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Original Research Paper

Water Quality Assessment of Various forms of Rainwater and Statistical Studies on Physico-Chemical Characteristics of Stormwater in Coimbatore, India

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ABSTRACT

Rain water harvesting, irrespective of the technology used, essentially means harvesting and storing water in days of abundance, for use in lean days. It has been construed as the most sustainable method for managing water scarcity situations, incorporating all type of water demands. Though rainwater is considered as a contamination free source, human activities particularly in the industrial and agricultural sectors pollute this pure form of water. The quality of various forms of rainwater, viz. direct rainfall, rooftop water and stormwater were assessed by analysing various physico-chemical parameters. The physico-chemical characteristics of stormwater were further subjected to statistical and correlation analyses. The results showed that the direct rainwater samples collected were pure and safe as drinking water. The surface stormwater runoff samples collected from the study location, which is mainly an urban and industrialised catchment, contained undesirable amount of sediment load and other chemical parameters; most of them are not within safe limits for drinking and irrigation use. The electrical conductivity and sediment concentration in samples collected from roofs were slightly above the desirable limit for drinking purpose. The mean, standard deviation (SD) and coefficient of variation (CV) of various physico-chemical parameters of stormwater were computed and compared. Similarly correlation coefficients were worked out to find out the relationship amongst physico-chemical characteristics of the water samples and a large number of significant correlations were obtained.

INTRODUCTION

Water resources development remains the primary key to open up the vistas of sustainability of agriculture and the standard of living by way of industrialization or urbanization. Technological advancements and industrial growth warrant an addendum of existing water resources that are primarily exploited by the agricultural sector. Though rainwater harvesting helps to stabilize the supply-demand equilibrium for water, the quality of water as required for the multi-facets of the water usage arena consistently undergo validity criteria for a fearless consumption. The quality criteria required for domestic purposes are quite different when compared to those for irrigation or industrial applications. At the same time the water quality indices of inlet water also vary depending on its source of origin, type of flow and method of collection. The qualitative assessment of different types of water supplies at different stages inevitably helps in effective management of rainwater in its various forms. This study assumes great significance in view of increasing importance of rainwater harvesting worldwide.

In theory, rainwater is the safest of all water sources. Although rainwater can become contaminated through the absorption of atmospheric pollutants, it is usually clean as it hits the earth, unless there is atmospheric pollution from industry. But the rainwater may get contaminated subsequently on the rooftop before it is being diverted to a harvesting tank. Pollutant additions to roof runoff include organic matter, inert solids, faecal deposits from animals and birds, trace amounts of some metals, and even complex organic compounds (Forster 1991). The surface stormwater is often contaminated through the release of industrial and domestic effluents directly into water bodies and land surface, and also from pesticide and agro-chemical run-off from fields. In agricultural areas, rainwater could have a higher concentration of chemicals due to fertilizer and pesticide residues in the atmosphere and/or crops. In industrial areas, rainwater samples can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the air (Thomas & Grenne 1993). Runoff quality also varies by catchment type. Ground catchments are prone to contamination from many sources including human and animal faecal matter, rotting vegetation and the soil itself.

MATERIALS AND METHODS

The studies were conducted at Coimbatore in Tamil Nadu State (India), which lies between 12°13’ to 12°50’ north latitude and 75°55’ to 75°27’ east longitude. The average annual rainfall of Coimbatore is 623.44 mm (10 years) and the total rainy days in a year range from 50 to 60 with a 60 % annual coefficient of variation. The average daily evaporation rate was recorded to be 1-4 mm. The area is generally plain and the average elevation is 400 m from m.s.l. The depth of the groundwater table varies between 1.54 and 39.03 m. The soil is poorly drained and clayey in nature.

The quality parameters of direct rainwater (DR), roof water (RW) and runoff/storm water (SW) collected from the study location were analysed for various physico-chemical characteristics. Input water samples were collected from 10 different locations within the Coimbatore city in pre-cleaned polythene bottles with necessary precautions as per standard procedures (IS: 3025 1987). The water samples were analysed for parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total solids (TS), total hardness (TH), total alkalinity (TA), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), phosphate (PO_4^{3-}), sulphate (SO_4^{2-}), chloride (Cl^{-}) and nitrate (NO_3^{-}) using standard methods and quality assurance procedures. The water analyses were conducted at water/soil testing laboratories of TNAU (Coimbatore), Tamil Nadu, Water Supply and Drainage Board (Coimbatore) and NABL accredited testing lab of SITRA (South India Textiles Research Association, Coimbatore). Other three parameters, which are useful in evaluating irrigation water quality such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and exchangeable sodium percentage (ESP), were also worked out.

The physico-chemical characteristics of stormwater were further subjected to statistical analysis to find out their mean, standard deviation (SD) and coefficient of variation (CV). In order to find out the relationship amongst physico-chemical parameters of the water samples, correlation coefficients were worked out. The significance of the observed correlation coefficients have been tested by using ‘*t*’ test.

RESULTS AND DISCUSSION

Quality parameters of various forms of rainwater: The direct rainwater (DR), roof water (RW) and runoff/stormwater (SW) samples collected were analysed for physico-chemical parameters, and the results are given in Table 1.

The direct rainwater (DR) samples were found to be pure and safe for use as drinking water. The surface water runoff samples contained undesirable amount of sediment load and other chemicals, most of them are not within safe limits for drinking and irrigation use. The EC and TS values of samples from roofs were slightly above the desirable limit for drinking purpose. The results of physico-chemical analysis of the collected water samples are discussed in detail.

pH: Generally pH of water is influenced by geology of catchment area and buffering capacity of water. The results as presented in Table 1 show that all the water samples were almost neutral or moderately alkaline (pH 7.2-7.76) and within the permissible limit (pH 6.5-8.5) of drinking water standards of WHO (2008).

Electrical conductivity: The EC values of RW and SW were observed to be above the desirable limit for drinking water. The EC of SW was found to be 2.65 dS m^{-1}, which is above the safe limit of 2.25 dS m^{-1} for use as irrigation water (CPCB 2008). The higher values of EC in SW may be because of mixing up of urban sewage water and dissolved salts from agricultural fields. When EC value exists at 3 dS m^{-1}, the germination of almost all the crops would be affected and it may result in much reduced yield (Srinivas et al. 2000). The higher values of EC obtained for SW of Coimbatore region were in good agreement with the EC values reported by Palanisamy et al. (2007) and Karunakaran et al. (2009) on the basis of their study conducted at Erode and Namakkal, adjacent districts of Coimbatore.

Temperature: The temperature was found to be in the range of 26.3 to 28.4°C during sampling.

Total solids: The TS were found to be within normal range for DR and RW, with a slightly increased value for RW. But the TS were found to be high in case of SW.

Total dissolved solids: The TDS value in DR was 0.025 g/L (56.27 % of TS), while that in RW it was 37.95 % of TS.

Table 1: Major quality parameters of various forms of rainwater.

Type of water	pH	EC***	TS**	TSS**	TDS**	Na^{+*}	K^{+*}	Ca^{2+*}	Mg^{2+*}	NO_3^{-*}	SO_4^{2-*}	PO_4^{2-*}	Cl^{-*}	TA*	TH*
Direct Rainfall	7.2	0.038	0.045	0.02	0.025	6	16	11.8	1.2	3.6	2.4	0.04	3.6	43	71
Roofwater	7.76	0.343	0.58	0.36	0.22	14.8	16.8	12.6	8.4	17	12	0.03	8.46	150	88
Stormwater	7.75	2.65	2.559	0.866	1.693	415	40	375	88	120	214	1.02	900	651	1305
Desirable limit[1] (Drinking water)	6.5-8.5	0.300	-	-	0.5	20	-	75	30	20	200	-	250	200	200
Permissible limit[1] (Non-potable)	6.5-8.5	0.750	-	-	1.5	80	-	200	75	50	1000	-	600	600	600

*Concentration in mg/L; **Concentration in g/L; ***EC in dS m^{-1}; [1]Source: IS: 2296:1992 and WHO (2008)

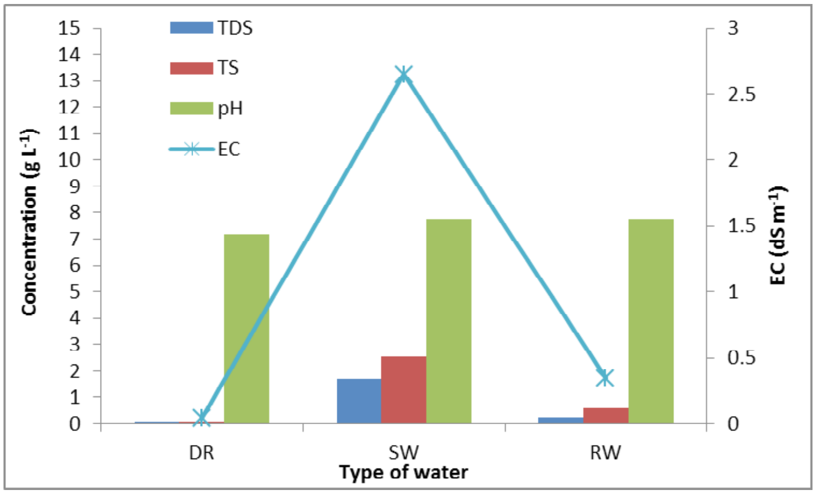

Fig.1: Variation of pH, EC, TDS and TS among different types of rainwater samples.

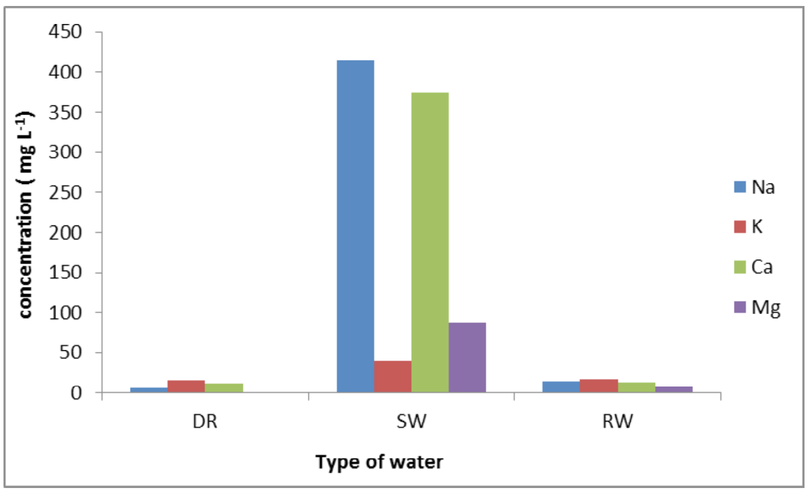

Fig.2: Variation of Na^+, K^+, Ca^{2+} and Mg^{2+} concentrations among collected rainwater samples.

In case of SW, the TDS value was as high as 1.693 g/L, which is similar to the results reported by Jothivenkatachalam et al. (2010). The TDS contributed 66.16% of TS. According to WHO, total dissolved solids in drinking water should be < 500 mg/L, and the safe limit for irrigation is fixed at 2100 mg/L as per CPCB. The desirable limit for other domestic uses is fixed at an average of 1500 mg/L of TDS. The analysed data showed that 60% of SW samples have more TDS than the maximum permissible limit for drinking water, while 33 % have more than the permissible limit for irrigation use. Water with high residue is normally less palatable and may induce an unfavourable physiological reaction in the transient consumer and even may cause gastrointestinal irritation (Adak & Purohit 2001). Water containing high solid concentration may cause constipation effects and high level of TDS may aesthetically be unsatisfactory for bathing and washing (Jameel & Sirajudeen 2006). The variation of pH, EC, TS and TDS in different forms of rainwater is depicted in Fig. 1.

Total suspended solids: The total suspended solids were found to be less in DR, while moderate values were observed for RW. Comparatively higher values of TSS were observed in SW.

Sodium, potassium, calcium and magnesium: Concentration of Na^+, Ca^{2+} and Mg^{2+} in all the sources of water were

Table 2: Values of SAR, ESP and RSC for collected rainwater samples.

Parameters	DR (Site A)	SW (Site A)	RW (Site A)	Permissible limit Excellent	Very bad
SAR	2.35	27.72	4.57	10	26
ESP	17.14	45.21	28.14	2	60
RSC (meq L^{-1})	0.58	8.42	0.67	1.25	3

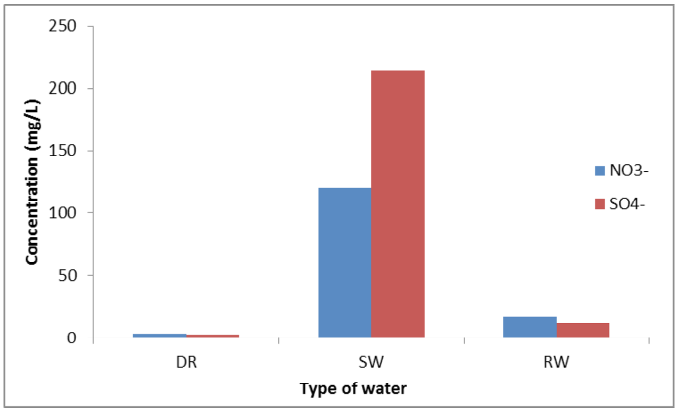

Fig.3: Variation of NO_3^- and SO_4^{2-} concentration among various forms of rainwater samples.

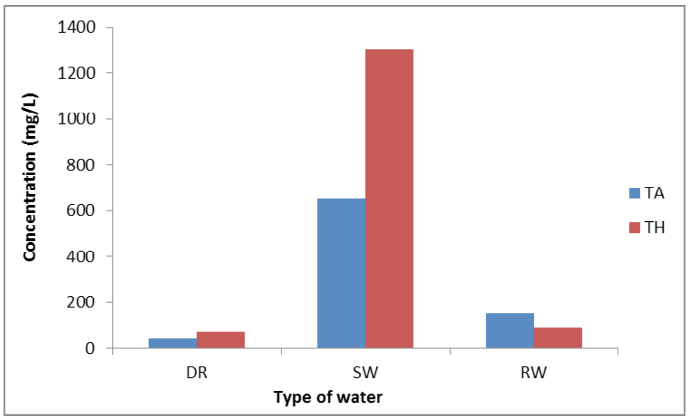

Fig.4 Variation of TA and TH among various forms of rainwater samples.

within safe limits, with an exception to SW, for which the concentration of Na^+ was 415 mg/L, while that of Ca^{2+} and Mg^{2+} were 375 and 88 mg/L respectively. The high concentration of Na^+, Ca^{2+} and Mg^{2+} may be attributed to the mixing up of salts in overland flow. The Ca^{2+} and Mg^{2+} values were in line with the values reported by Jothivenkatachalam et al. (2010) obtained from a study conducted in the same district. The K^+ concentration values observed were in good agreement with the corresponding range of values reported by Usharani et al. (2010). The concentration of Na^+, K^+, Ca^{2+} and Mg^{2+} in different types of water samples is shown in Fig. 2.

Sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and exchangeable sodium percentage (ESP) computed are given in Table 2. All the water samples, except SW were found to be within safe limit for irrigation.

Nitrate: The NO_3^- concentration was high for SW samples, which is possibly due to mixing up of fertilizers from agricultural fields with the stormwater. A high value of 120 mg/L was obtained for NO_3^- concentration in water samples collected from the study location, which is above the range of values reported by many researchers. However, Naz et al. (2009) reported such high values of NO_3^- in U.P. (India).

Sulphate: Sulphate concentration in DR was very low, while that in RW and SW was 12 mg/L and 214 mg/L, respectively. The observed values of RW are in line with the reported values by Areerachakul et al. (2009). Jothivenkatachalam et al. (2010) reported a maximum value of 169 mg/L SO_4^{2-} in Coimbatore district. The variation of NO_3^- and SO_4^{2-} concentration in direct rainfall, roofwater and stormwater is depicted in Fig. 3.

Phosphate: The phosphate concentration in DR was only 0.04 mg/L. Similar trend was visible in case of RW as the PO_4^{2-} concentration was only 0.03 mg/L. But SW from urban areas in the study site has a PO_4^{2-} concentration of 1.02 mg/L. The values obtained for SW are in good agreement with the study results presented by Usharani et al. (2010).

Chloride: Chloride is normally the most dominant anion in water, which can cause corrosion and pitting of iron plates or pipes. The Cl^- concentration was found less in both DR and RW water samples. However, high Cl^- concentration was observed in storm water runoff. Chloride content in SW was found to be 900 mg/L that may be due to mixing of fertilisers, pesticides and other chemicals in surface runoff from agricultural fields and urban areas. Jothivenkatachalam et al. (2010) also reported similar high value of 891 mg/L for chloride in Coimbatore district.

Total hardness: The stormwater samples showed hardness higher than the desirable limit of potable water. However, total hardness crossed the permissible limit of irrigation water. The hardness is due to dissolution of alkaline earth metal salts from geological matter (Karunakaran et al. 2009, Palanisamy et al. 2007).

Total alkalinity: Alkalinity of water is defined as the ionic concentration, which can neutralize the hydrogen ions. Total alkalinity was within the safe limits for both DR and RW. However, stormwater runoff showed a value of 650.8 mg/L that exceeded the permissible limit. Discharge of urban waste water might have led to the increase in alkalinity of SW. The total hardness and total alkalinity values in different types of rainwater samples collected in the study are shown in Fig. 4.

Statistical analysis of stormwater characteristics: The important statistical parameters viz., mean, range, standard deviation (SD), standard error (SE) and coefficient of variation (CV) of the physico-chemical characteristics of the analysed stormwater samples are presented in Table 3. The coefficient of variation of almost all parameters except pH and Cl^- showed higher values, and this is due to sample collection from different locations in the wide study area. Five out of the 14 parameters showed CV higher than 50 %. Jothivenkatachalam et al. (2010) also observed higher CV for 3 out of 10 parameters analysed for water samples collected in Coimbatore district, while Shah et al. (2008) observed high variability of 8 out of the 15 parameters analysed for a water quality study conducted at Gujarat. Very high standard deviations (SD) were observed for Na^+, Ca^{2+}, TA and TH, which can be attributed to the spatial and temporal variability in collected samples.

Correlation studies: A large number of significant correlations among various water quality parameters were obtained and the correlation matrix of 11 major physico-chemical variables is given in Table 4. It is clear from the results that the TS were negatively correlated with all the variables, except TDS. All other variables were positively correlated with all the studied parameters. It can also be observed that all variables, except two (EC and TS and TS and NO_3^-) were significantly correlated (at 0.05 level) with each other. Some of the highly significant correlations were discernible between pH and EC (R = 0.9630), pH and TDS (R = 0.8045), EC and TDS (R = 0.9132), EC and Ca^{2+} (R = 0.8004), EC and Mg^{2+} (R = 0.8142), SO_4^{2-} and TH (R = 0.8554) and between TH and EC (R = 0.8924). Apart from these, Na^+, Ca^{2+}, Mg^{2+} and SO_4^{2-} showed higher correlation with TH. It is also observed that TS showed very less significant correlation with pH and EC.

Table 3: Statistical parameters of stormwater samples.

Parameter	pH	EC	TS	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	SO_4^{2-}	PO_4^{3-}	Cl^-	TA	TH
Mean	7.756	2.65	2.559	1.693	415	40	375	88	120	214	1.02	900	651	1305
Max	8	4.48	6.560	2.824	520	50	510	102	150	254	1.34	960	905	1700
Min	7.66	0.28	0.030	0.177	310	30	240	74	90	174	0.7	840	397	910
Range	0.34	4.20	6.530	2.647	210	20	270	28	60	80	0.64	120	508	790
SD	0.142	2.116	3.505	1.351	148.49	14.14	190.92	19.8	42.43	56.57	0.453	84.85	359.21	558.61
CV (%)	1.836	79.87	136.9	79.81	35.78	35.36	50.91	22.5	35.36	26.44	44.37	9.428	55.178	42.81

Units for various parameters as per Table 1.

Table 4: Correlation matrix of the physico-chemical variables in stormwater

	pH	EC	TDS	TS	Na	K	Ca	Mg	NO_3^-	SO_4^-	TH
pH	1										
EC	0.9630*	1									
TDS	0.8044*	0.9132*	1								
TS	-0.2198*	-0.0366	0.3420*	1							
Na	0.7591*	0.7982*	0.6980*	-0.1096*	1						
K	0.3818*	0.3664*	0.2884*	-0.3335*	0.6848*	1					
Ca^{2+}	0.7673*	0.8004*	0.6262*	-0.2656*	0.9014*	0.4394	1				
Mg^{2+}	0.7824*	0.8142*	0.6467*	-0.2475*	0.9318*	0.4869*	0.9969*	1			
NO_3^-	0.6315*	0.6294*	0.5591*	-0.0813	0.9427*	0.7654*	0.7424*	0.7891*	1		
SO_4^-	0.7663*	0.7817*	0.6555*	-0.1834*	0.9955*	0.7024*	0.9041*	0.9340*	0.9512*	1	
TH	0.7240*	0.7292*	0.4970*	-0.3831*	0.8433*	0.3764*	0.9826*	0.9737*	0.6819*	0.8554*	1

*Indicates that correlation is significant at 0.05 level.

The linear regression analyses have been carried out for the water quality parameters which are found to have better and higher level of significance in their correlation coefficient. The regression equations obtained from the analysis are given below:

$pH = 0.0008 \times EC + 5.63$ ($R^2 = 0.927$)
$EC = 2946.59 \times TDS - 881.87$ ($R^2 = 0.834$)
$EC = 4.39 \times Ca^{2+} + 981.55$ ($R^2 = 0.64$)
$EC = 19.34 \times Mg^{2+} + 951.4$ ($R^2 = 0.662$)
$TH = 2.22 \times Na + 260.47$ ($R^2 = 0.711$)
$TH = 2.86 \times Ca^{2+} + 244.17$ ($R^2 = 0.965$)
$TH = 12.26 \times Mg^{2+} + 233.63$ ($R^2 = 0.948$)
$TH = 5.88 \times SO_4^{-2} - 67.465$ ($R^2 = 0.732$)

CONCLUSIONS

The quality of various forms of rainwater, viz. direct rainfall, roofwater and stormwater were assessed and found that the direct rainwater samples were pure and safe for use as drinking water. The surface water runoff samples collected from study area, which is mainly an urban and industrialised catchment, contained undesirable amount of sediment load and other chemicals, most of them are not within safe limits for drinking and irrigation use. The EC and TS values of samples collected from roofs were slightly above the desirable limit for drinking purpose. It can be concluded from the quality analyses that the direct rainfall is safe to use as potable water, but the roofwater should be subjected to some sort of filtration process to reduce the EC and sediment load before using as drinking water. The stormwater is neither suitable for drinking nor for irrigation use in its raw form, but can be used for various purposes other than drinking by appropriate filtration mechanisms.

Statistical analysis of physico-chemical characteristics of stormwater showed high percentage of coefficient of variation for most of the parameters except pH and Cl^-. Similarly, very high standard deviations (SD) were observed for Na^+, Ca^{2+}, TA and TH and this can be attributed to the spatial and temporal variability in collected samples. Correlation coefficients were worked out to find out the relationship amongst physico-chemical parameters of the water samples and a large number of significant correlations were obtained.

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