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Escherichia Coli and Biophysicochemical Relationships of Seawater and Water Pollution Index in the Jakarta Bay

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Abstract: Problem statement: Relationships between *Escherichia coli* (*E. coli*) and biophysicochemical properties of seawater at different seasons and water pollution index were investigated in the Jakarta Bay, Indonesia. **Approach:** Water quality data taken at different seasons (Early Rainy Season (ERS) in November 2007 and Late Dry Season (LDS) in August 2008) were analyzed. Additionally, to compare pollution level at different seasons, Nemerow-Sumitomo Water Pollution Index (WPI) was used. **Results:** Significant correlation of *E. coli* occured with only few parameters in the ERS, but with more parameters in the LDS. This might be due to the rainfall intensity in the ERS that was potential to dilute seawater and reduce concentration of some parameters, especially along the offshore stations. However, at the same time, the freshwater coming from land had capacity to force out the polluted water in 13 river systems flowing into the bay; hence it could generate more pollution along the onshore stations. Seawater pollution level slightly increased in the ERS in respect to the addition of polluted water from rivers. In this season, none station was clean, 20 stations were slightly polluted, six stations were moderately polluted and six stations were highly polluted. Meanwhile in the LDS, the number of stations following the above WPI criteria were 9, 16, 3 and 4, respectively, indicating less pollution level. **Conclusion/Recommendations:** The overall results showed that *E. coli* exhibited significant correlations with more water parameters in the LDS and the WPI showed a little increase in the ERS.

Key words: *Escherichia coli*, biophysicochemical, water pollution index, Jakarta bay, seasonal variations

INTRODUCTION

Like other metropolitan cities in the world, Jakarta city in Indonesia faces up some environmental problems as an impact of rapid development. Being the country's economic, cultural and political center, Jakarta is targeted by young people to finding jobs and better carrier. The population size of Jakarta almost tripled since the last five decades from 2.9 million in 1961-9.5 million in 2010, based on the tabulation of 2010 National Census.

Rapid development of Jakarta city especially during the centralization period where Indonesian GDP reaching an incredible increase of 5.7 percent per year between 1980 and 1992 (World Resources Institute, 1996) has made Jakarta city growing very fast. With such an economic growth, Jakarta embodies many of the contradictory forces at play in rapidly industrializing megacities of the world. Of course this "engines of growth" can play a vital role in economic development, however at the same time; worsening environmental problems may threaten economic prosperity and human health (World Resources Institute, 1996).

Some issues, such as air and water pollution (Sato and Harada, 2004; World Resources Institute, 1996)

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and urban waste (Steinberg, 2007), are among the impact of environmental aspects being faced by Jakarta Provincial Government. Garbage such as plastics, woods, bottles and other solid wastes are easily found in the canal and river systems, worsening the water quality. The wastes are drifted to the coastal zone of the Jakarta Bay as the final destination. The massive dead of fishes in 2004 in the Jakarta Bay could be an evidence of pollution level in 13 river systems in Jakarta City (Steinberg, 2007).

Jakarta Bay received three important sources of water pollution, i.e., industrial waste, household discharge and solid trash/garbage. The condition is worsened by poor drainage systems and weak law enforcement (Colbran, 2009; Willoughby *et al*., 1997). William *et al*. (2000) reported that high concentrations of heavy metals were found in the water column and sediment bed of the Jakarta Bay. This condition threatens the population of some biodiversities in the bay, such as molluscan fauna (Van der Meij *et al*., 2009). The pollution level also gives impact on the economic loss of the fisheries in the area as described by Anna and Fauzi (2008).

There are numerous water indicators that can be used to evaluate water quality level, including physical, chemical and biological parameters. Each parameter has associations with other environmental attributes, for example salinity with precipitation, turbidity with sedimentation rate, pH with alkalinity, etc. Among these water parameters, *Escherichia coli* (*E. coli*) concentration has been widely used as bioindicator to quantify water quality condition, for example in ground water (UNESCO, 2000) river water (Kido *et al*., 2009; Yisa and Jimoh, 2010) and seawater (Costa *et al*., 2000).

E. coli is widely known as biological indicator of soil and water pollution. It is one type of fecal coliform bacteria that is commonly found in the intestines of warm-blooded animals and human. Most *E. coli* strains are actually harmless, but some like O157:H7 can cause serious poisoning in human body. Besides human excrements, cattle faeces are among the important sources of this pathogen strain in the environment (Campbell *et al*., 2001). Like other bacteria, *E. coli* prefers to live in the water containing high nutrious elements and organic materials; therefore the presence in water is a strong indication of recent sewage or animal waste contamination (Jalal *et al*., 2010). One important factor that can exacerbate the high presence of *E. coli* in the environment is poor management of city sewage systems (Brussow *et al*., 1992).

Beside single indicator such as *E. coli*, scientists developed multi-parameter pollution indicators oftenly called Water Quality Index (WQI) and Water Pollution Index (WPI). Both indices are almost similar in use. WQI is used to evaluate water condition especially for consumable water, while WPI is more applicable for evaluating pollution level of a water ecosystem. WQI/WPI is calculated from several water parameters with a set of equations and circumstances. Terrado *et al*. (2010) lists about 55 different WQI and WPI introduced by many scientists in the world.

This paper attempts to 1) compare the relationships between *E. coli* concentration and biophysicochemical properties of seawater at different seasons in the Jakarta Bay; and 2) calculate and compare the WPI between offshore and onshore stations at different seasons.

MATERIALS AND METHODS

Study site: The study site is located in the Jakarta Bay with a total area of 285 km2, 33 km of the coastline and 8.4 m of the average water depth. There are 13 river systems flowing into the bay with the average water debit of 112.7 m3 sec-1. Some human activities like industries, harbors, fishing ports, marine aquaculture, tourisms, slum areas and luxury settlements are located along the coastline. For the purpose of analysis, the stations are divided into offshore stations, i.e., A, B, C and D and onshore stations, i.e., M1 - M9 (Fig. 1).

Data sources: Water quality data of the seawater was derived from the Jakarta Environmental Management Board (BPLHD). Two series of water quality data taken in November 2007, representing early rainy season (ERS) and in August 2008, representing late dry season (LDS), were analyzed. A total of 32 stations were defined throughout the Jakarta Bay, where 30 water parameters, including 5 physical, 20 chemical and 5 biological parameters, were measured in each station, as listed in Table 1.

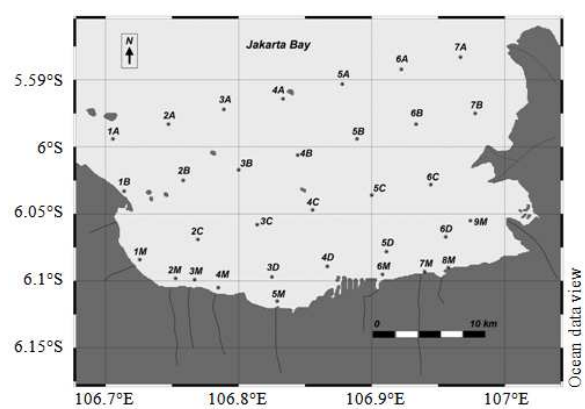


Fig. 1: Distribution of the sampling stations in the Jakarta Bay

Table 1: Mean values and standard deviations of the observed water properties and their PVs in the seawater.

				Values (Mean ± std. dev.)				
				Nov 07		Aug 08		
	No	Parameter	Unit	Offshore	Onshore	Offshore	Onshore	PV *
Phys.	1	TDS	mg l^{-1}	3.02E4 ± 2.05E3	2.22E4 ± 9.40E3	3.55E4 ± 5.32E3	2.04E4 ± 1.06E4	-
	2	TSS	mg l^{-1}	3.22 ± 1.35	24.89 ± 17.42	4.61 ± 2.19	26.33 ± 20.85	20
	3	Turbidity	NTU	1.26 ± 1.48	5.67 ± 1.80	1.87 ± 1.18	8.50 ± 7.24	5
	4	Temperature	°C	30.55 ± 0.44	30.35 ± 0.81	28.25 ± 0.32	29.21 ± 0.69	-
	5	Water transparency	m	2.94 ± 1.58	0.58 ± 0.36	2.93 ± 1.05	0.74 ± 0.66	-
Chem.	6	Salinity	‰	32.04 ± 1.46	27.72 ± 6.18	31.57 ± 0.65	29.22 ± 4.16	-
	7	Ammonia (NH_3)	mg l^{-1}	0.181 ± 0.132	2.746 ± 2.685	0.013 ± 0.022	1.292 ± 2.014	0.00
	8	$KMnO_4$	mg l^{-1}	64.90 ± 19.22	51.14 ± 13.21	106.31 ± 32.75	86.57 ± 25.71	-
	9	Nitrate (NO_3)	mg l^{-1}	0.004 ± 0.019	0.027 ± 0.080	0.000 ± 0.000	0.132 ± 0.112	0.008
	10	Disovld. Oxyg. (DO)	mg l^{-1}	7.68 ± 3.11	2.86 ± 2.26	5.31 ± 0.76	3.74 ± 2.73	5
	11	Phosphate (PO_4)	mg l^{-1}	0.007 ± 0.018	0.231 ± 0.234	0.023 ± 0.028	0.428 ± 0.466	0.015
	12	Phenol	mg l^{-1}	0.016 ± 0.005	0.018 ± 0.004	0.000 ± 0.002	0.012 ± 0.004	0.002
	13	Sulfide (H_2S)	mg l^{-1}	0.000 ± 0.000	0.019 ± 0.031	0.004 ± 0.008	1.134 ± 2.941	0.00
	14	Oil and Fat	mg l^{-1}	0.083 ± 0.105	0.064 ± 0.030	0.073 ± 0.052	0.103 ± 0.182	1.00
	15	Blue Methylene	mg l^{-1}	0.076 ± 0.059	0.081 ± 0.059	0.010 ± 0.000	0.407 ± 0.638	0.001
	16	COD	mg l^{-1}	102.4 ± 14.94	76.57 ± 13.20	33.76 ± 13.06	121.25 ± 37.14	-
	17	BOD at 20°C 5 days	mg l^{-1}	29.20 ± 8.45	31.05 ± 10.73	0.152 ± 0.05	34.20 ± 6.82	20
	18	pH		8.11 ± 0.19	7.67 ± 0.19	8.60 ± 0.18	7.83 ± 0.32	7 – 8.5
	19	Zink (Zn)	mg l^{-1}	0.033 ± 0.047	0.014 ± 0.011	0.015 ± 0.008	0.026 ± 0.010	0.095
	20	Mercury (Hg)	mg l^{-1}	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.002
	21	Copper (Cu)	mg l^{-1}	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.005
	22	Lead (Pb)	mg l^{-1}	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	-
	23	Cadmium (Cd)	mg l^{-1}	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.002
	24	Chromium (Total)	mg l^{-1}	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.002
	25	Nickel (Ni)	mg l^{-1}	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.075
Biol.	26	*E. coli* (log)	ind dl^{-1}	2.447 ± 1.423	5.388 ± 1.604	0.512 ± 0.481	5.239±2.005	2.30103**
	27	Fecal Coliforms (log)	ind/dl	1.986 ± 1.400	5.027 ± 1.678	0.365 ± 0.348	4.777 ± 1.540	3.0 **
	28	Phytoplankton (log)	ind m^{-3}	7.04 ± 0.47	7.94 ± 0.53	7.84 ± 0.91	6.35 ± 0.61	-
	29	Zooplankton (log)	ind m^{-3}	3.34 ± 0.37	3.94 ± 0.58	3.16 ± 0.54	2.42 ± 0.81	-
	30	Macrobenthos (log)	ind m^{-3}	3.08 ± 0.67	1.97 ± 0.40	2.82 ± 0.79	1.98 ± 1.29	-

Note: - * Ministry of Enviroment of Indonesia, regulation no. 51/2004 (for marine biota and tourism); ** in logaritmic format, - The underlined values have exceeded their PVs

Methods: Bivariate correlation and simple regression analysis between *E. coli* concentration and biophysicochemical properties of seawater were performed using SPSS ver. 16.0. Pearson-R correlation and *R*-squared linear coefficients were used to evaluate the magnitude and direction of the association between variables. Two-tailed test with a confidence level (α) of 0.05 and 0.1 was used to examine the significancy of the result. Ocean Data View (ODV) software version 4.2.1 was used to create an interpolation image of water transparency distribution by applying DIVA gridding technique. DIVA gridding has been incorporated in the last version of ODV and generally produces better results than Qucik Gridding in cases of sparse and heterogeneous data coverage and in cases the study area is separated by land masses (small islands), ridges or bathymetric barriers such as Jakarta Bay,

In order to analyze the pollution level of the Jakarta Bay at different seasons, a WPI was calculated from all measured water properties by using Nemerow and Sumitomo (1970) method. This method, one among numerous water quality indices, was used to measure water pollution index in several studies (Karami *et al*., 2009; Nemerow, 2007; Prakirake *et al*., 2008; Terrado *et al*., 2010). The Nemerow-Sumitomo method became formally used for water quality analysis in Indonesia, since it has been included in the regulation of the Ministry of Environment of Indonesia No. 115/2003 regarding Water Quality Measurement Guideline; therefore it was used in this study.

The function of this method was to standardize the concentrations of all water parameters such that the different concentration ranges for each water parameter were rescaled by the equation to produce a relative value that lies within a comparable range. The WPI is a function of relative values (C_i/L_i), where C_i represents the concentration of parameter i and L_i represents the PV of parameter i defined by a regulation:

WPI = a function of (C_i/L_i)'s (1)
= f $(C_1/L_1, C_2/L_2, C_3/L_3,...C_n/L_n)$
(i = 1, 2, 3, ..., n)

Then, the WPI for a specific water use j (WPI_j) is further expressed by the following equation:

$$WPI_j = \sum_{i=1}^{n} \sqrt{\frac{(C_i / L_{ij})_{max}^2 + (C_i / L_{ij})_{ave}^2}{2}} \quad (2)$$

where, C_i is the measured concentration of parameter i, L_{ij} is the PV for parameter i determined for water use j, and $(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$ are maximum and average values of C_i/L_{ij} for water use j, respectively.

For the water parameters for which the higher value represents a higher level of pollution, such as nitrate and heavy metals, the values of C_i/L_{ij} obtained from field measurements can be directly calculated using the above equation, with a prerequisite. The prerequisite is that if the value of C_i/L_{ij} obtained from the measurement is greater than 1.0, then the C_i/L_{ij} value must be standardized by applying the following equation:

$$(C_i / L_{ij})_{new} = 1.0 + k \times \log(C_i / L_{ij})_{ave} \quad (3)$$

where, k is the free constant (usually 5).

For the parameters where the lower value represents a higher level of pollution, such as Dissolved Oxygen (DO), the C_i/L_{ij} values obtained from field measurements must be standardized by using the following equation:

$$(C_i / L_{ij})_{new} = \frac{C_{im} - C_i}{C_{im} - L_{ij}} \quad (4)$$

where, C_{im} is the saturation value for any parameter at room temperature (e.g., for DO, C_{im} at 25°C is 7).

For parameters for which the PV (L_{ij}) is defined by a range of numbers, such as for pH, where the PV ranges from 6 to 8.5, a standardized value of C_i/L_{ij} is required, which is calculated by the following equation.

If $C_i \le$ average L_{ij}:

$$(C_i / L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{min} - (L_{ij})_{ave}} \quad (5)$$

If $C_i >$ average L_{ij}:

$$(C_i / L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{max} - (L_{ij})_{ave}} \quad (6)$$

where, $(L_{ij})_{min}$ and $(L_{ij})_{max}$ are, respectively, the minimum and maximum values of L_{ij} (e.g., pH: min = 6, max = 8.5). The $(L_{ij})_{ave}$ is the average value of L_{ij} (e.g., pH: (6 + 8.5) / 2 = 7.25).

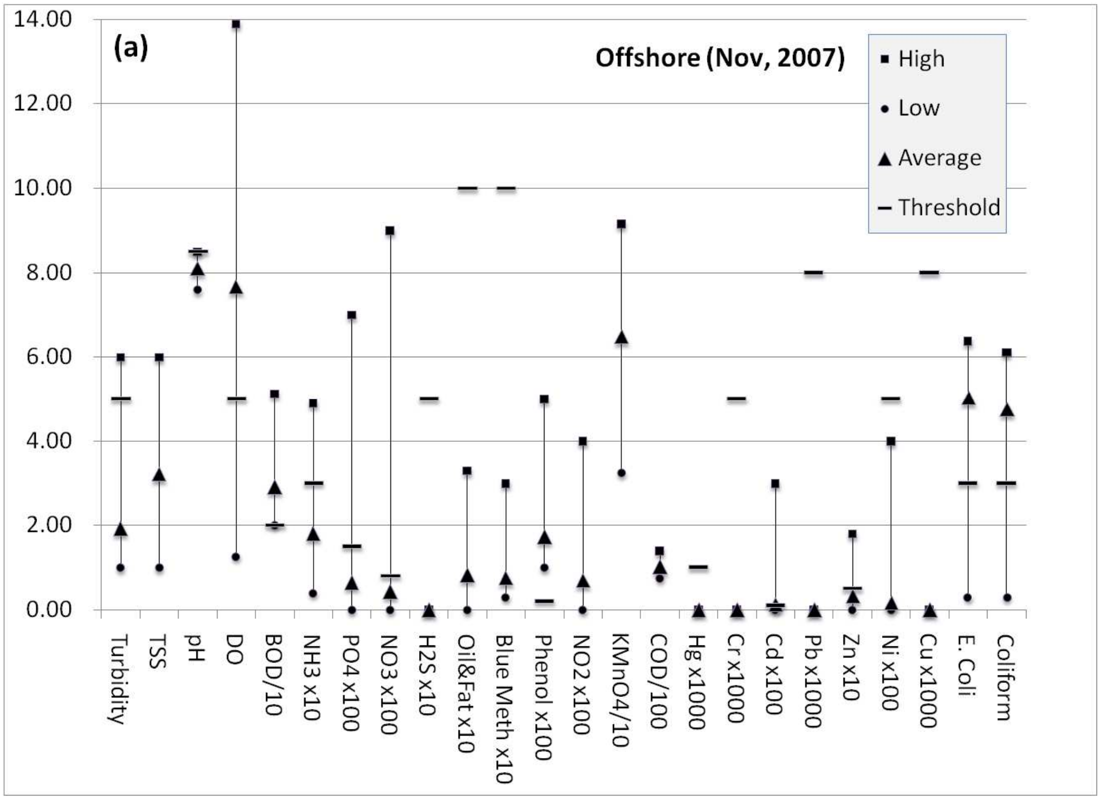
The pollution level is determined in four criteria as classified by the following definitions:

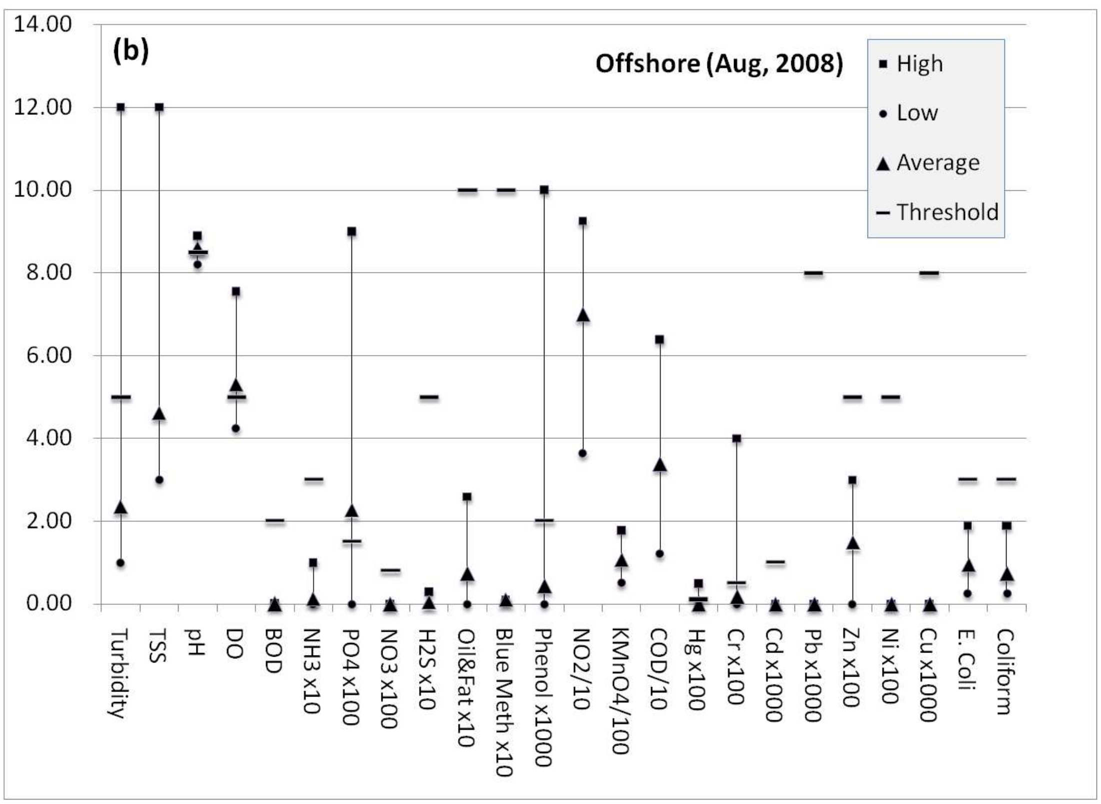
$0.0 \le PI \le 1.0$ = Clean (C)
$1.0 < PI \le 5.0$ = Slightly Polluted (SP)
$5.0 < PI \le 10$ = Moderately Polluted (MP)
$PI > 10$ = Highly Polluted (HP)

According to the above equations, Nemerow-Sumitomo WPI needs a set of PV for each parameter as an input for the equation and this PV is likely to be designed by a government regulation. Table 1 lists the mean value and standard deviation of all measured parameters along with their PVs in seawater designated by the regulation of Ministry of Environment of Indonesia no. 51/2004. This regulation is designed for the purpose of marine tourism activities and marine living organism. Although in total 30 water properties have been measured in the ERS and LDS, but only the parameters having designated PVs were inputted in the WPI equations (Table 1). Some parameters such as TDS, temperature, salinity, were excluded from WPI calculation, because their PVs are not defined by the regulation.

RESULTS

Biophysicochemical properties of seawater at different seasons: For comparison, the sampling stations were divided into offshore (23 stations) and onshore (9 stations) area (Fig. 1). In general, the mean value of biophysicochemical water parameters in the onshore area was several times higher (in case of Dissolved Oxygen [DO], lower) than the mean value of water parameters in the offshore area, both in early rainy and late dry season. In the onshore area, 12 parameters have exceeded the PVs in both seasons, i.e., Total Suspended Solid (TSS), turbidity, ammonia, nitrate, DO, phosphate, phenol, sulfide, blue methylene, Biological Oxygen Demand (BOD), *E. coli* and fecal coliforms. Meanwhile in the offshore area, only five parameters in both seasons have exceeded the PVs (Table 1 and Fig. 2).


(a)
Offshore (Nov, 2007)
High
Low
Average
Threshold
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Turbidity
TSS
pH
DO
BOD/10
NH3 x10
PO4 x100
NO3 x100
H2S x10
Oil&Fat x10
Blue Meth x10
Phenol x100
NO2 x100
KMnO4/10
COD/10
Hg x1000
Cr x1000
Cd x100
Pb x1000
Zn x10
Ni x100
Cu x1000
E. Coli
Coliform


(b)
Offshore (Aug, 2008)
High
Low
Average
Threshold
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Turbidity
TSS
pH
DO
BOD
NH3 x10
PO4 x100
NO3 x100
H2S x10
Oil&Fat x10
Blue Meth x10
Phenol x1000
NO2/10
KMnO4/100
COD/10
Hg x100
Cr x100
Cd x1000
Pb x1000
Zn x100
Ni x100
Cu x1000
E. Coli
Coliform

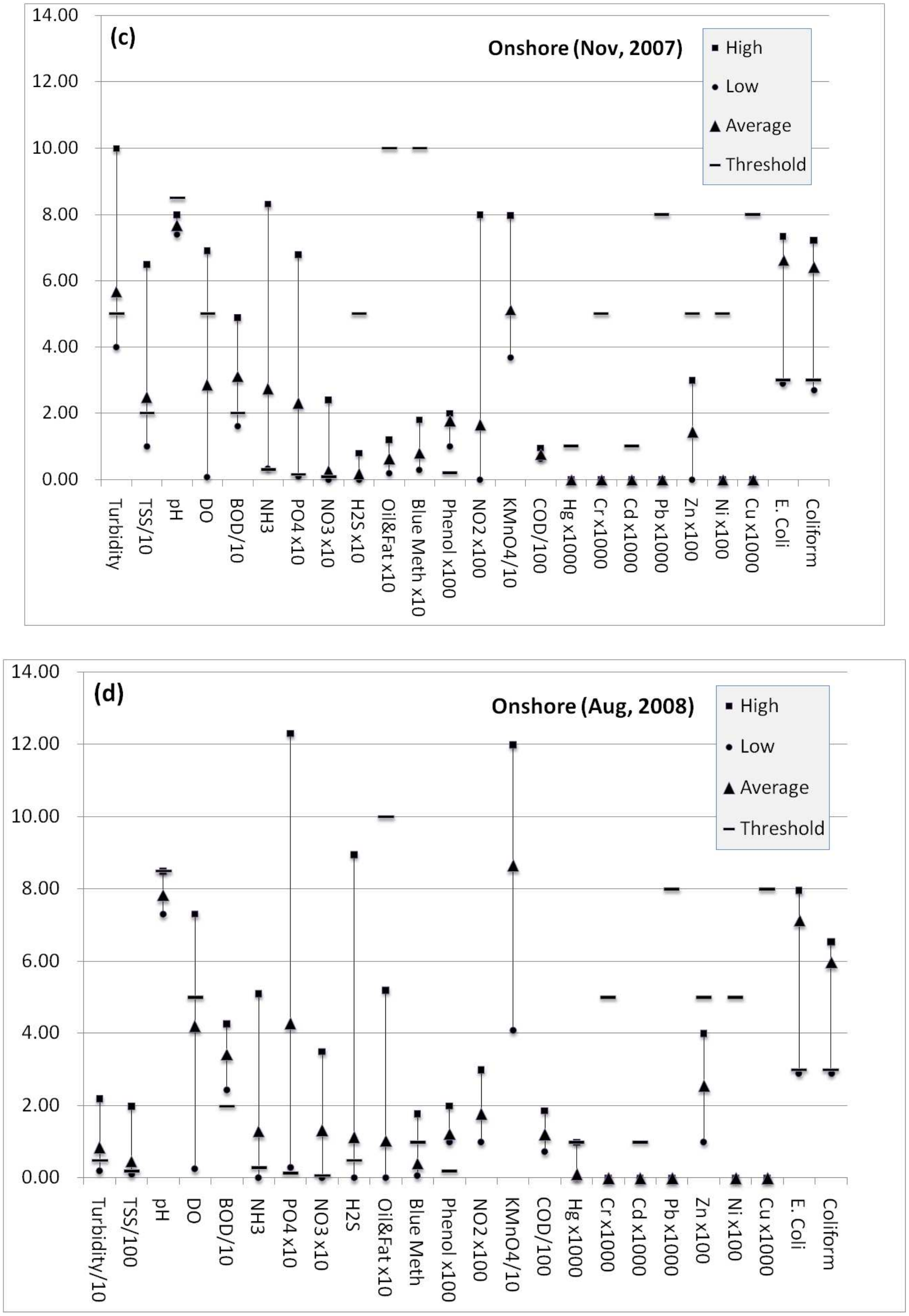


Fig. 2: The standardized PV, minimum, maximum and average values of water parameters in the offshore and onshore stations at different seasons

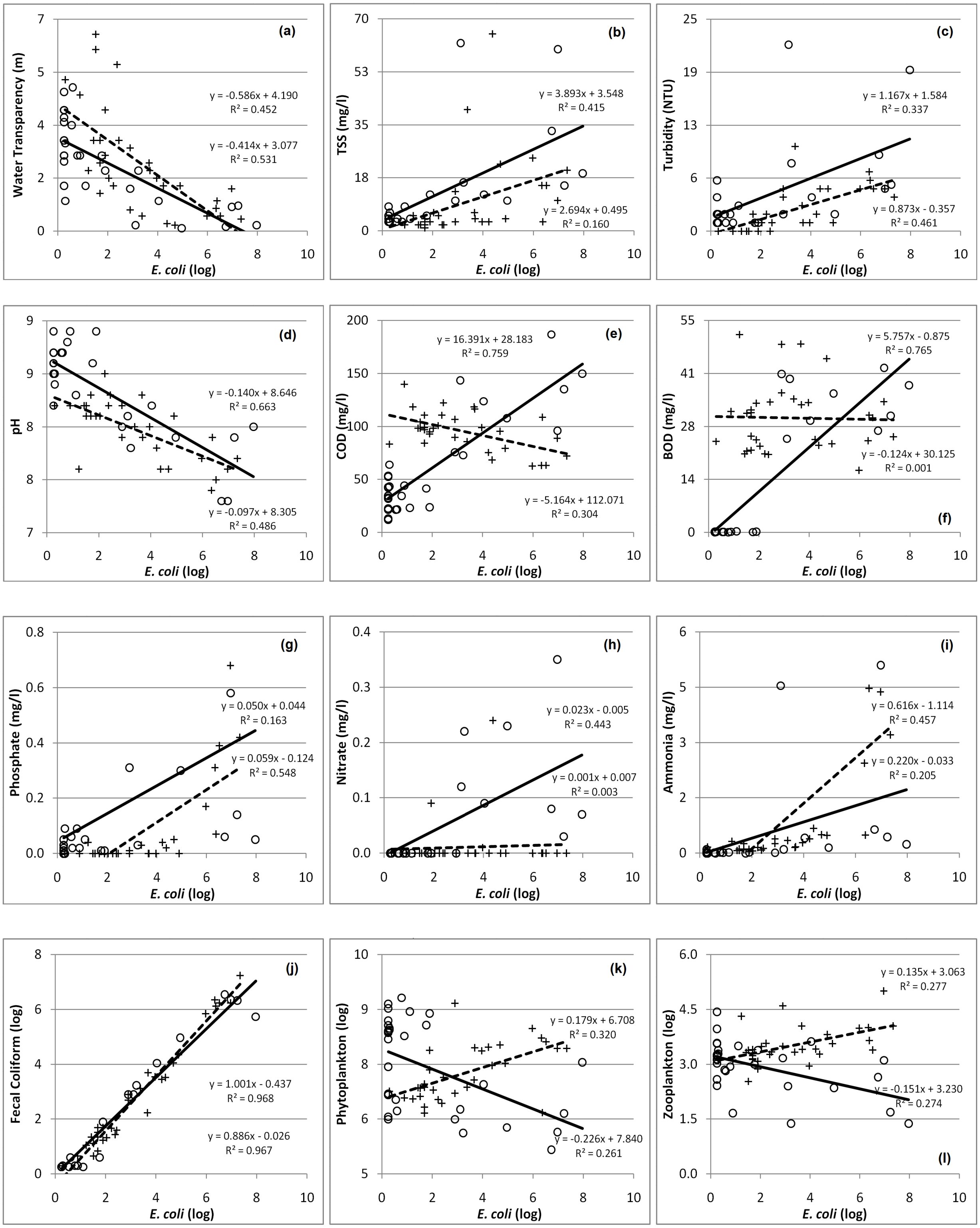


Fig. 3: Relationships between *E. coli* and some physical (a – c), chemical (d – i) and biological (j – l) properties of seawater at the ERS (+ / ---) and LDS (○ / —)

Table 2: Regression and correlation coefficients between *E. coli* concentration and other water parameters

		Physical				Chemical					Biological			
		Transp	Turbid	TSS	pH	Cod	Bod	PO_4	NH_3	NO_3	Coliforms	Phyto	Zoopl	WPI
E. coli (Nov, 2007)	r	-0.672**	-0.679**	0.399*	-0.697*	-0.551**	-0.027	0.740**	0.676**	0.054	0.984**	566**	526**	0.605**
	Sig	0.000	0.000	0.024	0.000	0.001	0.883	0.000	0.000	0.768	0.000	0.001	0.002	0.000
	r^2	0.452	0.461	0.160	0.486	0.304	0.001	0.548	0.457	0.003	0.968	0.320	0.277	0.366
E. coli (Aug, 2008)	r	-0.729**	0.581**	0.644**	-0.814**	0.871**	0.875**	0.404*	0.453**	0.665**	0.983**	-0.511**	-0.523**	0.942**
	Sig	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.009	0.000	0.000	0.003	0.002	0.000
	r^2	0.531	0.337	0.415	0.663	0.759	0.765	0.163	0.205	0.443	0.967	0.261	0.274	0.886

Table 3: Results of WPI in the offshore and onshore stations at different seasons

	Early rainy season Nov 2007 Number of station			Late dry season Aug 2008 Number of station		
Criteria	Offshore	Onshore	Total	Offshore	Onshore	Total
Clean (C)	0	0	0	9	0	9
Slightly Polluted (SP)	18	2	20	14	2	16
Moderately Polluted (MP)	4	2	6	0	3	3
Highly Polluted (HP)	1	5	6	0	4	4
Total	23	9	32	23	9	32

Relationships between *E. coli* and water parameters: In this study, we focused on *E. coli* concentration and its relation to physical, chemical and biological properties of seawater (Fig. 3). Table 2 summarizes the results of bivariate correlation and simple regression analysis between *E. coli* and other water parameters at different seasons in the Jakarta Bay.

Water Pollution Index: Table 3 summarized number of stations in the offshore and onshore stations in both seasons that were classified based on the WPI criteria. The results indicate that most of the sampling stations fall within SP criteria with 20 stations (62.5%) in the ERS and 16 stations (50%) in the LDS. Overall, the water tended to be more polluted in the ERS (C = 0, SP = 20, MP = 6 and HP = 6) compared to that of in the LDS (C = 9, SP = 16, MP = 3, and HP = 4).

DISCUSSION

Biophysicochemical properties of seawater at different seasons: In respect to seasonal variability, water parameters were responsive to precipitation. For example, in the ERS, although rainfall intensity in this period was not as much as in mid rainy season (Fig. 4), but the presence of rainwater in this period was sufficient to slightly dilute seawater as can be observed from most of water parameters. Therefore some parameters showed relatively lower mean values than those of in the LDS, especially in the onshore area, for example turbidity, potassium permanganate ($KMnO_4$), nitrate, salinity, phosphate, sulfide, blue methylene, TSS, Chemical Oxygen Demand (COD) and BOD.

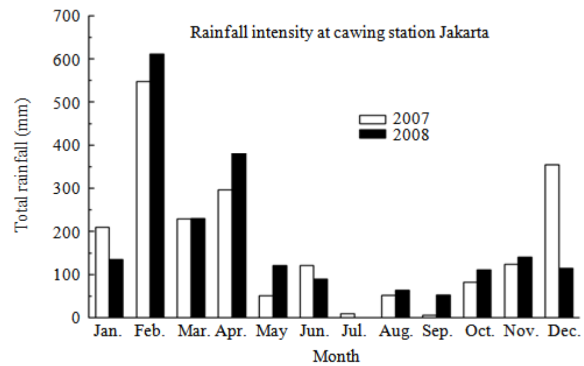


Fig. 4: Monthly changes of precipitation (mm) during 2007 and 2008 at the Cawang rainfall gauge, Jakarta (Suwandana *et al*., 2011)

However, at the same time, rainfall intensity has also capacity to force out the polluted river water flowing into the bay. Therefore few parameters also showed higher values, i.e. ammonia, phenol, DO, *E. coli* and fecal coliforms. The resultant of water current from rivers that meets with the waves from open sea could also be the explanatory why the polluted water was more concentrated in the coastal area.

Relationships between *E coli* and water parameter: From five physical parameters, three parameters showed moderate correlation, i.e., water transparency, TSS and turbidity, both in the ERS and LDS. These parameters are associated with sedimentation rate in the water. Suspended solid in the water body provides suitable media for bacterial microorganisms, such as coliforms, to grow (Narkis *et al*., 1995). Relationship between *E. coli* and turbidity is also essential especially for the raw material of drinking water, where the median of turbidity should be below 0.1 NTU (Nephelometric Turbidity Unit) (Allen *et al*., 2008).

The impact of rainwater to the physical parameters can be observed from Fig. 3a-c where the value of each parameter, in general, was lower than that of the LDS. Temperature did not show strong correlation with *E. coli* (not shown in Table 2) because there was not significant difference in temperature between ERS and LDS.

Among the chemical parameters, pH exhibited a very strong correlation with *E. coli* in both seasons. Such strong negative correlation indicated that *E. coli* preferred to grow in a normal to an acidic environment. A laboratory experiment done by Jordan *et al*. (1999) proved that *E. coli* concentration was very high at pH 3.0 after 24-h incubation, and even some survivals could still be found after 3-days of experiment.

Among oxygen-related parameters like DO, BOD and COD, two parameters, i.e. COD and BOD, showed high positive correlation with *E. coli* in the LDS. COD is a very important indicator for *E. coli* growth as it measures the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrate. BOD also showed a strong positive correlation with *E. coli*. Figure 3e and f show that BOD and COD concentrations in the LDS were linearly correlated. However, in the ERS, the relationship between *E. coli* and BOD/COD was not so clear. The relationship between COD and BOD is actually not necessarily to be linear in nature. However, the study done by Jin *et al*. (2009) concluded that in the water containing relatively high concentration of sewage contamination, a linear correlation could exist.

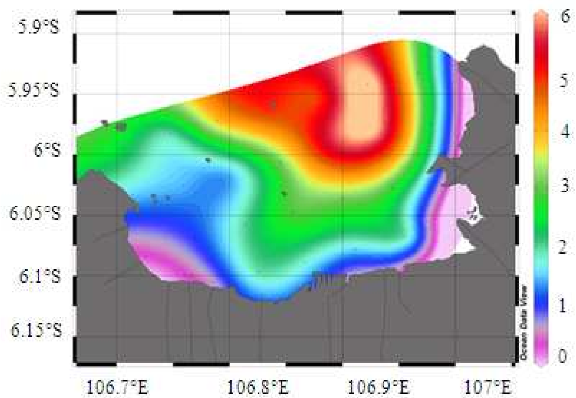
The relationships between *E. coli* and other chemical parameters like phosphate, nitrate and ammonia exhibited from low to moderate correlations based on pearson-r coefficients as presented in Table 2. The correlation of these parameters was not clearly understood and the role of rainwater to these parameters was not clear either. Suppostedly, *E. coli* should have a strong linear relationship with those three elements. The presence of high organic matter and nutrients, such as phosphorus and nitrites in the seawater can increase the bacterial colony, e.g., *E. coli*, as reported by Jalal *et al*. (2010) and Gauthier *et al*. (1993). Therefore, more field surveys are required, especially in the extreme conditions like in mid rainy and mid dry season, in order to get more precise data.

Beside physicochemical parameters, which their contibution is very important in creating a suitable enviroment for *E. coli* growth, some biological parameters were also analyzed in this study. There were three biological indicators measured during the survey, i.e., fecal coliforms, phytoplankton and zooplankton. The results revealed that *E. coli* showed strong correlations with fecal coliforms in both seasons (R^2 = 0.967-0.968, $P < 0.001$), because in fact *E. coli* is one type of fecal coliforms. The environmental conditions which are suitable for *E. coli* growth are also suitable for other fecal coliform bacteria, hence the relationship between those two bioindicators was nearly perfect (see Fig. 3j. On the contrary, the relationship with macrobenthos was insignificant. As organisms living on sediment, macrobenthos is not easily influenced by the changes in the seawater properties.

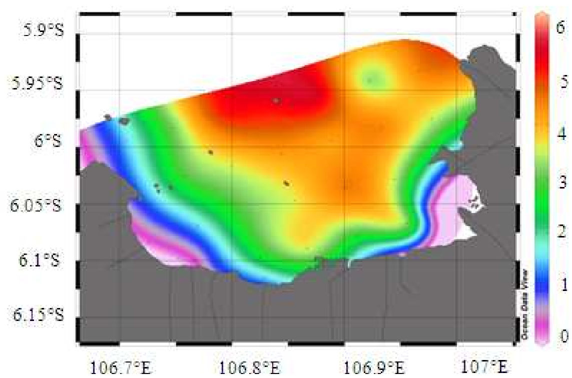
An interesting fact can be observed in the phytoplankton and zooplankton relationships to *E. coli*. In the LDS, though the correlation coefficient was only 0.261 for phytoplankton and 0.274 for zooplankton, but the trend line was able to describe their association in nature. The negative linears shown in see Fig. 3k and (l) explain that the more the water got polluted, the less the number of phytoplankton and zooplankton was found. A study done by Fachrul and Syach (2006) in the Jakarta Bay reported that biodiversity index of phytoplankton in the polluted area was around 0.26, similarity index was close to 0, and dominance index is nearly 1, meaning that only one species was dominating the polluted area.

Different situation occured in the ERS, where a positive correlation occurred both for phytoplankton and zooplankton. The average concentration of phytoplankton in the onshore area was higher ($\bar{x}$ = 7.94 ± σ = 0.53) compared to the one in the offshore area ($\bar{x}$ =7.04 ± σ = 0.47). The same situation was performed by zooplankton, where the average concentration was $\bar{x}$ = 3.94 ± σ = 0.58 for the onshore and $\bar{x}$ = 3.34 ± σ = 0.37 for the offshore area.

The reason for high concentration of phytoplankton and zooplankton found in the onshore area during the ERS could be related with the occurrence of high precipitation. Rainfall intensity and nutrients upload from land and river systems might have triggered phytoplankton to start multiplying their population. Within this period, upwelling often occurs, nutrient enrichment takes place and sometimes this may lead to the alga bloom phenomenon (Sellner *et al*., 2003). Many studies have reported that, with this kind of circumstances, phytoplankton, and then followed by zooplankton, is very sensitive to the increase of nutrient elements introduced by rainwater (Sellner *et al*., 2003; Lee *et al*., 2009) and the growth of some phytoplankton species respond very quickly to the rainfall (Al-Homaidan and Arif, 1998).



(a)



(b)

Fig. 5: Interpolated-water transparency distribution data in the (a) ERS and in the (b) LDS

Water pollution Index: Although *E. coli* concentration in water column can itself be used as indicator for pollution level, scientists developed numerous water quality indices calculated from multi-parameters of water properties. Instead of relying only on a single pollution indicator, these WPI can better explain the association of whole water properties because all parameters are incorporated in the calculation.

Although, in general the average value of water parameters in the ERS was lower compared to that of in the LDS, but in some stations the concentration was very high due to the influence of water input from river systems, producing high WPI on those stations. This was the reason why, to some extents, it was necessary to conduct a multiple-parameter pollution index, instead of depending only on one pollution indicator such as *E coli*. According to Terrado *et al*. (2010), the presence or absent of certain organisms in water, which is used as a single bioindicator, has been introduced since 1848 in Germany, but sometimes it is not sufficient because it does not take into account other toxicological effects nor contaminant substances.

The results of this study could not answer clearly why the WPI in the ERS was more polluted compared to that of in the LDS. However, the supply of rainwater, which started to increase in November 2007 as the onset of the rainy season, could be one reason, because rainwater supply was able to force out the polluted water in 13 river systems flowing into the bay. Some literatures reported that most of the river systems in Jakarta have been classified into highly polluted (Colbran, 2009; Steinberg, 2007; UNESCO, 2000). Therefore, the existence of sufficient rainwater in this period could be an explanatory for the increase of water pollution in the Jakarta Bay.

Unfortunately, the amount of water debit from all river systems in the ERS was unknown; hence it was difficult to statistically measure the impact of rainfall intensity to the increase of water pollution in the bay. However, an attempt was made to overcome this situation by creating a water transparency distribution map from the water transparency point data using DIVA gridding interpolation method (Fig. 5). The water transparency point data was measured by using secchi disk, where the deeper the secchi disk can be visually seen from the water surface, the more transparently (clearer) the seawater is.

It is clearly seen from Fig. 5, there is a significant supply of fresh water from river systems in the ERS (Fig. 5a), as shown by the expansion of purple and blue colors over green and orange colors. The water transparency in this season was more turbid especially in the onshore area ($\bar{x} = 0.58 \pm \sigma = 0.36$) compared to that of in the LDS ($\bar{x} = 0.74 \pm \sigma = 0.66$).

CONCLUSION

Most of the biophysicochemical properties of seawater in the Jakarta Bay had significant correlations with *E. coli* concentration. Some of those parameters were very essential for *E. coli* growth; hence many significant correlations occurred. The concentration of most water parameters can also be differentiated between offshore and onshore area, where high concentration values occurred mostly in the onshore area, evenmore some already exceeded the PVs. The concentration of water properties was also very responsive to precipitation. The freshwater coming from land (river systems) had two important roles in this environment; one was related its potential in diluting seawater and the other one was related to its capacity in forcing the polluted water in the river systems out into the bay.

Most of the WPI in the sampling stations fall within slightly polluted criteria, with 62.5% and 50%

for the ERS and LDS, respectively. More polluted waters were concentrated nearby the onshore area, while the offshore area was relatively cleaner. The results also show that more polluted stations were found in the ERS compared to the LDS. Although, in general, the average value of most parameters reduced during this season, but the capacity of rainwater was able to bring out the polluted river water coming out into the bay, generating more polluted water in the bay.

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REFERENCES

Allen, M., R. Brecher, R. Copes, S. Hrudey and P. Payment, 2008. Turbidity and Microbial Risk in Drinking Water. Ministry of Health Province of British Columbia, pp: 69. http://www.health.gov.bc.ca/protect/pdf/TACsubmitted

Al-Homaidan, A. and I. Arif, 1998. Ecology and bloom-forming algae of a semi-permanent rain-fed pool at Al-Kharj. Sau. Arabia. J Arid Environ., 38: 15-25. DOI: 10.1006/jare.1997.0319

Anna, S. and A. Fauzi, 2008. Economic loss of pollution to fisheries: An economic analysis of the Jakarta Bay fisheries. Am. Fish. Soc. Symp., 49: 265-272. http://pustaka.unpad.ac.id/wp-content/uplads/2009/05/1_anna.pdf

Brussow, H., H. Rahim and W. Freire, 1992. Epidemiological analysis of serologically determined rotavirus and enterotoxigenic *Escherichia coli* infections in Ecuadorian children. Am. Soc. Microbiol., 30: 1585-1587. http://jcm.asm.org/cgi/reprint/30/6/1585

Campbell, G.R., J. Prosser, A. Glover and K. Killham, 2001. Detection of *Escherichia coli* O157:H7 in soil and water using multiplex PCR. J. Applied Microb., 91: 1004-1010. PMID: 11851807

Colbran, N., 2009. Will Jakarta be the next atlantis? Excessive groundwater use resulting from a failing piped water network. Law. Environ. Dev. J., 5: 20-37. http://www.lead-journal.org/ content/09018.pdf

Costa, Jr. O.S, Z.M.A.N Leao, M. Nimmo and M.J. Attrill, 2000. Nutrification impacts on coral reefs from Northern Bahia, Brazil. Hydrobiologia, 440: 307-315. DOI: 10.1023/A:1004104118208

Fachrul, M.F. and J.N. Syach, 2006. The effect of water quality disturbances on phytoplankton communities in Jakarta Bay, Indonesia. http://www.balwois.com/balwois/administration/full_paper/ffp-1199.pdf

Gauthier, M.J., G.N. Flatau, R.L. Clement and P.M. Munro, 1993. The loss of culturability by *Escherichia coli* cells in seawater depends on avaiability of phosphate ions and phosphate transport systems. Microb. Ecol., 26: 29-35. DOI: 10.2307/4251307

Jalal, K.C.A., Y. Kamaruzzaman, A. Fairuz, B. Akbar and S. Shahbudin *et al*., 2010. Bacterial communities in Kuantan Estuary of Pahang Malaysia. J. Applied Sci., 10: 652-657. DOI: 10.3923/jas.2010.652.657

Jin, X.L., M. Jing, X. Chen, Z.X. Zhuang and X.R. Wang *et al*., 2009. A study on the relationship between BOD5 and COD in coastal seawater environment with a rapid BOD measurement system. Water Sci. Technol., 60: 3219-3223. PMID: 19955646

Jordan, K.N., L. Oxford and C.P. O'Byrne, 1999. Survival of low-pH stress by *Escherichia coli* O157:H7: correlation between alterations in the cell envelope and increased acid tolerance. Appl. Environ. Microb., 65: 3048-3055. PMID: 10388702

Karami, B., K.N. Dhumal, M. Golabi and N. Jaafarzadeh, 2009. Optimization the relationship between water quality index and physical and chemical parameters of water in Bamdezh Wetland. Iran. J. Applied Sci., 9: 3900-3905. DOI: 10.3923/jas.2009.3900.3905

Kido. M., Y. Syawal, M.S. Sulastri, T. Hosokawa and S. Tanaka *et al*., 2009. Comparison of general water quality of rivers in Indonesia and Japan. Environ. Monit. Assess., 156: 317-329. DOI: 10.1007/s1066 1-008-0487-z

Lee, M., B. Kim, Y. Kwon and J. Kim, 2009. Characteristics of the marine environment and algal blooms in Gamak Bay. Fish Sci., 75: 401-411. DOI: 10.1007/s12562-009-0056-6

Narkis, N., R. Armon, R. Offer, F. Orshansky and E. Friedland, 1995. Effect of suspended solids on wastewater disinfection efficiency by chlorine dioxide. Water Res., 29: 227-236. DOI: 10.1016/0043-1354(94)E0117-O

Nemerow, N.L. and H. Sumitomo, 1970. Benefits of Water Quality Enhancement. Report No. 16110 DAJ, prepared for the US Protection Agency. December 1970. Syracuse, University, Syracuse, NY, pp. 202. http://nepis.epa.gov/

Nemerow, N.L., 2007. Industrial Waste Treatment: Contemporary Practice and Vision for the Future. 30 Corporate Drive, Suite 400, Burlington, MA 01803, USA., ISBN: 0123724937, pp: 516.

Prakirake, C., P. Chaiprasert and S. Tripetchkul, 2008. Development of specific water quality index for water supply in Thailand. Songkl. J. Sci. Technol., 31: 91-104. http://www.rdoapp.psu.ac.th/html/sjst/journal/31-1/0125-3395-31-1-91-104.pdf

Sato, N. and H. Harada, 2004. Trends and prospects of water environmental issues in Jakarta. Indo. Envi. Sys. Res., 32: 11-19.

Sellner, K.G., G.J. Doucette and G.J. Kirkpatrick, 2003. Harmful algal blooms: Causes, impacts and detection. J. Ind. Microbiol. Biot., 30: 383-406. DOI: 10.1007/s10295-003-0074-9

Steinberg. F., 2007. Jakarta: Environmental problems and sustainability. Habitat. Inter., 31: 354-365. DOI: 10.1016/j.habitatint.2007.06.002

Suwandana, E., K. Kawamura and E. Soeyanto, 2011. Assessment of the heavy metals and nutrients status in the seawater, sediment and seagrass in Banten Bay, Indonesia and their distributional patterns. J. Fish. Internat., 6: 18-25. DOI: 10.3923/jfish.2011.18.25

Terrado, M., E. Borrel, S. Campos, D. Barcelo and R. Tauler, 2010. Surface-water-quality indices for the analysis of data generated by automated sampling networks. Trends. Anal. Chem., 29: 40-52. DOI: 10.1016/j.trac.2009.10.001

UNESCO, 2000. Reducing megacity impacts on the coastal environment-alternative livelihoods and waste management in Jakarta and the Seribu Islands. Coastal Region and Small Island Papers 6, UNESCO, Paris, pp. 59. http://www.unesco.org/csi/pub/papers/mega.htm

Van der Meij, S.E.T., R.G. Moolenbeek and B.W. Hoeksema, 2009. Decline of the Jakarta Bay molluscan fauna linked to human impact. Mar. Pollut. Bull., 59: 101-107. DOI: 10.1016/j.marpolbul.2009.02.021

William, T.M., J.G. Rees and D. Setiapermana, 2000. Metals and trace organic compounds in sediments and waters of Jakarta Bay and the Pulau Seribu Complex, Indonesia. Mar. Pollut. Bull., 40: 277-285. DOI: 10.1016/S0025-326X(99)00226-X

Willoughby, N.G., H. Sangkoyo and B.O. Lakaseru, 1997. Beach litter: An increasing and changing problem for Indonesia. Mar. Pollut. Bull., 34: 469-478. DOI: 10.1016/S0025-326X(96)00141-5

World Resources Institute, 1996. World Resources 1996-97: The Urban Environment. ISBN 0-19-521160-X, pp: 365.

Yisa, J. and T. Jimoh, 2010. Analytical Studies on Water Quality Index of River Landzu. Am. J. Applied Sci., 7: 453-458. DOI: 10.3844/ajassp.2010.4 53.458.