USE OF PRINCIPAL COMPONENT ANALYSIS AS A VERSATILE TOOL TO EVALUATE THE QUALITY OF RUNOFF FROM URBAN ROAD SURFACES

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ABSTRACT

Correlations between runoff quality and urban road surfaces in different land uses were determined using Principal Component Analysis (PCA) which is a well known multivariate data analysis technique, subsequent to the univariate data analysis. Three urban road surfaces having same characteristics were selected from each land use namely residential, commercial and industrial in Galle, Sri Lanka. Physical, chemical and biological parameters were tested for the runoff collected from each road surfaces maintaining minimum antecedent dry period of five days between each event while ensuring not to mix with other wastewater according to standard method of water and wastewater analysis published by American Public Health Association. Univariate data analysis was used to identify significant pollutants for each land use with respect to the standards for inland waters of Sri Lanka, CLASS 1 Waters: Drinking water with simple treatment published by Central Environment Authority in 2001. Commercial land use is dominant in contaminating the runoff as all parameters, COD, BOD_5, turbidity, alkalinity and fecal coliform which have been exceeded the standards are noticed with in road surfaces in commercial land use, but there is no any strong relationship is found among sampling locations of commercial land use with the runoff quality. Besides, industrial and residential land use show discriminated characteristics of runoff in physiochemical parameters according to the PCA. Thus, PCA is a versatile tool that can be used to recognize the patterns between land use type and runoff quality parameters.

Key words**:** Principal Component Analysis (PCA), quality of runoff, urban road surfaces

1. INTRODUCTION

Urban stormwater runoff has become a major concern for deteriorating quality of water in the receiving water bodies [1, 2]. Thus, mitigating measures on stormwater pollution are vital importance. Characteristics of stormwater runoff is essential to determine to propose mitigation strategies [1]. However, the effectiveness of such mitigation is limited due to lack of knowledge on pollutants generated on different urban land uses. It is possible to relate stormwater runoff characteristics to different urban land use [3, 4, and 5].

Principal component analysis PCA is a well-known pattern recognition technique of multivariate statistical data analysis which reduces raw data into multiple components while retaining the most variance within the original data in order to identify possible patterns between objects and variables [1, 5]. PCA has been used as a major analytical tool in numerous water quality studies [1, 6, 7, and 8]. PCA has been used for the evaluation of spatial and temporal variations of water quality of in Lake Laier, USA [9] while recognizing a set of water quality data from six catchments in Queensland State, Australia has been carried out by PCA [5]. On the other hand PCA has been to analysis the data of marine water quality [10]. Similarly, PCA has also been used to identify the stormwater quality in different urban surface types in Macuau [1].

Characteristics of urban stormwater runoff quality in Galle still remain poorly understood. Researches on evaluating stormwater quality in different impervious surfaces have been carried out [11]. Thus, the main objectives of this research are to clarify the major pollutants of runoff from urban road surfaces from different land uses and identify the linkages between runoff quality and land use namely residential, commercial and industrial through PCA method.

2. METHODOLOGY

Figure 1 shows the sampling locations selected, three road surfaces having same characteristics in each land use.

Residential

R1: Around Hapugala

R2: Inside the Faculty of Engineering

R3: Near Ambalangoda

Commercial

C1: Around Galle bus stand

C2: Near fish and fruit market

C3: Around Co-operative hospital

Industrial

P1: Near Holcim cement factory

P2: Around Galle Harbour

P3: Near Koggala Trade Zone

Figure 1: Sampling Locations

Stormwater runoff samples were collected to polyethylene bottles maintaining five days of minimum antecedent dry period between each event and ensured not to mix with other wastewater. 1.5 L of stormwater runoff in each location was collected within 10 – 20 min for each event during the period from May to November in 2015.

Collected runoff samples were preserved and tested for physical, chemical and biological parameters according to standard method of water and wastewater analysis published by American Public Health Association [11, 12].

Identification of major pollutants of urban runoff from different land uses which has been exceeded the standards for inland waters of Sri Lanka, CLASS 1 Waters: Drinking water with simple treatment published by Central Environment Authority in 2001 were done based on the univariate data analysis considering mean and standard deviation.

Pattern recognition of land uses and runoff quality was carried out PCA.

3. RESULTS

Univariate analysis revels that turbidity, BOD_5, and COD are exceeded in urban runoff collected all three land uses. It indicates, the organic matter concentration is extremely high in runoff though it still flows to receiving water bodies without treatment. Alkalinity and fecal coliform have also exceeded the limits in commercial and residential land use respectively. Interestingly, mean concentration of alkalinity and fecal coliform are in considerably low level.

Standard deviation of parameters shows great uncertainties revealing quality control of runoff is more difficult and depicts that contaminating runoff from urban road surfaces is dominated by commercial land use.

Table 1 shows the parameters which have been exceeded the standards.

Table 1: Summary of parameters exceeded the standards in univariate analysis

Land use	Turbidity (NTU)	BOD_5 (mg/l)	COD (mg/l)	Alkalinity (mg/l)	Fecal Coliform
Residential					
Mean	65.13	38.67	198.59	133.33	1186.67
SD	54.83	4.51	173.36	75.06	125.83
Commercial					
Mean	277.30	82.33	266.50	253.33	206.67
SD	224.55	33.61	156.06	159.48	179.54
Industrial					
Mean	178.33	65.67	177.15	170.00	116.67
SD	36.95	10.69	116.70	72.11	41.63
Standard [a]	≤ 5	≤ 3	≤ 15	≤ 200	≤ 600

a Standards for inland waters of Sri Lanka, CLASS 1 Waters: Drinking water with simple treatment published by Central Environment Authority in 2001

PCA was further carried out to determine the correlations between runoff quality and land use. XLSTAT 2014.4.08 was used for PCA. Physical and chemical parameters with three land use were undertaken in PCA. The distribution of principal loading bi-plots for physical and chemical land uses are presented in Figure 2 and

3. Thus, maximum of five principal components (PCs) were calculated and it is worth to note that first and second PCs (PC1 and PC2) were plotted in a common plot because first two components are usually responsible for the most of the variance. The angle between the lines (loadings) or to be more precise, the cosine of the angle between the lines, approximates the correlation between the variables they represent. The angles closer to 90^0 or 270^0 shows a very less correlation while 0^0 angle represents a strong correlation [1, 13].

Moreover, PCA provides scree plot, and correlation matrix which are also useful for the identifying correlation and patterns of the data. Correlation matrix is used to determine the degree of relationship of two variables, here it refers to parameters measured. Correlation coefficients in correlation matrix vary from -1 to +1. If correlation coefficient is closed proximity to ± 1, it reveals a perfect correlation between those two parameters; hence the best correlated parameters can be identified using the correlation matrix.

Just as shown in Figure 2, PC1 was concerned with the physical parameters, turbidity, total solids (TS) and total suspended solids (TSS) for all three land uses. TSS is a subgroup of total Temperature and turbidity are also in positive region of both PC1 and PC2. It has correlation coefficient of 0.81 which is considerably strong relationship. Industrial and residential land use show two discriminated clusters as shown in Figure 2. It depicts that their characteristics are discriminated each other.

Similarly, Figure 3 also shows there are two discriminated cluster formation among sampling locations of residential and commercial land uses. This is caused by the different activities take place in two different land use types. But, commercial land use does not show any relation among three sampling locations in physiochemical parameters. Besides, NO_3^{-1}, chloride alkalinity, hardness and electrical conductivity (EC) are closed each other. Hardness is a measure of the quantity of divalent ions such as Calcium, Magnesium, and or ion in the water. In addition, Calcium Carbonate ($CaCO_3$) which is dissolved in water flow through geology that has limestone and marble is one source of alkalinity. Furthermore, most of the sampling locations are located in Galle that are near to the sea, thus high concentration of $CaCO_3$ can be recorded. Hence, hardness and alkalinity of the stormwater runoff are proportionate each other. Besides, EC in stormwater is also measure based on existing ion concentration of hardness, alkalinity and chloride etc. Correlation coefficient of EC with alkalinity, chloride and NO_3^{-1} are 0.86, 0.91 and 0.77 respectively. Therefore, EC, alkalinity, chloride and hardness are strongly correlated parameters which are also proportionate each other.

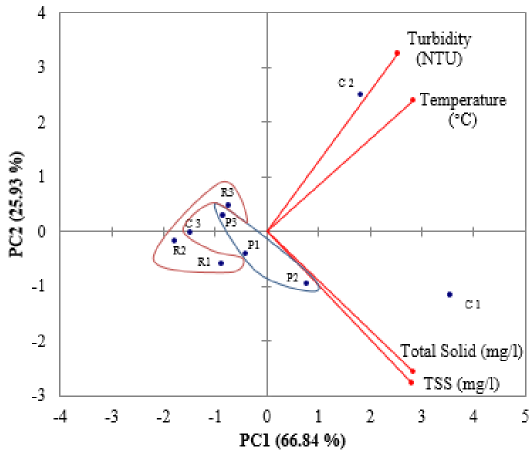

Figure 2: Bi-plot for physical parameters in residential, commercial and industrial land uses

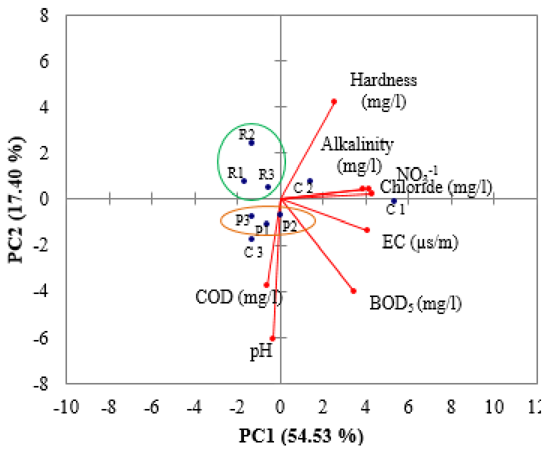

Figure 3: Bi-plot for chemical parameters in residential, commercial and industrial land uses

4. CONCLUSIONS

Parameters which have been exceeded the standard limits should be treated before it receives to the water bodies. For the organic pollutants which demand the oxygen, structural stormwater improvement measures such as detention basins or sediment traps would be effective, BOD_5 and COD can be controlled.

Since there is correlation between land use type and pollutants, zoning can be done in future infrastructure development. Then it is convenient to treat the stormwater washoff in economical and efficient way.

5. REFERENCES

[1] J. Haung, P. Du, C. Ao, M. Ho, M. Lei, D. Zhao and Z. Wang, *"Multivariate Analysis for Stormwater Quality Characteristics Identification from Different Urban Surface Types in Macau"*, Journal of Bull Environ ContamToxicol, vol. 79, pp. 650-654, 2007.

[2] R. Yufen, W. Xiaoke, O. Zhiyun, Z. Hua, D. Xiaonan and M. Hong, "*Stormwater runoff quality from different surfaces in an urban catchment in Beijing, China*", Journal of Water Environment Research, vol. 80, no. 8, pp. 719-722, 2008.

[3] J. Forster, "*Variability of roof runoff quality"*, Wat. Sci. Tech., vol. 39, no. 5, pp.137-144, 1999.

[4] M. Chang and C. M. Crowly, "P*reliminary observations on water quality of storm runoff from four selected residential roofs",* Journal of Water Resource Bulletin, vol. 29, no. 5, 1993.

[5] A. Goonetilleke, E. Thomas, S. Ginn and D. Gilbert, *"Understanding the role of land use in urban stormwater quality management"*, Journal of Environmental Management, vol.74 (1), pp. 31-42, 2005.

[6] A. Thielemans and D. L. Massart, "*The use of Principal Component Analysis as a display method in the interpretation of analytical chemical, biological environmental and epidemiological data"*, 1985.

[7] M. Bahar, O. Hand, M. Yamamuro, "*Relationship between river water quality and land use in a small river basin running through the urbanizing area of Central Japan",* 2008.

[8] N. S. Miguntanna, P. Egodawatta and A. Goonetilleke, *"Pollutant characteristics on roof surfaces for evaluation as a stormwater harvesting catchment"*, 2009.

[9] X. Zeng and T. C. Rasmussen, "*Multivariate statistical characterization of water quality in lake Lanier, Georgia, USA*", Journal of Environmental Quality, vol. 34, pp. 1980-1991, 2005.

[10] F. Zhou, H. Guo, Y. Liu and Y. Jiang, "*Chemometrics data analysis of marine water quality and source identification in Southern Hong Kong"*, Marine Pollution Bulletin, no. 54, 745- 756, 2007.

[11] American Public Health Association, *"American Water Works Association and Water Environment Federation, Standard methods for the examination of water and wastewater"* part 1000-3000, American Public Health Association, Washington, 1998.

[12] American Public Health Association, *"American Water Works Association and Water Environment Federation, Standard methods for the examination of water and wastewater"* part 4000-10000, American Public Health Association, Washington, 1998.

[13] T. G. J. S. Bandara and Y. M. D. L. Y. Bandara, *"Evaluation of harvested rainwater quality as a drinking water source in urban land uses in Southern province Sri Lanka"*. B.Sc. thesis, university of Ruhuna, Galle, Sri Lanka, 2012.