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Water Quality Index: an Indicator of Surface Water Pollution in Eastern part of Peninsular Malaysia

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Abstract

Water quality deterioration in eastern part of peninsular Malaysia especially in Gebeng is the impact of anthropogenic activities due to rapid industrialization. This area is of particular importance in the study of surface water quality because; industrial and municipal wastes, agricultural and run-off from developing areas were mixing with river flow and surrounding water body thereby deteriorating the quality. The aim of the study was to assess the WQI in order to evaluate the water quality of the area for public use, irrigation and other purposes. To fulfill the objectives 240 water samples were collected for 12 months and comprehensive physico-chemical analysis was done using APHA and HACH standard methods of analysis. The WQI was calculated using DOE-WQI based on the concentration of DO, BOD, COD, SS, pH and NH_3-N. Results showed the sequence of monitoring stations I4< I3< I2< B2< B3< I1< U1< B1< S2< S1based on WQI value; where the first 8 stations (river part) were categorized as class IV (highly polluted) and the last 2 were classified as class III (polluted). The lowest WQI value was 35.37 and the highest value was 57.53. It was mainly because of low concentration of DO and high concentration of BOD, COD and NH_3-N due to the industrial activities. The results indicated that the surface water of the areas was highly polluted and according to the INWQS, Malaysia water of the area cannot be used except irrigation.

Keywords: Water quality index, ammoniacal nitrogen (NH_3-N), bio-chemical oxygen demand (BOD), chemical oxygen demand (COD).

Introduction

Surface water is the main source of available as well as fresh water for mankind. These resources are diminishing rapidly[1]. Its deterioration is the major concern nowadays. Fresh water is the important part of environment and essential for all living being. But, the total fresh water is only 2.5% of all water of the earth that makes it as a scarce resource; and again the amount of available water for use is only 0.4% of total fresh water, which is like a tea spoon compare to all surface water[2]. So, surface water resources are not adequate to fulfill the demand of water[3]. This little water source is also under pressure of anthropogenic activities that polluting throughout the world. Water quality is largely depends on the natural processes and anthropogenic activities like industrial activities, municipal waste management, homesteads and agricultural activities; which constitute a continuous polluting source[4,5]. Rapid industrialization along with speedy population growth made tremendous pressure on the demand of fresh water for the last few decades[6,7] and thus the availability of fresh water through surface water sources is becoming critical day to day[8]. In Malaysia, its bounty of water resources is contributing to the economic and industrial development of the country[9]. But, the water quality of the country is deteriorating every day[10]. Industrial development leads to pollution of the surface water; which is increasing since last couple of years[10,11]. Rising industries are generating multifarious conventional and non-conventional pollutant and discharging into the river flow that causes the deterioration of water quality[12]. Similar scenario is prevailing at eastern part of peninsular Malaysia especially in Gebeng industrial estate. The wastes of the industrial park are polluting the water of the adjacent river Tunggak and the surrounding areas.

Water quality index (WQI) as a means of water quality assessment through the determination of physico-chemical parameters of surface water; it can act as an indicator of water pollution because of natural inputs and anthropogenic activities[6,13]. WQI is one of the most effective tools to provide feedback on the quality of water to the policy makers and environmentalists[13]. It provides a single number expressing overall water quality status of a certain time and location[14]. It is actually the categorization counting the combined influence of different important water quality parameters; as it is calculated based on the concentration of several important attributes[6,14]. It acts as a simple indicator of water quality. In the present study, we used DOE-WQI where, it serves as the basis for assessment of water quality in relation to pollution load characterization and classification of water under the Inland National Water Quality Standards for Malaysia (INWQS). The objective of the study is to assess the WQI as an indicator to evaluate the water pollution status for public use, irrigation and other purposes; based on the analysis of physico-chemical parameters of the surface water of eastern part of peninsular Malaysia; especially the Gebeng areas including Tunggak river, and to classify the water according to INWQS, Malaysia.

Material and Methods

Study area: The study area is located in eastern coastal region of peninsular Malaysia which is lies between 3° 55' 0" to 4° 01' 0" N and 103° 22' 0" to 103° 27' 0"E (figure 1). Industrialization at this area (GIE) has been established since 1970s. The GIE discharged almost all their effluents either filtered or unfiltered in the river flow of Tunggak [12]. The Tunggak River originated at the uphill of Gebeng area and flows into South China Sea[11,12]. For sampling and data collection, 10 monitoring stations were established of which eight were from river basin and two from surroundings of the GIE, considering the land use pattern, point sources of pollution and river network (figure 1).

Figure-1
Location map of the study area indicating monitoring stations

Sampling and analysis: Surface water samples were collected monthly from February 2012- January 2013. A total of 240 samples were collected and analyzed. Water from about 10 cm below the water surface was collected using 1000ml HDPE bottles. The dark BOD bottles (300 ml) were used to collect sample for BOD analysis. Collected samples were preserved in cool box during sampling and transported to the laboratory for analysis following standard procedure[15,16]. Using YSI *in-situ* parameters such as temperature, pH, dissolved oxygen (DO), turbidity, electrical conductivity (EC), and total dissolved solids (TDS) were measured during sampling. The samples were analyzed in laboratory for measuring selected *ex-situ* parameters in accordance with APHA and HACH standard methods of analysis[15,16].

Laboratory analysis: Collected samples were analyzed in laboratory for determining the physico-chemical properties. The Physico-chemical properties could help to assess the function and structure of concern water body[17]. In the present study the concentration of ammoniacal nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), phosphorus (PO_4^{3-}), sulfur (SO_4), COD, BOD and total suspended solids (TSS) were analyzed. Regarding BOD determination, the first DO reading was taken just after collecting the samples and the second one was taken after 5 days preservation in incubator at 20^0C temperature.

Statistical analysis: The statistical analysis was done with SPSS 16.0 statistical software. BOD was calculated with the following formula (1):

$$BOD(mg/L) = \frac{(DO_i - DO_5)}{P} \quad (1)$$

Where, DO_i = DO (mg/L) of diluted sample about 15 minutes after preparation, DO_5 = DO (mg/L) of diluted sample after 5 days incubation at 20^0C C and P = decimal volumetric fraction of sample [15].

Water quality index: WQI was calculated based on the comparison of water quality parameters with their respective regulatory standards [18]. On the basis of the concentration of DO, BOD, COD, ammoniacal-N, SS and pH of the study area, WQI was calculated [19,20]. In the present study WQI calculation was done using DOE-WQI, Malaysia (DOE, 2009). The following formula (2) was used to calculate the DOE-WQI;

$$WQI = 0.22 \times SIDO + 0.19 \times SIBOD + 0.16 \times SICOD + 0.15 \times SIAN + 0.16 \times SISS + 0.12 \times SIPH \quad (2)$$

Where, SI=sub-indices of those parameters that were obtained from a series of equations.

Results and Discussion

The summary of the statistical analysis of parameters has been shown in table 1. The table showed that, pH which is an important indicator for the water quality[6] varied between 4.2 and 9.1 with a mean pH value of 6.6. The pH at upper part (Upper, U1) of the river was found to be acidic compare to the middle (Industrial areas, I1-I4) and lower stream (Balok, B1-B3); where neutral to alkaline pH was observed. The pH value of the surrounding areas (Surrounding, S1-S2) was also acidic in nature. The highest pH was recorded due to the addition of industrial effluents consist of polymer, chemical, metal, gas and power industries and high temperature at those stations[12,21]. On the contrary, the lowest value was perhaps due to the industrial effluents of those areas (U1, S1 and S2) contained acidic substances from chemical and mining industries and also the submerged condition at S1 might be the reason. However, the mean value of pH at maximum stations was within the standard level of Malaysia [22]. DO is the essential parameters for fresh water and an index of several physical and biological process in water [23]. The concentration of DO was recorded very low at the whole study area varied from 0.41 mg/L at station S1 to 5.34 mg/L at station I1 (table- 1). The average value was recorded 2.61 mg/L; which indicated that the water of that area was highly deoxygenated. It was due to the discharge of organic matter and nutrient rich industrial effluents [6]; that influenced faster microbial activities[24] and resulted low DO concentration. Based on the observed concentration of DO, all the stations were categorized as class III and IV according to INWQS threshold level for Malaysia surface water.

COD and BOD were analyzed and results were shown in table-1. The highest value 140 mg/l of COD was recorded at station I3 followed by I4, B1 and I2. It revealed that, the concentration was higher in the river water especially the industrial zone (I1-I4); which contained a lot of multifarious industries; that indicated the presence of both oxidisable organic and inorganic pollutants from effluents; that were polluting the solids wastes[25]. The overall mean concentration 38.83 mg/L was beyond the threshold level of Malaysia[22]. The trend of BOD was almost similar to the COD (Table 1); as they were found positive significantly correlated (table- 2). Moreover, the positive significant correlation between pH and both COD and BOD also might be the cause of higher concentration of both the parameters at those stations (table- 2). The highest concentration was recorded at station I4 (38.35 mg/L) followed by I3, I1 and I2. Similar to COD, the average value was found higher than threshold level. Based on the concentration of COD and BOD, water of the study area was found to be in class V according to the classification of INWQS, Malaysia[22].

TSS concentration was varied from 1.00 mg/L to 2171.00 mg/L with an overall mean value of 55.48 mg/L. The highest value was recorded at station I4 during November 2012; it was because, at that time there was an establishment work of a new industry and also due to heavy rain as it was wet season. Other than that the average TSS values were almost within the standard limit of Malaysia. Regarding TDS, the concentration varied between 7.7- 658000 mg/L. High concentration of TDS in surface water is the indicator of excessive anthropogenic activities besides the study area[6]. The highest value was observed at station I3 on January 2013; it was because of hill cutting was taken place at that time for establishing of new industry and also the reason of heavy rain during wet season. Higher TDS value was also observed at the lower part of the river might be due to the presence of tidal influence, forested area and homestead activities in those areas[12] again, TDS was found positively highly correlated with TSS (table- 2). However, the overall mean of TDS was recorded 13953.5 mg/L which was beyond the Malaysian threshold level[22]. The turbidity of water samples in the study area varied from 1.59 NTU 1534 NTU (table-1). The highest concentration was observed at station I3 on January 2013 because of the same reason as TDS. Hence, TDS and turbidity are strongly correlated (table-2) the trend was similar all over the study area. However, turbidity level was higher than the threshold level in all part of the area[22].

Water quality degradation due to ammoniacal nitrogen remains a crucial environmental and public concern worldwide; because, it can cause eutrophication[26]. In the present study it was found that, the concentration of NH3-N was higher at all part of the study area compare to the national threshold level for Malaysia and based on the concentration maximum stations were categorized as class V (very highly polluted)[22]. High concentration of NH_3-N was due to industrial activities, especially chemical and petrochemical industries in the area[26]. The value of NO_3-N content was within the safe level (<0.4) [22], except four mid-stations (I3, I2, I1 and B3); those were in the vicinity of polymer, chemical, metal, gas and power, and wooden industries and some agricultural practices; and thus received most of their effluents[27]. The phosphate values were varied from 0.00- 37.2 mg/L with an average value of 1.10 mg/L. The highest value was recorded at S2 on July 2012; this area was newly developing area and the cause of higher concentration may be the natural and agricultural sources; also due to development work soil phosphorus might be released and mixed with surface water. The average concentrations in all other stations were also higher than the threshold limit[22]. The range of sulfate concentration was recorded 0-1280 mg/L with a mean value of 125.9 mg/L. The concentration was almost within the standard limit except station B1, B2 and I4 (table - 1). It might be due to station B1and B2 received sea water containing higher level of SO_4 [28] and station I4 is adjacent with some industries that produce detergent and discharged sulfur rich effluents into the river. At the same time $SO^{2-}{}_4$ was found highly correlated with TDS (table-2); at those stations TDS concentration was also higher.

Water quality index: Water quality index was calculated based on the sub-indices (SI) values as stated in methodology. The best fit equations as mentioned in table - 3 were used to estimate the SI values of the water quality parameters. SI values of six water quality parameters were obtained in every station and for both season (dry and wet) to show the spatial and temporal variation. Based on the SI values water quality classification was done and demonstrated at table- 4. Table - 4 showed spatial variation of WQI and the overall water quality status of the study area. As can be seen, SI values of DO were obtained 0 in all cases, because of its lower concentration throughout the study area for both seasons. Low index was obtained also in case of NH_3-N as all stations contained higher amount of NH_3-N. The result revealed that, lowest (worst) WQI was found at station I4 with 35.37 followed by station I3 and I2. The spatial variation of WQI of the study areas can be arranged in the following sequence (from the lowest value): I4< I3< I2< B2< B3< I1< U1< B1< S2< S1. The study explored that, the surface water quality of the area was found polluted at all parts including river and surrounding areas. Table - 4 also indicated that all station of river Tunggak were found to be highly polluted; whereas, the surrounding stations of GIE were found to be polluted. And at the same time overall status of surface water of the area was highly polluted.

Table-1
Descriptive statistics of the physico-chemical analysis (n=240) of the Tunggak River and surrounding area of GIE

M. Station	Stat. tools	pH	DO (%)	BOD (mg/L)	COD (mg/L)	SS (mg/L)	NH_3-N (mg/L)
B1	Range	5.6-7.5	1.29-4.77	2.9-13.1	18-116.0	6-345	0.20-2.46
	Mean	6.5±0.4	2.45±1.02	8.5±3.2	37.9±30.9	64.6±96.8	1.46±0.69
B2	Range	6.3-7.9	0.83-4.75	6.1-35.9	7.0-79.0	3-210	1.13-3.90
	Mean	7.1±0.4	2.43±1.29	16.4±9.4	38.7±21.3	37.6±56.2	2.28±0.69
B3	Range	6.5-8.4	0.74-5.04	7.1-37.2	3.0-72.0	4-208	0.85-4.05
	Mean	7.3±0.5	2.94±1.48	18.7±10.9	36.0±21.9	27.7±46.2	2.12±1.08
I1	Range	6.2-8.5	1.22-5.34	6.8-37.5	5.0-68.0	2-73	0.73-3.25
	Mean	7.4±0.6	3.60±1.19	18.9-10.7	37.8±20.0	17.6±20.7	1.61±0.74
I2	Range	5.7-9.0	0.65-4.68	5.7-37.1	8.0-111.0	5-67	0.43-3.25
	Mean	7.3±0.9	2.82±1.19	21.6±11.4	50.0±29.8	25.5±28.1	1.44±0.78
I3	Range	6.4-9.1	0.53-4.35	7.8-37.6	7.0-140.0	2-517	0.31-3.35
	Mean	7.5±0.7	2.12±1.23	21.4±12.7	54.4±39.7	73.8±157	1.55±0.94
I4	Range	5.4-8.6	2.11-4.59	7-38.4	1.0-116.0	3- 2171	0.57-1.76
	Mean	7.0±0.8	3.67±0.87	27.1±12.6	59.6±39.9	274.7±714	1.18±0.43
U1	Range	4.2-5.8	0.82-4.78	1.4-22.9	4.0-78.0	2-39	0.61-2.27
	Mean	4.9±0.4	2.33±0.91	10.3±6.1	35.0±19.5	12.4±9.1	1.44±0.53
S1	Range	4.2-7.8	0.41-2.29	0.1-10.9	2.0-79.0	2-36	0.00-0.62
	Mean	5.2±1.2	1.38±0.51	6.9±3.1	24.8±18.5	11.4±8.1	0.32±0.18
S2	Range	4.9-6.4	0.79-4.04	2.2-18.5	5.0-41.0	1-22	0.71-3.40
	Mean	5.5±0.5	2.30±0.88	9.2±5.1	14.0±8.5	9.5±6.6	1.96±0.77

M. Station	Stat. tools	NH_3N (mg/L)	NO_3N (mg/L)	SO_4 (mg/L)	PO_4^{3-} (mg/L)	NH_3N (mg/L)
B1	Range	0.01-0.23	39-1280	0.06-1.15	3330-107000	7.69-755
	Mean	0.11±0.07	585±408	0.5±0.32	39E3± 32480	91.4±189.5
B2	Range	0.08-1.40	14.0-680	0.11-2.07	762-24000	9.1-555
	Mean	0.37±0.30	136±153	1.0±0.62	6869.2±6246	85.4±178
B3	Range	0.00-2.30	11.0-140	0.11-1.74	499-4720	8.6-247
	Mean	0.44±0.56	51.0±34.0	0.89±0.54	2231±1531	45.4±73.4
I1	Range	0.01-2.70	9.0-260.0	0.1-1.93	457-5320	8.4-186
	Mean	0.78±0.98	63.3±71.7	0.67±0.56	2113±1586	35.1±50.5
I2	Range	0.00-4.50	25.0-310	0.09-2.21	542-5170	8.9-355
	Mean	1.01±1.52	75.1±87.4	0.76±0.66	2004±1391	58.9±82.9
I3	Range	0.00-3.70	10.0-430	0.01-3.20	649-658000	9.0-1534
	Mean	1.04±1.13	85±131.3	0.68±0.86	84001±219E3	206±496
I4	Range	0.00-0.42	1.00-680	0.02-1.41	128-2290	5.4-843
	Mean	0.12±0.13	198±219	0.13±0.27	765±691	108.9±260
U1	Range	0.00-0.03	0.0-51.00	0.0-0.12	19.6-515	4.6-57.7
	Mean	0.003±0.01	13.3±16.0	0.04±0.03	171.6±173.7	18.6±13.1
S1	Range	0.00-0.00	0.0-3.00	0.01-2.94	7.70-63.70	1.6-35.8
	Mean	0.00-0.00	0.50±0.98	0.18±0.59	39.35±19.48	10.7±9.8
S2	Range	0.03-0.28	30.0-90.0	0.04-37.2	333-2950.00	6.7-59.4
	Mean	0.15±0.08	52.0±18.3	6.13±12.03	1903±988.73	16.8±14.5

Table-2
Pearson correlation co-efficient (r) between the Water Quality parameters (N= 240)

	pH	DO	Turbidity	TDS	BOD	COD	SS	NH_3N	NO_3N	SO_4	PO_4^{3-}
pH	1										
DO	0.113	1									
Turbidity	0.041	**0.338****	1								
TDS	-0.003	0.123	**0.765****	1							
BOD	**0.562****	0.022	-0.092	-0.093	1						
COD	**0.331****	**-0.221***	-0.170	-0.073	**0.717****	1					
SS	0.063	**0.244****	**0.617****	**0.186***	0.015	-0.093	1				
NH_3N	**0.262****	**-0.145***	0.026	0.116	0.104	0.115	-.038	1			
NO_3N	**0.227***	0.007	-0.093	-0.061	-0.015	0.031	-.061	**0.272****	1		
SO_4	0.085	-0.062	-0.092	0.100	0.023	**0.234****	-.039	0.005	0.068	1	
PO_4^{3-}	-0.062	**-0.157***	-0.051	-0.035	-0.081	-0.099	-.031	**0.283****	0.011	-0.056	1

Significant level denoted as * for $p < 0.05$ and ** for $p < 0.01$

Table-3
Best fit equations for the estimation of the sub-index values

Sub-index	WQI Calculation	Ranges
SIDO	= 0 = 100 = - 0.395 + 0.03 x2 – 0.0002 x3	For x ≤ 8 For x ≥ 92 For 8 < x < 92
SIBOD	= 100.4 – 4.23 x = 108 e0.055x – 0.1 x	For x ≤ 5 For x > 5
SICOD	= - 1.33 x + 99.1 = 103 e0.0157x – 0.04 x	For x ≤ 20 For x > 20
SIAN	= 100.5 – 105 x = 94 e0.573x – 5 l x – 2 l = 0	For x ≤ 0.3 For 0.3 < x < 4 For x ≥ 4
SISS	= 97.5 e0.00676x +0.05 x = 71 e0.0061x – 0.015 x = 0	For x ≤ 100 For 100 < x < 1000 For x ≥ 1000
pH (SIPH)	= 17.2 – 17.2 x + 5.02 x2 = - 242 + 95.5 x – 6.67 x2 = - 181 + 82.4 x – 6.05 x2 = 536 – 77 x + 2.76 x2	For x < 5.5 For 5.5 ≤ x < 7 For 7 ≤ x < 8.75 For x ≥ 8.75
WQI	= 0.15 x SIAN + 0.19 x SIBOD + 0.16 x SICOD + 0.22 x SIDO + 0.16 x SISS + 0.12 x SIPH	

Source: Department of Environment, Malaysia, 1986

Table-4
WQI values of all monitoring stations and overall water status of the study area

Station	DOSI	BODSI	CODSI	ANSI	SSSI	PHSI	WQI	Class	WQ Status
B1	0	67	55	38	66	97	49.47	IV	Highly Polluted
B2	0	42	55	24	77	99	44.62	IV	Highly Polluted
B3	0	37	57	27	82	98	45.13	IV	Highly Polluted
I1	0	36	55	35	87	97	46.73	IV	Highly Polluted
I2	0	31	45	38	83	98	43.91	IV	Highly Polluted
I3	0	31	42	36	63	97	39.75	IV	Highly Polluted
I4	0	22	38	44	42	100	35.37	IV	Highly Polluted
U1	0	60	58	38	90	52	47.18	IV	Highly Polluted
S1	0	73	69	70	91	63	57.53	III	Polluted
S2	0	64	80	30	92	74	53.18	III	Polluted
Overall	0	43	54	37	70	97	45	IV	Highly Polluted

The spatio-temporal variation of WQI has been shown in figure - 2. The figure demonstrated that, almost in all cases the WQI was higher in wet season compare to the dry one except station I4. However, the status of WQI in both seasons was more or less similar with little fluctuation. As can be seen, irrespective of spatial and temporal variation WQI of the surface water of Tunggak River and surrounding areas of GIE was found to be very low. It was the indication of higher anthropogenic activities at the area. Actually, most of the chemical, petrochemical, metal, wooden, gas and power, mining and food industries were producing wastes and discharged untreated or partially treated wastes to the river flow and surrounding water body, which, resulted more deterioration of water quality at the region. According to the INWQS, Malaysia, that water was found to be un-usable without irrigation. Only, the surrounding stations were found to be class III (table 4), which can be used for water supply even after extensive treatment and for fisheries with tolerant species[22].

Conclusion

The study result revealed that, the surface water of the eastern part of peninsular Malaysia especially the GIE along with Tunggak River was not suitable for public consumption even after extensive treatment. Only at surrounding two stations, which were at submerged and less industrial zone, were found to be polluted that can be used for water supply after extensive treatment and for some selective tolerant species of fish cultivation. However, the water of Tunggak River can be used for only irrigation as per the INWQS Malaysian standards. The study also showed that, application of Water Quality Index (WQI) as a tool of assessing the overall surface water pollution was helpful and easily understandable. Although, all parameters were not considered, this method of water quality index assessment is seems to be more systematic; and it is easy for public understanding about the water pollution as well as a useful tool for water quality management in many ways.

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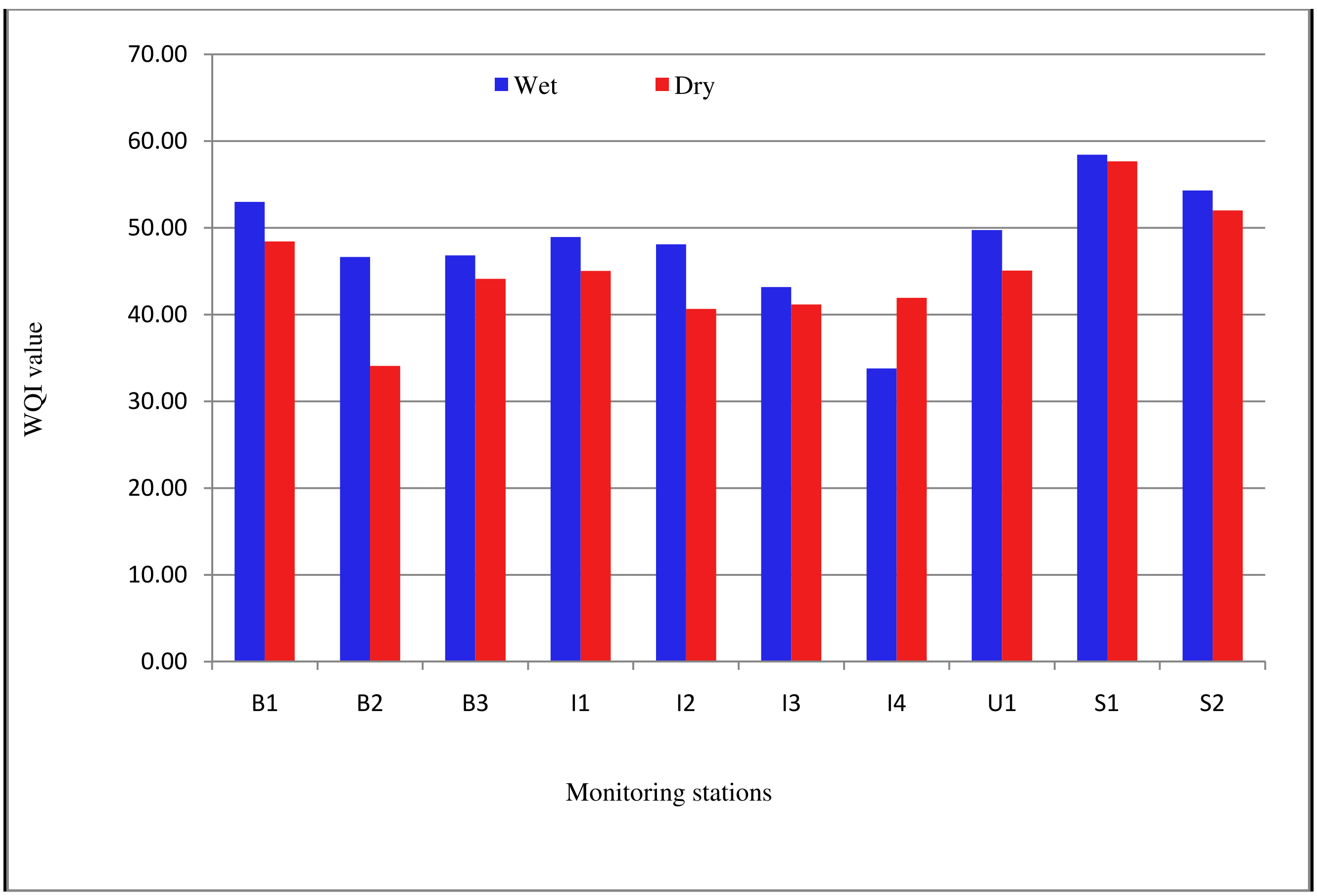

Figure-2
Spatio-temporal variation of WQI at the study area

References

1. Kushwah R.K., Malik S. and Singh A., Water Quality Assessment of Raw Sewage and Final Treated Water with Special Reference to Waste Water Treatment Plant Bhopal, MP, India**,** *Res. J. Recent Sci.,* **1(ISC-2011),** 185-190 **(2012)**
2. Czarra F., Fresh Water: Enough for You and Me? Occasional paper from *The American Forum for Global Education*, **(174**) 2-10 **(2003)**
3. Biswas A., Jana A.,and Sharma S. P. Delineation of Groundwater Potential Zones using Satellite Remote Sensing and Geographic Information System Techniques: A Case study from Ganjam district, Orissa, India, *Res. J. Recent Sci.,* **1(9),** 59-66, **(2012)**
4. Kazi T.G., Arain M.B., Jamali M.K., Jalbani N., Afridi H.I., Sarfraz R.A., Baig J.A. and Abdul Q. S., Assessment of water quality of polluted lake using multivariate statistical techniques: A case study, *Ecotoxicology and Environmental Safety*, **72(2)**, 301– 309, **(2009)**
5. Singh K.P., Malik A., Mohan D. and Sinha S., Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti river (India): a case study, *Water Res.*, **38(18)**, 3980–3992, **(2004)**
6. Yisa J. and Jimoh T., Analytical Studies on Water Quality Index of River Landzu, *American Journal of Applied Sciences*., **7(4)**, 453-458, **(2010)**
7. Ramakrishnaiah C.R., Sadashivalah C. and Ranganna G., Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, Indian, *J. Chem*., **6(2)**, 523-530, **(2009)**
8. Murhekar G. H., Trace Metals Contamination of Surface Water Samples in and Around Akot City in Maharashtra, India, *Res. J. Recent Sci.,* **1(7),** 5-9,**(2012)**
9. Ravichanddran M. and Ganesan J., Ethics and sustainability: a review of water policy and management, *American Journal of Applied Sciences*, **9(1)**, 24-31, **(2012)**
10. Department of Environment, Environmental Quality Report, 2010, Chapter 2. River water quality, Kuala Lumpur, Malaysia, **(2011)**
11. Nasly M. A., Hossain M. A., and Mir Sujaul Islam, Water Quality Index of Sungai Tunggak: An Analytical Study, In. Proceeding of *3rd International Conference on Chemical, Biological and Environment Sciences (ICCEBS'2013)*Kuala Lumpur Malaysia, 40-44, **(2013)**.
12. Hossain M. A., Mir S. I., Nasly M. A., Wahid Z. A., & Aziz E. A., Assessment of Spatial Variation of Water Quality of Tunggak River Adjacent to Gebeng Industrial Estate, Malaysia. *Assessment*, **501(47)**, A1-07 **(2012)**
13. Amadi, A. N., Olasehinde P.I., Okosun E.A. and Yisa J., Assessment of the Water Quality Index of Otamiri and Oramiriukwa Rivers, *Physics International* **1 (2)**, 116-123 **(2010)**
14. Sengupta, M. and Dalwani, R,(edited), Determination of water quality index and sustainability of an urban water body in Shimoga town, Kornataka, Proceedings of *Taal 2007: The 12th World Lake Conference*, 342-346, **(2008)**
15. Andrew D. Eaton, Lenore S. Clesceri, Eugene W. Rice, Arnold E. Greenberg and Mary Ann H. Franson, Standard methods for the examination of water and wastewater, *American Public Health Association (APHA),* Washington, USA. **(2005)**
16. HACH Company, Water analysis guide, USA, **(2005)**
17. Patil Shilpa G., Chonde Sonal G., Jadhav Aasawari S. and Raut Prakash D., Impact of Physico-Chemical Characteristics of Shivaji University lakes on Phytoplankton Communities, Kolhapur, India, *Res. J. Recent Sci.,* **1(2),** 56-60**(2012)**
18. Khan F, Husain T and Lumb A, Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada, *Environ. Monit. and Assess,* **88,** 221-242, **(2003)**
19. Norhayati Mustapha, Indices for water quality in a river, in *Master's thesis*, Asian Institute of Technology, Bangkok, **(1981)**
20. Haque M. A., Huang Y. F. and Lee T. S., Seberang Perai rice scheme irrigation water quality assessment, *Journal - The Institution of Engineers, Malaysia*., **71(4),** 42-49, **(2010)**
21. Booth J. Ashley T., Erika E. McPhee-Shaw, Paul Chua, Eric Kingsley, Mark Denny, Roger Phillips, Steven J. Bograd, Louis D. Zeidberg, William F. Gilly, Natural intrusions of hypoxic, low pH water into near shore marine environments on the California coast. *Continental Shelf Research,* **45 (2012)** 108–115, **(2012)**
22. Department of Environment, Interim National Water Quality Standards for Malaysia. DOE, Kuala Lumpur, Malaysia **(2008)**
23. Parihar S.S., Kumar A., Kumar A., Gupta R.N., Pathak M., Shrivastav A. and Pandey A.C., Physico-Chemical and Microbiological Analysis of Underground Water in and Around Gwalior City, MP, India, *Res. J. Recent Sci.,* **1(6),** 62-65, (2012)
24. Patnaik, K.N., Studies on environmental pollution of major industries in Paradip Area, in *Ph.D. Thesis*, Utkal University, Bhubneshwar, India, **(2005)**
25. N.K. Nagpal, Technical Report-Water Quality Guideline for Cobalt, Water Protection Section, Water, Air and Climate Change Branch, Ministry of Water, Land and Air Protection, PROV GOVT Victoria BC V8W 9M1, **(2004)**

26. Feifei Wang, Yuanhong Ding, Lei Ge, Hongqiang Ren, Lili Ding, Effect of high-strength ammonia nitrogen acclimation on sludge activity in sequencing batch reactor, *Journal of Environmental Sciences*., **22(11)**, 1683–1688, **(2010)**

27. Sujaul Islam Mir, M. A. Hossain, Sobahan M.A., Zularisam, A.W. and Edriyana, A. Aziz, Spatial Variation of Water Quality Parameters in Gebeng Industrial Area, Pahang, Malaysia. In. Proceedings of *International Conference on Environment, Chemistry and Biology IPCBEE, Hong Kong*.**(2012)**

28. Otukune, T.V. and C.O. Biukwu, Impact of Refinery Influent on Physico-chemical properties of a water body on Niger Delta, *J. Applied Ecol. Environ. Res.,* **3(1)**, 61-72, **(2005)**