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Rainwater Harvesting for Drinking: A Physiochemical Assessment in Port Vila, Vanuatu

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Abstract

Rainwater harvesting for drinking purpose has been a great source for survival by many societies since ages and now scarcity in water resources has been forcing many others to follow. Even though, rainwater harvesting is an exploitative practice where there is abundance of rainfall, but the methods in which harvesting process are carried needs to be studied in detail. The present study was a systematic physiochemical analysis of harvested rainwater for drinking purpose in Port Vila, Vanuatu where 22 sites were studied for two consecutive seasons. Notable mean variations were observed in total dissolved solids (TDS) with 63.84 mg/L, pH 0.4 and electrical conductivity (EC) with 98.9 μS/Cm. The mean standard deviation of 3.6 mg/L in acidity of pre and post monsoon seasons was also been a noted concern. Timing, extent of rainfall along with the usage had shown variations in the constituent's concentrations. The study revealed that the standards for the harvested drinking water are compromised at some sites either in one or multiple physiochemical parameters. People in Port Vila continue to consume the harvested water due to cultural practices and beliefs related to rainwater. It was observed that proper management and adaptation to new technologies would yield better quality of the harvested water.

Keywords: *Rainwater harvesting, Port Vila, Physiochemical, Water quality*

1. Introduction

Rainwater harvesting for drinking has been an ancient practice for human civilization. According to Pacey and Cullis (1986), rainwater harvesting is the gathering and storage of water running off surfaces on which rain has directly fallen, could be a potential alternative in small communities that cannot be served by centralized water supply systems. The climate-change impacts on water resources are troublesome, especially for small island developing states (SIDS) which experiences decrease in already limited freshwater availability due to change in rainfall patterns, saline intrusion into freshwater aquifers from sea-level rise and El Niño intensity and frequency. It also causes increased incidence of floods, changes in storm tracks, impeded drainage and elevated water tables, and heightened frequency as well as severity of droughts (UNFCCC 2005). Pandey *et al*. (2003) has correlated human efforts for rainwater harvesting as an adaptation to abrupt climate fluctuations, like aridity and drought. Meter *et al.* (2014) stated that rainwater harvesting has been chosen as a soft path addressing towards ensuring food security and alleviating problems of water security.

Rainwater harvesting consists of a wide range of technologies that can be divided into in situ and ex situ techniques (Barron, 2009). However, in Port Vila, capital of Vanuatu, rainwater harvesting is considered as a mandatory set up in civil planning and has also been accepted widely at both public and private places in the world (Kim, 2000). Haebler and Waller (1987) observed that the local circumstances such as environmental factors, the degree of atmospheric pollution, the type of construction materials and level of maintenance of the rainwater catchment system are crucial factors in deciding the physiochemical quality of the harvested water. On the other hand, Magliano *et al*. (2015) besides quantifying the daily input had warned of the storage aspects of the rainwater harvesting. However, the level of risk associated with drinking rainwater is a product of the concentration of pathogens/toxins present, their exposure and the vulnerability of the individual or population exposed (Gould, 1999). It is obvious that as ambiguity always remains on the quality of the harvested rainwater which is being used for drinking and other purposes and quality criteria needs a second thought. Silva *et al*.

(2015) reported that there should be a proper evaluation of rainwater harvest for best possible results.

In Port Vila, rainwater harvesting for drinking purposes has been regarded as a part of lifestyle. However, the raw consumption of the harvested water is a free carrier of many diseases like fluorosis (Allibone *et al*., 2012), gastrointestinal disturbances (Ahmed *et al*., 2012; Heyworth *et al*., 2006), salmonellosis (Koplan et al., 1978) and Legionnaires' disease (Simmons et al., 2008). It is an obvious fact that the constituents in the harvested water change with respect to place, extent of rain, methods of collection and usage levels (Coyne, 2000). Yaziz *et al*. (1989) have reported physiochemical variations in harvested rainwater whereas Thomas and Greene (1993) showed that in most urban areas even the direct rainwater is unsafe for drinking. Most recently, Furumai (2016) reported that climate change and rapid urbanization had brought water scarcity and qualitative fluctuations and Port Vila best fits for these observations. In view of these studies, the present study was initiated to assess the physiochemical characteristics of the harvested rainwater in Port Vila. The assessment study was also aimed at the factors that contribute to the qualitative fluctuations based on construction, material and usage levels of the harvested rainwater.

1.2. Study Area

Vanuatu is located on the Pacific ring of fire, where the Pacific tectonic plate is sliding under the Indo-Australian plate. The Y-shaped chain of 80 islands lies between Fiji and Queensland, Australia and being part of the Melanesia group. It was around 3500 years back the Austronesian inhabitants migrated here from the Solomon Islands. The present population is 97% Melanesians while 3% constitute Polynesians, Asians and Europeans. Port Vila, the capital of Vanuatu, is rich in cultural heritage and is the main tourist destination of the country with population little over 50,000. It is located on the island of Efate at approximately l7° 44' S and l68° l9' E where the island experiences a humid tropical climate and South Easterly trade winds. The average annual rainfall is 2360 mm with an average 211 rain days per year. On average Port Vila, the study area of the present investigation, experiences at least one tropical cyclone per year (VMGD website).

2. Materials and Method

The harvested rainwater was assessed in the present study to gain knowledge of the different constituents and thus the quality. Following the standard methods for the examination of water and wastewater (APHA, 1995), the harvested rainwater samples were collected from 22 designated sites in Port Vila as shown in Figure 1. The sampling was carried out during May to December 2016 considering the fact that they represent the wet and dry months. The coordinates of the sampling station were noted at the site along with the conditions of the harvest systems and the surroundings. The water samples were collected after running considerable amount of water from the source after triple rinse of the containers. The average rainfall and rainy days during the sampling period is shown in Figure 2. The sampling sites of the rainfall harvesting included the areas with advanced technological setups as well as the custom based collective centres in the rural dwellings representing public and the private collection centres. Only the criterion of drinking purpose was considered in the present study excluding the collection centres used for other purposes like domestic, agriculture etc. The sites which were maintained periodically and treatments being done for the collected water were also eliminated from the present study.

A total of 12 parameters were analyzed for all the harvested rainwater samples collected during the two seasons. These included: temperature, EC, pH, turbidity, TDS, hardness, acidity, alkalinity, dissolved oxygen (DO), phosphates, nitrates and carbon dioxide. These assessments of the harvested rainwater were carried following APHA (1995) methods for drinking water analysis where all chemicals used were of analytical reagent grade. The physical parameters like turbidity, temperature, EC and pH were assessed at the site itself using appropriate probes. TDS was measured using gravimetric method. Acidity, alkalinity, nitrates and phosphates were determined following titrimetric analysis. Winkler's method was used in the determination of DO (Montgomery *et al*., 1964). Hardness in the water samples was measured using EDTA method. Carbon dioxide was estimated through coulometric titration (APHA, 1995). Throughout the analysis, triple distilled water was used in the preparation of the required standard solutions. Turbidity was visually assessed. The complete results of the physical and chemical parameters analysis have been tabulated in Table 1 and 2. A statistical mean representation of the results of different parameters determined for the collected harvested water samples was shown in Table 3.

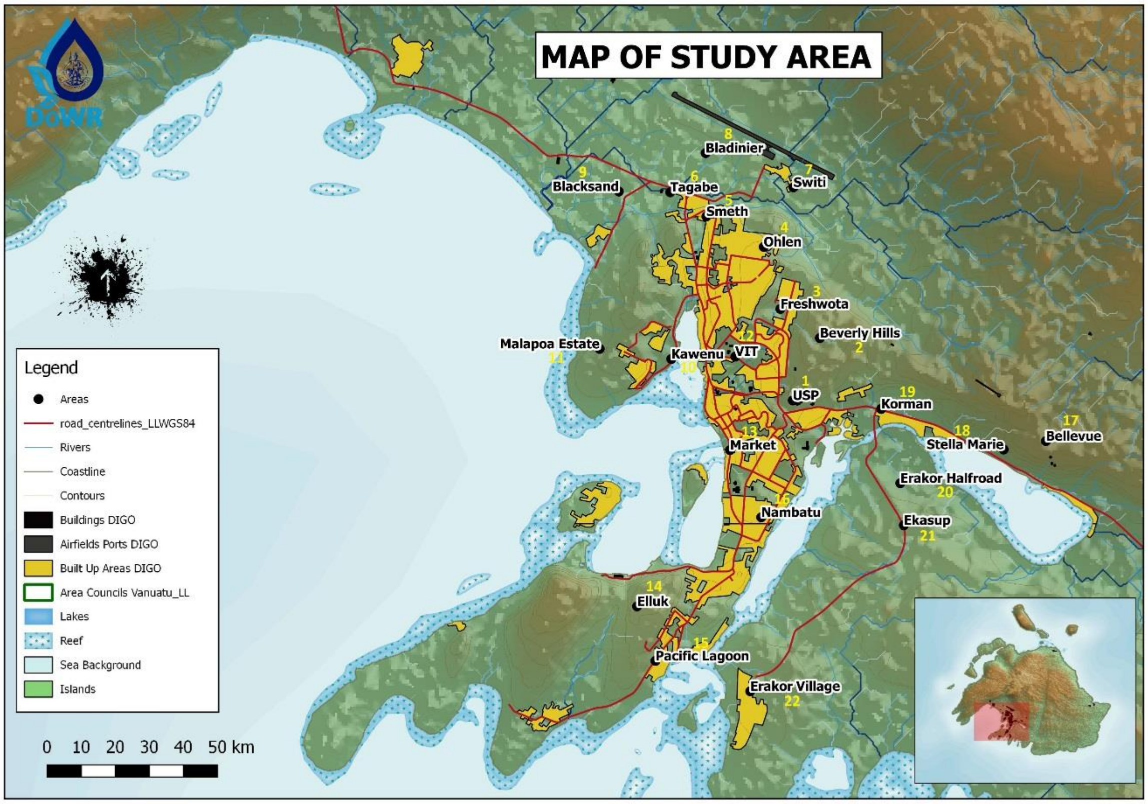

Figure 1. Map of 22 sampling sites in the study area in Port Vila, Vanuatu.

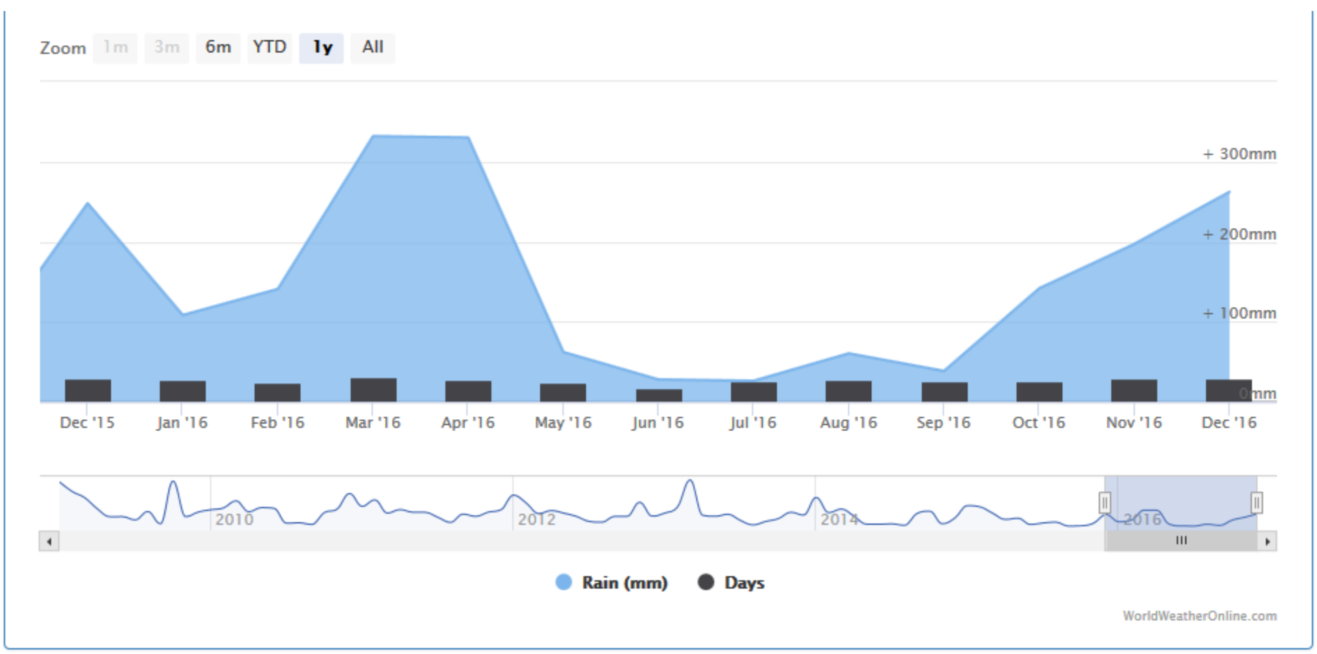

Figure 2. Average rainfall pattern in mm in Port Vila (Efate island) during the study period May to December 2016.

Table 1. Concentrations of the different parameters analyzed in pre-monsoon and post-monsoon seasons of the study area.

Site no.	Sites	Temperature (^{0}C)		pH		EC (µS/Cm)		TDS (mg/L)		Turbidity (Visual)	
		PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
1	USP	26	24.3	7.53	6.63	67	382	18.0	188.0	Clear	Clear
2	Beverly Hills	23	24	6.6	6.21	101	189	46.0	71.0	Moderate	Moderate
3	Freshwota	24.2	23.6	7.85	7.1	75	372	21.0	139.0	Clear	Clear
4	Ohlen	24.2	25.1	6.65	6.88	118	249	62.0	89.0	Turbid	Moderate
5	Smeth	24.2	24.9	6.59	6.54	216	171	41.0	67.0	Clear	Moderate
6	Tagabe	24.1	24.8	6.39	6.62	118	207	58.0	112.0	Clear	Moderate
7	Switi	23.6	25.5	6.2	6.55	167	122	30.0	42.0	Moderate	Clear
8	Bladinier	23.2	24.3	6.3	6.12	312	262	170.0	82.0	Turbid	Moderate
9	Blacksand	24	25.1	6.46	7.14	198	388	71.0	201.0	Clear	Turbid
10	Kawenu	23	23.8	6.24	6.32	79	218	34.0	152.0	Clear	Turbid
11	Malapoa Estate	23.5	24.6	7.12	6.82	131	126	22.0	46.0	Clear	Clear
12	VIT	23.6	25.6	6.1	6.44	112	182	24.0	61.0	Moderate	Clear
13	Market	26.2	24.2	6.61	6.72	41	32	12.0	18.0	Clear	Clear
14	Elluk	25.9	23.9	6.8	7.12	152	342	39.0	181.0	Clear	Turbid
15	Pacific Lagoon	24.9	25.1	6.4	6.62	88	121	19.0	46.0	Clear	Moderate
16	Nambatu	23.5	24.6	6.7	6.55	120	362	62.0	114.0	Moderate	Turbid
17	Bellevue	24.9	23.8	7.2	6.85	134	171	28.0	56.0	Clear	Clear
18	Stella Marie	25	25.9	6.1	6.23	118	122	32.0	28.0	Clear	Moderate
19	Korman	24.7	26.1	6.8	7.01	192	402	112.0	212.0	Turbid	Turbid
20	Erakor Halfroad	23.5	24.5	7.14	6.64	201	412	82.0	241.0	Moderate	Moderate
21	Ekasup	22.6	25.6	7.55	6.85	148	368	61.0	189.0	Clear	Turbid
22	Erakor Village	22.9	23.4	6.15	6.33	318	506	222.0	284.0	Moderate	Turbid

Table 2. Concentrations of the different chemical parameters analyzed in pre-monsoon and post-monsoon seasons of the study area.

Site no.	Sites	Acidity (mg/L)		Alkalinity (mg/L)		DO (mg/L)		Phosphate, PO_4^{-3} (mg/L)		Nitrate, NO_3^- (mg/L)		Hardness (mg/L)		Carbon dioxide (mg/L)	
		PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
1	USP	7.0	4.0	24.0	58.0	8.0	12.o	2.0	2.0	0.0	0.0	63.0	42.0	6.2	4.6
2	Beverly Hills	4.0	11.0	27.0	31.0	7.2	6.5	0.0	5.0	1.0	0.0	51.0	87.0	2.2	3.4
3	Freshwota	5.0	7.0	66.0	46.0	7.7	5.9	1.0	2.0	0.0	2.0	69.0	56.0	0.0	1.2
4	Ohlen	4.0	4.0	31.0	40.0	7.5	8.2	0.0	1.0	0.0	0.0	54.0	32.0	2.0	0.3
5	Smeth	4.0	13.0	32.0	45.0	9.4	11.6	3.0	1.0	3.0	1.0	72.0	55.0	7.0	4.1
6	Tagabe	5.0	8.0	48.0	31.0	7.8	6.8	2.0	4.0	0.0	0.0	87.0	23.0	2.9	1.1
7	Switi	5.0	7.0	56.0	30.0	8.7	9.3	3.0	5.0	0.0	2.0	39.0	71.0	3.0	6.8
8	Bladinier	6.0	5.0	52.0	68.0	8.2	5.4	1.0	1.0	2.0	0.0	102.0	45.0	5.0	3.2
9	Blacksand	4.0	7.0	29.0	33.0	7.8	6.8	5.0	2.0	1.0	0.0	54.0	131.0	2.6	6.4
10	Kawenu	5.0	6.0	20.0	67.0	7.3	9.6	2.0	3.0	0.0	1.0	30.0	45.0	2.5	2.0
11	Malapoa Estate	6.0	9.0	27.0	18.0	8.2	2.8	0.0	1.0	0.0	2.0	66.0	52.0	1.8	4.2
12	VIT	3.0	2.0	20.0	37.0	7.6	5.5	0.0	3.0	0.0	0.0	57.0	45.0	3.4	5.2
13	Market	6.0	6.0	30.0	51.0	7.7	7.1	3.0	2.0	6.0	2.0	75.0	32.0	2.3	3.1
14	Elluk	4.0	6.0	28.0	44.0	7.1	6.2	2.0	0.0	0.0	0.0	82.0	56.0	2.8	0.4
15	Pacific Lagoon	6.0	4.0	31.0	30.0	6.8	7.3	0.0	2.0	0.0	2.0	56.0	34.0	3.1	1.2
16	Nambatu	8.0	14.0	36.0	31.0	7.3	4.3	1.0	0.0	2.0	0.0	49.0	69.0	1.9	2.4
17	Bellevue	7.0	12.0	26.0	28.0	7.6	6.1	0.0	2.0	0.0	0.0	55.0	67.0	4.2	2.6
18	Stella Marie	5.0	6.0	17.0	21.0	8.0	10.1	4.0	2.0	0.0	1.0	66.0	51.0	2.8	1.1
19	Korman	13.0	12.0	36.0	88.0	7.3	12.6	2.0	0.0	0.0	2.0	36.0	68.0	5.0	0.4
20	Erakor Halfroad	6.0	5.0	117.0	71.0	5.9	9.6	1.0	3.0	3.0	1.0	90.0	124.0	3.8	3.4
21	Ekasup	6.0	6.0	39.0	28.0	7.8	6.2	1.0	1.0	0.0	0.0	57.0	32.0	1.4	2.1
22	Erakor Village	19.0	17.0	24.0	54.0	5.2	7.3	0.0	3.0	1.0	0.0	81.0	122.0	5.2	2.2

3. Results

3.1. Statistical Interpretation

Ling *et al.* (2017) reported that statistical interpretation of surface river water data was useful in various qualitative assessments. The statistical interpretation of the results in the present study revealed significant variations in the minimum and the maximum concentrations of the parameters analysed (Table 3). The standard deviation (SD) observed among the sites during pre-monsoon (PRM) and post-monsoon (POM) seasons have been quite high for some parameters (Table 1 and 2). Variations in parameters make it difficult for taking decision for using the water for its drinking purpose so portability is compromised (Meera and Ahammed, 2006). These variations in concentrations and other parameters are due to the seasonal impacts on the different types of roof tops (Farreny *et al*., 2011). It was observed in the study area that there was a wide range of roof materials being used either for the approach, channels, covering or for the storage of the harvested water due to varied reasons such as, custom, cost effectiveness, temporary arrangement and so on. It was also observed that these variations might be due to improper/poor maintenance of the collecting systems. At some sites same old collecting pots are being used to transfer the water from the harvest tanks which are always kept open to various kinds of depositions that might also play an important role in the variation of assessed parameters. Added to these are the frequent changing weather conditions prevailing in the study area. At times there would be scorching temperatures and the next minute with unpredicted heavy downpour and thus Parry *et al*. (2004) felt that not only climate change impact food production but unpredicted rainfall as well.

The parameters like pH, TDS, EC and hardness clearly demonstrate variations which are evident from PRM to POM season. The variations with 63.84 mg/L in TDS, pH of 0.4 and EC with 98.9 μS/Cm were noteworthy. This might be a regular trend observed due to the effects of the rain which dissolves and carries whatsoever on its way. Some of the sites like 3, 4, 8, 14, 16, 19 and 20 have recorded over 100% increase in their EC values (Table 1), whereas sites 1, 3, 6, 9, 10, 14, 20, 21 and 22 had almost the same rise in their TDS concentrations (Table 1). It is also worthy to note that sites like 7, 11, 13, 15 and 18 had hardly shown any change in their EC values in PRM and POM which conflict with the above mentioned observations. No change in case of TDS concentrations was observed at sites of 2, 4, 5, 7, 11, 13, 15 and 18 (Table 1). In general, the average concentrations of these in harvested rainwater are pH (7.0-8.5), EC (0-50 μS/Cm) and TDS (10-50 mg/L). The observed variations may be attributed to the stagnancy or more frequent usages or a mix of both. The high standard deviations in case of EC, TDS, hardness and alkalinity are due to the variation among various sampling sites which arise because of the dissolutions that rainwater carries along their way (Likens *et al*., 1972).

The mean standard deviation of 3.6 mg/L in acidity (Table 3) in both seasons is a matter of concern as well. The acidity concentrations in most of the sites were at tolerable levels but at sites 2, 5, 16, 17 and 22 considerable increase was recorded in the POM. Acidity is often caused by dissolution of the mineral acids ions in the water and thus might be the reason for the rise in these sites. The components of atmospheric acidity like aerosols, fog water, cloud water and rainwater in the study sites might be other reasons for increase in acidity (Liljestrand, 1985). In case of other parameters like alkalinity, DO, phosphates and nitrates there might not be any alarming issues as these were within the WHO guidelines for drinking water quality (WHO, 2004).

3.2. Harvest Materials and Impact Assessment

It has been reported that the materials used in the collection of the rainwater play vital role in defining its quality (Mendez *et al*., 2011). Therefore, the present study also focused on the type of material of construction of the rainwater collector, type of collection and maintenance of the harvest tanks to judge the quality of the harvested water. Some traditional methods of collection with palm and coconut heads and leaves were found in the villages whereas advanced collection methods were seen at expatriate settlements. The sites with long channels of collections from the roof had shown more turbid waters and also increased TDS concentrations. The same was observed at the sites (3, 6, 9, 10, 16, 19, 20 and 21) having large open mouth collection tanks where intrusion of impurities through the large opening areas significantly affected the physical parameters as well as the chemical constituent's concentrations. The sites where closed net filters were used at the mouths of collection tank acted as good filters but needed regular cleaning of the segregates and algal blooms. Thomas et al. (2014) had reported that the type of gutters used would significantly impact the quality in the harvested water.

In the collection sites like 4, 13, 15 and 18, there has been hardly any alarming changes in the determined parameters in the PRM and POM seasons. This was most probably due their freeness from dust, small channel from roof and periodic maintenance. However, in case of the collection sites 3, 6, 9, 10, 14, 16, 20 and 21, the considerable variations of parameters in the POM season may be due to their improper construction, poor maintenance and long channels with less usage. In addition, there might be an influence of the biological growth inside the tanks due to improper maintenance (Simmons *et al*., 2001). It has been reported that most contamination of rainwater occurs after contact with the catchment surface (roof or ground) and during subsequent delivery and storage (Waller, 1989). The factors like cleaning of the filters, channels, tanks and removal of debris around the systems would yield better quality of the harvested water.

The qualitative aspects in regards to the capture and storage of the rainwater in Port Vila need to be reviewed for betterment. Fonseca *et al*. (2017) have reported that usage of web application and geo-referenced rainfall pattern for the construction of the rainwater storage tank and their installation at relevant sites for maximum water collection and proper storage give the best possible results in quantity as well as quality. It was observed in this study that there were many sites with varied tank sizes and their placement was another concern. In regards to placement, Kotra (2016) reported that the infrastructure damage during cyclones was a major factor resulting in compromised water quality. Most communities have been observing the rainwater harvest as bill savers but have ignored the periodic maintenance of storage tanks leading to adverse health issues. The sites where visual qualitative implications like turbidity were evident and could have been correlated to water stagnancy but on discussions with the communities it was learned that the major contributing root cause was poor –maintenance. The problem that was observed at some of these sites is that they were built too high and too big to reach to clean completely. In such cases it would be better to adopt Ojwang *et al*. (2017) report to use calcification which would yield better roof top identification. Thus, the best way to mitigate the qualitative fluctuations at the study sites is to adapt to the best possible combinations of traditional and modern approaches.

Table 3. Statistical representation of the results of different parameters**.**

Parameter*	**Minimum**		**Maximum**		**Mean**	
	PRM	POM	PRM	POM	PRM	POM
Temperature	22.60	23.40	26.20	26.10	24.10 ± 1.03	24.60 ± 0.77
pH	6.10	6.12	7.85	7.14	6.70 ± 0.50	6.64 ± 0.30
EC	41.00	32.00	318.00	506.00	145.72 ± 71.42	259.36 ± 126.38
TDS	12.00	18.00	222.00	284.00	57.54 ± 51.40	119.04 ± 76.29
Acidity	3.00	2.00	19.00	17.00	6.27 ± 3.49	7.77 ± 3.83
Alkalinity	17.00	18.00	117.00	88.00	37.09 ± 21.68	43.18 ± 18.14
Dissolved oxygen	8.00	5.20	9.40	9.40	7.60 ± 0.86	7.60 ± 2.52
Hardness	30.00	23	102.00	131.00	63.20 ± 18.09	60.86 ± 30.56
Carbon dioxide	0.00	0.30	7.00	6.80	3.20 ± 1.65	2.80 ± 1.86
NO_3^-	0.00	0.00	6.00	2.00	0.86 ± 1.52	0.72 ± 0.88
PO_4^{3-}	0.00	0.00	5.00	5.00	1.50 ± 1.44	2.04 ± 1.43

*Units: Temperature – °C; EC - μS/Cm; all others – mg/L

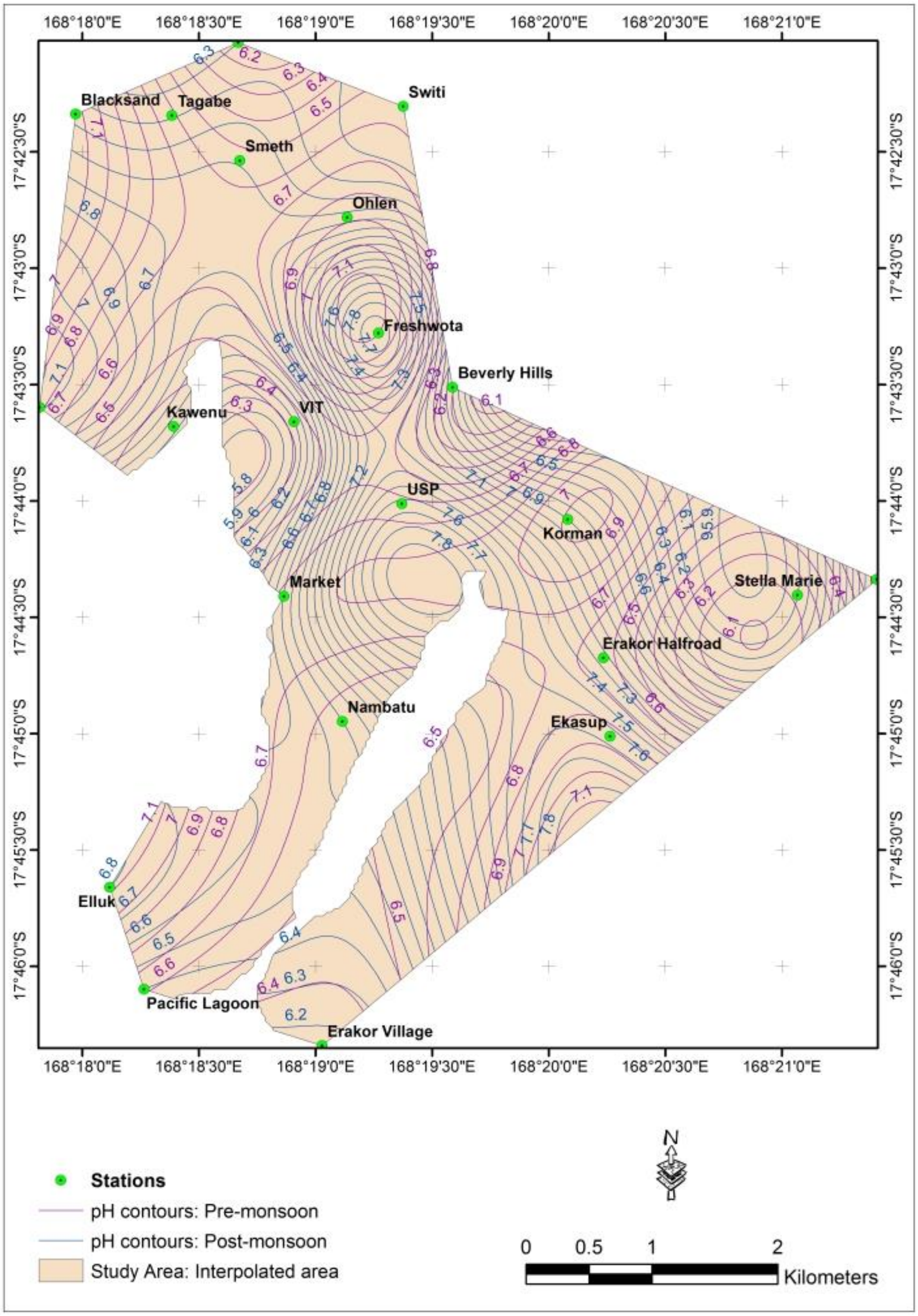

Figure 3. Distribution of pH in the PRM and POM seasons in the study area in Port Vila, Vanuatu**.**

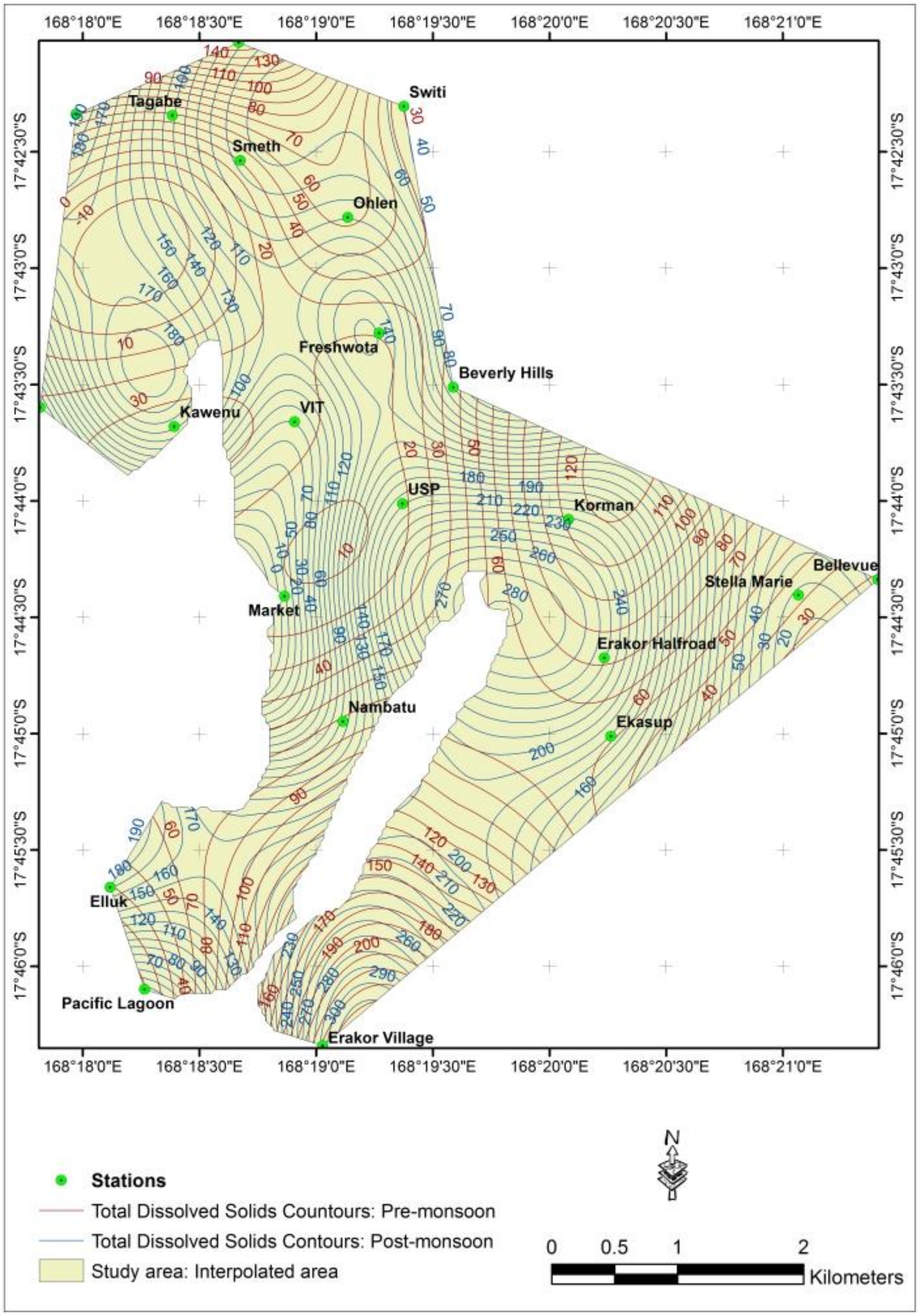

Figure 4. Distribution of TDS in the PRM and POM seasons in the study area in Port Vila, Vanuatu.

3.3. Spatial Interpolation

Spatial interpolation techniques are used to estimate values for any geographic region for a limited number of sample data points. Kriging, Inverse Distance Weighting, Spline are the most common interpolation methods which uses the values of nearby known sites to estimate the unknown (Burrough, 1998). Spline interpolation method was used in the present study that estimates values at unknown location (Samanta *et al*. 2012). Kumar and Jhariya (2016) and Sayl *et al.* (2016) have used Geographic Information System (GIS) based remote sensing approach to estimate the physical variables of rainwater harvesting. Thus, in the present study TDS and pH characteristics at 22 sample location were interpolated based on their PRM and POM observations. Contours were derived using 3D analysis techniques from the interpolated datasets using ArcGIS software which gave two composite maps for pH and TDS as shown in Figure 3 and 4 respectively.

Interpolated pH map (Figure 3) shows higher pH value (about 7.0) in the middle and the minimum (about 6.0) in the Eastern part of the study area in the PRM season. Some patches of high pH (about 7.0) are observed in the North, middle and South parts of the study area. The mean of pH estimation was calculated as 6.70 and 6.64 for PRM and POM respectively (Table 3). The variation of pH distribution is very high in the PRM season with SD 0.5 as compared to POM season as 0.30. This can be attributed to the segregation of the water which causes chemical exchange, while the monsoon might be reason for the increase in pH towards the basic character. The standard deviations were higher for the sites where the frequency of water withdrawal or usage was low and vice versa.

Interpolated map for the TDS factor shown in Figure 4 indicates that during POM season the TDS was higher in the central part of the study area and decreased towards all directions. However, in the PRM the TDS pattern was found to be higher in the North and Southern parts of the study area and lower in the central part. The SD for TDS distribution was 51.40 mg/L during PRM and 76.29 mg/L during POM season (Table 3). The variation in TDS distribution is much more during POM season than during PRM which may be due to the topographic lows in the study area where dust accumulation in water reservoir is increased by the lime stone roads. These accumulate on roof tops, relocate along with the rain water flow and thus cause high TDS during the POM season. At sites 8 and 18 where the concentrations during PRM are more than that of POM might have mixed reasons while for the sites 1, 3, 6, 9, 10, 14, 20 and 21 (Table 1) the TDS has shown a drastic rise due to constant rise of the dust as these sites are on high traffic zones. In addition, some of these collection sites have the tarpaulin covers over the normal iron sheets which might have dissolved in the harvested waters. These high TDS values correlated to high EC (Zhang *et al.* 2017).

4. Conclusion

The physiochemical assessment of the harvested rainwater in Port Vila, Vanuatu for two seasons has revealed mixed results in terms of drinking water quality. The concentrations of some parameters had shown considerable increase in POM season in comparison to PRM season, whereas some sites had hardly shown any change. The parameters like pH, EC, TDS and acidity had varied considerably in some of the harvested sites. The use of the roof materials, frequency in usage and maintenance of collection tanks were found to be the main factors that influenced drastic rise in the concentrations of the chemical constituents. Both the traditional and advanced methods had their pros and cons in regards to the quality of the harvested water.

Results of the study along with recommendations were disseminated to the communities and Department of Water Resources, Government of Vanuatu for necessary action.

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References

Ahmed, W., Hodgers, L., Sidhu, J.P.S. and Toze, S. 2012. Fecal indicators and zoonotic pathogens in household drinking water taps fed from rainwater tanks in Southeast Queensland, Australia. Applied and Environmental Microbiology 78, 219-226.

Allibone, R., Cronin, S.J., Charley, D.T., Neall, V.E., Stewart, R.B. and Oppenheimer, C. 2012. Dental fluorosis linked to degassing of Ambrym volcano, Vanuatu: A novel exposure pathway. Environmental Geochemistry and Health 34, 155-170.

APHA, AWWA and WPCF. 1995. Standard Methods for the Examination of Water and Waste water (19th ed.), Washington DC: APHA, 1–47pp.

Barron, J. (2009). Rainwater harvesting: A lifeline for human well-being. UNEP/Earthprint, p9.

Burrough, McDonnell. 1998. Principles of Geographical Information Systems. Oxford University Press, New York, p26.

Coyne, T. 2000. Lifestyle diseases in pacific communities. Noumea: Secretariat of the Pacific Community, File no: 219, 24p.

Farreny, R., Morales-Pinzón, T., Guisasola, A., Taya, C., Rieradevall, J. and Gabarrell, X. 2011. Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. Water Research 45, 3245-3254.

Fonseca, C.R., Hidalgo, V., Díaz-Delgado, C., Vilchis-Francés, A.Y. and Gallego, I. 2017. Design of optimal tank size for rainwater harvesting systems through use of a web application and geo-referenced rainfall patterns. Journal of Cleaner Production 145, 323-335.

Furumai, H. 2016. Evaluation of rainwater harvesting and use potential considering climate change in Arakawa watershed. Modélisation/Models-Réutilisation des eaux pluviales/Stormwater reuse. http://documents.irevues.inist.fr/bitstream/handle/2042/60473/3B72-233FUR.pdf

Gould, J. 1999. Is rainwater safe to drink? A review of recent findings. Proceedings of the 9th International Rainwater Catchment Systems Conference held at Hawaii, USA. http://www.eng.warwick.ac.uk/ircsa/pdf/9th/07_04.pdf

Haebler, R.H. and Waller, D.H. 1987. Water of rainwater collection systems in the Eastern Caribbean, Proceedings of the 3rd International Conference on Rain Water Cistern Systems, Khon Kaen University, Thailand, 1-16pp.

Heyworth, J.S., Glonek, G., Maynard, E.J., Baghurst, P.A. Finlay-Jones, J. 2006. Consumption of untreated tank rainwater and gastroenteritis among young children in South Australia. International Journal of Epidemiology 35, 1051-1058.

Kim, R.H. 2000. Rainwater utilization and functional changes in building roof. Construction Technology Review 220, 13–19.

Koplan, J.P., Deen, R.D., Swanston, W.H. and Tota, B. 1978. Contaminated roof-collected rainwater as a possible cause of an outbreak of salmonellosis. Journal of Hygiene 81, 303-309.

Kumar, T. and Jhariya, D.C. 2016. Identification of rainwater harvesting sites using SCS-CN methodology, remote sensing and geographical information system techniques. Geocarto International 1-22. http://www.tandfonline.com/doi/abs/10.1080/10106049.2016.1213772

Kotra, K.K. 2016. Impact of cyclone Pam on rainwater harvesting prospects in the Pacific region. British Journal of Applied Science and Technology 12, 1-11.

Likens, G.E., Bormann, F.H. and Johnson, N.M. 1972. Acid rain. Environment: Science and Policy for Sustainable Development 14, 33-40.

Liljestrand, H.M. 1985. Average rainwater pH, concepts of atmospheric acidity, and buffering in open systems. Atmospheric Environment 19, 487-499.

Ling, T.Y., Soo, C.L., Liew, J.J., Nyanti, L., Sim, S. F. and Grinang, J. 2017. Application of multivariate statistical analysis in evaluation of surface river water quality of a tropical river. Journal of Chemistry 2017, 1-13.

Magliano, P.N., Murray, F., Baldi, G., Aurand, S., Páez, R.A., Harder, W. and Jobbágy, E.G. 2015. Rainwater harvesting in Dry Chaco: Regional distribution and local water balance. Journal of Arid Environments 123, 93-102.

Meera, V. and Ahammed, M.M. 2006. Water quality of rooftop rainwater harvesting systems: A review. Journal of Water Supply: Research and Technology-AQUA 55, 257-268.

Mendez, C.B., Klenzendorf, J.B., Afshar, B.R., Simmons, M.T., Barrett, M.E., Kinney, K. A. and Kirisits, M.J. 2011. The effect of roofing material on the quality of harvested rainwater. Water Research 45, 2049-2059.

Meter, K.J.V., Basu, N.B., Tate, E. and Wyckoff, J. 2014. Monsoon harvests: The living legacies of rainwater harvesting systems in South India. Environmental Science and Technology 48, 4217–4225

Montgomery, H., Thom, N.S., and Cockburn, A. 1964. Determination of dissolved oxygen by the Winkler method and the solubility of oxygen in pure water and sea water. Journal of Chemical Technology and Biotechnology 14, 280-296.

Ojwang, R.O., Dietrich, J., Anebagilu, P.K., Beyer, M. and Rottensteiner, F. 2017. Rooftop rainwater harvesting for Mombasa: Scenario development with image classification and water resources simulation. Water 9, 359-368.

Pacey, A. and Cullis, A. 1986. Rainwater harvesting: The collection of rainfall and runoff in rural areas. Intermediate Technology Publications, UK, p49.

Pandey, D. N., Gupta, A, K. and Anderson, D. M. 2003. Rainwater harvesting as an adaptation to climate change. Current Science 85, 46-59.

Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M. and Fischer, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change, 14, 53-67.

Samanta, S., Pal, D.K., Lohar, D. and Pal, B. 2012. Interpolation of climate variables and temperature modeling. Theoretical and Applied Climatology 107, 35-45.

Sayl, K.N., Muhammad, N.S., Yaseen, Z.M. and El-shafie, A. 2016. Estimation the physical variables of rainwater harvesting system using integrated GIS-based remote sensing approach. Water Resources Management 30, 3299-3313.

Silva, C.M., Sousa, V. and Carvalho, N.V. 2015. Evaluation of rainwater harvesting in Portugal: Application to single-family residences. Resources, Conservation and Recycling 94, 21-34.

Simmons, G., Hope, V., Lewis, G., Whitmore, J. and Gao, W. 2001. Contamination of potable roof-collected rainwater in Auckland, New Zealand. Water Research 35, 1518-1524.

Simmons, G., Jury, S., Thornley, C., Harte, D., Mohiuddin, J. and Taylor, M. 2008. A Legionnaires' disease outbreak: A water blaster and roof-collected rainwater systems. Water Research 42, 1449-1458.

Thomas, P.R. and Greene, G.R. 1993. Rainwater quality from different roof catchments. Water Science and Technology 28, 291-299.

Thomas, R.B., Kirisits, M.J., Lye, D.J. and Kinney, K.A. 2014. Rainwater harvesting in the United States: A survey of common system practices. Journal of Cleaner Production 75, 166-173.

UNFCCC: United Nations Framework Convention on Climate Change, 2005. Climate Change: Small Island Developing States. Bonn: UNFCCC. http://unfccc.int/resource/docs/publications/cc_sids.pdf

VMGD (Vanuatu Meteorology and Geohazards Department) http://www.vmgd.gov.vu/vmgd/index.php

Waller, D. 1989. Rain Water - An alternative source in developing and developed countries. Water International 14, 27-36.

WHO (World Health Organization) (2004). Guidelines for drinking-water quality: Recommendations (3rd Edition). World Health Organization, Geneva, 181, 215 and 375.

Yaziz, M.I., Gunting, H., Sapari, N. and Ghazali, A.W. 1989. Variations in rainwater quality from roof catchments. Water Research 23, 761-765.

Zhang, C., Zhang, W., Huang, Y. and Gao, X. 2017. Analysing the correlations of long-term seasonal water quality parameters, suspended solids and total dissolved solids in a shallow reservoir with meteorological factors. Environmental Science and Pollution Research 24, 6746-6756.

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