Short Communication

Estimation of Correlation Between Electrical Conductivity, Solids and Hardness of Highway Stormwater Run-off

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(received April 7, 2021; revised January 1, 2023; accepted January 27, 2023)

Abstract. A comprehensive understanding of pollutants of highway stormwater run-off is required for accurate prediction of various constituents and for planning and assessment of proposed or existing highway corridors. Besides the adequate availability of staff and laboratory equipment, regular monitoring and estimation of all constituents in highway runoff water is very difficult. Hence, alternate statistical methods for the comparison of constituents are highly appreciated. In this research work, an attempt was made to estimate the relationship between electrical conductivity (Ec), total dissolved solids (TDS), total suspended solids (TSS) and hardness of highway stormwater run-off to decrease the time and cost required for collection, testing and measurement of samples for quality data. Eight consecutive storm events were monitored during monsoon season from June to July 2019 and twenty-four stormwater samples were collected from an urban highway in Lahore, Pakistan and analyzed for pH, temperature (T), Ec, TDS, TSS and hardness to determine physiochemical properties of highway run-off water. After analyzing selected physiochemical parameters, regression-based predictive relationships were developed between these parameters. A strong linear relationship with a high coefficient of determination *i.e.*, 0.97 was found between Ec and TDS, while the correlation of Ec with TSS and hardness is very poor having a weak coefficient of determination *i.e.*, 0.49 and 0.76 respectively revealing the unreliability of developed correlations.

Keywords: urban areas, highway stormwater, physiochemical, regression analysis, determination coefficient

Infiltration rate of the soil is adversely affected by urbanization due to increased impervious surfaces. The increased impervious area caused a serious reduction in percolation of water into the ground and resulted as enhanced run-off volume during the rain events (Al-Mashaqbeh, 2014; Kamali *et al*., 2012; Chow and Yusop, 2009). Rainwater harvesting is an effective alternative practice, particularly within urban regions. However, due to the increase in atmospheric pollutants, the quality of rain-water has gradually decreased (Abdullah *et al*., 2021). The source of ionic components in rain water was found to be mainly originated from sea salt ions and anthropogenic activities (Fazillah *et al*., 2022). Rainfall run-off becomes stormwater run-off due to the reduction in infiltration rate of the soil (Fernando and Rathnayake, 2018). Surface run-off quantity and quality has been significantly changed due to the growing population and urbanization. Many natural catchments have been transformed into urban areas with highly impervious surfaces (Chow and Yusop, 2014; Al-Obaidy and Al-Mashhadi, 2013; Wang *et al*., 2013; Arora and Reddy, 2012). Road surfaces accumulate significant quantities of pollutants including nutrients, solids, heavy metals and hydrocarbons originating from traffic activities. Highway stormwater run-off is considered a major source of pollution in the environment (Helmreich *et al*., 2010).

Highway stormwater run-off is discontinuous in time and space and hence is a classic nonpoint pollutant source. To enable accurate prediction of the various constituents, a comprehensive understanding of the constituents of highway stormwater run-off and more importantly, how these constituents vary both temporally and spatially, is required (Herngren *et al*., 2005; Thomson *et al*., 1996). Continuous monitoring of many quality parameters is essential for effective maintenance of water quality. Although adequate manpower and laboratory facilities are available, regular monitoring of all parameters is very difficult. Collection of samples, lengthy and time consuming procedures and expensive equipment and chemical reagents are the main deterrents (Rusydi, 2017; Mitali *et al*., 2006; Thomson *et al*., 1996). Therefore, comparison of the physiochemical parameter, an alternative approach based on statistical correlations has been used to develop a mathematical relationship (Bhandari and Nayal, 2008; Shah *et al*., 2007; Garg *et al*., 1990).

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Table 1. General characteristics of sampling sites

Sampling site	Surrounding characteristics of campling	Slope (%)	Gradient (%)	Area (m^2)
A	Commercial buildings, housing societies, industries	4.5	2.5	33000
B	Villages, open fields	3.8	1.4	36000
C	Housing societies, small industries	4.2	2.0	23100

Many researchers and practitioners performed diverse statistical analysis to develop correlations between different physiochemical parameters of various types. Bhandari and Nayal (2007) Karl-Pearson correlation coefficient (r) calculated for river water and an appreciable significant positive correlation was found for Cl with pH, Mg, Na, hardness and TSS and sodium (Na) with hardness, Ec and SO_4. Whereas, a significant negative correlation was found between potassium (K) with turbidity, Cl, Ec and hardness. The existence of a strong linear relationship between turbidity and TSS concentration within a combined sewer system confirmed by Hannouche *et al*. (2012) and Wolkersdorfer (2008). The linear regression analysis and also concluded that TDS can be easily estimated from measurements of Ec by applying conversion factor. The conductivity and TDS are easily correlated and usually expressed by a simple equation; TDS = k Ec (in 25 °C) as concluded by Rusydi (2017). The analysis of TDS concentration from Ec value can be used to give an overview of water quality. Keeping in view the literature review, present research work aimed to evaluate relationship of easily measured parameter such as Ec value with time consuming parameters *i.e*. TDS, TSS and hardness values for highway stormwater run-off. Ec can be easily measured *in-situ* with a portable instrument whereas the procedure for the determination of TDS, TSS, hardness is expensive and time consuming. Hence, in this research work, Ec values were used as predictors for TDS, TSS and hardness.

Three segments of Lahore ring road sothern loop were selected as sampling sites in the city of Lahore, Punjab, Pakistan. Lahore ring road is a six-lane Urban highway having a total constructed length of 62.4 Km with an average daily traffic (ADT) of 90353 vehicles/day. This traffic includes 75% cars, 11% buses and 14% trucks and trailers. Selected sampling sites, mentioned as sampling site A, sampling site B and sampling site C were located close to each other minimizing the variability of storm distribution. Each site has relatively higher gradients and slopes resulting in minimizing the time of concentration of storm for each segment. The characteristics of each sampling site are shown in Table 1.

Samples were taken from 8 consecutive rainfall events during monsoon season from June to July in 2019. Rainfall parameters for each monitored storm event are shown in Table 2. Twenty-four samples, eight samples from each site, were collected and analyzed for pH, T, Ec, TDS, TSS and hardness of highway run-off water. Samples were collected manually at the discharge point in 2 L plastic containers before getting stormwater into the drainage system. Sampling interval was 5 min in first 30 min of rainfall and after that interval was 10 min during the remaining storm event (Iqbal and Baig, 2015; Chinwe *et al*., 2010).

Temperature, pH and Ec were measured *in-situ* by a portable instrument with multi-probes. TDS and TSS were measured in the laboratory through the gravimeter method. Hardness was determined by the standard method, 2340 B of APHA-2017. After analyzing stormwater for physiochemical parameters, correlation of Ec with TDS, TSS and hardness was estimated by using linear regression analysis. Ec was selected as independent variable due to its ease of estimation whereas TDS, TSS and hardness were selected as response due to their tedious and time consuming procedure as well as their direct effect on Ec values of any type of water. The type of regression analysis was selected based on correlation coefficient.

Test results of selected physiochemical parameters of stormwater are summarized in Table 3.

Table 2. Rainfall parameters for the monitored events

Event no.	Event date	Rainfall depth (mm)	Rainfall duration (h)	Mean rainfall intensity (mm/h)	Antecedent dry period (h)
1	20.06.2019	37.6	1.50	25.1	39.0
2	24.06.2019	22.0	2.25	9.8	91.5
3	05.07.2019	13.0	1.25	10.4	276.7
4	11.07.2019	24.0	1.50	16.0	125.7
5	14.07.2019	26.0	2.00	13.0	70.5
6	16.07.2019	67.0	3.00	22.3	55.0
7	24.07.2019	26.4	1.75	15.1	190.0
8	25.07.2019	50.4	2.50	20.2	16.3

Due to its ease of measurement, Ec was selected as a major indicator parameter. To depict the relationships between Ec, TDS, TSS and hardness of highway run-off water, regression analysis was performed. The equation of the best fit line and the coefficient of correlation (R^2) were determined for each test result.

Before applying regression analysis, scatter plots of data were plotted to visualize the test results. By plotting Ec against TDS, TSS and hardness on a scatter plot, it can be visualized that Ec values shows a normal behaviour with TDS and TSS values as shown in Fig. 1(a, b) whereas hardness values show an abnormal behavior (Fig. 1c). A linear relationship can be developed between Ec, TDS and TSS by plotting Ec as an independent variable, while TDS and TSS as a response. An excellent positive linear relationship exists between Ec and TDS with a high coefficient of correlation (R^2) as shown in Fig. 2a. The equation of determination of TDS from Ec with their coefficient of correlation is given as below:

TDS = 0.7802(Ec) – 5.7892 R^2 = 0.97 .... (1)

From Fig. 1b, it can be visualized that a good relationship can't be developed between Ec and TSS values due to extensive scattering of data. A poor linear relationship exists between these parameters with a lower coefficient of determination as shown in Fig. 2b. The equation of determination of TSS from Ec with the coefficient of correlation is given as:

TSS = 0.0871(Ec) + 3.1594 R^2 = 0.49 .... (2)

Figure 1c revealed that test results of samples collected from location B shows different behaviour than normal. All the points are not along a single slop line. To develop a better relationship between Ec and hardness, test results of samples collected from location B can be ignored. By plotting Ec as independent variable and hardness as a response, a normal linear relationship exists between them with a better coefficient of correlation (R^2) as shown in Fig. 2c. The equation of determination of hardness from Ec with correlation coefficient is given as:

Hardness = 0.1384(Ec) + 11.663 R^2 = 0.76 ..... (3)

To check the validity of derived equations for the estimation of TDS, TSS and hardness from Ec values, the concept of the confidence interval was used, the 95% confidence interval was determined for all test results. The values of TDS, TSS and hardness were estimated by using derived equations (Table 4). By estimating values of TDS from equation (1), observed that all the estimated values lie within the confidence interval range. All values of TDS fall near the slop line by plotting measured values against estimated values from equation (1) (Fig. 3a). This fact, as well as high correlation coefficient of 0.97, reveals the strength and validity of the developed relationship between Ec and TDS. On the other hand, estimated values of TSS from equation (2) does not lie within the 95% confidence interval range. The same situation was observed by plotting measured values of TSS against estimated values of TSS from equation (2). Most of the estimated

Table 3. Statistical analysis of test results

Site	Parameters	pH	T (°C)	TDS (ppm)	TSS (ppm)	Ec (µs/cm)	Hardness (ppm)
A	Minimum	7.00	29.4	168.0	22.4	212.0	44.9
	Maximum	8.39	39.2	291.0	39.0	382.0	59.1
	Mean	7.59	34.9	211.9	30.6	270.5	52.3
	Coefficient of variance (%)	7.4	11.8	23.0	16.7	25.0	8.3
	Mean ± SD	7.59 ± 0.56	34.9 ± 4.1	211.9 ± 48.7	30.6 ± 5.1	270.5 ± 67.6	52.3 ± 4.3
	95% Confidence interval	7.2 – 8.0	32 – 37.8	177.8 -246.0	27.0 – 34.2	223.2 – 317.8	49.3 – 55.3
B	Minimum	6.87	28.4	138.0	17.5	178.0	18.8
	Maximum	8.09	38.6	201.0	27.1	273.0	24.9
	Mean	7.28	35.5	164.4	21.5	222.6	22.0
	Coefficient of variance (%)	5.2	11.4	12.6	15.7	16.5	9.4
	Mean ± SD	7.28 ± 0.37	35.5 ± 4.0	164.4 ± 20.7	21.5 ± 3.4	222.6 ± 36.8	22.0 ± 2.1
	95% Confidence interval	7.0 – 7.5	32.7 – 38.3	149.9 – 178.9	19.1 – 23.9	196.8 – 248.4	20.5 – 23.5
C	Minimum	6.11	34.2	92.0	8.8	138.0	24.5
	Maximum	7.80	38.2	128.0	18.4	172.0	34.3
	Mean	6.82	36.4	109.9	13.5	152.3	29.6
	Coefficient of variance (%)	9.5	4.1	11.6	26.3	8.8	10.0
	Mean ± SD	6.82 ± 0.65	36.4 ± 1.5	109.9 ± 12.7	13.5 ± 3.6	152.3 ± 13.4	29.6 ± 3.0
	95% Confidence interval	6.4 – 7.3	35.4 – 37.5	101.0 – 118.8	11.0 – 16.0	142.9 – 161.7	27.4 – 31.8

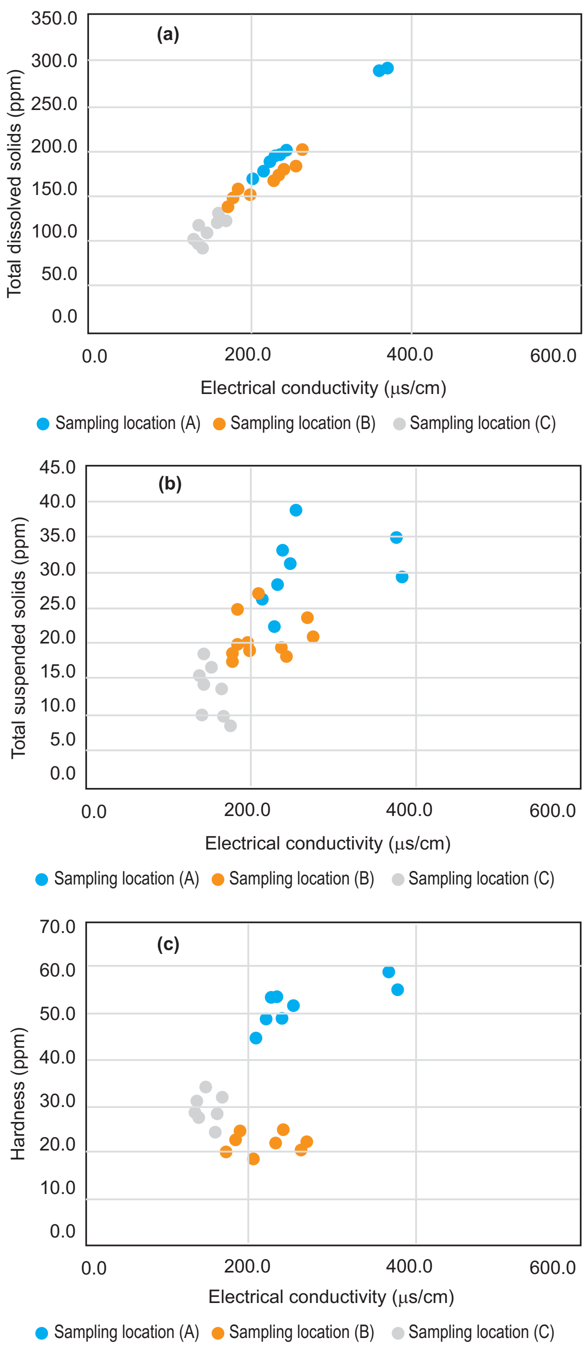

Fig. 1. Scatter plot of Ec values with TDS, TSS and hardness values.

values of TSS lie away from the slope line with a very poor correlation coefficient of 0.49 revealing the weakness and invalidity of this relationship between Ec and TSS as shown in Fig. 3b. The estimated values of hardness from equation (3) were also plotted against measured values of hardness to check the validity of the developed relationship between Ec and hardness. It was observed that the estimated values of hardness are very scattered and away from the slop line (Fig. 3c). This fact, as well as very poor coefficient of determination of 0.30, shows the weakness and invalidity of this relationship.

The goal of a reliable relationship is to predict the constituent of concern for highway stormwater run-off and yet reflect the high variability of this non-point source. Commonly predefined correlations without proper site-specific validations are used. These correlations differ for a different type of waters depending upon major constituents, sampling locations and sampling seasons. This study, based on the following correlations which were developed between Ec, TDS, TSS and hardness of highway stormwater run-off.

$$TDS = 0.7802(Ec) - 5.7892 \qquad R^2 = 0.97 \text{ .... } (1)$$

$$TSS = 0.0871(Ec) + 3.1594 \qquad R^2 = 0.49 \text{ .... } (2)$$

$$Hardness = 0.1384(Ec) + 11.663 \qquad R^2 = 0.76 \text{ .... } (3)$$

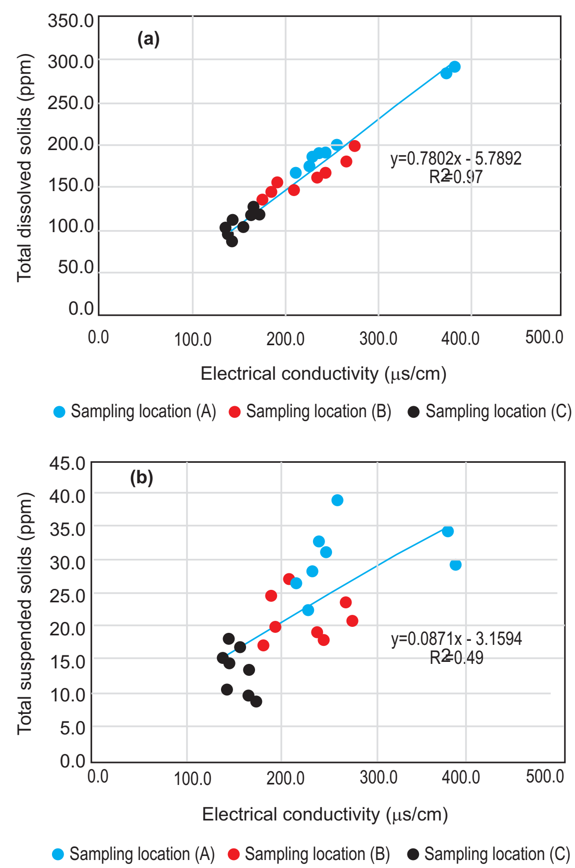

Fig. 2. **(a)** Relationship between Ec and TDS **(b)** relationship between Ec and TSS.

Table 4. Estimated values of TDS, TSS and hardness from equation 1, 2 and 3

Sample no.	Sample location	x = Ec (µs/cm)	(Eq. 1) y=0.780x - 5.7892 y = TDS (ppm)	(Eq. 2) y=0.0871x + 3.1594 y = TSS (ppm)	(Eq. 3) y=0.1384x - 11.663 y=Hardness (ppm)
1	A	374.0	245.9	35.7	40.1
2		382.0	246.2	36.4	41.2
3		226.0	177.5	22.8	19.6
4		245.0	185.3	24.5	22.2
5		212.0	179.6	21.6	17.7
6		256.0	193.9	25.5	23.8
7		238.0	179.9	23.9	21.3
8		231.0	178.4	23.3	20.3
1	B	273.0	178.2	26.9	26.1
2		242.0	168.0	24.2	21.8
3		266.0	177.7	26.3	25.2
4		236.0	178.3	23.7	21.0
5		208.0	156.5	21.3	17.1
6		178.0	153.1	18.7	13.0
7		192.0	159.0	19.9	14.9
8		186.0	165.3	19.4	14.1
1	C	172.0	118.4	18.1	12.1
2		138.0	101.9	15.2	7.4
3		142.0	105.0	15.5	8.0
4		153.0	113.6	16.5	9.5
5		140.0	103.4	15.4	7.7
6		143.0	105.8	15.6	8.1
7		164.0	112.1	17.4	11.0
8		166.0	113.7	17.6	11.3

It was concluded that a strong positive linear relationship exists between Ec and TDS of highway stormwater run-off. The correlation coefficient of this relationship was also very strong *i.e.*, 0.97 governing the strength, authenticity and validity of the developed equation. This developed correlation between Ec and TDS of highway stormwater run-off matches with the previously developed correlations between these two constituents for different types of waters (Hubert and Wolkersdorfer, 2015; Niekerk *et al*., 2014; Ali *et al*., 2012; Atekwana *et al*. 2004; Mc-Neil and Cox, 2000). On the other hand, Ec showed a very poor linear relationship with TSS and hardness with very weak coefficients of determination *i.e.*, 0.49 and 0.76 respectively.

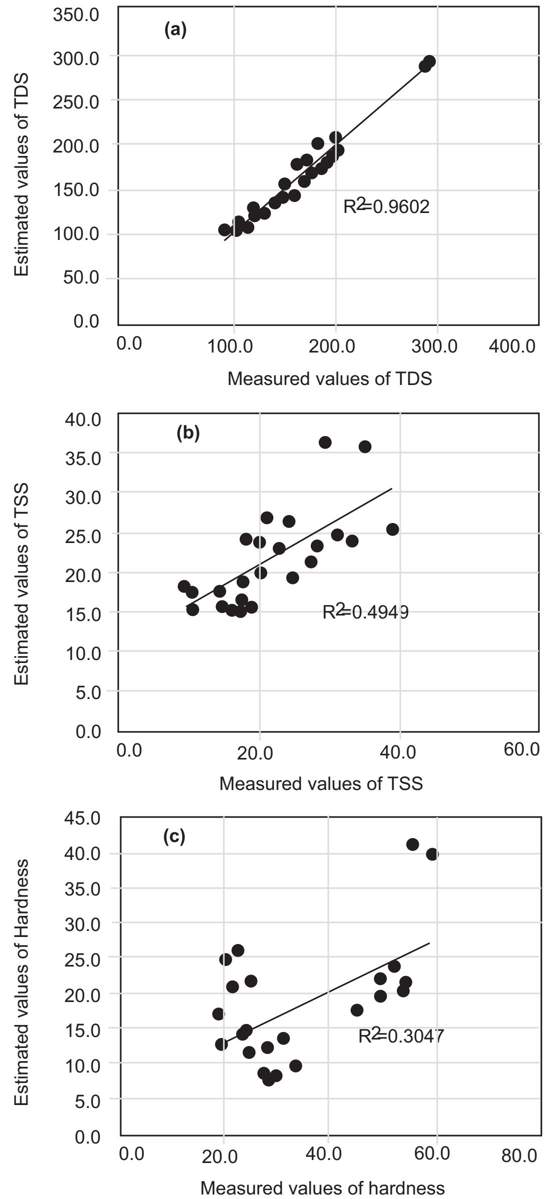

Fig. 3. Relationship between measured and estimated values of TDS, TSS and hardness from Ec values.

Conclusion

The findings indicate that the developed correlations are purely site-specific with similar environmental conditions. An attempt to estimate TDS, TSS and hardness from Ec value as predictor variable resulted in limited success. Hence care should be taken in sampling as well as in selecting surrogate and predictor variable. Moreover, developed correlations depend upon mean values, therefore the number of samples should be increased for more valid relationships.

Conflict of Interest. The authors declare that they have no conflict of interest.

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