**Quantity of Roof-harvested Rainwater: Effects of Roofing Material**

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**ABSTRACT**

This paper reports the influence of roofing material on the quality of roof harvested rainwater. About 50 roof harvested rainwater samples from 4 different roof surfaces (viz., cement concrete, tile, galvanized iron and asbestos were analyzed for water quality parameters. Results show that the enrichment factor ( that is the ratio of concentration in roof runoff to that in free-fall rain) was >1 for most of the parameters tested indicating the significant effect of roofs as a source of pollutants either by weathering of roof material and/or by deposition. For roof runoff, parameters like pH, concentration of metals, iron and lead and bacteriological quality were not conforming to the drinking water quality standards which indicates that quality of roof runoff should not be taken for granted.

**INTRODUCTION**

It is now accepted that water scarcity and the lack of safe drinking water are the most serious challenges of the twenty-first century(Elimelech,2006).At present one-third of the world’s population lives in water-stressed countries and, by 2025,this figure is expected to rise to two thirds. Chronic shortage of safe drinking water leading to waterborne diseases creates an important public health problem in developing countries. Water-stressed countries or regions turn to non traditional sources to augment their water supplies. In this context, rooftop rainwater harvesting is receiving increased attention worldwide as an alternative source of drinking water. While rainwater is generally considered as non-polluted or at least not significantly polluted. Contamination occurs when it falls on the roof, collects dirt, dissolves some heavy metals in case of metal surfaces, and then flows into storage. There are several factors, which influence the quality of roof runoff. These can be summarized as (Forster 1996)

* Roof material-chemical characteristics, roughness, surface coating, age, weather ability, etc.
* Physical boundary condition of the roof –size, inclination and exposure;
* Precipitation event-intensity, wind, pollutant concentration in the rain;
* Other meteorological factors-season, weather characteristics, antecedent dry time;
* Chemical properties of the substance-vapour pressure, solubility in water, Henry’s constant, etc.;
* Concentration of the substance in atmospheric boundary layer-emission, transport, half-life, phase distribution, etc.;
* Location of the roof-its proximity to pollution sources.

Studies reported in the literature reveal the prevalence of microbiological and chemical contaminants especially heavy metals in roof-collected rainwater (Yaziz et.al.1989; Forster 1996; Simmons et al.2001; Lye 2002; Chang et al.2004; Meera and Ahammed, 2006).Few studies have been reported from India on the quality of roof-harvested rainwater. This paper evaluates the effect of roofing material on quality of roof-harvested rainwater. Roof runoff samples were collected from roofs of four different materials, viz. concrete, tile, galvanized iron (GI) and asbestos. The samples were analyzed for different water quality parameters so as to assess the suitability of roof-harvested rainwater as a source of drinking water.

**MATERIALS AND METHODS**

**Site Location and Roof Catchment Details**

House roofs were located in Nedumbassery, Kochi (Cochin), kerala. Kochi, the commercial capital of Kerala is the second largest city of the state with a population around 31 lakhs. It lies at approximately 9°58’N latitude and 76°13’E longitude. The heights of concrete, tile, asbestos and galvanized iron(GI)roofs were 3.6m,2.5m,2.5m and 3.0m respectively from ground. The site is located close to Nedumbassery International Airport and a National Highway. Details of the roofs are given in Table 1.Overhanging tree branches were found above GI roof. The approximate age of the roofs were:concrete-5 years,tile-25 years.GI and Asbestos-15 years.45 samples were collected during nine rainfall events during the summer and south west monsoon in the year 2004.

 **Table 1:Details of the roofs**

|  |  |  |  |
| --- | --- | --- | --- |
| Sr.No. | Material of roofs | Area of roof,m2 | Material of gutter and down spouts |
| 1. | Concrete | 12.00 | PVC |
| 2. | Tile | 4.81 | PVC |
| 3. | Asbestos | 2.60 | PVC |
| 4. | GI | 2.60 | PVC |
|  |  |  |  |

**SAMPLE COLLECTION AND STORAGE**

Samples were taken from plastic storage tanks after rainfall events. The storage tanks were fitted with first-flush device to discard the first 2 mm of rainfall. Samples were taken in pre-cleaned polyethylene containers. Details of the rainfall events for which samples were collected are shown in table 2. Great care was taken to ensure that the integrity of sample. Sample were stored at low temperature if the analysis was not done immediately after sampling. For heavy metal analysis, the samples were acidified using conc HNO3. Rainwater is also collected from the open by placing plastic containers on the roof. The various parameters tested were compared with that of free to assess the portion of substance originating from dry deposition and weathering or deterioration or roof materials.

**WATER QUALITY ANALYSIS**

The analytical derermination of different physiochemical parameter was carried out within te holding time of each parameter according to standard methods(APHA,1998).

 All sample were tested for becterial indicater, namely total colliforms was estimated by maltipal tube fermentation method (most probable number method) by employing lauryl tryptose broth (HiMedia labrotary, Mumbai). The inoculated sample were incubated at 37oC for 48 h. The result is expressed as most probable number per 100mL (MPN/100mL). The tesr was conducted in accordance with tne techniques described by American Public Health Association (APHA 1998).

 **Table 2: Details of rainfall eventsfor runoff samples from roofs**

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No |  Sampling data | Dry period | Amount of rainfall |
| 1 | 25/3/2004 | 60 | 1 |
| 2 | 28/3/2004 | 3 | 18 |
| 3 | 30/3/2004 | 1 | 16 |
| 4 | 6/4/2004 | 7 | 6 |
| 5 | 21/4/2004 | 15 | 4 |
| 6 | 28/5/2004 | 2 | 5 |
| 7 | 30/5/2004 | 1 | 17 |
| 8 | 2/6/2004 | 1 | 38 |

**STATISTICAL ANALYSIS**

The data generated where subjected to statistical analysis to find the mean significant level and pearson’s correction coeficient. Pearson’s correction coeficient was estimated to acces the degree of association between different parameter in freefall and in various roof run off . The statistical significant level was set at α=0.05.

**RESULT AND DISCUSSION**

Concentration of different quality parameter in run off collected from four roofs are given in table 3. Conc. In freefall rain also presented in this table. All parameter tested shown significant difference (p<0.04) in there main value. Comparision with IS 10500 (1991) drinking water guideline indicates free departure for parameter like pH,turbidity,iron,lead and bacteriological quality. Table no. 4 gives the % of sample exceeding the IS limits with respect to different water quality parameter.

All runoff sample were slightly acidic except that from conc roof which was almost neutral. The lowest value of pH was observed for runoff from tile with it mean valur significantly lower than that of other roofs. Shife toward alkaline value was observed for concrete and asbestos, 89% sample from tile roof did not mest this IS limit where as all sample from concrete roof conform to the standards. Variatin in alkalinity and hardness values were obsevred for runoff from different material the values were in general higher for runoff from asbestos and concrete roofs. High were also obsevered for G.I roof . tubidity value exceed acceptable limit for all roofs. the tubidity value for free fall rain was in general significanty lower then that for roof runoff. The mean value of turbidiy for GI roof was significanty higher then other roofs with maximum no. Of sample (56%) exceedind limits. Low conc of anion like chloride,sulphate, nitrate was detected roof runoff on in freefall rain. The mean value of sulphate and chloride for GI roof was significantlyhigher then when compaired to other runoff sample and freefall with regard conductivity, GI roof had the higher value significantly greater then other roof . The value for asbestos for asbestos and coc roof were almast the same. The DO values for roof run off were significantly then that fr direct rain. Lowest value was observed for GI and tile . variability in calcum conc was observed for runff and conc was significanty higher for concrete asbestos and GI when compaired to free fall value

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**Table 3:mean anf range of quality parameter for free-fall rain and runoff from roof**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **parameter** | **Free fall** | **GI** | **Asbestos**  | **tile** | **Concrete** |
| **pH** | 6.52 | 6.59 | 6.73 | 6.23 | 7.09 |
| **Alkalinity** | 21 | 34 | 40 | 20 | 37 |
| **Turbidity** | 4.3 | 15.5 | 10.9 | 12.4 | 13 |
| **Hardness** | 22 | 90 | 57 | 41 | 47 |
| **Chloride** | 1.10 | 13.01 | 3.23 | 2.21 | 3.31 |
| **Conductivity** | 47.26 | 187.90 | 119.16 | 54.88 | 113.78 |
| **DO** | 6.8 | 4.5 | 5.5 | 4.6 | 5.2 |
| **Nitrate** | 3.83 | 8.32 | 8.46 | 2.28 | 7.63 |
| **Sulphate** | 7 | 27 | 10 | 11 | 16 |
| **Sodium** | 0.4 | 1.8 | 1.0 | 1.0 | 1.8 |
| **Calcium** | 15.5 | 65.4 | 45.5 | 23.5 | 47.8 |
| **Total coliforms** | 239 | 7300 | 1258 | 2536 | 5142 |

Iron was detected in all runoff sample but was absent in free fall rain. Highest concentration of iron was observed for gi with its mean value significantly higher than that for other roofs.

**Table 4: Percentage samples for parameters exceeding drinking quality standars**

 **IS 10500 (1991)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Parameters** | **Free-Fall** | **GI** | **Asbestos** | **Tile** | **Concrete** | **Permissible limit** |
| pH | 56 | 22 | 11 | 89 | 0 | 6.5-8.5 |
| Turbidity | 0 | 56 | 33 | 22 | 33 | 10NTU |
| Iron | 0 | 33 | 0 | 11 | 11 | 1mg/lit |
| Lead | 0 | 33 | 0 | 33 | 0 | 0.05mg/lit |
| Total coliforms | 60 | 60 | 100 | 60 | 80 | <10MPN/100ml |

33% samples exceeded limits in GI roof and 11% in tile and concrete. Lead was detected in runoff from tile and GI roof with 33% samples exceeding IS limits in tile and GI roofs. Zn was detected in all samples with GI roof runoff showing the highest concentration. Very low concentration of copper was detected in runoff from concrete, tile and GI roofs and cadmium in tile roof.

 Total coliform are present in most of the all runoff samples. A few samples from free fall rain were also contaminated with total coliforms. Coliform concentration was found to be highest for GI roof. All samples from asbestos,80% samples from concrete and 60% from GI and tile roofs exceeded the limits.

 The relationship between the various ionic species in free fall rain and in roof- intercepted rainfall were determined by conclation analysis and Table 5 shows the Pearson’s correlation coefficient(r) for concrete roof. (similar tables were generated for other roofs and free fall rain also but data are not shown.) Very good positive correlation was found between alkalinity and hardness (r=0.96) for asbestos roof. For concrete, the value was0.77. Alkalinity value for roof- intercepted rainfall had high positive correlation (r>0.6) with conductivity, sulphate and calcium. In general,hardness in all samples showed positive correlation with conductivity, and coliform content for all roofs except asbestos.calcium in roof- intercepted rain had a high positive correlation with coliform content, conductivity,chloride and sulphate. Chloride in roof intercepted rain showed high correlation with conductivity and sulphate. High positive correlation between chloride and coliforms content was also found for all runoff except concrete.

**Table 5: Pearson’s correlation values for roof intercepted rain from concrete**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **pH** | **Alkalinity** | **Turbidity** | **Hardness** | **Chloride** | **TDS** | **DO** | **Nitrate** | **Sulphate** | **Sodium** | **Calcium** | **Total coliforms** |
| **pH** | **1.00** |  |  |  |  |  |  |  |  |  |  |  |
| **Alkalinity** | **0.24** | **1.00** |  |  |  |  |  |  |  |  |  |  |
| **Turbidity** | **0.22** | **0.67** | **1.00** |  |  |  |  |  |  |  |  |  |
| **Hardness** | **-0.12** | **0.77** | **0.34** | **1.00** |  |  |  |  |  |  |  |  |
| **Chloride** | **0.14** | **0.98** | **0.66** | **0.8** | **1.00** |  |  |  |  |  |  |  |
| **TDS** | **-0.06** | **0.86** | **0.71** | **0.62** | **0.89** | **1.00** |  |  |  |  |  |  |
| **DO** | **-0.02** | **-0.43** | **-0.34** | **-0.11** | **-0.52** | **-0.69** | **1.00** |  |  |  |  |  |
| **Nitrate** | **-0.09** | **0.59** | **0.09** | **0.5** | **0.62** | **0.66** | **-0.53** | **1.00** |  |  |  |  |
| **Sulphate** | **-0.17** | **0.66** | **0.61** | **0.69** | **0.72** | **0.87** | **-0.56** | **0.46** | **1.00** |  |  |  |
| **Sodium** | **-0.65** | **0.30** | **0.44** | **0.57** | **0.36** | **0.52** | **-0.03** | **0.18** | **0.70** | **1.00** |  |  |
| **Calcium** | **-0.05** | **0.87** | **0.61** | **0.66** | **0.90** | **0.98** | **-0.71** | **0.76** | **0.86** | **0.47** | **1.00** |  |
| **Total coliforms** | **0.79** | **0.82** | **0.99** | **-0.97** | **0.42** | **0.85** | **-0.99** | **-1** | **0.70** | **-0.42** | **0.85** | **1.00** |

Values of enrichment factors (that is the ratio of concentration in roof to that in free-fall rain) for different parameters in runoff are given in table 6.enrichment factor indicates the role of roof as a source or sink of pollutants. A value greater than 1 indicates that the roof is acting as a source of pollutants either due to weathering or deposition during antecedent dry time, and a value less than 1 shows that it is acting as sink by retaining the pollutants. Variation reflects diffrences in roofing materials and its treatments, air quality of region, characteristics of precipitation etc. (forster 1996;chang et al 2004)

In general, the physico-chemical characteristics except pH and turbidity conformed to the drinking water quality standards. pH of all roof runoff samples were slightly acidic. Slight increase in pH after falling on roofs was observed for asbestos and concrete. Mean value of pH for runoff from tile alone did not meet standards. Among the different roofs least value of pH was observed for runoff from tiles. Many studies reported in the litreture also show that physico-chemical quality of the roof-harvested rain water generally meets the guideline values with the notable exception of pH. Chemical analyses by forster (1996) revealed pH differnces between various roofing materials( concrete, fibrous, cement, tiles, zinc and tarfelt). Shift towards alkaline values for asbestos and concrete observed in the present study can be attributed to the dissolution of cement from the roofs. Alkalinity, hardness and calcium were found to be greater for cement containing materials like concrete and asbestos whereas, iron, zinc, lead and conductivity values were significantly higher for GI roof. This indicates that tis ion parameters originates mainly from dissolution of roofing materials rather than by dry or wet deposition. Studies by forster(1998) found cations like calcium originated from fibrous cement and concrete tiles, and Adeniyi and Olabanji (2005) found high values of hardness in asbestos roof. Pearson’s correlation coefficient showed high positive correlation (r>0.6) between alkalinity and hardness, alkalinity andcalcium, and hardness and calcium, in concrete and asbestos. Many studies found metal surfaces in contact with running off will dominate the runoff.

 **Table 6: Enrichment factors of different quality parameters for roofs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameters** | **GI** | **Asbestos** | **Tile** | **Cocrete** |
| Alkalinity | 1.62 | 1.91 | 0.96 | 1.77 |
| Turbidity | 3.59 | 2.53 | 2.88 | 3.01 |
| Hardness | 4.08 | 2.57 | 1.86 | 2.12 |
| Chloride | 11.83 | 2.94 | 2.01 | 3.01 |
| Conductivity | 3.98 | 2.52 | 1.16 | 2.41 |
| DO | .66 | 0.81 | 0.68 | 0.76 |
| Nitrate | 2.17 | 2.21 | 0.60 | 1.99 |
| Sulphate | 4.17 | 1.60 | 1.62 | 2.43 |
| Sodium | 4.09 | 2.23 | 2.35 | 4.02 |
| Calcium | 4.21 | 2.93 | 1.51 | 3.08 |
| Zinc | 22.17 | 1.27 | 1.62 | 1.42 |
| Total coliforms | 31 | 1.30 | 10.60 | 22 |

Pattern, which accounts for the higher concentration of zinc and iron in GI roof in the present study. Lead in runoff from GI roof may be due to dissolution from the roof, as lead was reported to be present in runoff from GI roof (Yaziz et al. 1989; Chang et al. 2004). The low concentration of anions like sulphate, nitrate, and chloride present in all roof runoff samples and free-fall, with similar mean values in all runoff, can be attributed to deposition rather than dissolution (Forster 1998).

 Studies suggest that metallic roofs generally have lower bacteriological contamination (Yaziz et al. 1989; Ghanayem 2001). In the present study, the coliform concentration was highest for GI roof, which contradicts the general observation that microbial contamination is lower for a metallic roof. This may be linked to the overhanging trees, which resulted in increased bird droppings, turbidity, and organic contamination, all favoring increased bacteriological contamination. Higher value of COD in GI roof runoff further supports this. The mean value of most of the water quality parameters was significantly higher for GI roof. This may be due to the combined effect of enrichment by dissolution of substances from the roof and deposition especially from the overhanging trees. This suggest that the overhanging trees can greatly affect the quality of roof-harvested rainwater.

**CONCLUSION REMARKS**

 While there are many factors which influence the quality of harvested rainwater from rooftops, this study focused on the influence of roofing materials. Heavy metals, zinc and iron, in general, were higher the metallic roofs whereas alkalinity and hardness were higher than cement containing materials like concrete. Higher conductivity values were observed for runoff from metallic roofs. Concentration of various contaminants in roof runoff was generally higher than that in direct rain. The enrichment factor was >1 for most of the parameters tested indicating the significant effect of roofs as a source of pollutants either by weathering of roof material and or by deposition. This can be attributed to weather ability of roofing materials and dry deposition. For roof runoff, parameters like pH, concentration of metals, iron and lead, and bacteriological quality were not conforming to the drinking water quality standards. The study thus indicates that quality of roof runoff should not be taken for granted. Proper treatment methods, especially for adjustments of pH, and removal of heavy metals and microbiological contamination are necessary to reduce potential health risk associated with these contaminants.

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