ASSESSMENT OF WATER QUALITY IMPACTS OF HIGHWAY AND ROAD CONSTRUCTION PROJECTS

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ABSTRACT

This paper presents the outcomes of a research study conducted to understand the water quality impacts from high way and road construction projects in natural water bodies in Sri Lanka. The knowledge generate through the study contribute to strengthen the design and implementation of Best Management Practices (BMPs) to safe guard the water quality of natural water bodies adjacent to the construction sites. The study was conducted based on the number of surface water samples collected at several highway and road construction projects which have been recently undertaken in Sri Lanka. The collected samples were tested for six parameters namely pH, Electrical Conductivity (EC),Total Suspended Solids (TSS), Escherichia Coli(E. coli), Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO). It has been noted that the both highway and road construction projects impose a significant threat on the water quality of natural water bodies. It is of crucial importance to focus on minimizing the soil erosion and the dust accumulation at the highway and road construction sites when design and implementing the BMPs. However, in this context detail understanding on gradation of solids and the adherence of pollutants to different particles sizes of solids is recommended to design effective BMPs. Furthermore, it is important to consider the difference of geographical and surface characteristics when design and implementing BMPs. Additionally, pH was identified as a surrogate to monitor the water quality of water bodies adjacent to construction sites.

Key words**:** Water Quality, Construction, Best Management Practices

1. INTRODUCTION

Construction activities have historically identified as a major source of pollutants to natural water bodies such as rivers, lakes and streams [2,9]. The sources of water pollutants at construction sites primarily include soil erosion, diesel and oil, paint, solvents, cleaners and other harmful chemicals and construction debris and dirt. Pollutants generate from these sources are added to adjacent water bodies through both direct discharge by workers at the sites and as well as non-direct discharge results with the storm water runoff leading to physical, chemical and biological degradation of water quality [5, 11, 12].

Most importantly, safe water is a precondition for health and development and a basic human right (10). However, escalating rate of construction activities such as building, highway and dam construction in the world resulting with rapid increase of population and urbanization during recent past has already created a significant threat on water quality of scares natural water bodies [7, 12]. In this context, regulatory authorities recently have focused increasing attention on implementing the good construction practices and best management practices (BMPs) to safeguard the water quality of adjacent water bodies. For example, legalizing the requirement of conducting the environmental risk assessments (ERA) for all construction activities and materials likely to cause pollution and then identify and implement specific measures such as silt fence barriers, diversion ditches and vegetative covers that can be taken to mitigate the risks [3].

Notably, Sri Lanka is currently in an era of rapid development of infrastructure facilities to achieve the goals of the development process in the country. In this context, the construction of roads and highways and rehabilitation of existing road network have drawn a wide spread attention as millstones of this development process. However, in order to achieve the concepts of sustainable development for the country it is in crucial importance to take the remedies to minimize the impacts of the highway and road construction on the scares natural water resources in the country. Although, the regulatory authorities have already focused on this, the success of these efforts are still limited. This is mainly attributed to the lack of knowledge and understanding on the pollutants generate from different construction activities and time and cost consuming in water quality monitoring studies.

This research study carried out to understand the water quality impacts of highway and road construction projects and the road rehabilitation projects which have been recently undertaken in Sri Lanka. The knowledge generate from this study is contributed to design and implementation of BMPs at highway and road construction projects to safe guard the water quality of adjacent water bodies in Sri Lanka.

2. METHODOLOGY

Water quality data for this research study was collected based on four major highways and road construction and rehabilitation projects which have been undertaken from 2006 to 2010 in Sri Lanka (See Figure.1).

Figure 1:Projects locations

Most importantly, this includes two main highway projects which led a remarkable foundation for the widely spread road network in Sri Lanka. Table 1 shows a brief description of each project.

Table.1: Project Description.

Project	Description
OCH-PHASE2	Greater Colombo Urban Transport Development Project- Outer Circular Highway-Phase 2(from Kaduwela to Kadawatha.)
KMP-UM	ADB funded national highway sector project-Kandy_Mahiyangane_Padiyathalawa from Udatanne to Mahiyangane road.
NB	ADB funded national highway sector project-Nuwaraeliya_Badulla road.
STDP-KG	Southern Transport Development Project –from Kurundugaha to Galle.

The water samples were collected weekly and monthly basis from number of pre-defined sampling points at the adjacent streams to the road construction sites in all the projects when the construction work is on progress. The sampling points were selected along a stretch of at least 8 km in all the selected streams adjacent to the sites. Most importantly, for each sampling point one baseline sample was collected before starting the construction work. This was done for the comparison purposes in the data analysis. The number of sampling points and the number of samples collected at each road is shown in Table.2

All the samples collected were tested for six parameters namely pH, Electrical Conductivity (EC),Total Suspended Solids (TSS), Escherichia Coli (E. coli), Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO) according to the standard water quality testing procedures (Central Environmental Authority(CEA) standards). These parameters were selected based on the understanding generated from the comprehensive literature review conducted to understand the key indicators of the receiving water quality [2, 4].

The collected water quality data was then analysed using both univariate and multivariate data analytical techniques with the support of MS excel 2010 and StatistiXL Version 1.9 software packages.

Table.2: Project details and sampling locations.

Project	Duration	Road Stretch	Sampling Point 1	Sampling Point 2	Sampling Point 3	Sampling Point 4	Sampling Point 5	Sampling Point 6
OCH	Jan. 2012 to Jan. 2015	8.9km	ihalabiyanwila road, kadawatha, 1st culvert of the paddy field.	paddy field culvert of jayanthimawatha, biyagama.	Kelaniya-biyagama road bridge.	kelani river at rakgahawaththa ferry.		
KMP	June 2007 to May 2010	41km	Km 40+260	Km 43.150	Km 62+950	Km 66+900	Km 72+000	
NB	June 2007 to May 2010	54.78km	Gregory Lake-Nanuoya (77/8)	Uma Oya - Welimada Town (99)	Labutota bridge (102/2)	Girambaya bridge (108/1)	HaliElabridge(125/4)	Mahabokkuwa (129/4)
STDP	Mar. 2008 to Nov. 2011	96km	Gin ganga	Keembiaya Ella	Holuwa godaEla	Polwatta ganga	Sulthanagodawela	

3. DATA ANALYSIS

The laboratory data obtained for the six parameters measured for all the samples collected at each site as described in Section 2 was subjected to data analysis. As shown in Table 2, due to the number of samples collected at each site and the number of parameters measured on each sample the data analysis of this research study was conducted using both univariate statistical data analysis techniques and the multivariate data analysis techniques.

3.1. Univariate analysis techniques

Univariate statistical analysis techniques were used to explore the primary variability of data in terms of mean and standard deviation (SD). These are two widely used univariate statistical measurements to describe the characteristics of a single variable data set [1]. In this study the univariate analysis was conducted using MS Excel 2010.

3.2. Multivariate analysis techniques

The application of univariate data analysis techniques was limited because of the constraints associated with manipulating and investigating multiple measurements on many samples. This was overcome by the application of multivariate data analysis technique namely principal component analysis (PCA). PCA was employed for pattern recognition and to visually display the relationships between variables and objects. The PCA was conducted with the support of StatistiXLVer 1.6.

PCA transforms multivariate data into orthogonal components called principal components (PCs) which are uncorrelated with each other and are linear combinations of the original variables. PCs retain the most variance within the original data so that transformation is achieved without loss of information in the data set. The first principal component describes most of the data variance while the second PC the next largest amount and so on until as many PCs are generated depending on the number of variables. However, though PCA produces a number of PCs, the first few PCs are selected for interpretation as they represent most of the variance in the data set [1].

Before proceeding with PCA, the original data was arranged into a matrix representing variables by columns (water quality parameters) and objects by rows (samples). In order to avoid the influence of the different scales of variables, the data was pre-treated using method of auto scaling [8]. This was done by subtracting the column mean from each element in the respective columns and dividing by the standard deviation for that column.

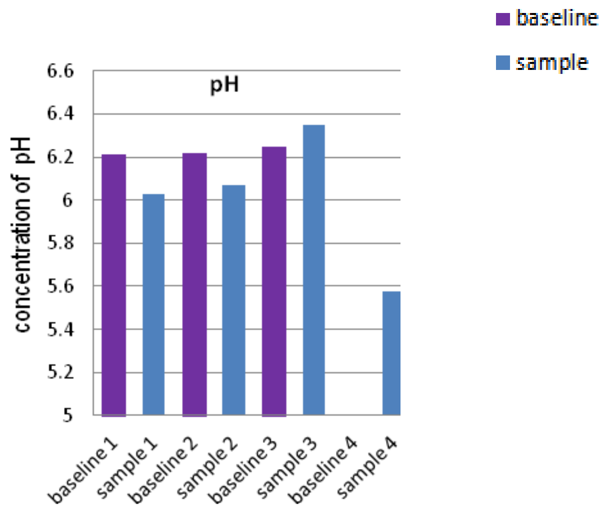
The pre-treated data matrix was then subjected to PCA. Each PC generates scores and loadings. The scores are projections of the objects on to a particular PC and the loadings are a measure of the contribution of original variables to a particular PC. Therefore, the data can be conveniently displayed as a PC scores–scores plot and as a PC loadings plot. These plots provide guidance for the recognition of important variables and objects on a PC. Most importantly, valuable information can be obtained from a biplot, which overlays the loadings over a scores plot. The degree of correlation between variables is decided depending on the angle between variable vectors in the biplot. An acute angle between two vectors indicates strong correlation between the respective variables whereas obtuse angle indicates weak correlation. Right-angled vectors indicate no correlation [6].

4. RESULTS AND DISCUSSION

4.1. Univariate analysis

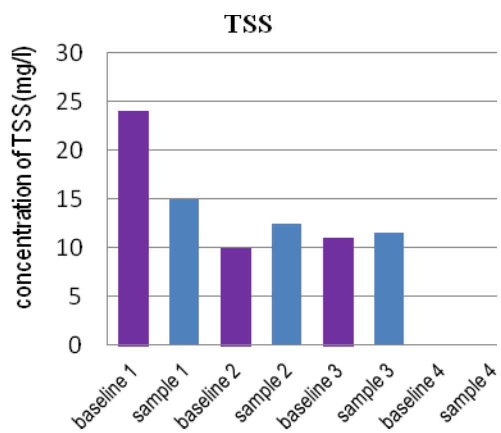
Univariate analysis was done primarily in two stages. Firstly, the mean and SD of each parameter were obtained for all the samples collected at each sampling point in each site. These data was then compared with the base line data at each sampling point in order to understand the variability of water quality during the construction.
Secondly, an overall analysis of variation of parameters between each project is conducted by comparing the change in the water quality parameters as a percentage. In this analysis firstly, the mean value of all the base line data of all the sampling points for each parameter at each project was obtained. Next the mean of all the sample data was determined and obtain the change as a percentage compared to the mean of the baseline data. This was done due to the difference in the baseline data at each project base on the different geographical and climatic conditions at different sites.

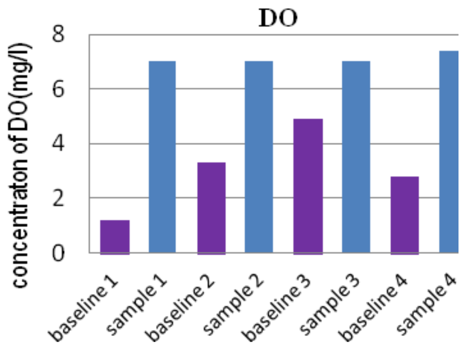
Figure 2a to 2e show results of the variation of water quality parameters at each sampling location for OCH project. According to Figure 2, most of the parameters show considerable variation when compared with the baseline data. Same trend was observed for the other projects also. This indicates that the construction activities considerably influence the water quality variation of adjacent water bodies which further confirms the findings of several researchers as discussed in Section 1.



(a)

(b)





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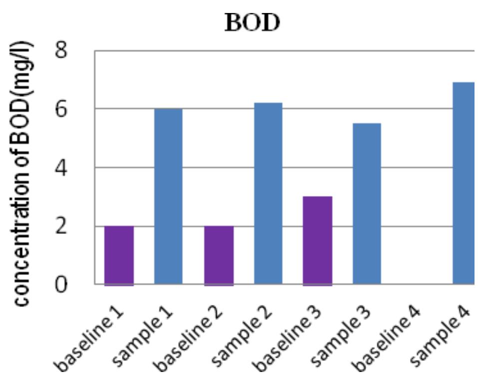

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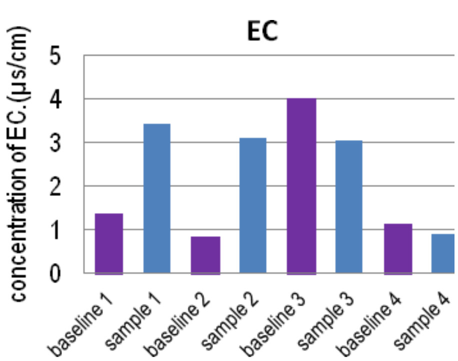

(e)

Figure 2:Water quality variation at each sampling point at OCH project

Table 3 shows the results obtained from the overall analysis of variation of parameters between each project as a percentage. The upward arrow (↑)indicated the increase compared to baseline where as downward arrow (↓) represents the decrease.

As can be seen in Table 3, TSS, BOD and E. coli show relatively higher variation at all the construction projects compared to that for pH, DO and EC for most of the construction projects. This suggests that construction activities impose a significant threat on the water quality in terms of physical and biological perspective.

Most importantly, considerably larger increase of TSS at KMP, NB and STDP suggests the importance of focusing on minimizing the soil erosion and the dust accumulation at the highway and road construction projects when implementing the BMPs. Furthermore, as can be seen in Table 3, NB shows markedly larger increase of percentage for TSS compared to that of the other projects. This can be mainly attributed to the higher rate of runoff off due to the relatively larger slopes of the road surfaces based on the geographical conditions in the area. This indicates the importance of consideration of such characteristics when implementing the BMPs to mitigate the solids export from the construction sites to adjacent water bodies.

On the other hand, as shown in Table 3 OCH shows notable increase of the DO which is approximately double the amount of the base line value compared to that of the other projects. Even though the reason is unclear within the scope of this study it can be postulated that the construction activities could significantly impact on DO levels of adjacent streams of the construction sites under certain circumstances such as flood events.

Furthermore, according to Table 3 a considerable increase of E.coli has occurred in OCH-construction site. This could be attributed to the uncontrolled Discharge of sewerage and runoff contaminated with animal waste from the site.

Moreover, KMP shows the largest increase for BOD whereas OCH shows the second largest variation of that. According to Table 3, it can be postulated that both highway and road construction activities significantly impact the water quality of natural water bodies irrespective of whether the highway or road construction.

Table 3: Overall variation of parameters as a percentage compared to the baseline data

Project	Percentage change of parameter					
	pH	*EC*	*TSS*	*E. coli*	*BOD*	*DO*
OCH-phase2	4.33% ↓	34.32% ↑	19 52% ↓	184.21% ↑	138.67% ↑	192.31% ↑
KMP	22.4% ↑	29.17% ↓	100.7% ↑	84.7% ↓	167.23% ↑	2.28% ↑
NB	7.93% ↑	7.39% ↑	238.38% ↑	65.97% ↓	43.26% ↓	21.97% ↑
STDP	6.14% ↓	38.08 ↓	85.55% ↑	*no data_*	90.67% ↓	37.85% ↓

4.2. Multivariate analysis

The PCA of this research study was conducted on each constriction projects separately. This is mainly due to the inconsistency in the base line data depending on the factors such as geographical location, climatic characteristics and land use characteristics in different regions in the country. The same set of variables as discussed in Section 2 was used for the analysis. Following describes the outcomes of PCA for each project separately.

KMP

Figure 3 shows the PCA bi-plot obtained for KMP project. As can be seen in Figure 3 the first two PCA explain a relatively high variance which accounts for 69% of the total variance. This indicates that the majority of the data has been used in the analysis.

As can be seen in Figure 3 TSS, BOD, E coli and EC are strongly correlated to each other. This indicates that the increase of suspended solids increase the BOD, E coli and EC level. This can be mainly attributed to the greater affinity of pollutants such as nutrients, heavy metals, pathogens and hydrocarbons to the particulate fraction of solids wash off as noted by several researchers [2, 6].This suggests that the importance of targeting the direct wash off of solids generate from the construction sites when implementing the best management practices to safe guard the water quality at adjacent water bodies. This is further confirmed by the considerable increase of TSS at most of the construction sites studied in this research project as noted in the Section 4.1.

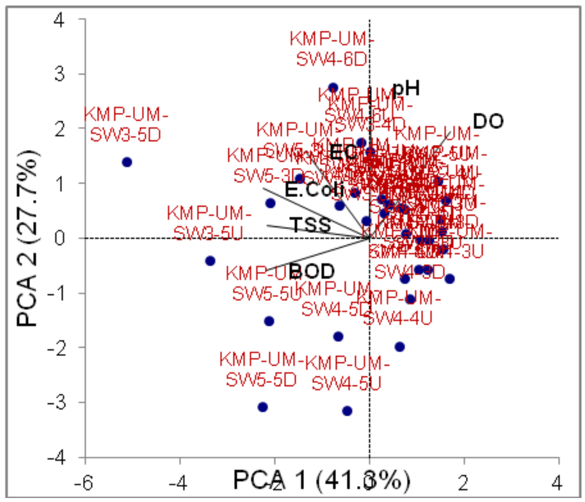

Figure 3: PCA biplot for the KMP project site

NB

Figure 4 shows the PCA bi-plot obtained for NB project. According to Figure 4 the first two PCA explains with total variability of 57.9% explained on the graph.

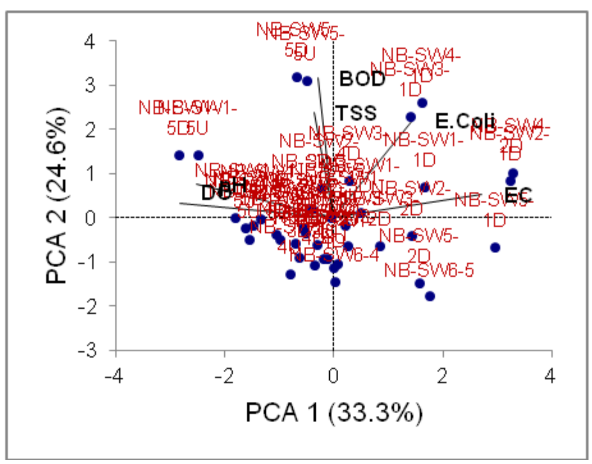

Figure 4: PCA biplot for the NB project site

A strong correlation can be seen between pH and DO as the included angle between the two variables is small. Similar trend between pH and DO can be observed for other projects also as can be seen in Figure 3, Figure 5 and Figure 6. Most importantly, measurement of pH can be done more easily compared to measurement of DO. Therefore, this suggests that the possibility of using pH level to predict the DO levels in the water when conducting water quality monitoring programs undertaken at construction sites. This is of crucial importance as it leads to reduce the time and cost consuming in the laboratory testing conduct to measure DO.

Similar to the KMP project, in NB project also BOD and TSS display a strong relationship. This further confirms the importance of targeting the solids export from construction sites in designing the BMPs. TSS increases with the increase of wash off. Organic matter which resides in wash off particles has led to an increase of BOD. However, as can be seen in Figure 4, no correlation can be observed between TSS and EC. This can be attributed to the change in EC due to the dissolved solids such as dissolved salts use in the site.

STDP

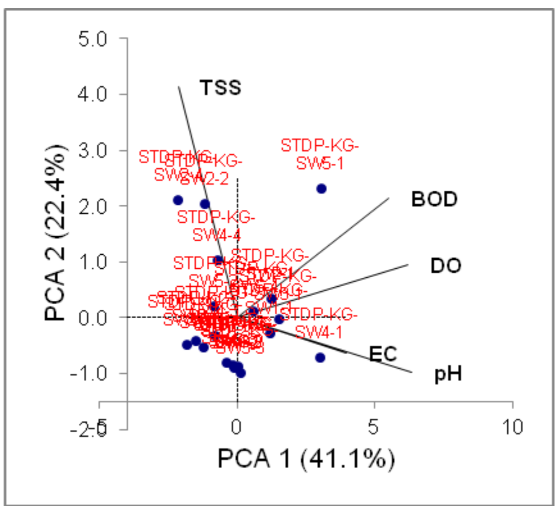

Figure 5: PCA biplot for the STDP project site

Figure 5 shows the PCA bi-plot obtained for STDP project. As shown in Figure 5 the first two PCA explains a relatively high variance which accounts for 63.5% of the total variance indicating that most of the data has been considered.

According to Figure 5, pH shows strong correlation to both EC and DO which further confirms the use of pH as a surrogate in water quality monitoring at construction sites.

OCH

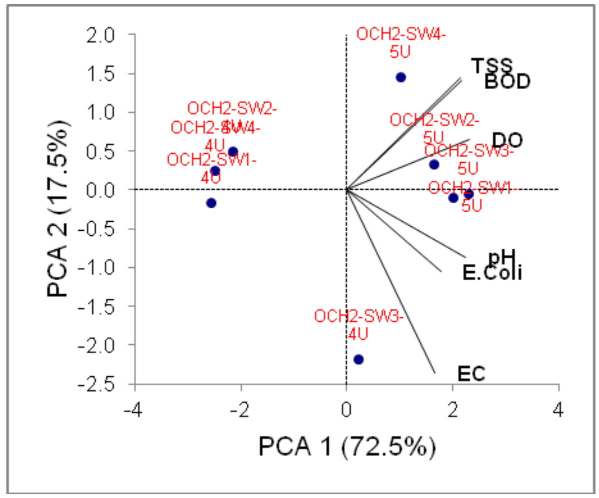

Figure 6: PCA biplot for the OCH project site

Figure 6 shows the PCA bi-plot obtained for OCH project. According to Figure 6, the first two PCA explains a relatively high variance which accounts for 90% of the total variance. This high percentage means that most of the data has been considered in the analysis.

As can be seen in Figure 6, TSS shows a strong correlation to BOD and DO and a good correlation to pH and E.coli further confirming the importance of implementing the BMPs to mitigate the solids export at construction sites. Furthermore, the strong correlation between pH, E.Coli and EC further confirms the suitability of considering pH measurement as a surrogate to understand the extent of pollution of the water bodies near the construction sites.

5. CONCLUSION

Both highway and road construction projects impose a significant threat on the water quality of adjacent water bodies. It is noteworthy to focus on minimizing the soil erosion and the dust accumulation at the highway and road construction sites when design and implementing the BMPs. However, in this context the understanding of different particle sizes of solids and the affinity of different types of pollutants to those would be significant for effective design of BMPs such as silt fence barriers, lined channels, ditches and water diversion structures. Furthermore, it is important to consider the difference of geographical and surface characteristics when design and implementing these practices. Moreover, pH can be recommended as a good surrogate indicator to monitor the water quality of water bodies adjacent to construction sites in order to minimize the cost and time consuming in water quality monitoring programs undertaken at such areas.

6. ACKNOWLEDGEMENT

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