INTERNATIONAL PERSPECTIVES

Although most of the information presented in the Journal refers to situations within the United States, environmental health and protection know no boundaries. The Journal periodically runs International Perspectives to ensure that issues relevant to our international membership, representing over 20 countries worldwide, are addressed. Our goal is to raise diverse issues of interest to all our readers, irrespective of origin.

Risk Assessment of Rooftop-Collected Rainwater for Individual Household and Community Use in Central Kerala, India

Y. Jesmi, MPhil
School of Environmental Sciences
Mahatma Gandhi University

K.M. Mujeeb Rahiman, PhD
A.A.M. Hatha, PhD
Lal Deepu, MSc
School of Marine Sciences
Cochin University of Science and Technology

S. Jyothi, MSc
School of Environmental Sciences
Mahatma Gandhi University

Abstract **Water quality of rooftop-collected rainwater is an issue of increased interest particularly in developing countries where the collected water is used as a source of drinking water. Bacteriological and chemical parameters of 25 samples of rooftop-harvested rainwater stored in ferrocement tanks were analyzed in the study described in this article. Except for the pH and lower dissolved oxygen levels, all other physicochemical parameters were within World Health Organization guidelines. Bacteriological results revealed that the rooftop-harvested rainwater stored in tanks does not often meet the bacteriological quality standards prescribed for drinking water. Fifty percent of samples of harvested rainwater for rural and urban community use and 20% of the samples for individual household use showed the presence of *E. coli*. Fecal coliform/fecal streptococci ratios revealed nonhuman animal sources of fecal pollution. Risk assessment of bacterial isolates from the harvested rainwater showed high resistance to ampicillin, erythromycin, penicillin, and vancomycin. Multiple antibiotic resistance (MAR) indexing of the isolates and elucidation of the resistance patterns revealed that 73% of the isolates exhibited MAR.**

Introduction

Though 70% of the earth's geographical area is covered by water, only 1% of it is potable; the rest is unsafe for consumption. Lack of investment, growing water demand, overexploitation of existing sources, pollution, and maintenance problems make the supply of potable water in developing countries extremely difficult to obtain. The availability of an adequate supply of safe water is fundamental to the development process in all sectors with benefits such as improved labor productivity (Gadgil, 1998). The microbial quality of many drinking water sources in India, both groundwater and surface water, is affected by human activities (Pushpangadan, 2003) and it is reported that nearly 44 million people in India are directly affected by water quality problems, either due to bacteriological or chemical pollution (Nigam, Gujja, Bandyopadhyay, & Talbot, 1998).

Due to decreasing supply and the ubiquitous contamination of surface and groundwater resources by microbial and chemical contaminants, rainwater harvesting has become more relevant now in areas that enjoy high rainfall. Rainwater harvesting can provide a renewable supply of natural, soft, clear, and odorless water that could be used for a range of purposes and could represent the primary source of household water in some areas. Governmental agencies across the world are now introducing policies to promote increased use of rainwater. In India, awareness is growing of the potential of rainwater harvesting to meet the demand of safe water throughout the country, especially in rural locations. Several state governments including in Kerala have introduced legislation that makes it obligatory to incorporate rooftop harvesting systems in newly constructed buildings in urban areas. Governments are also providing subsidies to promote the use of rainwater harvesting systems.

The National Sample Survey Organization (1999) has reported that the most significant risk to human health related to drinking water quality is from microbiological sources through

Rainwater-Harvesting Tank in Study Area

fecal contamination. In general the quality of rainwater is not treated for bacteriological quality and is assessed at the household level because of the presence of leaves and other materials such as mosquito larvae, insects, rodents, frogs, etc. The World Health Organization (WHO) proposed appropriate treatment techniques to use harvested rainwater as a safe drinking water source (WHO, 2006). Researchers revealed the value of solar disinfection (SODIS) as a low-cost, sustainable, and simple method of treating contaminated water in developing countries (Acra, Jurdy, Muallem, Karahagopian, & Raffoul, 1989; Acra, Raffoul, & Karahagopian, 1984; Sommer et al., 1997).

Though Kerala receives adequate annual rainfall, many parts of the state are experiencing severe drinking water shortages due to poor water management. As a proactive measure, the government of Kerala is promoting rainwater harvesting in rural and urban areas for household use and community use in schools. Monitoring of this rooftop-collected water, however, is not carried out. Hence our study had an objective to determine the bacteriological and nutrient quality of rooftop-harvested and stored rainwater for individual household use as well as for community use in rural and urban settings. General bacterial flora of rooftop-collected water were characterized and the risk assessment of these strains was carried out by drug resistance analysis.

Methods

Collection of Samples

The rooftop-harvested rainwater stored in ferrocement tanks (see photo above) was collected from rural and urban areas of Kottayam, Alappuzha, and Eranakulam districts of Kerala. Ferrocement tanks are made of a thin sheet of cement mortar reinforced with a cage of wire mesh and steel bars. The rainwater from the rooftop is directed to the tank by gutters and polyvinyl chloride pipes to the inlet of ferrocement tanks. Except the inlet and outlet portions, all the sides are closed to prevent groundwater entry to the tanks. The samples were aseptically collected in sterile bottles from the outlet pipe of the tanks and transported to the laboratory in an ice box. Nine storage tanks for individual household use and eight storage tanks each for rural and urban community use were selected at random for sample collection.

Analysis of Physicochemical Parameters

Temperature was recorded with the help of a Celsius thermometer and the pH was monitored with the help of an electronic pH meter. Turbidity was measured using nephelometric turbidity units and total dissolved solids (TDS) and electrical conductivity was measured using a conductivity meter. Acidity, alkalinity, chlorinity, hardness, dissolved oxygen (DO), phosphate, nitrate, and nitrite were measured using standard methods (Clesceri, Greenberg, & Eaton, 1998).

Bacteriological Analysis

Total Heterotrophic Bacterial Count

Water samples were serially diluted aseptically up to 10^{-2} using sterile distilled water. Aliquots of 0.2-mL samples from each dilution were spread plated in triplicate on R2A medium for the enumeration of total aerobic heterotrophic bacteria, which is expressed as total viable count (TVC). The plates were then incubated at room temperature (around 30ºC) for 48–72 hours. After incubation, plates with 30–300 CFUs were selected for counting and isolation of bacterial cultures.

Isolation and Identification of Bacterial Isolates

After recording the morphological characters and pigmentation, representative types constituting at least 10–20 numbers of colonies on plates were selected and restreaked onto R2A plates to ensure purity. All the purified isolates were maintained on R2A slants for further characterization and identified to generic level using the taxonomic key for identification by Barrow and Feltham (1993), Holt and co-authors (2000), and Harley and Prescott (2002). Further characterization of the members of the family Enterobacteriaceae was not carried out; however, it was considered as a single genus for counting the number of genera present in the samples. The isolates were characterized based on Gram staining, spore staining, motility test, Kovac's oxidase test, oxidation fermentation test, and catalase test (Jeena, Deepa, Mujeeb Rahiman, Shanthi, & Hatha, 2006).

Analysis of Fecal Coliform (Most Probable Number [MPN] Method)

The MPN load of fecal coliform (FC) bacteria was determined by three-tube dilution method using *E. coli* (EC) broth as the medium (Hatha, Chandran, & Mujeeb Rahiman, 2004). Ten mL, 1 mL, and 0.1 mL of water samples were inoculated into respective dilution tubes containing inverted Durham's tubes. Ten-mL samples were inoculated into 10 mL double strength EC broth; 1-mL and 0.1-mL samples were inoculated into single strength EC broth of 10 mL each. Inoculated tubes were incubated at 44.5°C for 24 hours and observed for growth and gas production. Tubes that showed growth and gas production were recorded as FC positive and used for calculating the MPN index. The density of FC was expressed as MPN per 100 mL of water.

Isolation of E. coli

In order to confirm the presence of *E. coli*, positive FC tubes in the presumptive MPN tests were streaked on eosin methylene blue (EMB) agar, and incubated at 37°C for 24 hours. After incubation the plates were observed for typical *E. coli*–like colonies (colonies with green metallic sheen). Whenever present at least two colonies per plate were picked up and restreaked to ensure purity and stored on nutrient agar vials for further biochemical characterization using indole, methyl red, Voges-Proskauer, and citrate (IMViC) test. The cultures giving + + - - reaction for IMViC test were confirmed as *E. coli* (Hatha et al., 2004).

Analysis of Fecal Streptococci (MPN Method)

The MPN load of fecal streptococci (FS) bacteria was determined by the three-tube dilution method using azide dextrose broth (ADB) as medium (Hatha et al., 2004). Ten-mL, 1-mL, and 0.1-mL samples were inoculated into respective dilution tubes. Ten-mL samples were inoculated into 10 mL double strength ADB; 1-mL and 0.1-mL samples were inoculated into single strength ADB of 10 mL each. Inoculated tubes were incubated at 37°C for 24 hours and observed for turbidity in the medium. Tubes showing turbidity in the medium were recorded as FS positive and used for calculating the MPN index. The density of FS was expressed with MPN per 100 mL of water.

Risk Assessment of Bacterial Isolates From Harvested Rainwater

Risk assessment of bacterial isolates from harvested rainwater was determined by drug resistance analysis. A total of 100 bacterial isolates from various rainwater samples collected from the different rainwater harvesting tanks were tested against 12 antibiotics by using disc diffusion method (Bauer, Kirby, Sherris, & Turck, 1966). The following are the antibiotics and their concentrations used for our study: ampicillin (A, 10 mcg); amikacin (Ak, 30 mcg); chloramphenicol (C, 30 mcg); ciprofloxacin (Cf, 5 mcg); erythromycin (E, 10 mcg); gentamicin (G, 10 mcg); kanamycin (K, 30 mcg); nalidixic acid (Na, 30 mcg); penicillin G (P, 10 units); streptomycin (S, 10 mcg); tetracycline (T, 30 mcg); and vancomycin (Va, 30 mcg). The isolates were inoculated into tryptic soy broth and enriched by incubating at 30°C for 6–8 hours. Using a sterile cotton swab, the enriched cultures were swabbed onto the surface of sterile Muller-Hinton agar plates. After a prediffusion time of 15 minutes antibiotic disks were applied on the seeded agar surface by using disc dispenser. The plates were incubated for 24 hours at 30°C. After incubation, the diameter of the zone of inhibition was measured and compared with the zone interpretive chart and classified as resistant and sensitive. Percentage multiple antibiotic resistance (% MAR) of bacterial isolate was also carried out by using standard formula and a value greater than 20 indicated that the isolate was MAR.

Statistical Analysis

The data were analyzed by two-factor analysis of variance using the statistical tool package of Microsoft Office Excel 2007 software. Wherever the treatments were found to be significant, least significant were calculated and significant treatments were identified. Whenever necessary the results were presented as the average and standard deviation.

TABLE **1**

Physicochemical Characteristics of the Rooftop-Collected and Stored Rainwater for Individual Household and Community Use

Parameter Analyzed	Source of Harvested Rainwater		
	Rural Individual	Rural	Urban
	Household Use (n = 9)*	Community Use (n = 8)*	Community Use (n = 8)*
pH	9.03	9.06	8.51
Temperature (°C)	28.78	28.93	29.03
Conductivity (mS[a])	0.09	0.21	0.18
Total dissolved solids (ppm[a])	52.85	101.99	88
Turbidity (NTU[a])	0.67	0.89	0.5
Acidity (mg/L)	0.56	0.00	0.63
Alkalinity (mg/L)	47.22	60.63	55.63
Chloride (mg/L)	9.16	9.05	15.62
Salinity (mg/L)	16.54	16.36	28.21
Hardness (mg/L)	40.78	40.13	56.38
Dissolved oxygen (mg/L)	3.83	4.16	3.76
Nitrite (mg/L)	0.0023	0.0741	0.0329
Nitrate (mg/L)	1.4185	1.5593	6.9100
Phosphate (mg/L)	0.0512	0.0142	0.0232

[a]mS = milli Siemens; ppm = parts per million; NTU = nephelometric turbidity units.
*Mean values of parameters.

Results

Physicochemical Parameters and Nutrient Concentration of Harvested Rainwater

Mean values of the different physicochemical parameters of the rooftop-collected and stored rainwater for use in rural household, rural community, and urban community use are presented in Table 1. All the physicochemical parameters except pH were within the guidelines for these parameters. pH of the harvested and stored rainwater samples was highly alkaline in nature with a pH up to 11.32 in the rainwater samples from one of the tanks. Our study also showed the DO content of all the rooftop-harvested rainwater samples analyzed were in the range of 3.25–4.87 mg/L. Result also showed significantly

TABLE **2**

Bacteriological Parameters of Harvested and Stored Rainwater for Individual and Community Use

Sample #	Source of Water	TVC[b] (CFU/mL)	FC[b] (CFU/100 mL)	FS[b] (CFU/100 mL)	FC/FS Ratio	Presence of *E. coli*
1	RI[a]-1	2.05 x 10^3	1.10 x 10^3	4.60 x 10^2	0.24	+
2	RI-2	2.89 x 10^3	4.60 x 10^2	1.10 x 10^3	0.42	+
3	RI-3	5.90 x 10^3	9.30 x 10^1	2.40 x 10^2	0.39	–
4	RI-4	8.40 x 10^4	2.40 x 10^2	0.00	-	–
5	RI-5	1.74 x 10^4	0.00	2.30 x 10^1	0.00	–
6	RI-6	1.28 x 10^4	0.00	1.50 x 10^2	0.00	–
7	RI-7	2.88 x 10^4	0.40 x 10^1	1.50 x 10^2	0.03	–
8	RI-8	1.54 x 10^4	0.00	4.30 x 10^1	0.00	–
9	RI-9	8.20 x 10^3	0.00	4.60 x 10^2	0.00	–
10	RC[a]-1	2.51 x 10^3	4.60 x 10^2	4.60 x 10^2	1.00	–
11	RC-2	5.15 x 10^2	2.40 x 10^2	9.30 x 10^1	2.58	+
12	RC-3	4.93 x 10^3	2.10 x 10^1	4.30 x 10^1	0.49	+
13	RC-4	2.44 x 10^4	1.50 x 10^3	4.60 x 10^2	3.26	+
14	RC-5	1.74 x 10^4	4.30 x 10^1	7.50 x 10^1	0.57	+
15	RC-6	4.90 x 10^2	0.00	3.90 x 10^1	0.00	–
16	RC-7	3.00 x 10^2	0.00	0.40 x 10^1	0.00	–
17	RC-8	4.40 x 10^4	0.40 x 10^1	9.30 x 10^1	0.04	–
18	UC[a]-1	2.28 x 10^4	1.50 x 10^2	4.60 x 10^2	0.33	+
19	UC-2	2.04 x 10^4	2.10 x 10^3	2.40 x 10^2	8.75	–
20	UC-3	1.74 x 10^3	0.70 x 10^1	0.40 x 10^1	1.75	+
21	UC-4	5.80 x 10^3	0.00	0.70 x 10^1	0.00	–
22	UC-5	3.20 x 10^4	4.60 x 10^2	2.40 x 10^2	1.92	+
23	UC-6	1.31 x 10^4	0.00	2.40 x 10^2	0.00	–
24	UC-7	5.52 x 10^4	0.90 x 10^1	2.10 x 10^2	0.04	+
25	UC-8	2.48 x 10^4	0.00	2.40 x 10^2	0.00	–

[a]RI = rural individual household use; RC = rural community use; UC = urban community use.
[b]TVC = total viable count; FC = fecal coliform; FS = fecal streptococci.

higher concentration of nitrate ($p < .001$) than nitrite and phosphate, though no significant difference existed between samples.

Bacteriological Quality of the Rooftop Harvested and Stored Rainwater

The bacteriological quality of harvested rainwater is presented in Table 2. Total heterotrophic bacterial count ranged from 3.00 x 10^2 to 8.40 x 10^4 CFU/mL. While FC load ranged between zero to 2.10 x 10^3, FS load was from zero to 1.10 x 10^3 cells/100 mL. Our study revealed that 64% of harvested rainwater samples had FC and 96% of harvested rainwater samples had FS. The FC/FS ratio was less than 0.7 in 76% of the water samples indicating pollution from nonhuman sources. While *E. coli* was isolated from two of the nine rooftop-harvested rainwater samples for household use, water from 50% (4/8) of the storage tanks for community use in rural and urban areas showed the presence of this organism.

A total of 100 bacterial cultures from the harvested rainwater were characterized up to generic level and the percentage occurrence of different genera of bacteria in the rooftop-harvested rainwater is presented in Table 3. The harvested rainwater for urban community use had more diverse bacterial flora when compared to that of rural areas. Nine genera of bacteria were isolated with various frequencies. *Alcaligenes* and members of the family Enterobacteriaceae were isolated from all the samples while *Moraxella* and *Micrococcus* were isolated from only one sample. *Bacillus* was the predominant genera from rural household sample, while Enterobacteriaceae and *Alcaligenes* formed the dominant genera in water for rural community use and urban community use, respectively.

Antibiotic Resistance of the Bacterial Isolates From Harvested and Stored Rainwater

Antibiotic resistance among the heterotrophic bacteria from the harvested and stored rainwater is presented in Figure 1. Overall antibiotic resistance was higher among isolates from urban samples; the only exceptions were erythromycin and tetracycline. Resistance to antibiotics such as ampicillin, erythromycin, penicillin, and vancomycin was frequent among the bacterial isolates from harvested rainwater. More than 70% of bacterial isolates were sensitive, however, to amikacin, chloramphenicol, ciprofloxacin, and gentamicin. Percentage MAR and resistance profiles (data not shown) of viable bacterial isolates from harvested rainwater showed that 73% of bacteria had % MAR greater than 20. The highest % MAR was shown by *Alcaligenes* (83.3%) followed by *Bacillus* and Enterobacteriaceae (75%).

Discussion

Physicochemical Parameters and Nutrient Concentration of Harvested Rainwater

Except for pH, other parameters were within the drinking water quality guidelines and were in agreement with the observations of other researchers from different parts of the world (Chang, McBroom, & Beasley, 2004; Radaideh, Al-Zboon, Al-Harahsheh, & Al-Adamat, 2009; Simmons, Hope, Lewis, Whitmore, & Gao, 2001). The pH of rainwater usually ranges from 4.5 to 6.5 but increases slightly after falling on the roof and during storage in tanks (Meera & Mansoor, 2006). In our observations, the pH of the freshly collected rainwater was 6.01. The alkaline nature of the stored rainwater is most likely due to the insufficient curing of the storage tanks before usage. The storage tanks were made of ferrocement, which have been reported to cause alkalinity of stored rainwater (Handia, 2005; Simmons et al., 2001). The tanks from which the samples were collected during our study were newly constructed because the rainwater harvesting started only recently in the study area. It is argued, however, that the pH value declines with age of tank and period of storage.

DO is the most important parameter in potable water systems for its effect on other chemicals in the water as it oxidizes both organic and inorganic compounds and alters their chemical and physical states (Nduka, Orisakwe, & Ezenweke, 2008). DO levels of stored rainwater in urban and rural areas were above 3 mg/L. Relatively low DO may be due to the lack of replenishment of oxygen from atmospheric mixing/photosynthesis (that are possible in well water) as well as due to the consumption of oxygen by the microbial community for oxidation of organic material present, if any. DO of water is dependent on temperature, turbulence at the surface, surface area exposed to the atmosphere, atmospheric pressure, and amount of oxygen in the surrounding air, which are not favorable for stored water in the harvesting tanks.

Wide variations in the concentrations of major ions like calcium, magnesium, sodium, potassium, chlorides, sulfates, and nitrates due to differences in roofing material and its treatment, orientation and slope of roof, air quality of region, characteristics of precipitation, etc., were reported by various researchers (Chang et al., 2004; Forster, 1996; Wu, Huizhen, Junqi, Hong, & Guanghui, 2001). Chloride ions are essential for life and in small concentrations they are not harmful to humans in drinking water. WHO (2004) permitted up to 200 mg/L chloride in potable water. Unlike well water, rainwater is adversely affected by local air pollution and debris in the rainwater catchment and conveyance areas. The result of our study indirectly points to good ambient air quality in the study area. While rainwater is considered pure, a large number of human-made atmospheric pollutants exist such as sulfur dioxide, nitrogen oxides, and various hydrocarbons, which together are the principal causes of acid rain. Such water can be unsafe to drink, especially in areas of heavy pollution such as industrialized urban areas. The nitrite and nitrate concentrations of the rainwater samples of our study were less than those reported by Radaideh and co-authors (2009) from the harvested rainwater from different regions.

TABLE **3**

Percentage Occurrence of Different Genera of Heterotrophic Bacteria in the Rooftop–Collected Rainwater for Individual Household and Community Use

Genera	% Occurrence in Rooftop-Collected Rainwater		
	RI[a] (*n* = 24)	RC[a] (*n* = 32)	UC[a] (*n* = 44)
Gram negative			
Acinetobacter	8.33	–	11.36
Alcaligenes	8.33	21.88	47.72
Enterobacteriaceae	33.34	65.63	15.91
Moraxella	–	–	2.27
Pseudomonas	–	3.12	6.82
Vibrio	–	6.25	4.55
Gram positive			
Bacillus	50.00	3.12	–
Micrococcus	–	–	6.82
Unidentified	–	–	4.55
Total	100.00	100.00	100.00

[a]RI = rural individual household use; RC = rural community use; UC = urban community use.

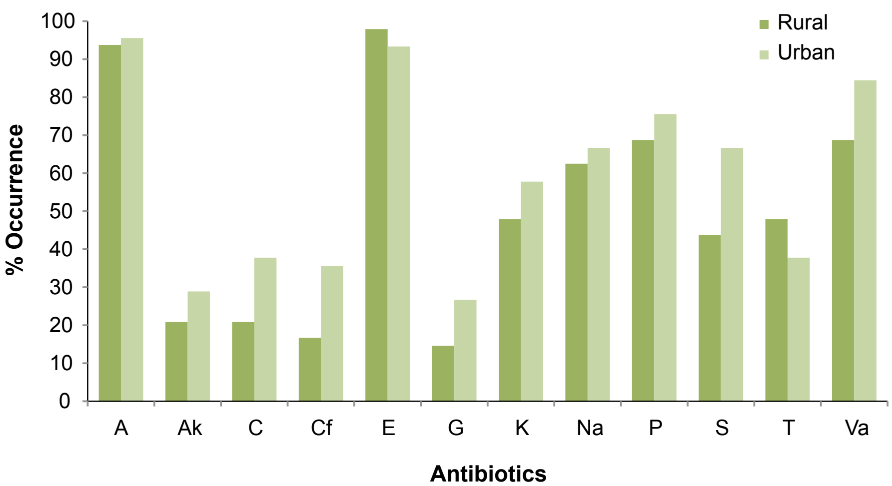
Bacteriological Quality of the Rainwater

The TVC load of the samples analyzed in our study were much lower than those reported in earlier studies (Simmons et al., 2001; Uba & Aghogho, 2000). FC and FS load were also relatively lower, though *E. coli* was isolated from nearly 50% of samples for community use and 20% samples for household use. Previous studies (Simmons et al., 2001) reported that 56% of domestic roof-collected rainwater supplies exceeded the microbiological criteria of <1 FC/100 mL and recorded the presence of total coliforms, FC, and *E. coli* in considerable number of samples (Radaideh et al., 2009). In Kerala, around 40% of the communicable diseases have been attributed to waterborne infections and in some of the coastal villages of Kerala diarrheal disease was ranked as the second most important cause of illness (Remani, 2004). Previous reports on microbiological quality of rainwater (Handia, 2005; Radaideh et al., 2009) revealed that rainwater harvesting systems do not often meet the microbiological quality standards for drinking water. In our study FC/FS ratios were worked out to track the source of fecal contamination. The major limitation of the FC/FS ratio is the difficulty to use it effectively when mixed pollution sources are present. Since the rooftops are not protected from the entry of mongooses and birds the possibility of mixed sources of contamination is present. The results of our analysis, however, revealed nonhuman sources of fecal contamination. Though a difference of opinion exists on this method to identify the source, the results agree with previous observations (Appan, 1997).

Since the earliest microbiological investigations of drinking water quality, the detection of fecal indicator bacteria in drinking water has been used as a means of predicting the possible presence of pathogenic bacteria (WHO, 2004). Tank rainwater is usually harvested from a roof catchment area that is open to the environment and can be accessed by birds, insects, and animals. Fecal droppings from birds, lizards, mice, rats, and possums that can access the roof catchment may contain pathogenic microorganisms that are harmful to health when ingested. Pacific Islands Applied Geo-Science Commission's report (Mosley, 2005) had recommended several measures such as trimming of tree branches overhanging the roof, prevention of entry of mongooses to the rooftop, and regular cleaning as these may act as potential sources of entry of pathogenic bacteria into the rooftop-collected rainwater.

FIGURE **1**

Antibiotic Resistance Among the Heterotrophic Bacteria From Harvested Rainwater for Rural and Urban Use



A = ampicillin; Ak = amikacin; C = chloramphenicol; Cf = ciprofloxacin; E = erythromycin; G = gentamicin; K = kanamycin; Na = nalidixic acid; P = penicillin G; S = streptomycin; T = tetracycline; Va = vancomycin.

The results of our study revealed relatively better quality of rooftop-collected rainwater in the study area when compared to reports from other developing countries (Mbaka, 2004; Sazakli, Alexopoulos, & Leotsinidis, 2007). The FC and FS values of the harvested rainwater samples analyzed ranged between zero to 2.10 x 10^3 and zero to 1.10 x 10^3 CFU/100 mL, respectively, which was comparable to observations made by Fewtrell and Kay (2007). Detection of specific pathogens was also reported in harvested rainwater (Albrechtsen, 2002; Simmons et al., 2001; Uba & Aghogho, 2000). Since the FS and FC loads were comparatively low, we did not analyze the samples for specific pathogens.

Antibiotic Resistance of the Bacterial Isolates

Our study revealed that most bacterial isolates from harvested rainwater were resistant to ampicillin, erythromycin, penicillin, and vancomycin. Specific reports on drug resistance among the bacterial isolates from harvested rainwater are not available for comparison, though presence of drug-resistant bacteria in bottled mineral water/drinking water were available (Zeenat, Hatha, Viola, & Vipra, 2009). Ours may be the first report of drug-resistant bacteria in rooftop-harvested rainwater. MAR indexing of the isolates and elucidation of the resistance patterns (results not shown) revealed that 73% of the isolates were MAR in our study. Apart from variations among different genera, wide variations in the MAR index and resistance patterns were also noticed within the different strains of the same genera, indicating the diversity of the strains. One interesting observation was the higher frequency of resistance among bacterial isolates from urban area samples. Also resistance to most antibiotics was relatively high when compared with bacterial isolates from polluted household water, especially to chloramphenicol, ciprofloxacin, and streptomycin. This is an interesting observation, as we feel most of the urban flora might have originated from humans as a result of spillage of oral microflora or by sneezing or cough. These antibiotics are specific to human use and the resistant forms may be of human origin. The occurrence of MAR bacteria in the environment is certainly a well-known phenomenon. Many investigators believe that these drug-resistant organisms have become more common recently due to the extensive use of antibiotics in medicine and agriculture throughout the world.

The situation in India is more serious where the misuse of antibiotics is prevalent. Antibiotics are readily available over the counter without any prescription, and the general public is not aware of the consequences of improper and frequent use of antibiotics. This concern is particularly relevant in light of the discovery that resistance characteristics can be transferred to nonresistant recipient cells via R-factor plasmid vectors (Mitsuhashi, 1977). The microflora that could be present in the rainwater are most likely the transient aerobic microflora, which could be mostly of human origin in a highly populated country like India. The sampling locations in our study were located among dense rural and urban community and most of the drug-resistant forms that are encountered might have possibly originated from a human source.

Conclusion

The rooftop-collected water in the study area for individual and community use was found to be within the WHO chemical quality for drinking except for the pH and lower DO levels. The bacteriological quality did not often meet the standards prescribed for drinking water, however, and was found to contain FS and FC in several samples. The multidrug-resistant nature of the bacteria from the samples is a matter of concern. The gastroenteric pathogen *E. coli* was detected in 40% of the harvested rainwater. *Alcaligenes*, Enterobacteriaceae, *Pseudomonas*, *Vibrio,* etc. were also isolated from the rainwater harvesting tanks. Our study suggests that some form of low-cost treatment of harvested rainwater such as SODIS is necessary before it can be used as a source of drinking water. To reduce the probability of coliform in rainwater harvesting systems it is recommended to keep the rain catchment area clean and free of debris and should be cleared of overhanging branches of trees.

Corresponding Author: A.A. Mohamed Hatha, Associate Professor, Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, Cochin 682 016, Kerala, India. E-mail: mohamedhatha@gmail.com.

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