247	0.347	-0.121	-0.284
DO			1	0.144	0.096	0.252	0.719*	-0.802*	-0.071	-0.771*	-0.604	-0.349	0.084	-0.382	0.123
Turbidity				1	0.452	0.190	-0.405	-0.381	-0.485	0.359	0.327	-0.072	-0.024	0.434	-0.135
TSS					1	0.238	-0.071	-0.238	-0.447	0.228	-0.376	-0.060	0.286	0.181	0.049
BOD						1	0.143	-0.476	-0.225	0.204	-0.133	-0.072	-0.095	-0.325	-0.123
COD							1	-0.595	0.524	-0.695	-0.837**	-0.395	0.429	-0.771*	-0.110
O&G								1	-0.089	0.347	0.461	0.084	-0.048	0.566	0.307
NH_3-N									1	-0.064	-0.280	-0.077	0.358	-0.698	-0.625
Al										1	0.531	0.187	0.000	0.285	-0.432
Cr											1	0.390	-0.473	0.601	0.088
Cu												1	-0.766*	-0.055	-0.080
Fe													1	-0.072	-0.061
Ni														1	0.559
Zn															1

Source: Author

Table 5. Spearman Correlation Analysis on the Low-water Conditions on the Physical, Chemical, Organic Pollutants, and Heavy Metal Concentrations. N = 8

	Temp	pH	DO	Turbidity	TSS	BOD	COD	O&G	NH_3-N	Al	Cr	Cu	Fe	Ni	Zn
Temp	1	0.524	-0.373	0.120	-0.180	0.587	-0.707	-0.539	-0.102	-0.380	0.931**	-0.349	-0.635	-0.353	0.401
pH		1	-0.627	0.467	0.491	0.503	-0.826*	0.804	0.604	-0.760*	0.569	-0.470	-0.647	-0.111	0.408
DO			1	-0.395	-0.371	-0.287	0.539	0.156	-0.086	-0.760*	-0.440	-0.783*	0.072	0.622	0.321
Turbidity				1	0.571	-0.119	-0.167	-0.071	0.514	-0.630	0.437	-0.228	0.071	0.027	-0.110
TSS					1	-0.095	-0.429	0.500	0.405	-0.756*	0.000	-0.060	-0.238	0.234	0.037
BOD						1	-0.476	0.238	-0.171	-0.126	0.360	0.072	-0.524	-0.577	0.147
COD							1	0.071	-0.234	0.756*	-0.669	0.419	0.857**	0.069	-0.552
O&G								1	0.109	0.000	-0.617	0.563	-0.048	0.096	-0.037
NH_3-N									1	-0.330	0.084	-0.274	-0.234	0.522	0.410
Al										1	-0.544	0.507	0.378	0.145	-0.130
Cr											1	-0.440	-0.514	-0.238	0.345
Cu												1	0.048	0.277	0.136
Fe													1	-0.220	-0.786*
Ni														1	0.553
Zn															1

Source: Author

a)PCA at High Tides

Four components (eigenvalues > 1) contribute to 33.6%, 26.9%, 14.1% and 12.4% of the total variance, during high tide (Table 6). The results from the analysis of the varimax matrix components at high tide with the four extracted components are shown in Table 7.

Table 6. The Output Value of the Total Variance of Water Quality in the High Tide using PCA

Extraction Sums of Squared Loadings				Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.040	33.598	33.598	4.357	29.045	29.045
2	4.042	26.949	60.547	3.745	29.969	54.014
3	2.110	14.067	74.614	2.875	19.167	73.182
4	1.857	12.381	86.995	2.072	13.814	86.995

Source: Author

Table 7. Rotated Component Matrix for the Quality of Water in a Malaysian Port at High Tide Conditions (Rotated Component Matrixa)

Parameter	Component			
	1	2	3	4
Temp.	0.837	-0.254	0.282	-0.035
pH	-0.304	0.885	0.072	0.177
DO	-0.244	-0.506	-0.715	-0.005
Turbidity	0.499	-0.452	0.350	-0.074
TSS	0.319	-0.619	-0.180	0.182
BOD	0.046	-0.903	0.072	0.278
COD	-0.794	-0.081	-0.552	0.066
O&G	0.399	0.850	0.230	-0.031
NH3-N	-0.888	0.351	0.118	0.237
Al	0.122	0.023	0.966	0.029
Cr	0.493	0.295	0.609	-0.337
Cu	-0.040	0.330	0.257	0.869
Fe	-0.151	0.092	0.105	-0.974
Ni	0.984	0.104	0.076	0.048
Zn	0.568	0.414	-0.601	0.205

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization
a rotation centered in 12 iterations
(Note: The analysis of the components above 0.500)

Source: Author

PC1 comprises physicochemical factors, the temperature of the water (strong), and turbidity (in moderation) (33.6%). While meeting the standards set by the IMWQS, these parameters are the largest contributors to the effects on marine water quality in this Malaysian port. Stable water temperature plays an important role in water quality, as most of the physical, chemical and biological features of the ocean are directly influenced by marine water temperature. An increase in water temperature will result in a reduction in the amount of DO. Said et al. (2004) and Smith (2004) argue that generally, there is less oxygen in the water at a high temperature, which would ultimately lower the DO. Changes in marine water temperature in the study were influenced by the ambient temperature, surface runoff, turbidity, and direct contact with sunlight.

PC2 explained 26.9% (Table 6) of the total variance and has a high correlation between pH and O&G. This component measures the relationship between the chemical parameter pH and the organic parameter O&G. Only some of the pH values exceed the standards. However, all O&G readings on all sampling dates and locations exceed the standards, even at very high concentrations. Surface runoff is mixed with oil, and daily washing activities in each pier area contribute to the flow of oil into marine waters. The combination of small oil spills from ships into the water during loading and unloading of liquid petroleum cargo containing chemicals also contributes to the increase in the concentration of O&G. Surface runoff increases the pH of the water, according to SRCC findings. As a result, the pH rise is affected by O&G. According to ITOPF (2011), an oil spill is a release of a liquid petroleum hydrocarbon into the environment due to human activity; the term often refers to marine oil spills. Oil spills include releases of crude oil from tanker ships, directly from accidents, and indirect from ship operations, offshore platforms, drilling rigs, and wells, as well as spills of refined petroleum products, such as gasoline, diesel, and their by-products and heavier fuels such as bunker fuel used by large ships, or the spill of any oily white substance refuse or waste oil (Hulsey and Ludivina, 2012).

PC3, explaining 14.1% (Table 6) of the total variance, represents a strong concentration of Al and Cr (medium). Therefore, PC3 can be categorized as the factor of trace metals. Other parameters included in this component are excluded, as they are low or negative. Based on this analysis, it is clear that Al is the largest contributor to metal contamination in this Malaysian port, followed by Cr. PC4, accounting for 12.4% (Table 6) of the total variance, representing trace concentrations of Cu. Identified waste materials containing Cu in the water come from ship antifouling paints designed to protect them from chemical degradation, weathering, and biological effects (Chen et al., 2013). An increase in the concentration of Cu was observed from the pier to W24/25 and W8 because the flow of the water carried Cu from one pier to the next.

It can be concluded that the water temperature, turbidity, pH, O&G, and concentration of trace metals such as Al, Cr, and Cu are major sources of water pollution in this tidal port study under high tides conditions.

a)PCA at Low Tides

Four components (eigenvalues > 1) contribute to 33.6%, 26.9%, 14.1% and 12.4% of the total variance, during high tide (Table 8). The results from the analysis of the varimax matrix components at high tide with the four extracted components are shown in Table 9.

Table 8. The Output Value of the Total Variance of Water Quality in the Low Tide using PCA

Extraction Sums of Squared Loadings				Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.688	37.922	37.922	4.969	33.124	33.124
2	2.945	19.634	57.557	2.652	17.679	50.803
3	2.615	17.434	74.991	2.565	17.099	67.902
4	1.758	11.721	86.712	2.200	14.666	82.568
5	1.161	7.742	94.454	1.783	11.885	94.454

Source: Author

Table 9. Rotated Component Matrix for the Quality of Water in a Malaysian Port at Low Tide Conditions (Rotated Component Matrixa)

Parameter	Component				
	1	2	3	4	5
Temp.	0.089	0.271	-0.746	-0.445	-0.399
pH	0.852	0.326	-0.309	0.115	-0.213
DO	-0.541	0.314	0.426	0.195	0.681
Turbidity	0.919	-0.160	0.294	0.058	0.143
TSS	0.854	-0.022	0.024	0.403	-0.017

BOD	0.252	0.206	-0.904	0.020	0.054
COD	0.852	-0.210	0.323	0.102	0.227
O&G	0.259	-0.017	-0.093	0.957	0.088
NH3-N	0.445	0.391	0.204	0.562	-0.139
Al	-0.929	0.003	0.138	-0.022	0.199
Cr	0.608	0.171	-0.213	-0.684	-0.097
Cu	-0.131	0.110	-0.044	0.020	-0.980
Fe	0.082	-0.902	0.220	-0.164	-0.012
Ni	0.195	0.614	0.747	-0.131	-0.084
Zn	0.125	0.935	-0.010	-0.176	0.227

a rotation centered in 6 iterations
(note: the analysis of the components above 0.500)
Source: Author

Table 9 shows that PC1 was strongly affected by physical parameters (turbidity), chemical parameters (pH), organic parameters (COD), and the parameters associated with suspended solids (TSS) (37.9%). These components can be categorized as organic factors, with the source of contamination resulting from the disposal of domestic waste and nutrients (Hamza & Hafizan, 2015). Domestic waste and nutrients from human activities such as inland and water shipping and untreated sewage from toilets discharged straight into marine water have resulted in parameter difficulties. The concentration of particles in the water will increase due to decreased water depth at low tide. Therefore, an increase in TSS and turbidity will result in interference and reduced light penetration. Therefore, marine photosynthesis will be reduced (Gupta et al., 2005). These parameters will damage and kill fish and marine organisms and lead to high pH values. Moreover, it can be concluded that suspended solids and organic sediment caused the higher concentration of COD in water at low tide.

PC2 and PC3 accounted for 19.6% and 17.4%, respectively (Table 8) of the total variance; Zn and Ni were strong components. While both of these parameters meet the standards of IMWQS, Zn and Ni were the greatest metal pollutants in this Malaysian port at low tide conditions, followed by Fe and Cu. PC4 was associated with concentrations of NH3-N and O&G and identified as organic pollutants. People's waste is dumped into the water without treatment; hence there are no toilet facilities right on the shoreline. This directly increases the NH3-N concentration of marine water. Then, surface runoff is mixed with oil, and daily washing activities in each pier area contribute to the flow of oil into marine waters. The combination of petroleum oil spills from ships into the water body during the loading and unloading of goods and chemicals also contributes to the increase in O&G.

In conclusion, pH, turbidity, TSS, COD, O & G, NH3-N, DO and trace metals such as Cr, Zn and Ni are major sources of water pollution in this Malaysian port at low tide conditions.

Hierarchical Cluster Analysis (HCA)

Four statistically significant HCA clusters were identified for the HCA analysis at both tidal conditions as shown in Figures 2 and 3, respectively. For the high tide condition, Cluster 1 corresponds to the sampling stations on piers W16, W19, and W22/23, while Cluster 2 corresponds to the sampling stations on piers W8 and W14, which both serve cargo ships from Asia and Europe. Cluster 3 corresponds to the sampling stations on piers W24/25 and W25/26, serving cargo ships handling fine particulates, and Cluster 4 corresponds to sampling stations on pier W10.

While the stations categorized in Cluster 1 serve different types of ships resulting in the release of varying forms of pollution, including kernel oil particles at pier W16, marine litter at pier W19 and LPG spills at pier W22/23, these groups have similar values of pH, O&G, Cu, Ni and Zn concentrations. Washing activities on daily basis in the driveway of the W16 pier to clear excess kernel oil particles have contributed to the direct flow of oil into marine waters at the W19 and W22/23 piers. Moreover, the small oil spills released into the water from containers and ships during loading and unloading of containers of liquid LPG have increased the concentrations of O&G. Research clearly indicates that the combinations of Cluster 2 and Cluster 3 are due to the shared environmental context and the port activities at the relevant sampling stations. Cargo from Asia and Europe and construction activities on pier W8 aimed at improving and developing the port system has resulted in highly similar values of BOD and COD in Cluster 2. This suggests that an increase in the concentration of NH3-N does not directly increase the BOD concentration. As construction has progressed, the number of workers has increased rapidly, resulting in a higher discharge rate of untreated sewage. Toilet facilities located on the waterfront at W8 and W14 do not have proper septic systems, leading to the discharge of untreated sewage into the water without treatment. This suggests that the high COD concentrations were caused by a layer of organic antifouling compounds released from ships.

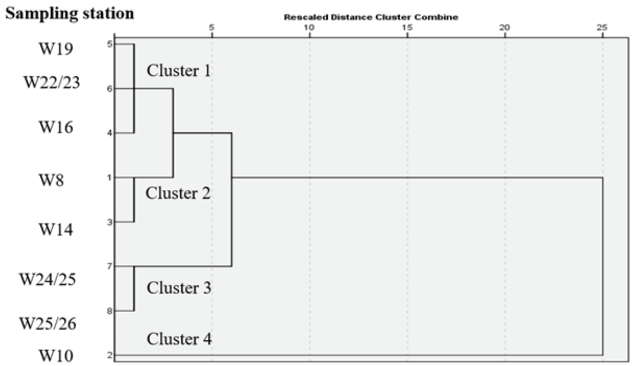

Figure 2. The Cluster Analysis Dendrogram at High Tide at 8 Sampling Stations

Source: Author

Then, at low tide, Cluster 1 corresponds to the sampling stations on piers W10, W14, and W16, while Cluster 2 corresponds to the sampling stations on piers W19 and W22/23. Cluster 3 is ideal, including only the sampling stations on pier W8, and Cluster 4 corresponds to the sampling stations on piers W24/25 and W25/26. Only the piers groups W24/25 and W25/26 had the same port activities, while other groups had a similar environmental context but different port activities.

Cluster 1 shows a relationship between TSS and NH3-N concentration. The handling of kernel oil particles (kernel) on W16 and W10 and port development at W14 improved the NH3-N and TSS. Cluster 2 (sampling stations W19 and W22/23) had similar values of TSS, O&G, COD, Cu, Ni, and Zn. This group had similar contamination properties as at high tide; furthermore, the release of small oil spills from the pier and ships into the water during the loading and unloading of containers containing liquid LPG at W22/23 increased the value of O&G. Cluster 3 (W8), which includes the first wharf at this Malaysian port, has the greatest temperature and the highest concentrations of NH3-N and COD but the lowest Cu concentrations. This is because Cluster 3 is different from other clusters. High ambient temperatures at the time of sampling, the inclusion of groundwater flow and the amount of suspended particles upstream and at pier W8 itself caused the rise in temperature and the concentration of NH3-N, while the COD value and the low Cu concentration were due to lower shipping activity on the pier as a result of the construction of the new pier. In conclusion, further studies are important to assess port quality.

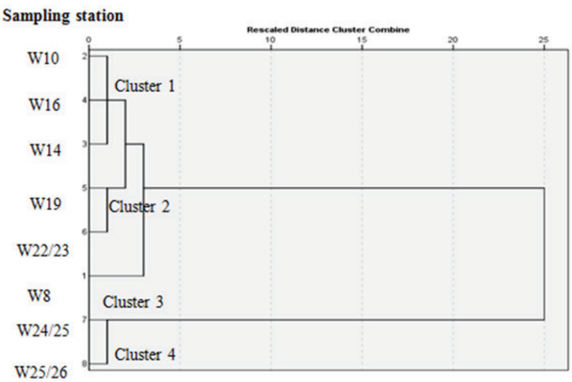

Figure 3. The Cluster Analysis Dendrogram at High Low at 8 Sampling Stations

Source: Author

CONCLUSION

A port in Malaysia is an important asset for a country that needs to protect in every aspect from time to time. It should be maintained to preserve both public health and the natural environment. The multivariate analysis comprised SRCC, PCA, and HCA. According to the Spearman's Rank Order correlation analysis, there is a strong correlation between DO, pH, and Al concentration with other study parameters. Principal component analysis decided that 87.0% of variances explained by four components accounted for 33.6%, 26.9%, 14.1%, and 12.4% of the total variance during high tides. Then, 94.5% of the total variance with five components accounted for 37.9%, 19.6%, 17.4%, 11.7%, and 7.7% of the total variance, respectively, during low tides. PC1 identified by physicochemical factors, namely water temperature, and turbidity, cause major factor changes in water quality. During low tide, the PC1 with 37.9% comes from organic-nutrient factors and is the largest contributor to water quality. Next, hierarchical cluster analysis clustered eight sampling stations into four groups with similar water characteristics at both tides. Based on the information received, the cluster's similarity level unites the most similar sampling stations in terms of similar characteristics, pollution levels, and locations with similar environmental surroundings and port operations. In conclusion, the types of contaminants found in the harbour at high tide include water temperature, turbidity, pH, O&G, and the concentration of trace metals such as Al, Cr, and Cu. However, increasing pollution at low tide was also observed: pH, turbidity, TSS, COD, O&G, NH3-N, DO, and concentrations of trace metals such as Cr, Zn, and Ni were major sources of pollutants in this marine water port study. As a result, a thorough investigation into the causes of various contaminants in ports should be considered. The analysis of noise pollution, air pollution, and marine water pollution should be combined, and the findings of this research should be used to determine better follow-up action to improve the existing value, particularly while maintaining the port's overall quality.

ACKNOWLEDGEMENT

Support provided by the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, in this study is greatly appreciated.

FUNDING

There is no funding for this research.

CONFLICT OF INTEREST

No conflicts of interest to declare.

AUTHOR CONTRIBUTION

Suja' F., Hamzah F.M., and Zain S.M. conceived the original idea. All authors discussed and agreed with this paper's main focus and ideas. The experiments and the paper's main text were written and performed by Jani W.N.F.A. Other authors helped edit the manuscript.

REFERENCES

AAPMA (Association of Australian Ports and Marines Authority). 2001.

Chen, W.H., Lin, Y.C., Chien, G., Chiang, P.C. & Lin, Y.C. (2013). Multivariate analysis of heavy metal contaminations in seawater and sediments from a heavily industrialized harbour in Southern Taiwan. *Marine Pollution Bulletin*, 76, 266 – 275.

Department of Environment (DOE), (2019). *Marine & Island*: Marine Water Quality.

Derraik, G.B. (2002). The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin*.

Diane, B., Thomas, P., Gina M.S., Todd, R.C., Gail, R.F., Julie, M. & Bella, T. (2004). *Harboring Pollution*. Strategies to Clean Up U.S Ports. NRDC.

Ford, R. G., Natalie, A. S. & Rowan, G. C. (2008). *Using Historical Oil Spill Data to Predict Seabird Mortality from Small oil Spills*. University of Rochester School of Medicine and Dentistry, USA.

Gulgundi, M. S. & Shetty, A. (2018). Groundwater quality assessment of urban Bengaluru using multivariate statistical techniques. *Appl Water Sci*, 8, 43.

Gupta, A.K., Gupta, S.K. & Rashmi, S.P. (2005). Statistical analysis of coastal water quality for a port and harbour region in India. *Environmental Monitoring and Assessment,* 102, 179 – 200.

Hulsey & Ludivina., (2012). *Marine Pollution.* New Delhi: World Technologies.

IMO and Sustainable Development International Maritime Organization (2020) GloMEEP and IAPH. Port Emissions Toolkit Guide No. 1: *Assessment of port emissions.* GloMEEP Project Coordination Unit and International Association of Ports and Harbors (IAPH), Lewes, East Sussex. 2018.

ITOPF., (2011). Effects of oil pollution on the marine environment.

Jani, W. N. F.A. (2021). Assessment of physical, chemical and dissolved trace metals parameters of marine water quality in East Malaysia's port. *Malaysian Journal of Chemical Engineering & Technology, 4*(1), 50-57. https://doi.org/10.24191/mjcet. v4i1.12987

Jo O'Brien, 2011. *mpacts of Shipping*. Davey Street, Hobart.

Kamaruddin, S. A., Rusli, H. H., Abd.Aziz, K. N. & Roslani, M. A. (2020). Characteristics and Distribution of Microplastics in Surface Sediment ff Selat Pulau Tuba, Langkawi, Kedah. *Malaysian Journal of Sustainable Environment, 7*(2), 139 – 160. https://doi.org/10.24191/myse.v7i2.10269

Kamaruddin, S. A., Abd Aziz, K. N., Roslani, M. A., Tajam, J., Zaınolabdın, S. N., & Mohd Razman, N. F. (2018). Mapping of Salinity Level using Spline Interpolation Techniques over the Water of Sungai Merbok, Kedah. *Malaysian Journal of Sustainable Environment, 5*(2), 114. https://doi.org/10.24191/myse.v5i2.5620

Kazi, T.; Arain, M.; Jamali, M.; Jalbani, N.; Afridi, H.; Sarfraz, R.; Baig, J. & Shah, A.Q. (2009). Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. Ecotoxicol. *Environ. Saf.* 72, 301–309.

Li, T., Li, S., Liang, C., Bush, R. T., Xiong, L. & Jiang, Y. (2018). A comparative assessment of Australia's Lower Lakes water quality under extreme drought and post-drought conditions using multivariate statistical techniques. *J Clean Prod,* 190, 1-11.

Liu, C. W., Lin, K. H. & Kuo, Y. M. (2003). Application of factor analysis in the assessment of groundwater quality in blackfoot disease in Taiwan. *The Science of the Total Environment*, 313, 77–89.

Machiwal, D. & Singh, P. K. (2015). Understanding factors influencing groundwater levels in hard-rock aquifer systems by using multivariate statistical techniques. *Environmental Earth Sciences 74*(7), 5639–5652

.

Masoud, A.A. (2013). Spatio temporal evaluation of the groundwater quality in Kafr Al-Zayat District, Egypt. *Hydrological Processes 27*(20), 2987–3002.

Masoud, N. & Amir, G. (2016). Groundwater quality analysis using multivariate statistical techniques (case study: Fars province, Iran). *Environ Monit Assess*, 188, 419.

Réhman, S., Hussain, Z., Zafar, S., Ullah, H., Badshah, S., Ahmad, S., Saleem, J. & Jinnah, F. (2018). Assessment of Ground Water Quality of Dera Ismail Khan, Pakistan, Using Multivariate Statistical Approach. *Sci Technol Soc*, 37, 173-183.

Said, A., Stevens, D.K. & Sehlke, G. 2004. An innovative index for evaluating water quality in streams. *Environmental Management, 34*(3), 406-414.

Smith, J.M. (2004). *Water quality trends in the Blackwater River Watershed Canaan Valley*, West Virginia. West Virginia University. Master of Science Theses. 8- 80.

SoE (State of the Environment Advisory Council), 1996. *'Australia State of the Environment 1996'*. Department of Environment Sport and Territories, Canberra.

Su, S., Zhi, J., Lou, L., Huang, F., Chen, X. & Wu, J. (2011). Spatio-temporal patterns and source apportionment of pollution in Qiantang River (China) using neural-based modeling and multivariate statistical techniques. *Phys. Chem. Earth* 36, 379–386.

Wu, Z.Z., Che, Z.W., Wang, Y.S., Dong, J.D. & Wu, M.L. (2015). Identification of surface water quality along the Coast of Sanya, South China Sea. *PLoS ONE 10*(4), e0123515. https://doi/10.1371/journal.pone.0123515