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Characterization of spatial and temporal variability in hydrochemistry of Johor Straits, Malaysia

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ABSTRACT

Characterization of hydrochemistry changes in Johor Straits within 5 years of monitoring works was successfully carried out. Water quality data sets (27 stations and 19 parameters) collected in this area were interpreted subject to multivariate statistical analysis. Cluster analysis grouped all the stations into four clusters ($(D_{link}/D_{max}) \times 100 < 90$) and two clusters ($(D_{link}/D_{max}) \times 100 < 80$) for site and period similarities. Principal component analysis rendered six significant components (eigenvalue > 1) that explained 82.6% of the total variance of the data set. Classification matrix of discriminant analysis assigned 88.9–92.6% and 83.3–100% correctness in spatial and temporal variability, respectively. Times series analysis then confirmed that only four parameters were not significant over time change. Therefore, it is imperative that the environmental impact of reclamation and dredging works, municipal or industrial discharge, marine aquaculture and shipping activities in this area be effectively controlled and managed.

Surface water by definition is water systems that naturally open to the ecosystem such as rivers, lakes, reservoirs, estuaries and coastal waters (Noori et al., 2010). Surface waters are most vulnerable to pollution due to their easy accessibility for wastewater disposal (Boyacioĝlu et al., 2013). Good quality of water resources depends on a large number of physical, chemical or biological parameters, as well as the magnitude or source of any pollution load into water bodies (Satheeshkumar and Khan, 2012). Deterioration of surface water quality has been linked to both types, either natural processes (atmospheric deposition, climate change, tidal effect) or anthropogenic activities, namely land use for agriculture, aquaculture, industry, human settlement and sewage discharge (Bu et al., 2010; Ouyang et al., 2006).

In the recent decade, the rapid growth of population, urban development and numerous industries have exercised great impact on marine environments. Marine water has received a large amount of toxic chemicals or harmful substances from numerous sources of pollutions (Gupta et al., 2009). Contaminants of major concern include the occurrence of excessive nutrients, toxic metals, radionuclides, macro- or microplastic debris and pharmaceutical residues (Cole et al., 2011; Fang et al., 2012; Fendall and Sewell, 2009; Islam and Tanaka, 2004). Basic information on the health of marine water is important in order to understand their ability to support the diverse habitats living in the marine environment (Pawar, 2013). Indeed, monitoring work of marine water quality is crucial and smart strategies of water protection are required.

Huge data sets of water quality are usually available in multidimensional structure such as space, time and multi-variables (Dong et al., 2010). Classic interpretations of data sets are difficult to analyze meaningfully and data reduction methods are required to simplify the data structure (Dong et al., 2010). By applying the statistical analysis approach, the complex data of monitoring work are able to extract and explain about the latent factor or their relationship with minimal loss of original information. Multivariate is effective statistical methods to facilitate interpretation of complex data in characterizing and evaluating surface water quality or ecological status, pattern recognition of spatial and temporal variations (natural or anthropogenic factors), identifying chemical species, recognizing point or non-point pollution sources, forecasting future trends, as well as developing rapid solutions to pollution problems (Beiras and Durán, 2014; Boyacioĝlu et al., 2013; Gupta et al., 2009; Karydis and Kitsiou, 2013; Noori et al., 2010; Phung et al., 2015).

Some recent studies have successfully applied multivariate statistical analysis to evaluate marine water quality, namely Aerial Bay, Chidiyatappu Bay, Port Blair Bay (India), Kuwait Bay (Kuwait), Daya Bay (China), Mid-Black Sea (Turkey), Victoria Harbour (Hong Kong), Kwangyang Bay, Jinhae Bay (South Korea), as well as Malacca Strait and Port Dickson in Malaysia (Akbal et al., 2011; Al-Mutairi et al., 2014; Jha et al., 2014, 2015; Kim et al., 2013, 2015; Leung et al., 2015;

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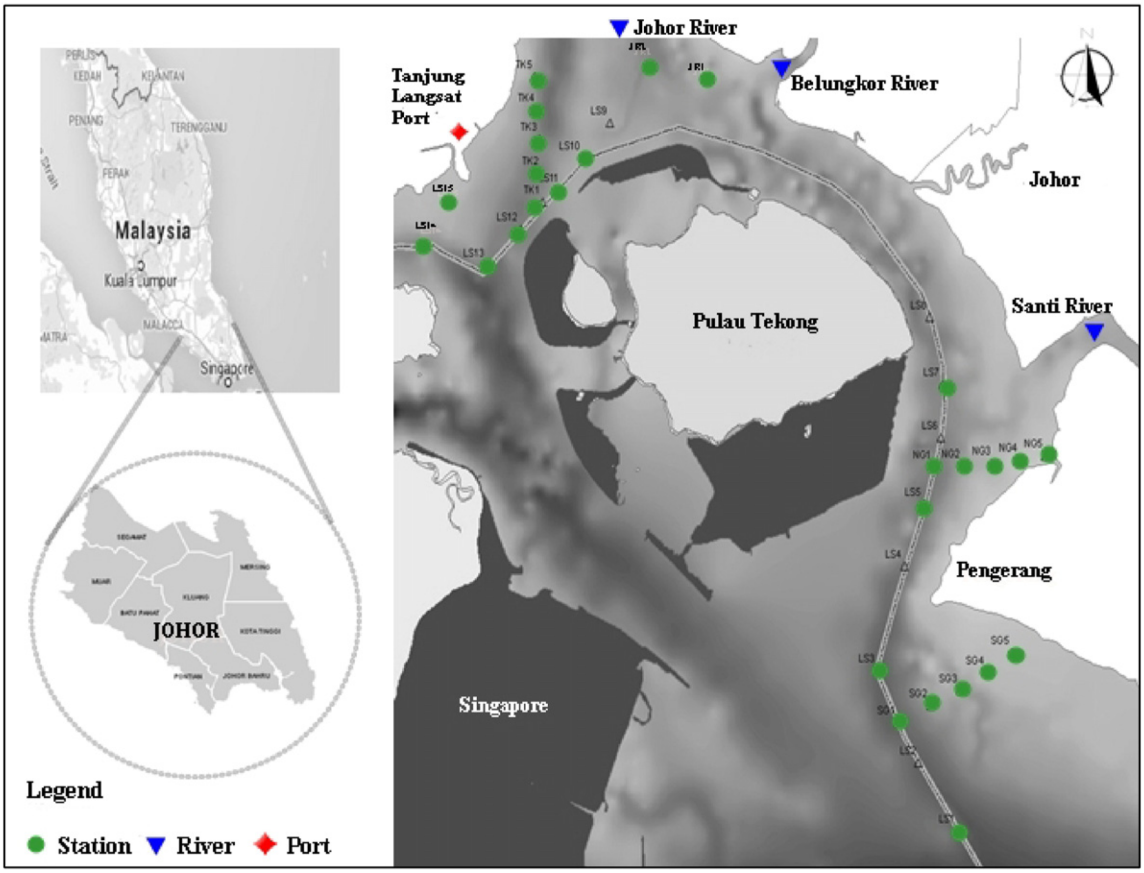

Fig. 1. The map of the location of sampling stations (inside the small map of Peninsular Malaysia and the state of Johor).

Looi et al., 2013; Praveena and Aris, 2013; Sahu et al., 2013; Wu et al., 2010). In this study, the water quality of Johor Straits was subjected to the evaluation of hydrochemistry changes within 5 years of monitoring period. Multivariate statistical analysis was applied to i) examine the similarities among stations and seasonal interval, ii) identify the possible sources of pollution background, iii) discriminate latent parameters in temporal and spatial variations, and iv) recognize the trend of latent parameters in time series analysis.

Johor Straits is a tropical marine ecosystem situated along the coast of Johor state in Peninsular Malaysia. Johor Straits separates the Peninsular Malaysia to the north and from Singapore Island to the south. It lies between the Johor River estuary to the east and the Pulai River estuary to the west (Hadibarata et al., 2012; Kazemi et al., 2014). In the past few decades, the Johor state has witnessed a major increment of economic, social and industrial development. The main pollutants in the Johor Straits originate from the anthropogenic activities of agriculture, aquaculture, urban development, shipping and chemical industries (Azman et al., 2012). Oil pollution has been identified as the major contributor to the water pollution in the strait of Johor. Moreover, the eastern side of the strait is more polluted than the western side since marina, petrochemical plants and port activities developed well in this area (Eugene Ng et al., 2013). Some research studies have highlighted the impact of land-use change on food source such as green muscle and gastropod (Azman et al., 2012; Eugene Ng et al., 2013; Said et al., 2013), but the details of water chemistry changes in east side of straits have not yet been discussed.

The LS series was station located along the border between Malaysia and Singapore close to the northern and southern end of Tekong Island reclamation activities. Meanwhile, NG series (across Johor Straits into Santi River), SG series (the southern end of Tekong Island reclamation toward Pengerang), TK series (across Johor Straits toward Tanjung Langsat) and JR series (aquaculture areas toward the Johor River). The distance of each station in NG, SG, and TK series is 200 m. All stations are located in the east region of Johor Straits. In this study, twenty-seven sampling stations were grouped into five series namely LS (LS1, LS3, LS5, LS7, LS8, LS10, LS11, LS12, LS13, LS14), NG (NG1–NG5), SG (SG1–SG5), TK (TK1–TK5) and JR (JR1–JR2), which are presented in Fig. 1. The location of the sampling station was measured and validated using digital global positioning system (Topcon, USA).

Water samples were collected monthly from January 2008 to December 2012 during high tides. Samples were analyzed for 19 parameters, namely conductivity, dissolved oxygen, pH, salinity, temperature,

Table 1
The basic descriptive statistics of water quality data sets.

	Unit	Range	Mean (±SD)	Std. error
Temperature	°C	29.32–30.20	29.78 (0.18)	0.03
pH		7.60–8.91	7.82 (0.08)	0.01
Conductivity	$\mu S\ cm^{-1}$	44.60–49.54	47.22 (1.68)	0.32
Dissolved oxygen	$mg\ L^{-1}$	5.43–5.71	5.57 (0.06)	0.01
Turbidity	NTU	4.80–13.18	7.40 (1.66)	0.03
Salinity	$g\ L^{-1}$	26.99–32.02	29.41 (1.36)	0.26
Suspended solids	$mg\ L^{-1}$	28.07–59.37	36.52 (7.44)	1.43
Oil and grease	$mg\ L^{-1}$	1.11–2.62	2.31 (0.33)	0.06
Organic carbon	$mg\ L^{-1}$	1.01–5.05	1.32 (0.28)	0.05
Chlorophyll-a	$\mu g\ L^{-1}$	1.47–3.09	2.41 (0.53)	0.10
Ammoniacal nitrogen	μM	0.55–2.95	2.08 (1.03)	0.19
Total nitrogen	μM	14.27–19.03	17.76 (1.32)	0.25
Phosphate	μM	0.02–0.21	0.13 (0.04)	0.01
Manganese	$\mu g\ L^{-1}$	30.29–47.77	36.32 (6.01)	1.15
Nickel	$\mu g\ L^{-1}$	33.93–80.96	43.74 (14.17)	2.72
Zinc	$\mu g\ L^{-1}$	40.83–251.16	113.89 (66.52)	12.80
Cadmium	$\mu g\ L^{-1}$	29.26–51.66	32.65 (6.12)	1.17
Lead	$\mu g\ L^{-1}$	ND–15.51	4.00 (3.05)	0.66
Copper	$\mu g\ L^{-1}$	27.11–285.97	68.77 (67.90)	12.83

ND: not detected.