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PERFORMANCE OF ROOFTOP RAINWATER HARVESTING SYSTEM AS A SOURCE OF DRINKING WATER

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Abstract

Rainwater Harvesting Systems (RWHSs) are increasingly being used as an alternative or supplementary source of water to curb the water supply deficit in the Kathmandu valley. The harvested rainwater is primarily used for non-potable purposes like flushing toilets and irrigation, but the knowledge on the use of rainwater for potable purpose is remarkably sparse. This study assesses the suitability of rainwater in terms of quantity and quality in a public school that adopts Rooftop RWHS as the source of drinking water. In this study, we observed that the volume of rainwater being harvested is sufficient to address the current demand of drinking water, with a mean rainfall of 1664 mm on a catchment area of 372 m^2. Storage capacity needs to be expanded if the demand increases. Physico-chemical and microbial analyses of water samples (before and after a series of treatments) were carried out for the winter, monsoon, and post-monsoon seasons. The values of physico-chemical parameters of the water samples, in all the seasons, were well within both the National Drinking Water Quality Standards (NDWQS, 2005) and the World Health Organisation (WHO, 2017) guidelines for drinking water, while fecal coliforms were detected in the storage tank, but were absent in tap water after the treatments. Based on the findings, we suggest that the harvested rainwater could be used for drinking purposes if properly treated. RWHS use at the institutional level, like in schools, on the one hand, curbs the increasing demand for water in water-deficit locations like Kathmandu, and on the other, encourages the adoption of such sustainable technologies for the water supply.

Keywords: Water demand, Water quality, Rainwater harvesting, Sustainable technologies.

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1. Introduction

The world's freshwater resources are depleting, particularly that of developing countries, due to population growth, landuse change and urbanization, and climate change (Khatri *et al.*, 2008). As such, the water crisis is one of the world's most pressing issues today. Kathmandu valley is no exception to this either; it has been facing a constant supply-demand deficit for years (Udmale *et al.*, 2016). With the ongoing urbanization and tremendous population growth putting stress on the environment, the water crisis scenario is bound to worsen in the future (Thapa, 2017).

The inhabitants of Kathmandu valley have been mainly using groundwater to overcome the water shortage; however, increasing population density and landuse change have resulted in over-extraction of the groundwater causing its water level reduction. Pandey *et al.* (2010) reported a decreasing level of groundwater, 13–33 m during 1980–2000 and 1.38–7.5 m during 2000–2008, in Kathmandu valley whereby the extraction of groundwater (21.56 million m^3/year) exceeded the recharge (9.6 million m^3/year). In addition, the majority of the valley's groundwater is at risk of pollution due to human activities (Shrestha *et al.*, 2016). Regarding the water quality, the physical and microbiological water quality of the groundwater of Kathmandu does not meet the requirements set by the WHO guidelines (Chapagain *et al.*, 2010). With regards to both the quality and quantity, alternative water sources are urgently required to meet the needs of the inhabitants. For areas with acute water shortages, such as Kathmandu valley, increasing the use of alternative water sources, such as Rainwater Harvesting System (RWHS) is a plausible option (Tzanakakis *et al.*, 2020).

Rainwater harvesting is the technique of collecting and storing rainwater before it is lost as surface runoff, so that it can be used when necessary (Dagwal *et al.*, 2016). RWHSs have been proven to be efficient in the management of water, saving both water and costs (Ward *et al.*, 2012). In a Rooftop RWHS, rain that falls on a rooftop (catchment surface) is directed into a storage tank via conveyance pipes. It has been useful in urban areas such as Tokyo and Hong Kong for sustainable management of water (An *et al.*, 2015). Several countries are realizing the capacity of RWH to serve as a solution to deal with problems related to urban flooding, water shortages, and climate change (Han *et al.*, 2009; Rygaard *et al.*, 2011)

The potential of Rooftop RWHS for has been explored in many countries like Bangladesh (Islam *et al.*, 2010), Australia (Chubaka *et al.*, 2018), Indonesia (Syamsiah *et al.*, 1994), China (Liang and van Dijk, 2011), USA (Ghimire *et al.*, 2012), Italy (Campisano and Lupia, 2017), Germany

(Nolde, 2007) and South Africa (Kahinda *et al.,* 2008) for multiple purposes, such as drinking, agricultural irrigation, alleviating drought, toilet flushing, garden irrigation, and laundry. Majority of these studies however have focused on the non-potable uses of harvested rainwater, such as flushing and irrigation.

In Nepal, previous studies have primarily focused on the use of RWHS for domestic purposes, like washing or recharging groundwater (Thanju, 2012). Studies have also recommended RWHS in Nepal to be utilized as a supplementary water source for domestic purposes which would reduce water demand that couldn't be fulfilled by conventional sources, minimize stress on groundwater as well as reduce the risk of flash floods in Kathmandu (Dixit and Upadhya, 2005; Gautam, 2017). Although the water harvested through RWHSs are suitable for multiple purposes, there has been considerable questions regarding the use of rainwater for drinking purpose. However, a study conducted in the Kathmandu valley indicated that anthropogenic sources have a negligible impact on the quality of rainwater (Shrestha *et al.,* 2013). Although the presence of air contaminants in the rainwater cannot be overlooked, most of the contaminants are removed after the first flush, thereby improving the quality of harvested rainwater (Abu-Zreig *et al.,* 2019). In recent days, the use of RWHS at the household and community level has been increasing in Kathmandu as a way to reduce water demand (Pasakhala *et al.,* 2013; Molden *et al.,* 2020).

Small scale RWHSs are found to meet the domestic drinking water demand reliably all year round (Alim *et al.,* 2020). In Bangladesh, rainwater has been found to be a potential source for the drinking water, as an alternative for the arsenic contaminated water (Islam *et al.,* 2010). In Kathmandu, where an alternative is groundwater or municipal supply, rainwater subjected to proper treatment systems can be a good alternative source for drinking water. For this, assessing the suitability of RWHS for drinking purposes is necessary. Hence, this study was conducted in a public school in Kathmandu that utilizes RWHS to supply drinking water. The specific objectives of the study are to (a) estimate the annual and monthly rainwater harvesting potential for the study area, (b)assess whether the harvested rainwater is able to fulfill the drinking water demand, and (c) evaluate the suitability of harvested rainwater for drinking purposes.

2. Materials and Methods

Study Area

This study was carried out in the Prithvi Narayan Secondary School (PNSS), a public school located in Tarakeshwor Municipality of Kathmandu, Nepal. Tarakeshwor, one of Kathmandu's 11 municipalities, covers 34.9 km^2 and has a population of 151,508 (CBS, 2021). The study site is located at ward number 5 of the municipality, at an elevation of approximately 1330 masl (Figure 1).

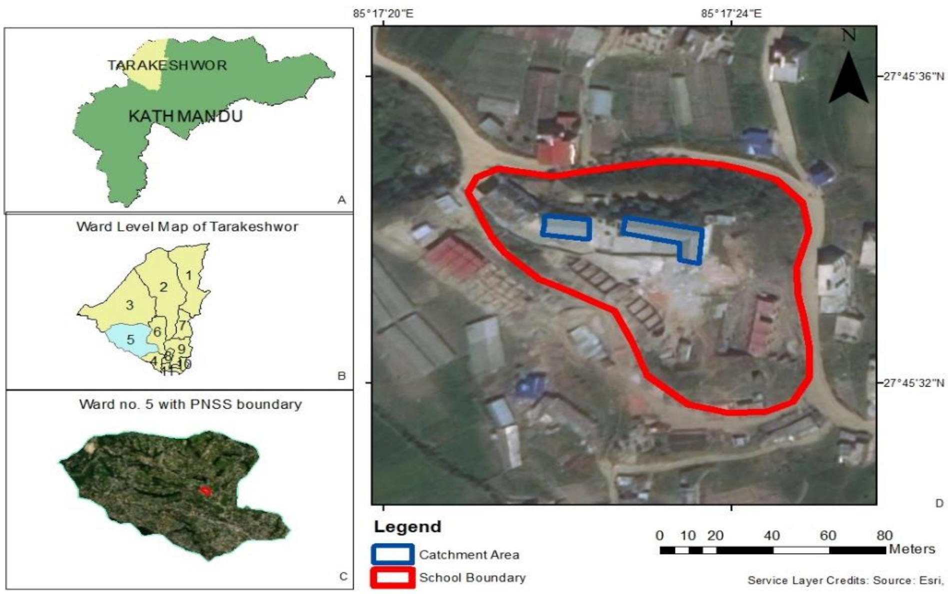

Figure 1: Location of the Prithvi Narayan Secondary School (PNSS) in Kathmandu Valley and its catchment areas

The PNSS has a population of over 1050 individuals, including students, teachers and other staff. There are two water sources: (a) a rooftop rainwater harvesting system and (b) bore water. However, according to the key informant, only Rooftop RWHS water has been used for drinking needs and has been sufficient to meet the drinking water demand since the monsoon of 2017 when RWHS was installed and started its operation. Roofs, made of corrugated metal sheets, of two of the school buildings, each with an area of 132 m^2 and 240 m^2 are used as catchments for Rooftop RWHS.. The water used as drinking water goes through three stages of filtration processes: rapid sand filter, biosand filter, and a combined filtration system (Figure 2). The combined filtration system consists of a mesh strainer, Ultra-Filtration membrane, and carbon filter.

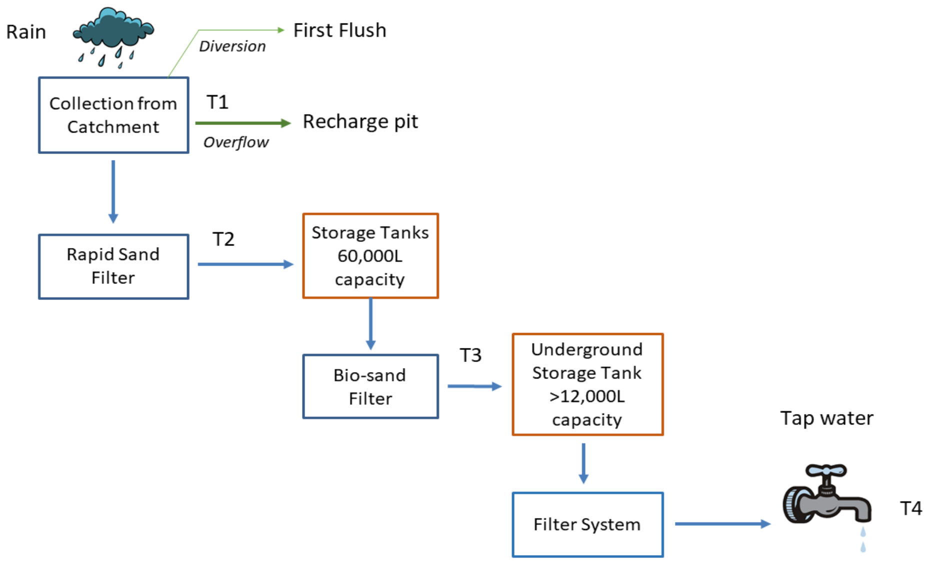

Figure 2: RWHS components in the school for drinking water supply including filters and storage; T1, T2, T3, and T4 indicate points where water samples were collected, T1 indicates raw rainwater, T2 indicates rainwater after rapid sand filter, T3 indicates rainwater after biosand filter and T4 indicate tapwater after filter system

Data Collection and Analysis

A first field survey was conducted in December, 2019, which included direct observation of RWHS, measurement of catchment area, and a semi-structured interview with key informants. One key informant was janitor of PNSS from whom information about the installed RWHS, its components, storage capacity and water demand was gathered. Another key informant was an administrative staff who provided the data related to number of students and staffs and number of working days. The catchment area was determined by measuring the perimeters of foundations of the two buildings whose roofs are used as catchments. Monthly precipitation data for 23 years (1998-2020) was acquired from the Department of Hydrology and Meteorology (DHM) of Ministry of Energy, Water Resources, and Irrigation of the station "Nagarjuna" (GSID: 11, Index no: 1079).

Estimation of Rainwater Harvesting Potential

The potential of rainwater harvesting volume can be estimated using the total roof area, the average annual rainfall and the runoff coefficient (Gould and Nissen-Petersen, 1999). Thus, the total volume of rainwater that could be harvested in the study area was determined by using the equation below.

$$S = R * A * C_r$$

Where,

S = Annual volume of rainfall that could be harvested in the study area in m^3

R = Average annual rainfall of the study area in m

A = Catchment area in m^2

C_r = Runoff coefficient

The runoff coefficient of a catchment area is the ratio of the volume of water that runs off to the volume of rain that falls on to the surface (Pacey and Cullis, 1989). It justifies that not all of the rainfall on the catchment can be harvested since part of it would be lost owing to processes such as retention on the catchment surface, first flush driving mechanism, and evaporation. For this study, runoff coefficient of 0.8 was used as an average for the range of 0.7-0.9, as given by Pacey and Cullis (1989) for catchment surfaces made of corrugated metal sheets. The equation by Gould and Nissen-Petersen (1999) is given for annual rainwater harvesting potential. However, we have calculated annual as well as monthly rainwater harvesting potential using the equation by using monthly precipitation data in the latter case.

Supply vs Demand Modelling

After the estimation of the total volume that can be harvested each month, i.e. monthly rainwater harvesting potential from the catchment area, drinking water demand, excess volume, and storage volume were calculated.

The domestic demand for the water use depends on factors such as the number of connections, price of water, level of education, and the amount of rainfall (Babel *et al.*, 2007) but as our study on the demand in a school, the main driving factor is the number of days the school operates, age group of the student, and season. In this study, we have only considered the number of working days for analysis of harvest versus demand.

The drinking water demand per month was calculated as a product of three parameters, the number of individuals in the institution, the average water demand per individual, and the number of working days in the particular month. The storage volume is taken as 72,000 L which is a sum of

6 storage tanks of 10,000 L each and 1 underground tank of 12,000 L. If the net amount exceeds, 72,000 L, the excess volume is considered as overflow which is not stored.

At last, it was analysed whether drinking water demand was being fulfilled each month by supply or not. Here, the supply has two sources, direct rainwater (calculated as monthly rainwater harvesting potential) and storage (calculated as storage volume). Storage is used in the months when rainwater harvesting potential is less than the water demand.

Sample Collection and Water Quality Analysis

The sampling of water was carried out during three seasons: winter (January, 2020), monsoon (July, 2021) and post-monsoon season (November, 2021) for water quality analysis. A total of four samples were taken each season, at four stages within RWHS: rainwater before any forms of treatment (T1), water after rapid sand filtration (T2), water after biosand filtration (T3), and water from taps after combined filtration system (T4) (Figure 2).

Temperature, pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS) were measured on-site using a portable multi parameter probe (Company: HANNA, Model number: HI98129). For the remaining analysis, samples were collected in the pre-cleaned High Density Polyethylene (HDPE) bottles which were properly labeled and instantly transported to the laboratory of the Central Department of Environmental Science (CDES), Tribhuvan University, Kirtipur. Analysis was started within 1-2 hrs of the sample collection, following standard procedures (Table 1). Samples for microbial analysis were collected directly into sterile HDPE bottles to avoid bacterial contamination and transported to the CDES laboratory in a chilled-cold box.

Table 1: Water quality parameters analysed in the laboratory with their respective method of analysis

S.N.	Parameter	Method of analysis	Digital instrument used
1.	Turbidity	Nephelometric method (APHA, 2017)	Bench turbiditimeter, Company: Wagtech
2.	Chloride	Argentometric titration (APHA, 2017)	-
3.	Alkalinity	Titration (APHA, 2017)	-
4.	Ammonia	Phenate method (APHA, 2017)	Spectrophotometer, Company: SSI, Model Number: UV2101
5.	Hardness	Ethylenediamine tetraacetic acid (EDTA) titrimetric method (APHA, 2017)	-
6.	Calcium Hardness (as $CaCO_3$)	EDTA titrimetric method (APHA, 2017)	-
7.	Nitrate	Brucine method (Jenkins and Medsker, 1964)	Spectrophotometer, Company: SSI, Model Number: UV2101
8.	Fecal coliform	Membrane Filter method (APHA, 2017)	-

3. Results and Discussion

Annual Precipitation and its Trend

The mean annual rainfall of the area reported from the nearest meteorological station is 1664 mm (DHM, 2021). Though annual rainfall in the study area has fluctuated throughout the years, the rainfall was found to be slightly increasing in trend over 23 years (1998-2020) based on the observation of precipitation data (Figure 3). The annual precipitation in 1998 was 1790 mm, while the amount in 2020 was 1919 mm. During this period, the highest annual rainfall was 2139 mm in 2014, and the lowest was 1325 mm in 2001. The mean annual precipitation received per year was 1665 mm, with a standard deviation of 208 mm. The annual rainfall of the last four years (2017 to 2020) exceeded the average rainfall of 23 year period,

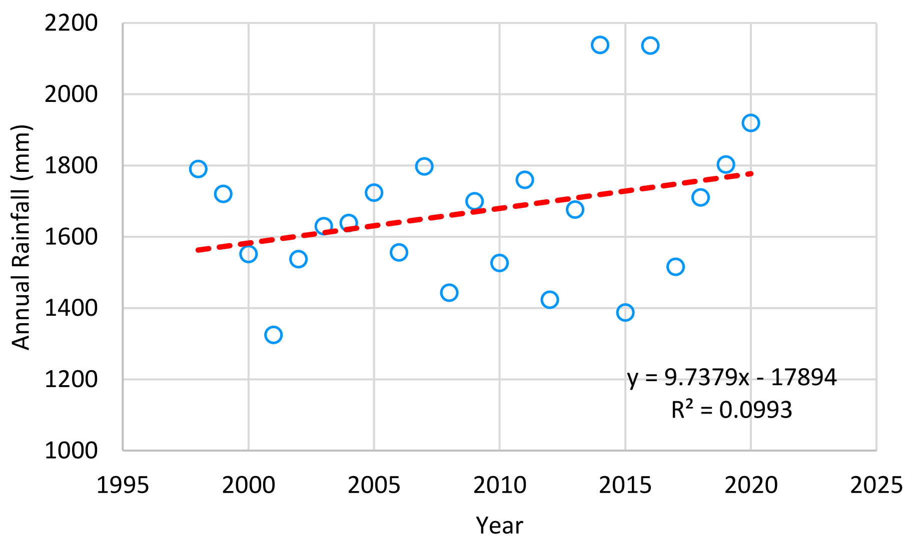

Figure 3: Annual precipitation trend of the study area for the 1998-2020 period

Rainwater Harvesting Potential

The volume of rainwater that can be harvested depends primarily on the amount of precipitation. Hence, the analysis of precipitation patterns in the area for assessing the sustainability of rainwater is important.

A study in Abyeokuta city of Nigeria where the average annual rainfall is only 1156 mm, has concluded that RWHS is ideal for flushing and laundry, with an annual harvested amount of 21,600 L and 29,400 L respectively (Aladenola and Adeboye, 2010). With an average annual rainfall of 1665 mm, rainwater harvesting potential of the study area was estimated to be 494,875

L per year. There was high seasonal variation in monthly rainwater harvesting potential, as the precipitation pattern in Kathmandu is not even. With high rainfall amount, monsoon months had accordingly higher rainwater harvesting potential, the highest in July (135,022 L) followed by August (124,376 L) and September (75,518 L), respectively (Figure 4). November, on the other hand, was discovered to be the driest month, with only 82 L of rainwater harvesting potential (Figure 4).

Supply vs Demand Modelling

The efficiency of RWHS depends on precipitation, catchment area, water demand, and runoff capture (Mun and Han, 2012). The patterns of precipitation and water demand are critical in assessing the perceived benefits of RWHS (Jensen *et al.*, 2010). This can be observed in this study as the monsoon months having higher supply, months with higher working days (May, June, August) having higher water demand, and months with lower working days (such as October/November with Dashain-Tihar vacation) having lower water demand.

From May to October, the rainwater harvesting potential exceeded the drinking water demand (Figure 4), leading to the surplus amount being stored in storage tanks. Whereas in other months, there was no surplus, hence the water was supplied through storage tanks. In all the months when demand exceeded harvesting potential, the stored water was found to be able to meet the drinking demand. This finding was also validated by firsthand observation (of storage tanks and water supply) during winter sampling and mirrored the information gathered through key informant interviews as well.

Higher rainwater harvesting potential does not translate to a higher supply of water as the water needs to be stored for future use. In the case when storage capacity does not suffice, the water is drained off. In the RWHS of our study area, the excess water is diverted to the recharge pit (Figure 1), which is a dug-well constructed near the storage tanks. There is a positive aspect of this in terms of groundwater recharge, which has added environmental benefit to areas like Kathmandu where groundwater level has been declining (Pandey *et al.*, 2010). In the case of saturation, the recharge pit could also act as a storage for harvested rainwater. Another advantage is that if supply is insufficient to meet water demand in the future, water from the well can be extracted for supply. However, whether the quality of the recharged water is similar to that stored in PVC and concrete tanks remains a question. There was excess water during July to October, amounting to 208,336 L of water led to a recharge pit. In the context of water supply, however, this is a limiting element. Lack of storage capacity is one of the factors that hinder the adoption of RWHS (Pasakhala *et al.*, 2013). Thus, appropriate infrastructures need to be developed for the safe and adequate storage of harvested rainwater.

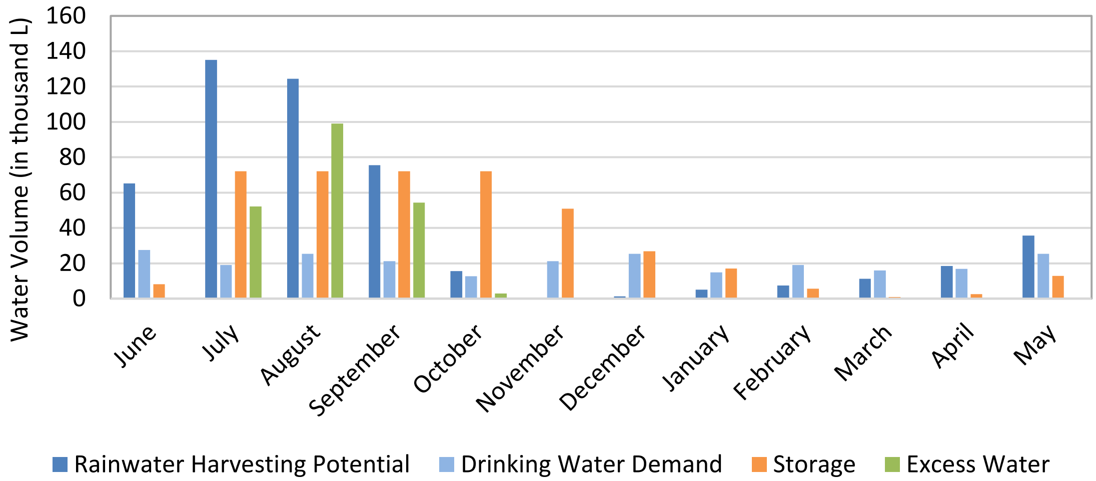

Figure 4: The volume of potential rainwater harvesting, drinking water demand, storage and excess water amounts

Similarly, the harvesting potential decreases from September and the water is supplied through storage tanks. Consequently, storage volume decreases from October to April throughout the year, and the storage is lower than drinking water demand in only three months: February, March, and April. During these months, the combination of direct rainwater and stored rainwater is able to fulfill the water demand.

In the present scenario of precipitation and drinking water demand, the RWHS adequately fulfills the water demand. However, if there is an increase in the number of working days and/or the number of students, and a change in precipitation trend, the current amount of harvested rainwater will not be enough for fulfilling the demands all year round. In such a case, storage tanks need to be added to collect all the water harvested. In the case of PNSS, the suitability of the dug well could also be tested. In the case that RWHS is not the only source of water, as in this study, this does not create much of a problem and alternative sources can be used to supply water dried months (from February to April).

Water Quality Analysis of Harvested Rainwater

Water samples were taken at different points within the RWHS components (Figure 1) and analysed seasonally. The temperature of water samples varied remarkably among seasons (range: 9.5 to 24.7 ^{o}C). The temperature also changed depending on the stages of water treatment and supply processes (Table 2 and Table 3). Although widely believed to be acidic, our rainwater samples in all seasons was found to be basic in nature. Values in the pH didn't show much variation between the seasons, but decreased through filtration stages (Table 3). Water samples were found to be more turbid during monsoon season in comparison to winter and post-monsoon season. The turbidity however decreased with series of treatment systems in each season (Table 3). In a study of groundwater quality of Kathmandu valley, average values of turbidity were found to be 45.9, 54.8, and 33.2 NTU, respectively, exceeding WHO limit by far. The values of turbidity in this study were very less in comparison to Pant (2011), and lies well within the WHO (2017) limit and NDWQS (2005).

The value of EC ranged from 20 to 112 µS/cm during three seasons and that of TDS ranged from 10 to 56 mg L^{-1}. EC and TDS increased after the filtration process which might be due to the use of sand in the filtration process. Pant (2011) attributed the high EC values in their assessment of groundwater to high ionic substances. The lower EC values in our study are due to low ionic concentration. The total alkalinity value was similar in all the three seasons, ranging from 10 to 45 mg L^{-1}. The raw rainwater, before going through any filtration process had the highest value of total and calcium hardness compared to other stages of water supply. Values of nitrate which are usually high in groundwater are exceedingly low in the study and also did not show remarkable seasonal variation either (Table 2 and Table 3).

Water from rooftop RWHS was reported to be of poor quality in New Zealand, where harvested rainwater is widely accepted as a source of drinking water in households (Simmons *et al.*, 2001). In contrast, the physico-chemical quality of the harvested rainwater in this study was found to be of excellent quality. None of the physico-chemical parameters (viz. pH, EC, TDS, Turbidity, Chloride, Total Alkalinity, Ammonia, Hardness, Ca Hardness, and Nitrate) exceeded WHO guidelines and NDWQS in all the three seasons. Most importantly, even the raw rainwater (T1) sampled before the series of treatments were within the guideline and standard value. Thus, considering the physico-chemical parameters, the harvested rainwater is suitable for drinking purposes. The quality of harvested rainwater is affected by the catchment, storage, and site environment (rural, urban or industrial) (Despins *et al.,* 2009). The excellent physico-chemical quality of rainwater harvested in our study suggests that the catchment, storage, and site environment was adequate.

Fecal coliforms showed significant variation within seasons. Remarkably higher colonies of coliform were detected in monsoon and post-monsoon season, the raw rainwater (T1) in monsoon season showing the highest number of colonies. Our results corroborated with several studies in which microbial quality was better during the winter season, such as Despins *et al.*, (2009). Mechanisms involved in microbial contamination of water harvested through rooftop RWHS include air-borne/atmospheric deposition, fecal contamination by animals and humans, leaching and weathering of metal roofs, plants colonisation, and the leaching of the accumulated particulate organic matter and flora of roof surfaces (Gwenzi *et al.*, 2015) In addition, the microbial composition is also affected by factors like as weather patterns, source location, landuse practices, and wind speed, posing a high risk of microbiological contamination (Evans *et al.,* 2006; Gwenzi *et al.,* 2015) Bird feces on the roofs are is one of the sources of fecal contamination in rainwater (Lohani *et al.,* 2008).

Table 2: Water quality parameters of water samples in three seasons: winter, monsoon and post-monsoon at different sampling points.
Win: Winter season, Mon: Monsoon season, Po-M: Post monsoon season; NTU: Nephelometric Turbidity unit; TNTC: Too numerous to count; CFU: Colony Forming Unit; #: Exceeded WHO (2017) guidelines and NDWQS (2005) values

SN	Water Quality Parameter	Values Obtained											
		T_1 (Raw rainwater)			T2 (Water after rapid sand filtration)			T3 (Water after biosand filtration)			T4 (Tap water after combined filtration system)		
		Win	Mon	Po-M	Win	Mon	Po-M	Win	Mon	Po-M	Win	Mon	Po-M
1	pH	8.35	8.40	8.00	8.03	8.00	7.30	7.84	8.00	7.30	7.62	7.70	7.10
2	Temperature (°C)	9.5	23.9	17.0	9.4	23.0	16.7	12.0	24.7	17.1	12.1	24.5	16.9
3	EC (μS cm^{-1})	46	20	26	30	39	36	48	55	56	90	112	80
4	TDS (mg L^{-1})	24	10	14	16	20	19	25	28	30	47	56	44
5	Turbidity (NTU)	0.78	2.64	1.66	0.43	1.22	0.42	0.38	0.69	0.17	0.31	0.58	0.11
6	Chloride (mg L^{-1})	25.56	11.36	28.4	14.2	5.68	21.30	7.10	18.46	24.14	11.36	4.26	25.56
7	Alkalinity (mg L^{-1})	25	20	25	10	20	20	10	20	15	15	45	15
8	Ammonia (mg L^{-1})	0.073	0.177	0.125	0.086	0.334	0.229	0.151	0.803	0.282	0.125	0.777	0.347
9	Hardness (mg L^{-1})	56	52	62	48	44	38	32	40	32	24	32	28
10	Ca Hardness (mg L^{-1})	20.04	24.05	40.88	8.02	16.03	21.64	13.63	17.63	17.64	16.03	18.43	17.64
11	Nitrate (mg L^{-1})	0.059	0.042	0.0567	0.051	0.0421	0.0665	0.064	0.0413	0.0584	0.067	0.0422	0.0425
12	Fecal Coliform (CFU per 100mL)	$4^{\#}$	TNTC $^{\#}$	$13^{\#}$	$3^{\#}$	$38^{\#}$	$6^{\#}$	0	$24^{\#}$	$3^{\#}$	0	0	0

Filtration systems were found to be efficient in removing the coliforms as no colonies of fecal coliform were observed in the tap water samples in all seasons (Table 3). Similar results were reported by Pradhan *et al.* (2022) where microbial contaminants were removed after treatments from Reverse Osmosis and UV disinfection (Pradhan *et al.*, 2022). At T4, fecal coliform was completely removed after being treated with an ultrafiltration technique and carbon filter. According to Zhang et al. (2019), ultrafiltration can help improve the microbiological quality of drinking water, especially when the high-quality source water is available (Zhang *et al.*, 2019). In a study conducted in Lalitpur, a neighboring district of Kathmandu, microbially safe drinking water was identified as one of the solutions for the prevention of intestinal parasitosis in school children (Tandukar *et al.*, 2013). The availability of safe, microbial-free water is crucial, especially in schools, which contain a vulnerable population of children of different ages.

The quality of drinking water in Kathmandu is reported to be poor by many studies such as Pant (2011) and Maharjan *et al.* (2018). Even the jar water, filtered water, and treated drinking water samples were detected with fecal contamination (Maharjan *et al.*, 2018). In terms of water quality, harvested rainwater subjected to treatment processes prove to be an excellent alternative to conventional water sources. To keep the drinking water safe, proper maintenance and cleaning of RWHS catchments and storage tanks are required (Abu-Zreig *et al.*, 2019).

Table 3: Water quality parameters at different points of the RWHS and treatment system (values are expressed as Mean ± S.D) and comparison with the WHO (2017) and the NDWQS (2005) for drinking water

S.N.	Parameters	T1	T2	T3	T4	WHO (2017)	NDWQS (2005)
1	pH	8.3 ± 0.2	7.7 ± 0.5	7.7 ± 0.5	7.5 ± 0.3	6.5-8.5	6.5-8.5
2	Temperature (°C)	16.8 ± 7.2	16.4 ± 6.8	17.9 ± 6.4	17.8 ± 6.3	-	-
3	EC (µS cm^{-1})	30.7 ± 13.6	35 ± 4.6	53.0 ± 4.4	94 ± 16.4	-	1500
4	TDS (mg L^{-1})	16.0 ± 7.2	18.3 ± 2.1	27.7 ± 2.5	49 ± 6.2	1000	1000
5	Turbidity (NTU)	1.7 ± 0.9	0.7 ± 0.5	0.4 ± 0.3	0.3 ± 0.2	5	5(10)
6	Chloride (mg L^{-1})	21.8 ± 9.1	13.7 ± 7.8	16.6 ± 8.7	13.7 ± 10.8	250	250
7	Alkalinity (mg L^{-1})	23.3 ± 2.9	16.7 ± 5.8	15 ± 5	25 ± 17.3	-	500
8	Ammonia (mg L^{-1})	0.12 ± 0.05	0.22 ± 0.12	0.41 ± 0.35	0.41 ± 0.33	1.5	1.5
9	Hardness (mg L^{-1})	56.7 ± 5	43.3 ± 5	34.7 ± 4.6	28 ± 4	-	500
10	Ca Hardness (mg L^{-1})	28.3 ± 11.1	15.2 ± 6.8	16.3 ± 2.3	17.4 ± 1.2	-	200
11	Nitrate (mg L^{-1})	0.05 ± 0.009	0.05 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	10	10
12	Fecal Coliform (CFU per 100mL)	TNTC	15.7 ± 19.4	9 ± 13.1	0	0	0

Note: Values in parenthesis are acceptable only when alternatives are not available

4. Conclusions

The RWHSs are effective in addressing the drinking water demand in institutions, such as schools throughout the year. Such practices can also be translated at household and community levels, with proper catchment areas and storage. The quality of harvested rainwater was observed sufficiently well with regard to the parameters considered in the study. Even the raw rainwater before any treatment systems was suitable for drinking in terms of physico-chemical quality. Fecal contamination was detected in the stored water which was reduced and finally removed through the successive filtration processes, namely rapid filtration, bio sand filtration, carbon filter, and ultrafiltration.

Thus, this study identifies rooftop RWHSs as a potentially reliable source of drinking water when equipped with adequate storage and treatment processes. The findings have significant implications for overcoming water shortages in locations, such as Kathmandu valley for reducing the water deficit. The lack of extensive evaluation of microbiological contaminants and trace metals, which can be a cause of deteriorated water quality in the harvested rainwater, is a limitation of the study. Future studies can consider and monitor trace metals and different microbiological pollutants in harvested rainwater. Similarly, factors such as seasons and age groups could be taken into account when estimating drinking water demand. Rainwater harvesting potential can be evaluated under different scenarios of precipitation behavior.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contribution Statement

MA: Conceptualization, Sample collection, Laboratory analysis, Literature review, and Manuscript preparation; PJ: Data acquisition, Data analysis, Literature review, and Manuscript preparation; ST: Supervision, Review, Proofreading, and Editing.

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