World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:10, No:8, 2016

Water Quality Assessment Based on Operational Indicator in West Coastal Water of Malaysia

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***Abstract*—**In this study, water monitoring was performed from Nov. 2012 to Oct. 2013 to assess water quality and evaluate the spatial and temporal distribution of physicochemical and biological variables in water. Water samples were collected from 10 coastal water stations of West Port. In the case of water-quality assessment, multi-metric indices and operational indicators have been proposed to classify the trophic status at different stations. The trophic level of West Port coastal water ranges from eutrophic to hypertrophic. Chl-a concentration was used to estimate the biological response of phytoplankton biomass and indicated eutrophic conditions in West Port and mesotrophic conditions at the control site. During the study period, no eutrophication events or secondary symptoms occurred, which may be related to hydrodynamic turbulence and water exchange, which prevent the development of eutrophic conditions in the West Port.

***Keywords*—**Water quality, multi-metric indices, operational indicator, Malaysia, West Port.

I. INTRODUCTION

IN the recent century, organic and inorganic pollutants are a cause of serious threat to marine organisms and human health and have become environment crises in marine ecosystems including oil spills, red tides, contamination of fish and shellfish, mortalities of marine mammals and fish, eutrophication and anoxia [1]-[4].

Biological indicator organisms have been widely used to assess the effects of pollutants. Bio-indicators can obviously show the ability of stressors to cause adverse effects in a marine environment [3]-[5]. As a matter of fact, they act as receptors, which respond to stressors by their alternation in population or histological structures [5]-[8]. Phytoplankton structure is one of the important bio indicators, which is widely used in studies of aquatic ecosystem function [9]. It is used for monitoring the response to environmental stressors, due to their fast population changes in aquatic ecosystem [10]-[12]. Alternation of abundance and diversity of phytoplankton reflects the nutrient potential and disturbance into the aquatic ecosystems and has direct relationship with the nutrient concentration. Nutrient enrichment makes phytoplankton fast growing as primary producers creating extra biomass accumulation, which can develop a toxic algae bloom. A bloom has negative effects on the aquatic ecosystem, such as hypoxia condition, oxygen depletion and turbidity, and ultimately causes high mortality of the aquatic organism due to oxygen defect or the attendance of the toxic phytoplankton species [13], [14]. West Port is a main gateway with the busiest shipping route on the west coast of Peninsular Malaysia and is extremely affected by port activities. Different important aspects of this area are: fisheries sites, ecological habitat, international commerce and industrial sites [15], [16].

The main purpose of this study are to assess water quality based on the physicochemical parameters, such as nutrient (NO_3^-,NO_2^-, DIN, PO_4^{3-}, NH_4^+, NH_3, $SiO_4^{4-}$and Chl-a) and chlorophyll, as biological indicators; to assess trophic levels based on marine biotic indices because these findings are significant to classify the contamination levels according to biological responds.

II. MATERIAL AND METHODS

A. Sampling and Field Work

In this project, a total of nine sampling stations were selected in West Port, and one station 40 kilometers north of West Port as a control point. All the stations were arranged into three parallel transects at three separate distances. The first transect was parallel to the berth line and industrial outlets, the second was the middle line of the strait, and the third was parallel to the mangrove line in West Port (Fig.1). The water quality was evaluated based on the physical and chemical parameters, and the Rutner sampler was used to collect the water samples. A multi-parameter probe (YSI 556 MPS) was applied to measure the physical parameters from the surface water layer (50 cm deep). Water transparency was measured using a Secchi disc, and a fish finder was used to measure the water depth at each station. The current meter (RDI Ocean Surveyor ADCPs™) was used to measure current speed in this research. Water samples of about a liter were taken from the same depth to measure the total suspended solid and dissolved nutrients (nitrite, NO_2^-; nitrate, NO_3^-; ammonium, NH_4^+; ammonia, NH_3^-), soluble reactive phosphate (orthophosphates), and soluble reactive silicate (SRSi). These water samples were transferred into dark polyethylene bottle, which were filled about three-quarters full. These samples were immediately filtered through a Millipore membrane filter (0.45 micrometre), using a vacuum pressure of < 400 mm Hg and analysed as soon as possible after filtering within 48 hours. Additional water (1 litre) was collected to estimate suspended solids by Hach DR/2400 Spectophotometry based on the photometric method [17], [18].

For measuring the chlorophyll *a*, a 1-liter water sample was poured into the opaque bottles and held on ice or at 4 °C. These samples were immediately filtered after being transferred to the laboratory on the same day [19].

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B. Experimental Methods

A Hach DR/2400 spectrophotometer was used to measure the nutrients and suspended solids based on the methods, which is published in Hach procedures manual June 2007 Edition 2. These methods were denoted by USEPA as standard method for water and wastewater analysis [19], [20]. Dissolved inorganic nitrogen (DIN) was estimated as the sum of nitrites, nitrates, and ammonium. The reasonable percent recovery values ranged between 80% and 120%. Also, laboratory reagent blanks and laboratory duplicate analysis were used to check performance [17], [19]. In this research method, USEPA 446 was used to measure the concentration of chlorophyll a [21].

Fig. 1 Location of the sampling stations in West Port Malaysia

Statistical analyses were performed using Microsoft Excel and SPSS 17 software (SPSS, Chicago, IL). Significant differences from each group were evaluated via Kruskal-Wallis one-way nonparametric ANOVA (level of significant is 0.05). Data variation was analysed by multivariate techniques such as principal components analysis (PCA). These methods are practical to estimate structure and relationships in multivariate data.

C. Tropic Level of Water

There are several Multi-metric eutrophication indices proposed to assess water quality and trophic status based on the single and multiple parameters as indicators [22].

Vollenweider suggested the use of the trophic index (TRIX) for the monitoring of trophic status. This index uses a linear combination of four parameters related to primary production and nutritional condition; namely, DIN, total phosphorus or inorganic phosphorus (as a nutritional compound), chlorophyll *a* I (as a proxy for phytoplankton biomass), and oxygen saturation (as a biotic component or measure of productivity). This index was classified to five trophic scales from two to eight, which are shown in Table I. The estimation of the TRIX index from the water bodies' image can be computed by [23]:

$$TRIX = \left[\log\left(chla \times \%DO \times DIN \times P \times 1.5\right)\right]/1.2$$

In 2010, Primp proposed another multi-metric index to assess trophic status on a five-point scale; namely, the Euthrophic Index (EI). The formula that expresses that this index is given by [22]:

$$E.I = 0.297C_{PO_4} + 0.261C_{NO_3} + 0.296C_{NO_2} + 0.275C_{HN_3} + 0.214C_{Chla}$$

where, *C* is nutrient and chlorophyll *a* is a concentration. This index was also divided into five levels, which are described below: less than0.04 is high quality, 0.04 to 0.38 is good, quality 0.38 to 0.85 is moderate quality, 0.85 to 1.51 is poor quality, and greater than 1.51 is bad quality.

Table II shows operational indicators were introduced in the several scientific literatures to assess trophic level of marine and coastal water [24], [25].

TABLE I
ASSESSMENT OF TROPHIC STATUS USING TRIX

TRIX value	Tropic status	Condition	Reorganization for study
<2	Ultra-oligotrophic	Very poorly productive	Excellent
2-4	Oligotrophic	Poorly productive	High
4-5	Mesotrophic	Moderately productive	Good
5-6	Mesotrophicto eutrophic	Moderate to highly productive	Moderate
6-8	Eutrophic	Highly productive	Poor

TABLE II
OPERATIONAL INDICATORS TO ASSESS TROPHIC STATUS

Operational indicator and indices	Secchi depth (cm)	Chl-a (µg/l)	Total-N (mg/l)	Total-P (mg/l)
Tropic status and Oligotrophic (high quality)	>1100	<2	<0.110	<0.015
Mesotrophic (good quality)	600-1100	2-6	.011-0.29	0.015-0.04
Eutrophic (Bad quality)	200-600	6-20	0.29-0.94	0.04-0.130
Hypertrophic (Poor quality)	<200	>20	>0.94	>0.13

III. RESULT

In the marine environment, a comprehensive assessment of water quality should include the monitoring of hydrological, physicochemical, and biological variables. Information about these properties can provide meaningful and practical conclusions to water-quality monitoring because of the direct effect of the properties on chemical components and biological communities [26].

A. Hydrological Parameters

All coastal water bodies are influenced by other water sources, from atmospheric to marine, via the hydrological cycle, hydrodynamic activities, river discharge, and underground transport; these systems are directly inter-connected [27], [28]. Tidal circulation is semidiurnal in the Klang Strait; the level of the surface water rises and falls at an average range of 1.4 m to 4.2 m within approximately 12.5 hours, depending on the position of the sun and moon [29]. The seasonal alternation between the northeast monsoon (November to March) and southern monsoon (May to September) causes the main rainfall pattern along the West Port. In the present study, the northeast monsoon (rainy season) started in November 2012 and lasted until March 2013. The southwest monsoon (dry season) started from June 2013 until October 2013, and the monsoon break was observed at the end of September, with an increase of daily rainfall (280mm). April and May were considered as the inter-monsoon period with a high amount of daily rainfall. Other researchers have reported that the river discharge at West Port is highly correlated with rainfall patterns, and as expected, the maximum river discharges were measured in November 2012 and April and May 2013.

B. Physical and Chemical Parameters

Water quality data from 10 stations during 12 months of sampling were summarized in Tables III and IV. Most of the physicochemical parameters showed significant differences ($P < 0.05$) in the spatial and temporal scales based on the Kruskal-Wallis test and only temperature (29.94-30.17 °C), pH, salinity, and current presented insignificant differences on a spatial scale. Generally, on the spatial scale, the water quality parameters are significantly different among the control point and West Port, and a Duncan test showed that water quality parameters (except temperature) at the control point were not homogenous with those of the other stations in West Port. The control area was characterized by the lowest concentrations of nutrients, total solids and chlorophyll *a (*chl-*a)* in comparison with West Port, and the range in values of salinity, dissolved oxygen (DO), and water transparency (Secchi depth) was higher in this area.

TABLE III
STATISTICAL DESCRIPTION OF PHYSICAL PARAMETERS

	pH	Salinity (%)	Shecci depths (m)	TS (mg/l)	DO (mg/l)	Current (Knot)
1. Mean	8.09	30.86	61.81	65.86	60.95	13.47
SD	0.10	1.70	28.30	22.18	5.85	0.25
2. Mean	8.01	30.98	71.97	63.73	63.32	13.47
SD	0.05	1.64	23.99	20.25	5.36	0.32
3. Mean	8.07	30.86	46.89	71.31	58.58	13.17
SD	0.10	1.44	16.55	19.44	5.58	0.26
4. Mean	8.04	30.44	66.78	63.63	61.95	13.60
SD	0.10	1.45	20.19	20.86	5.69	0.29
5. Mean	8.00	30.58	68.69	63.93	62.67	13.54
SD	0.08	1.47	22.96	20.97	6.15	0.27
6. Mean	8.04	30.75	57.81	70.35	60.72	13.39
SD	0.09	1.48	16.00	16.30	6.21	0.25
7. Mean	7.97	30.51	63.33	75.88	62.81	13.22
SD	0.10	1.48	22.20	9.26	5.98	0.32
8. Mean	7.96	30.63	65.28	74.15	63.79	13.33
SD	0.06	1.44	21.07	10.26	6.04	0.30
9. Mean	8.01	30.77	57.33	95.63	62.55	12.91
SD	0.04	1.46	20.94	28.81	6.02	0.24
***10.**Mean	8.03	31.30	159.00	46.41	65.87	13.39
SD	0.06	1.62	25.06	4.83	4.27	0.44

* Control Point; SD: standard division

A principal component analysis (PCA) was used to assess the variability of the water quality data and quantify the contributions (percentages) of the individual physicochemical parameters as shown in Table V. At West Port, the data were classified into three principal components (PCs). The first component accounted for 40.11% of the total variance, with high loading from pH, $\mathrm{NH_3}, \mathrm{PO_4^{3-}}$ and chlorophyll a levels. The second component accounted for 33.0% of the total variation, with strong loading from $\mathrm{NH_4^+}, \mathrm{NO_3^-}$, DIN, and $\mathrm{SiO_4^{4-}}$, which were strongly correlated with component two (PC2), while $\mathrm{NO_2^-}$ and total solids were significantly correlated with the third component. At the control area, the water quality data were classified into three main groups that explained 70.31% of the variability in this area. The first component included oxygen saturation, DO, transparency, total solids, nitrate, Ammonium, DIN and current speed, which accounted for 43.09% of the variation. PC2 accounted for 16.21% and was strongly correlated to $\mathrm{SiO_4^{4-}}$, while PC3 accounted for 17.36% with high loading from levels of chl-*a*.

TABLE IV
STATISTICAL DESCRIPTION OF CHEMICAL PARAMETERS

	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_3 (mg/l)	NH_4^+ (mg/l)	DIN (mg/l)	PO_4^{3-} (mg/l)	SiO_4^{4-} (mg/l)	**Chl-a** (μ/l)
1.Mean	0.70	0.009	0.068	0.578	1.29	0.110	8.72	7.42
SD	0.16	0.007	0.033	0.089	0.24	0.036	4.02	3.64
2.Mean	0.45	0.011	0.045	0.448	0.91	0.090	8.36	6.49
SD	0.17	0.006	0.017	0.077	0.23	0.026	3.83	3.17
3.Mean	0.73	0.012	0.062	0.585	1.32	0.125	7.01	9.92
SD	0.17	0.007	0.031	0.079	0.24	0.066	3.26	5.66
4.Mean	0.94	0.012	0.061	0.659	1.61	0.114	9.64	4.94
SD	0.44	0.007	0.033	0.116	0.50	0.042	2.65	1.48
5.Mean	0.57	0.012	0.045	0.475	1.05	0.084	7.22	5.55
SD	0.34	0.006	0.023	0.107	0.39	0.036	2.60	2.75
6.Mean	0.94	0.012	0.060	0.689	1.64	0.121	8.63	9.22
SD	0.24	0.006	0.036	0.127	0.36	0.037	3.59	4.45
7.Mean	0.99	0.014	0.034	0.765	1.77	0.118	12.71	7.15
SD	0.36	0.007	0.016	0.234	0.55	0.030	4.75	3.46
8.Mean	0.62	0.011	0.038	0.537	1.17	0.085	9.22	5.96
SD	0.25	0.005	0.017	0.124	0.35	0.038	2.98	2.42
9.Mean	1.09	0.015	0.047	0.759	1.86	0.113	9.68	7.70
SD	0.47	0.008	0.015	0.217	0.54	0.035	4.07	3.84
10.Mean	0.41	0.007	0.029	0.342	0.76	0.073	1.29	4.22
SD	0.09	0.002	0.011	0.076	0.14	0.022	0.48	1.29

The average annual concentration of operational indicators andtrophic indices are compared with the characteristic trophic categories of coastal and marine areas (salinity < 20‰) (Table VI). All of the sites except for the control area were at eutrophic to hypertrophic level according to the value of the Secchi depth, chl-a level, nitrogen concentration, and trophic indices. The control point showed different results and was at a eutrophic to hypertrophic level according to trophic categories based on Secchi depth, nitrogen, phosphorus and trophic indices, while it had a mesotrophic condition based on comparison with the chlorophyll a values.

TABLE V
PRINCIPAL COMPONENTS (PCS) FOR PHYSICOCHEMICAL PARAMETERS

Parameters	**West Port**			**Control Area**		
	PC1	**PC2**	**PC3**	**PC1**	**PC2**	**PC3**
T	.021	-.898	.147	-.429	-.564	.442
PH	.878	-.013	-.359	-.678	.450	.358
Current	-.162	-.050	-.970	.795	.315	.348
Secchi depths	-.798	-.055	-.496	.713	-.590	.083
TS	.034	.180	.935	.740	.416	-.299
Salinity	-.434	-.779	.172	.637	-.174	.149
DO	-.939	.181	-.176	.844	-.012	.483
O2 sat	-.966	-.004	.033	.895	.104	.363
NO_3^-	.217	.816	.472	.716	-.246	.065
NO_2^-	-.178	.428	.762	-.383	-.427	.058
NH_4^+	.190	.829	.512	.757	-.227	-.050
NH_3	.846	.002	-.403	-.842	.382	.164
DIN	.207	.823	.490	.722	-.248	.029
PO_4^{3-}	.748	.587	.246	.362	.461	-.333
SiO_4^{4-}	-.404	.774	.235	.245	.772	.388
chl*a*	.781	.075	.448	.262	.011	.569

TABLE VI
THE AVERAGE VALUE OF OPERATIONAL INDICATORS AND TROPHIC INDICES ARE COMPARED WITH THE CHARACTERISTIC TROPHIC CATEGORIES OF COASTAL AREAS

Operational indicator	Secchi depth (cm)	Chl-a (μg/l)	Total-N (mg/l)	Total-P (mg/l)	TRIX	EI
West Port	62.21±22.5	7.150±2.8	1.403±0.4	0.107±0.03	7.35±0.45	1.77±0.67
Control area	159±25.05	4.22±1.28	0.757±0.1	0.073±0.02	7.03±0.51	1.08±0.16
Oligotrophic	>1100	<2	<0.110	<0.015	2-4	<0.38
Mesotrophic	600-1100	2-6	.011-0.29	0.015-0.04	4-5	0.38-085
Eutrophic	200-600	6-20	0.29-0.94	0.04-0.130	5-6	0.85-1.51
Hypertrophic	<200	>20	>0.94	>0.13	6-8	>1.51

IV. DISCUSSION

The trophic condition in West Port exhibited a significant spatial and temporal variation despite a similar tropical climate throughout this study area. There several sources in marine systems those affect water quality, such as river discharges, upwelling, remineralisation, sedimenter-suspension, industrial waste and effluents. Thus, it is difficult to quantify the relative contributions of nutrient sources to marine and coastal systems [30].

In West Port, the high concentration of nutrients and chlorophyll *a* as a consequence of human activities (industrial discharges and berth platform washing) and natural processes of remineralisation, re-suspension, and turbulence led to increase nutrient concentrations in the water column and stimulated phytoplankton biomass. The inverse relationship between silicate and salinity indicates that the silicate is largely derived from anthropogenic sources. The concentration of silicate in West Port was significantly higher than at the other sites. This result was related to discharges from a cement factory because silicate is a primary ingredient of cement products. Additionally, 87% of the sediment samples of West Port were completely mixed with cement, especially in the vicinity of cement-factory outlets.

Additionally, the concentration of silicate at the control point is good evidence because silicate levels were significantly lower at the control point than other stations in West Port, with low standard deviation. Natural processes can be another source of silicate in this area. Most geological studies show that much of the bedrock in peninsular Malaysia consists of limestone, and the Klang Valley is one of the major

Open Science Index, Environmental and Ecological Engineering Vol:10, No:8, 2016 publications.waset.org/10005296/pdf

areas widely covered by limestone rock [30], [31]. Limestone is a type of sedimentary rock that includes the minerals calcite, dolomite, microcrystalline and amorphous silica, SiO_2, clay, organic matter and iron oxides [12], [31].

The chlorophyll *a* concentration is a major abiotic variable used to estimate phytoplankton biomass in aquatic sciences [24], [30]. Chlorophyll *a* levels changed seasonally and spatially in West Port due to the different processes that control the abundance of phytoplankton throughout this region. The highest concentrations of chl-*a* occurred during the north monsoon (rainy season) and inter-monsoon, while the lowest levels occurred during the south monsoon. The high concentrations of chl-*a* are mainly related to gradual nutrient increases during the rainy season and to sediment re-suspension due to strong water turbulence during the north monsoon [24], [30]. At West Port, the chl-*a* levels were likely due to nutrient discharges from the harbour and mangrove re-sustentation caused by benthic or microbial communities that occurred along mangrove line or due to strong winds and high wave action during the north monsoon.

Multivariate statistical (classification and ordination) methods were applied to describe associations among the environmental parameters and to explore the importance of hierarchy among the parameters. This analysis based on hydrological parameters revealed that West Port might represent the strong effects on both of the harbour activities and re-sustentation and re-mineralisation processes. In West Port, the high inverse relationship observed between salinity and the levels of all nutrients, total solids and chlorophyll *a* implies the effect of anthropogenic discharges, likely industrial discharges and harbour activities. Additionally, there is scientific evidence to confirm that in aquatic areas, $NH_3$and PO_4^{3-} can naturally originate from the decomposition of organic and inorganic matter, nitrogen reduction by microorganisms, and biotic excretion. These compounds are also loaded into aquatic areas by industrial outlets, fertiliser runoff, and urban waste.

At West Port, the association of all of the nutrients and chlorophyll *a* suggest the effect of nutrient loads and organic material derived from both industrial wastewater and natural interactions of mangrove forests, such as re-suspension processes, biotic decomposition and nitrogen reduction.

The control point was completely separated from the other stations, likely due to its lowest concentration of nutrients and highest water transparency. The results imply that the mean concentration and standard division of nutrients at the control point are significantly lower than at other stations inside West Port. This difference is good evidence that these stations are influenced by internal load of nutrients. At the control point, Dissolved Oxygen, Oxygen Saturation, transparency, total solids, currentspeed, DIN and SiO_4^{4-}accounted for 55.4% of the water quality variability. This result implies that the low effects of nutrient discharges are due to the location of this area far from coastline-oceanic interactions and anthropogenic discharges. In contrast, nutrients were significantly correlated with salinity in these sites, suggesting internal nutrient loading by natural sources. Based on the multivariate analyses, we suggest that the water quality at West Port is related to the levels of nutrients and biomass of phytoplankton (chlorophyll *a*), which result from industrial discharges, harbour activities, natural processes around mangrove forests and coastline-oceanic interactions.

Generally, the poorest water quality conditions were observed at West Port with the highest influence from anthropogenic activities, while good quality water conditions were located at the control area, far from the coastal areas. This finding indicates that the water health status is threatened in the West Port.

During this study, seasonal variation affected trophic variation. During the north monsoon (rainy season), hurricanes reduced the water quality by increasing land-based runoff and river discharges, suggesting an important connection between the coastal area and the sea; moreover, reduced transparency and increasing nutrient and sediment concentrations occurred in coastal waters. The impact of hurricanes was short-term for salinity and water transparency reduction, while the nutrient values increased due to land-based runoff, river discharges and remineralisation.

In the present study, the overall water quality was described based on the annual average of operational indicators and trophic indices. According to these results, the trophic level of West Port coastal water can be considered eutrophic to hypertrophic based on the DIN, phosphorus, water transparency, chlorophyll *a* and trophic indices (EI and TRIX). The trophic level of the control area ranged from mesotrophic to eutrophic based on the phosphorus concentration, DIN, chlorophyll *a* and eutrophication index (EI). The values of water transparency and the TRIX index were not used to classify the trophic level in the control area because their range was far from the range of other key indicators, especially chlorophyll *a*.

V. CONCLUSION

The variations of water-quality parameters (except temperature) were significantly different on spatial and temporal scales due to seasonal fluctuations, anthropogenic wastewater at the coast and biogeochemical processes (re-mineralisation and biodegradation processes around the mangrove line). Multivariate statistical methods (PCA and nonparametric analysis) revealed that nutrients (especially DIN and PO_4^{3-}), chlorophyll *a* and total solids are major variables that contributed to the control of water quality variability in West Port coastal water, while at the control point, most of the water quality variation resulted from physical parameters and water turbulence.

Multimetric indices (EI and TRIX) and operational indicators have been proposed to evaluate and classify coastal and marine systems based on eutrophication conditions or trophic status. According to these results, the trophic level of West Port coastal water (South Port, North Port and West Port) can be considered to range from eutrophic to hypertrophic based on levels of DIN, phosphorus, water transparency, chlorophyll *a* and trophic indices. The chl-*a* concentration was used as a biological response of phytoplankton biomass and showed a eutrophic condition in West Port and mesotrophic condition in the control area. West Port is most likely in an early stage of eutrophication, and the chlorophyll *a* concentration seems to reflect this result, but no eutrophication events or secondary symptoms, such as bloom conditions or oxygen depletion, occurred during the study period, perhaps related to hydrodynamic turbulence and water exchange, which prevent the development of eutrophic conditions in West Port.

ACKNOWLEDGMENT

The authors' gratitude goes to support of University Malaya Research Grant (UMRG) with project number RP014B-15SUS.

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