Water quality assessment during river channel alteration for flood mitigation in Metro Manila, Philippines

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ABSTRACT

This study investigates the water quality of the Pasig River in Metro Manila during the construction of river improvements through channel alteration. Statistical and trend analysis of surface water have been performed using the records (2008-2011) of 5 water quality parameters (pH, dissolved oxygen, biochemical oxygen demand, total suspended solids and EC) at 4 observation sites along the Pasig River. The trend analyses were performed using a moving average approach and non-parametric Spearman's rho technique. The results indicate that most of the water quality parameters do not show significant trend; except for BOD and EC where these were found to significantly increasing in some of the observation sites. TSS was significantly decreasing in one site. Apart from these analyses, 14 other water quality parameters, collected annually, were assessed by comparing the values with the Philippine water quality standards. The findings of this study provide useful references for the monitoring of river water quality in Metro Manila.

INTRODUCTION

The ecological and socio-economic importance of a river depends highly on its beneficial use. The quality of water dictates whether the river is suitable for natural habitation, biological consumption, irrigation or industrial use (Loukas, 2010). In recent years, the increase in water demand and excessive pollution of surface water due to agricultural and industrial activities caused intensive social and ecological predicaments in the environment of many river basins around the world (Kerachian and Karamouz, 2006). In urban watersheds, rivers usually carry municipal and industrial wastewater, which makes the river more susceptible to anthropogenic pollutants (i.e. chemical, physical and biological contaminants) (Paredes et al., 2010; Fan et al., 2010). The likelihood of water contamination increases when human activities are performed directly on the river, which is a likely case during river channel alteration (World Meteorological Organization, 2007).

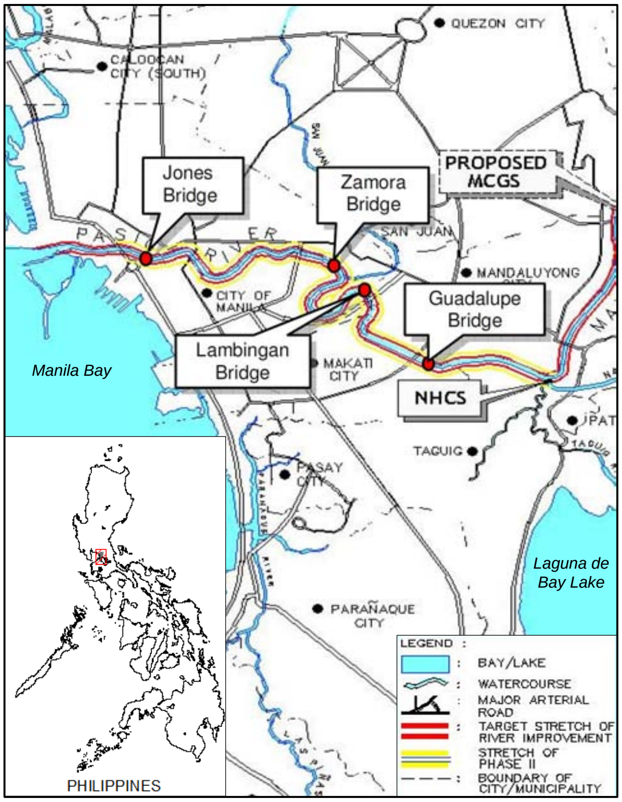

Figure 1. Location of river improvement works and water quality sampling sites.

In Metro Manila, flood problems are commonly addressed through drainage improvement and installation of flood protection facilities along major river systems. One major river channel that services the core area of Metro Manila is the Pasig River, as shown in Fig. 1. Many of the cities that surround the Pasig River are considered at high risk from extreme flood events. For this reason, the Pasig River has been placed in the high priority development objectives of the national government (Cruz, 1997), of which case the river banks shall be altered to accommodate better discharge capacity and better overflow prevention capability. The construction of the river improvement works started in July 2009, and will be completed by August 2012. The works involved are (1) construction and rehabilitation of revetments; (2) installation and modification of parapet walls; (3) installation of drainage pipes; and (4) removal of illegal structures, including informal settlements (Department of Public Works and Highways, 2011). Such activities may incur negative impacts on the quality of water in the Pasig River (World Meteorological Organization, 2007). Through the years, the populations of the aquatic biota (such as nektons) were seen to have significantly declined in the Pasig River due to human's disregard to the river's water quality. Recently, policies are being legislated to prevent further degradation of this water resource (Cruz, R, 1997), which makes it imperative to monitor the river's water quality to detect any significant harmful changes that have been incurred during the construction of the river improvements that may require immediate mitigation. These changes can be perceived using trend analysis techniques.

Trend analysis determines whether the measured values of a water quality parameter increase or decrease over a time period. There are different statistical techniques suitable for trend analysis depending on the characteristics of the data set. Because of the volume of data to be analyzed, and the various characteristics of the data, many trend analysis techniques were unsuitable or too time consuming to perform (Hirsch and Slack, 1984; Önöz and Bayazit, 2003). Antonopolous et al. (2001) even suggested that "it would be useful to describe the amount or rate of that change in terms of changes in some central value of the distribution such as mean or median". One such analysis is the moving average approach. The moving average approach is an exploratory technique that technically does not detect trends, but it allows the data examiner to visually identify changes and approximate trends from a “smoothened” time series plot without the constraints of mathematical functions (Helsel and Hirsch, 2002, 2001). Application of this approach (and its innovations) to water quality assessment has been well documented (Ebrahimi et al., 2011; Kim et al., 2012; Mariolakos et al., 2007; NIH, 2001)

Hirsch et al. (1982) suggested the use of Kendall non-parametric test (Kendall’s tau) for the detection of seasonally varying water quality time series. The robustness of Kendall’s tau is attributed to its ability to test time series with missing data (Antonopolous et al., 2001). Aside from Kendall’s tau, other common and equivalent measures of correlation are Spearman’s rho and Pearson’s r (Helsel and Hirsch, 2002). Quite a few studies investigated the use of Spearman’s rho in the examination of surface water quality (Antonopolous et al., 2001; Bouza-Deaño et al., 2008; Dawe, 2006; Kahya and Kalayci, 2004; Loukas, 2010; Tran et al., 2010). Louakas et al (2001) used the Student’s *t* test statistic to confirm the trend detected using the Spearman’s rho. Dawe (2006) suggested that the Spearman’s rho is highly robust and performs well in comparison to most trend analysis techniques. It is thus worth to examine the applicability of Spearman’s rho in the assessment of water quality parameters in the Philippines during the on-going works on river channel alteration as part of environmental monitoring. Such assessment approach has never been used for water quality monitoring in the Philippines, as far as the authors know. There is also no reference in any part of the world, as far as the authors know, on the use of the Spearman’s rho in the investigation of the effect of construction activities during channel alteration on the water quality of the river.

In this study, to detect the presence of trends in 5 water quality parameters (i.e. pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS) and electrical conductivity (EC)) that were recorded at 4 observation sites for a period of 35 months, a combination of time series plots, moving averages, and nonparametric Spearman’s rho were used. Furthermore, to assess the status of the water quality in the Pasig River, 14 other water quality parameters (i.e. nitrates (NO_3^{-1}), phosphates (PO_4^{-3}), chloride(Cl^{-1}), phenolic substances, cyanide(CN^{-1}), oil and grease, surfactant, organophosphate, total coliform, Cr^{6+}, As, Cd, Pb and total Hg) were examined against the Philippine water quality standards.

DATA USED AND METHODOLOGY

Data used

The value of trend analysis is as good as the data used, which makes it highly important to do a quality check on the data prior commencing to analysis (Kundzewicz and Robson, 2004). This is most useful when the quality of a water resource is already in poor condition, since the water quality is difficult to assess if the examination is merely a comparison of the monitored data with the water quality standards. In this study, water samples were taken at regular time intervals (bimonthly and annually) from 4 observation sites (i.e. Jones Bridge, Zamora Bridge, Lambingan

Bridge and Guadalupe Bridge) distributed along the 16 km stretch of Pasig River (Fig. 1). The water sampling technique complies with the Philippine standard for water sampling in ambient water (Environmental Management Bureau, 2008). The data used in this study were derived from both on-site and laboratory analyses of water samples. The instruments used for the on-site analysis of pH, DO and EC are regularly maintained and calibrated. Third party laboratory tests (with quality control) were performed on the other chemical parameters. Given the aforementioned quality procedures for water sampling and data collection, it was decided to consider all the collected data for trend analysis. Possible outliers were not ignored, since this could be attributed to some isolated phenomena. Bimonthly data were collected for pH, DO, BOD, TSS and EC in all the 4 observation sites for a period covering July 2008 to May 2011. Annual data for 14 water quality parameters (NO_3^{-1}, PO_4^{-3}, Cl^{-1}, phenolic substances, cyanide CN^{-1}, oil and grease, surfactant, organophosphate, total coliform, Cr^{6+}, As, Cd, Pb and total Hg) were collected in August 2008, August 2009 and September 2010. This is to observe the general water quality status of the Pasig River.

Methodology

The need for the statistical and trend analysis of water quality emanates from the fact that anthropogenic activities can generate negative effects on surface water resources and may be difficult to assess when the results are voluminous and highly varying (Simeonov et al., 2003; Taner et al., 2011). In this study, a typical visual approach and a robust statistical approach were employed for trend analysis. For the visual approach, a simple 6-month moving average plot (i.e. 3 values at 2 months sampling interval) was created for the water quality parameters pH, DO, BOD, TSS and EC taken from 4 observation sites. For the statistical approach, the Spearman's rho was used to evaluate the changes in the water quality. The Spearman's rho (r_S) is described by the formula (Hollander et al., 1999):

$$r_S = 1 - \frac{6\sum_{i=1}^{n}(D_i^2)}{n(n^2-1)} \quad (1)$$

Where n is the total number of values in each time series, D is the difference, and i is the chronological order number. The difference between rankings is computed as $D_i = S_{xi} - S_{yi}$, where S_{xi} is the rank of a measured variable in chronological order and S_{yi} is the series of measurements transformed to its rank equivalent, by assigning the chronological order number of the measurement in the original series to the corresponding order number in the ranked series, y. The null hypothesis, H_0: $r_S = 0$ (there is no trend) against the alternate hypothesis, H_1: r_S < or > 0 (there is trend), is checked with the test statistic (t_t) given by the formula (Antonopolous et al., 2001)

$$t_t = r_S \left[\frac{n-2}{1-r_S^2}\right]^{0.5} \quad (2)$$

Where t_t has Student's t-distribution, with $\upsilon = n - 2$ degrees of freedom (Kottegoda and Rosso, 1997). At a significance level of 5%, the time series has no trend if $t_c\{\upsilon, 2.5\%\} < t_t < t_c\{\upsilon, 97.5\%\}$, where t_c is the critical value of the Student's t test statistic. In this study, the absolute value of t_c is 2.12 based on the statistical tables of critical values of Spearman's rho (Kottegoda and Rosso, 1997).

To determine whether water quality parameter values had increased or decreased, time series of the water quality data and 6 months moving averages were plotted to have a rough visual context of the trends. For brevity, the time series with 6-month moving averages plots of 2 (i.e. TSS and BOD) of the 5 water quality parameters from all 4 observation sites were presented in this paper.

A tabulated summary of the Spearman's rho (the entire period of record) was produced and examined in conjunction with the time series plots. Other statistical values (minimum, maximum, mean and standard deviation) were included in the table to aid of the assessment process (Yilmaz et al., 2011). The trends are indicated either as "increase" or "decrease" with remarks of whether the trend is *significant* or *insignificant*

A summary of the annual data of 14 other important water quality parameters was tabulated and compared with the Philippine water quality standards to examine the general water quality status of the Pasig River.

RESULTS AND DISCUSSION

In this paper, times series plots of 6-month moving average were constructed for each water quality parameter of each observation site. Fig. 2 shows the time series plot of BOD concentration. By inspection, the trend in BOD, as shown by the 6-month moving average plot, is apparently increasing in all the observation sites, but the trend is most pronounced in Jones Bridge (Fig. 2a). The weakest trend is observed in Lambingan Bridge (Fig. 2c) where there are several high peaks and low troughs in the plot of actual values. Very high concentration of BOD was observed in Zamora Bridge, Lambingan Bridge and Guadalupe Bridge in Month 35. It is worth to note

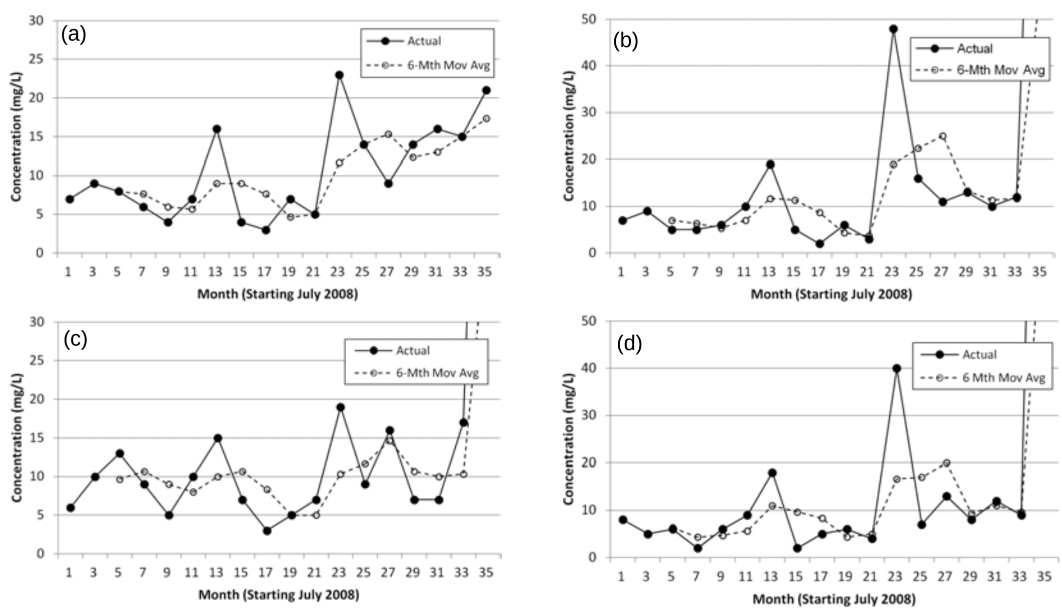

Figure 2. Time series and 6-month moving averages plots of BOD in (a) Jones Bridge, (b) Zamora Bridge, (c) Lambingan Bridge and (d) Guadalupe Bridge.

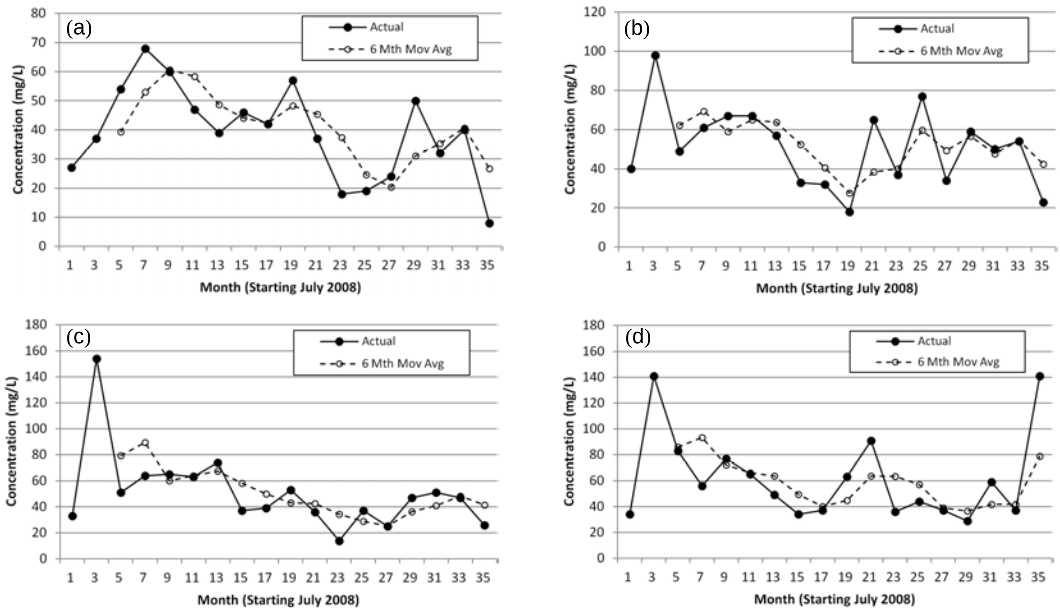

Figure. 3 Time series and 6-month moving averages plots of TSS in (a) Jones Bridge, (b) Zamora Bridge, (c) Lambingan Bridge and (d) Guadalupe Bridge.

that the trend is increasing in the lower stretch of the river, which indicates that the pollutants causing the high BOD are accumulating in the downstream. The concentration of BOD indirectly indicates the level of presence of organic matter in a water sample (Davis and Masten, 2004). In the case of the water samples from the observation sites, organic material was observed to be increasing, which is probably due to human activities since the whole vicinity of the river is highly urbanized. The Pasig River is a conduit for discharged storm water run-offs as well as for domestic wastewater (such as brown water) within the river basin. Nearby settlements are also suspects for directly discharging their domestic wastes into the river. However, relocation of informal settlers living on top of the river banks has been going on even before the construction works for the river improvements commenced, which should reduce the organic loads entering the river. With regard to channel alteration, activities such as river bed excavation and river bank incision may cause the re-suspension of highly organic silts. Several peaks of BOD concentration were observed during the construction phase of the channel alteration (July 2009 to May 2011). However, low concentrations were also observed during this period. To investigate the possible contribution of the re-suspension of silts to the increasing concentration of BOD, the concentrations of TSS in the 4 observation sites were examined.

Fig. 3 shows the time series plots of TSS. The trend in all observation sites are generally decreasing with the strongest trend observed in Lambingan Bridge. The weakest trend however is difficult to identify by inspection using the 6-month moving average plot. If the high concentration of BOD is due to the re-suspension of silts, it is only logical to assume that the increase in BOD should be supported by an increasing trend in TSS. However, this is not true based on the comparison of trends in Fig. 2 and Fig. 3. This indicates that the increase in BOD concentration is probably due to

Table 1. Summary of statistical analysis of water quality parameters.

Water Quality Parameters	Observation sites	No. of Obs.	Min	Max	Mean	Std Dev	Spearman's rho (r_S)	Test statistic (t_t)	Trend	Remarks
BOD	Jones Bridge	18	3.00	23.00	10.44	5.99	0.54	2.59	Increase	Significant
	Zamora Bridge	18	2.00	152.00	18.83	34.78	0.53	2.50	Increase	Significant
	Lambingan Bridge	18	3.00	105.00	15.00	22.92	0.28	1.17	Increase	Insignificant
	Guadalupe Bridge	18	2.00	225.00	21.39	51.53	0.52	2.42	Increase	Significant
TSS	Jones Bridge	18	8.00	68.00	39.17	15.91	-0.43	-1.93	Decrease	Insignificant
	Zamora Bridge	18	18.00	98.00	51.17	20.25	-0.29	-1.22	Decrease	Insignificant
	Lambingan Bridge	18	14.00	154.00	50.89	30.13	-0.48	-2.17	Decrease	Significant
	Guadalupe Bridge	18	29.00	141.00	61.83	34.08	-0.16	-0.63	Decrease	Insignificant
pH	Jones Bridge	18	6.62	8.19	7.35	0.48	-0.18	-0.72	Decrease	Insignificant
	Zamora Bridge	18	6.40	8.50	7.44	0.53	-0.33	-1.41	Decrease	Insignificant
	Lambingan Bridge	18	6.40	8.50	7.39	0.49	-0.18	-0.75	Decrease	Insignificant
	Guadalupe Bridge	18	6.40	8.50	7.40	0.50	0.04	0.15	Decrease	Insignificant
DO	Jones Bridge	18	0.95	4.30	2.06	0.83	-0.07	-0.28	Decrease	Insignificant
	Zamora Bridge	18	0.42	3.36	1.90	0.92	-0.23	-0.94	Decrease	Insignificant
	Lambingan Bridge	18	0.30	5.79	2.33	1.18	-0.24	-1.01	Decrease	Insignificant
	Guadalupe Bridge	18	0.43	4.64	2.77	1.05	-0.12	-0.47	Decrease	Insignificant
EC	Jones Bridge	18	5.30	33,900.00	2,536.51	7,878.98	0.57	2.78	Increase	Significant
	Zamora Bridge	18	0.00	8,420.00	873.24	1,916.71	0.40	1.76	Increase	Insignificant
	Lambingan Bridge	18	0.00	17,900.00	1,383.44	4,137.65	0.39	1.70	Increase	Insignificant
	Guadalupe Bridge	18	0.00	1,624.00	487.77	456.90	0.31	1.33	Increase	Insignificant

Note: the corresponding units of the water quality parameters are: BOD, mg/L; TSS, mg/L, pH, (no dimension); DO, mg/L; EC, μS/cm

other anthropogenic sources. To have a better picture of the trends, a more accurate technique in trend detection is needed.

To provide a mathematical basis for the trends, and to confirm the trend approximations made based on the inspection of the 6-month moving averages, the Spearman's rho (rank correlation) was used. In this study, a significance level (α) of 5% was used. Given that there are 18 observation values (n) for each parameter, the critical value (t_c), based on the table of cumulative Student's t distribution (Kottegoda and Rosso, 1997), is 2.12. Statistical values (i.e. minimum, maximum, mean and standard deviations) of the water quality data were also calculated.

Table 1 shows the summary of the statistical analysis of water quality parameters in each observation sites with calculated values of Spearman's rho (r_s) and test statistic (t_t). The trend is identified for each water quality parameter and sampling station by either *increase* or *decrease*. Finally, the identified trend is remarked as either *significant* or *insignificant*.

According to Table 1, the trend of BOD concentrations in all observation sites is increasing. This is consistent with the earlier approximation using the 6-month moving average plot. The range of values (3 to 24 mg/L) in Jones Bridge is relatively much smaller compared to the ranges of values of the other observation sites. The mean and standard deviation are smaller as well. The test for significance revealed that the BOD concentrations in Jones Bridge, Zamora Bridge and Guadalupe Bridge were significantly increasing. The highest trend (r_S = 2.59) was found in Jones Bridge, while the lowest trend (r_S = -0.28) is in Lambingan Bridge. This again is consistent with the earlier assessment made using the moving average approach. The maximum BOD concentrations in Zamora Bridge, Lambingan Bridge and Guadalupe Bridge (i.e. 152, 105 and 225 mg/L, respectively) are very high compared with the Philippine standard (10 mg/L) (DENR Admnistrative Order No. 34/1990), but the

Table 2. Summary of the values of 14 important water quality parameters.

Water Quality Parameters	Unit	Jones Bridge	Zamora Bridge	Lambingan Bridge	Guadalupe Bridge	Philippine WQ Standard
		Range	Range	Range	Range	
Nitrates	mg/L	0.25 to 0.43	0 to 0.53	0.23 to 0.37	0.25 to 0.52	10.00
Phosphates	mg/L	0.21 to 0.26	0.15 to 0.30	0.13 to 0.19	0.14 to 0.15	0.40
Chloride	mg/L	34.8 to 129.6	29.1 to 156.50	29 to 165.10	30 to 163.90	350.00
Phenolic substances	mg/L	0.00	0.00	0.00	0.00	0.02
Cyanide	mg/L	0.00	0.00	0.00	0.00	0.05
Oil and grease	mg/L	0.00	0 to 2.70	0 to 1.80	0 to 1.30	2.00
Surfactant (MBAS)	mg/L	0.00	0 to 0.12	0.00	0.00	0.05
Organophosphate	mg/L	0.00	0.00	0.00	0.00	3.00
Total Coliform	MPN/100mL	2.10×10^5 to 5.40×10^5	1.10×10^5 to 3.50×10^5	1.30×10^5 to 5.40×10^5	1.30×10^5 to 1.60×10^6	5.00E+03
Hexavalent Chromium	mg/L	0.00	0.00	0.00	0.00	0.01
Arsenic	mg/L	0.00	0.00	0.00	0.00	0.05
Cadmium	mg/L	0.00	0.00	0.00	0.00	0.01
Lead	mg/L	0.00	0.00	0.00	0.00	0.05
Total Mercury	mg/L	0.00	0.00	0.00	0.00	0.00

Note: MBAS, methylene blue active substances; MPN, most probably number; WQ, Water quality

mean and standard deviation are quite low, which indicates that the occurrence of high BOD concentrations are probably isolated cases that are not necessarily caused by the construction of river improvements in the Pasig River.

In the analysis of the TSS concentration, it was found that the trend is decreasing in all observation sites. This is consistent with the earlier assessment of TSS using the moving average approach. The strongest decreasing trend (r_S = -2.17) occurs in Lambingan Bridge (which is also statistically significant), while the weakest decreasing trend (r_S = -0.16) happens in Guadalupe Bridge. The identification of the weakest trend in TSS was difficult using the 6-month moving average approach, but this trend was easily identified using the Spearman's rho technique. The statistical results of the BOD are not consistent with the results of TSS analysis, thus it is highly probable that the significantly increasing trend in BOD concentration in 3 of the 4 observation sites is not due to the activities associated with the alteration of the Pasig River. Likewise, the significantly increasing trend of EC in Jones Bridge is probably due to the encroaching seawater, which mixes with the river water coming from the upstream. Sea water contains naturally occurring salts, which dissociates into cations and anions when in solution form. High presence of salts in water result to high EC (Najah et al., 2009). The mean of EC (~2,540 μS/cm) in Jones Bridge is quite high, which indicates that the mixture of seawater and river water is quite prevalent. The EC in the other observation sites, though relatively smaller compared to Jones Bridge, also indicate high presence of salt water. One possible reason is the occurrence of a phenomenon known as high tide. The operation of the Napindan hydraulic control system located at the upper stream of Pasig River allows the flow of the river water towards Laguna de Bay Lake when the water level in the lower stream rises due to high tide and storm run-offs (Fig. 1). This operation allows the passage of sea water across the 4 observation sites. The rest of the parameters (pH and DO) were observed to be generally decreasing with very low significance. Since the concentration of DO is inversely related with the concentration of BOD (Olutiola et al., 2010), the low values of DO justifies the high concentrations of BOD. There is very little change in the values of pH, which indicates that the water is probably buffered by synergistic substances, such as the complex interactions and speciation of cations and anions (McCutcheon et al., 1993). Overall, the results of the statistical approach provide a more informative assessment of the general conditions of the river.

For the general assessment of water quality of Pasig River, other important water quality parameters were tabulated and compared with the Philippine standards (DENR Admnistrative Order No. 34/1990). Table 2 shows the summary of tabulated values of 14 water quality parameters. The data of these 14 parameters were collected on an annual basis. The values of the water quality parameters generally comply with the Philippine water quality standards, except for oil and grease and surfactant concentration in Zamora Bridge, and the total coliform content in all observation sites. Oil and grease can come from waste water discharges and transportation vehicles plying over the observation sites (bridges). Small boats and other engine operated river crafts are also regularly seen on the river. Surfactants, in Metro Manila, commonly come from detergents and other cleaning implements. This is perhaps coming from the nearby commercial establishments and residential communities. The presence of high total coliform confirms the contribution of human activities in the pollution of Pasig River, even before the construction of the river improvements. The total coliform contents in 2008 already far exceed the permissible limit. This high density of coliform is directly related to the high concentrations of BOD (Olutiola et al., 2010) in all the observation points, since these organisms are essentially organic in nature and utilizes oxygen.

SUMMARY AND CONCLUSION

This paper examined the possible effects of the activities associated with the river channel alteration on the water quality of Pasig River in Metro Manila, Philippines using a typical visual approach and a robust statistical method for trend analysis. A conventional comparative approach was also used in the assessment for compliance of the water quality parameters to a set of local regulatory standards. To carry out the visual approach for trend analysis, time series plots of 6-month moving average was constructed for 2 important water quality parameters (BOD and TSS) collected in 4 observation sites from July 2008 to May 2011. The plots were useful in approximating the trends, but are not sufficient to accurately visualize the weak and strong trends. To address this limitation, the Spearman’s rho was used to statistically determine the trends of 5 water quality parameters (BOD, TSS, pH, DO and EC) collected within the same sampling period and same observation sites. This technique provided a more comprehensive assessment of the water quality in Pasig River, by also identifying the significance of each trend. The approximations by inspection using the moving average approach were very close to the results of the statistical approach.

The statistical trend analysis provided a clear distinction of the increasing and decreasing trend in all the statistically treated water quality parameters. Increasing trend of BOD concentration was found in all observation sites with strong significant increasing trend along the river’s lower stretch (Jones Bridge). In contrast, poorer water quality, in terms of BOD, was observed in the river’s upper stretch. The results of the statistical analysis of TSS supports the conclusion that the increasing BOD load in the Pasig River is most likely not caused by the activities associated with channel alteration, instead, it is believed that the high organic content is coming from human wastes discharged from the outpouring drainage facilities. Further examination of the water quality parameters revealed that the sea water encroaches towards Jones Bridge as indicated by the high values of EC, which perhaps dilutes the BOD concentration. The idea of dilution explains why the BOD load is relatively smaller in the lower stream than in the upper stream.

The examination of other important water quality parameters revealed that the quality of water in the Pasig River is fairly within permissible limits, with the exception of the high BOD concentration and total coliform. The former is associated with high organic content, while the latter is associated with human and animal wastes. Since the river basin is essentially inhabited by people, the reason for high total coliform content is probably due to the discharges of human wastes. Thus, the results of coliform and BOD analyses strengthen the idea that the activities associated with channel alteration (with works indicated in this study) do not create significant effect on the water quality of the river. Incidence of oil and grease exceeding the permissible level was also observed, but can easily be attributed to other regular anthropogenic pollution sources. These findings provide useful references to further understand the impacts of channel alteration on a river's water quality.

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