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Assessment of rainwater quality and potential for rainwater harvesting in Dallu Awas area, Kathmandu, Nepal

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Abstract

Nepal is rich in natural resources and it is among the richest in terms of water resource availability. The average annual rainfall of the country is in between 1500-3000mm. However, water scarcity is a major problem in Kathmandu valley as well as in some major cities of the country. In this context, rainwater harvesting may serve as one of the promising ways of supplementary water supply system to meet water demand in the valley. This study is aimed to analyze the potential for rainwater harvesting, the rainfall pattern and rainwater quality at Dallu Awas area which lies within the central-western part of the Kathmandu valley. Potential rainwater harvesting was determined by the questionnaire survey method and using a mathematical formula. The rainfall pattern was determined by analyzing the rainfall data supplied by the Department of Hydrology and Metrology, Government of Nepal and, the quality of rainwater was determined by analyzing its physico-chemical and microbial parameters in the laboratory. The study showed 90.33m^3 of rainwater harvesting capacity per household. Between 2006-2015 AD, the highest amount of rainfall (1829.4mm) was recorded in 2011 and the lowest (98.25mm) in 2009. For rainwater quality, a total of 81 rainwater samples were collected directly from atmospheric precipitation during rainy season from three different cluster zones viz., residential, school and hospital of the study area. The assessed physico-chemical, and microbial quality parameters were turbidity, electrical conductivity (EC), pH, biogenic compound, heavy metals (Fe, Mn, Pd and Zn) and total coliforms. Results revealed that the values of tested parameters were found within the guideline values set out by the NDWQS and WHO. Hence, the present study suggests that water scarcity in Kathmandu may be solved to some extent if proper rainwater harvesting system is adopted and collected rainwater may be used for multiple purposes following proper disinfection process.

Keywords: Rainwater quality; Rainwater harvesting, physico-chemical and microbial parameters, heavy metals, Kathmandu.

Introduction

These days, water crisis is being faced by approximately 36% of the world's population. Actually, rainwater is the water supply for much of the world's population. Although people in many areas depend on rainwater for drinking as well as many other domestic purposes in crisis situations, possibility of assess to this natural resource may not be easy due to various reasons[1]. It is believed that rainwater has substituted approximately 50% of potable water, and this value has increased upto 65% in public buildings[2]. People use rainwater for laundry, bathing, cleaning, sanitary facility flushing, car washing, gardening etc. Countries like Bangladesh and Kenya largely consume rainwater despite facing high risk of water deficit[3]. Owing to extensive rainwater consumption for a variety of household purposes, several countries have implemented rainwater harvesting and storage systems. During the period of drought, this valuable source of freshwater can minimize tap water demand to some extent[4]. Therefore, people are adopting rainwater harvesting technologies worldwide for support of water supplies[5,6]. The rainwater harvested system (RWHS) is considered as an inexpensive and sustainable alternative for water consumption particularly in remote areas with sparse housings and where high costs are required for building water supply systems[7,8]. The RWH system is also an effective technique as it is cost-effective, lowers water bills, reduces groundwater demand, reduces soil erosion and flood.

Nepal is the largest storehouse of freshwater, with more than 6000 rivers and rivulets[9]. The average annual rainfall of Nepal lies between 1500–3000mm and in Kathmandu valley, the average annual rainfall is 1900mm[10]. The Kathmandu valley had 1.003 million population in 2011 national census with 6.12% annual growth rate compared to the population figure of

2001. Obviously, water scarcity is inevitable due to population growth and the RWH system is, therefore important particularly for fulfilling water demand in the valley.

Myers[11] defined the RWH system as "a technique of collecting water from an area treated to enhance runoff from rainfall". It is simply accumulating and storing the naturally soft and pure rainfall[12]. Water harvesting methods are now receiving great attention in Nepal because rainwater can be a primary or supplementary source of water[13,14]. In Nepal, the rooftop RWH technique was first practiced in 1960[15]. Government of Finland, Biogas Support Program (BSP), Heivetas, Rural Water Supply and Sanitation Fund Development Board, Nepal Water for Health (NEWAH) are some of the major organizations establishing the RWH systems in the country[15] and benefitted thousands of people here. The use of rainwater and water policy, however were found variable country wise. Hatibu *et al.*[16] reported that 98% of crop production is rain-fed in Tanzania along with its use for domestic water supply, livestock, horticulture and groundwater recharge. In Chennai and New Delhi of India, it is compulsory to have a RWH system for a building to get construction approval[17]. The interim plan of Nepal (2007/08–2009/10) also considered RWH system as a key solution to fulfill water demand in the scare areas[18]. Ghimire *et al.*[19] reported that the rainfall pattern is not uniform in Nepal throughout the year and suggested RWH system an effective means for fulfilling water demand as harvested water can be utilized anytime. Though water supplied by KUKL (Kathmandu Upatyka Khanipane Limited) is the major source of water in Kathmandu valley, it only meets 25% of total water demand.

Rainwater is relatively clean and free from impurities unless the atmosphere is polluted. Change in time and space may both significantly affect the quality of rainwater harvested. Besides, the types of runoff surface, land use and catchment, local microclimate and atmospheric pollution are some of the factors that also influence the composition of rainwater. The rainwater quality may undergo deterioration during harvesting and storage. Several studies showed positive tests proving that rainwater may deteriorate physically, chemically, and microbiologically[20,21]. The highest levels of rainwater contamination in urban areas is likely to be due to dust particles emission, industrial power plants and vehicles[22,23].

The entry of microbial pathogens, such as bacteria, viruses, and protozoa also causes contamination of rainwater to greater extent[24]. Besides, faecal droppings from birds and animals, insects, wind-blown dirt, leaves, and the catchment areas with the contaminated litter can be potential pathways of rainwater contamination. The storage tanks filled with contaminated water can increase health risks. Therefore, it is very essential to know the quality of harvested water considering the public health importance. Such problem can be sort out by design of appropriate RWH systems. Besides, maintaining good sanitation at source points can reduce the health risk.

Studies on potential for rainwater harvesting and assessment of rainwater quality in Kathmandu are lacking. Therefore, this study aimed to analyze the potential for rainwater harvesting, the rainfall pattern, and rainwater quality at Dallu Awas area, Kathmandu because of its possible use for drinking and meeting many other domestic requirements in crisis conditions. Various types of physico-chemical and microbial measurements were conducted since these parameters affect rainwater quality. Besides, the study also assessed suitability for drinking rainwater by comparing against National Drinking Water Quality System (NDWQS)[25] and World Health Orgamization (WHO)[26] guidelines.

Materials and methods

Site Description: Dallu Awas area (Figure-1), ward no. 15 is situated in the west of Kathmandu Metropolitan City (KMC) covering an area of 20 hectares of land with a total of 761 households. It lies in the latitude of 27^{0}42′34.92″ and longitude of 85^{0}17′43.8″. The study area is bordered by Chetrapati in the east, Sitapaila in the west, Swuambhu in the north, and Tahachal in the south.

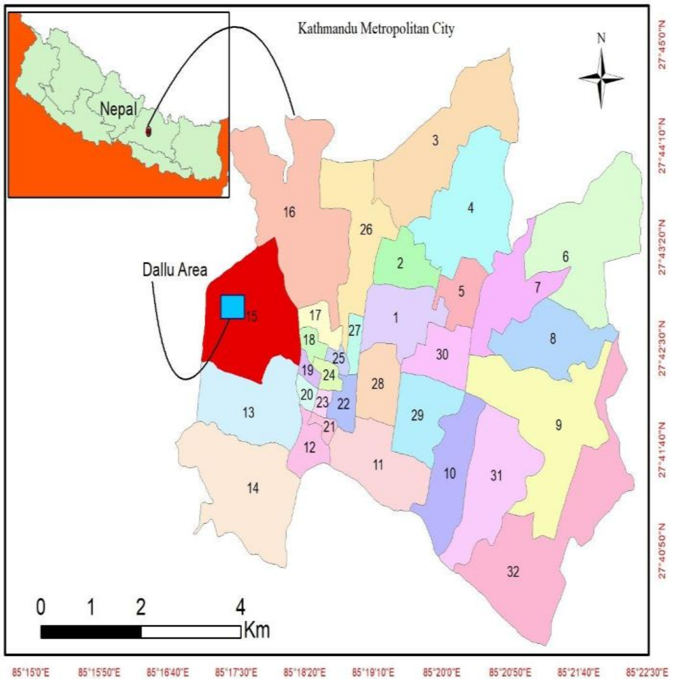

Figure-1: Sampling map of the study area.

Located very near to the area is the center of attraction and a World Heritage Site, the fabulous Swayambhu area which has made Nepal internationally well-known. With the increasing population in KMC, the area has become one of the people's choice for residential growth. The Dallu Housing Project and the nearby Bishnumati link road are two large projects carried out here. According to the project, 25% of the total land is allocated for road development and 7% for open space. Kathmandu Upatyeka Khanepani Limited (KUKL) is the public company that governs the responsibility for the operation and management of water and wastewater services in Kathmandu valley. This company has been registered under the Nepal Government's Company Act 2006 and operating on modality of the Public Private Partnership (PPP). Besides, people also reply on rainwater as well as ground and surface water sources here.

Rainfall estimation: Since the study area has no rain gauge station, rainfall data of Panipokhari from 2006-2015 were collected from the Department of Hydrology and Meteorology (DHM), Kathmandu. With these data, the mean annual rainfall of 10 years and mean monthly rainfall for the same period were estimated. The mean annual rainfall was estimated using Equation-1 and the mean monthly rainfall with Equation-2.

$$\text{Mean annual rainfall} = \frac{\sum \text{Mean annual rainfall of every year}}{10} \quad (1)$$

$$\text{Mean monthly rainfall} = \frac{\sum \text{10 years monthly rainfall of "X" month}}{10} \quad (2)$$

Potential for rainwater harvesting: To assess potential for rainwater harvesting at the study area, a detailed questionnaire was designed and administered to collect personal information of the respondents. The questionnaire survey also generated information on types of water treatment practice, the source of water, knowledge on rainwater harvesting, willingness to practice rainwater harvesting, daily water demand and supply and requirement of water for the different domestic purposes. Purposive sampling method was used for the questionnaire survey and the potential for rainwater harvesting was assessed from a sample size that included 30 households, 7 schools and 5 hospitals.

Makaju[27] estimated potential for rainwater harvesting by using Equation-3:

$$S = R_f * A * Cr \quad (3)$$

Where: S = Mean rainfall supply (ltr.); R_f = Mean annual rainfall (mm); A = Catchment area (m^2), and Cr = Runoff coefficient (Volume of runoff/Volume of rainwater).

Similarly, Makaju[27] also calculated monthly water demand of a family by using Equation 4.

Monthly demand=30*Per capita demand * No of individuals (4)

Here, the number of individuals and per capita demand was obtained through the questionnaire survey.

Ghisi *et al.*[28] used Equation 5 for potential estimation of the volume of rainwater harvested per month.

$$VR = R * H_{RA} * \frac{R_C}{1000} \quad (5)$$

Where, VR = Monthly volume of rainwater per household (m^3); R = Monthly rainfall depth (mm); H_{RA} = Household roof area (m^2), and Rc = Runoff coefficient (no unit).

Aladenola and Adeboye[17] estimated monthly balance of rainwater using Equation-6 as follows:

$$W_a = I_v + Vc - Vu \quad (6)$$

Where: W_a = Water available; I_v = Initial Volume; V_c= Volume collected, and V_u = Volume used.

Collection and analysis of rainwater sample: Eighty one rainwater samples (three replicate from each selected building) were collected from three cluster zones *viz.*, residential (n = 15), school (n = 7) and hospital (n = 5) of the study area. The hospital zone included main government hospital, health clinics at community level as well as dispensary buildings for the study. The study was carried out during monsoon period (June to July). For analytical purpose, rainwater samples were directly collected first into well cleaned containers placed at rooftops of respective buildings, about 2m above the ground level and after 15-20 minutes of continuous the first rainfall to collect unpolluted water samples. Collected water samples were then transferred into clean, well rainsed and labeled PET bottles. Temperature, electrical conductance (EC) and pH values of all rainwater samples were recorded at the sampling spots using a standard mercuric thermometer, hand type digital conductivity meter (DiST3 Tester-HI98303) and pH meter (Hanna HI 8314**)** respectively. Immediate delivery of the water sample bottles were made to laboratory for further analyses of physico-chemical parameters the same day.

The samples were placed in a refrigerator at 4^0C for preservation when immediate analyses were not possible. Standard methods for analyses of physico-chemical parameters were adopted as per the APHA[29] (Table-1). Besides, necessary produces were followed for precautions and preservation of collected water sample accordingly.

For microbial analyses, sterilized sample bottles were used for water sample collection. Analyses of total hardness (TH), Ca and Mg-hardness, total alkalinity (TA), sulphate, chloride and total coliforms were carried out at the Environment Science laboratory, Padmakanya Multiple Campus, Bagbazar, Kathmandu while turbidity, nitrogen compounds and heavy metals were determined at Aaastha Scientific Services, Dillibazar, Kathmandu. All rainwater samples were analyzed in triplicate.

Statistical analysis: Descriptive statistics such as frequency, percentage, mean and standard deviation were calculated using IBM-PC computer. Besides, Pearson's correlation analysis was performed for significance test among the selected physico-chemical parameters.

Table-1: Methods used for analyzing water quality parameters.

Parameters	Methods
Physical	
Temperature	Mercuric thermometer
Turbidity	Nephelometric method
EC	Digital conductivity meter
Chemical	
pH	pH meter
Total hardness	Complexometric titration
Ca-hardness	Complexometric titration
Mg-hardness	Complexometric titration
Total alkalinity	Acid-base titration
Chloride	Argentrometric titration
Sulphate	Turbidimetric method
NO_3^--N	Stannous chloride reduction method
NH_4^+-N	Neslerization method
Fe	1,10 phenanthroline method
Mn	Atomic Absorption Spectrophotometer
Pb	Atomic Absorption Spectrophotometer
Zn	Atomic Absorption Spectrophotometer
Microbial	
Total coliforms	Most probable number (MPN) method

Results and discussion

Rainfall data analysis: The mean annual rainfall of 10 years (2006-2015) is shown in Figure-2. The present study revealed that the average rainfall at Dallu Awas area was 1447.53 mm, the value in close approximation to the study conducted by Pandey *et al.*[30] who reported 1600mm as the average rainfall in Nepal. The highest amount of rainfall was recorded in 2011 (1829.4mm) and the lowest in 2009 (1170.9mm). This figure shows that the rainfall pattern in Nepal is not uniform throughout the year. This may be attributed to the climate change and its impact on precipitation patterns globally[31] and water resources as well[32]. While Baidya *et al.*[33] obtained an increasing trend in precipitation without any significant change in pattern, Shrestha *et al.*[34] reported no distinct trend in annual precipitation in Nepal. In Nepal, climate change has greatly affected crop production and hydrology[35]. Change in rainfall pattern has increased the scarcity of water citing rainwater harvesting system as one of the best options for the solution of the water problem.

The mean monthly rainfall from 2006-2015 is presented in Figure-3. July recorded the highest amount of rainfall (3785.8 mm) while the lowest amount of rainfall (37.4mm) occurred in December. Shrestha[36] also reported 80% of the precipitation in Nepal during monsoon period in consistent with the present study.

Potential for rainwater harvesting: The potential for rainwater harvesting systems in households, schools, and hospitals was found to be different. Per capita water demand, the total number of individuals, the roof area, and the runoff coefficient are the major factors influencing the potential for the RWH system. The value of these influencing factors is shown in Table-2.

In July and August, the harvested rainwater is greater than the water demand of households. Similarly, in November, December, and January the water demand fulfill by rainwater is very low as 80% of precipitation occurs during monsoon in Nepal. The estimated value of annual RWH potential per household was 90.33m^3 as shown in Table-3. A similar study conducted by Aladenola and Adeboye[17] in Abeokuta, Nigeria showed 73.96m^3 of rainwater harvesting per household.

In comparison to households, the monthly water demand at school is very high as the total number of individuals in school is 13 times greater than the total number of individuals in households. Table-4 shows that 289.51m^3 of rainwater can be harvested in schools. This total monthly water demand in schools is of 26 days as the schools are closed on every Saturday. The harvested rainwater in schools is used for flushing and washing. In some cases, it is also used for drinking purposes by using the bio-sand filtration method. RWH system has saved the water budget in every school.

Table-2: Values of influencing factors of the RWH system in different sectors.

Name of sector	Roof area (m^2)	Mean annual rainfall (mm)	Runoff coefficient	Total number of individuals	Per capita water demand/day (ltr.)
Household	78	1.4	0.8	8	90
School	250	1.4	0.8	400	10
Hospital	315	1.4	0.69	120	50

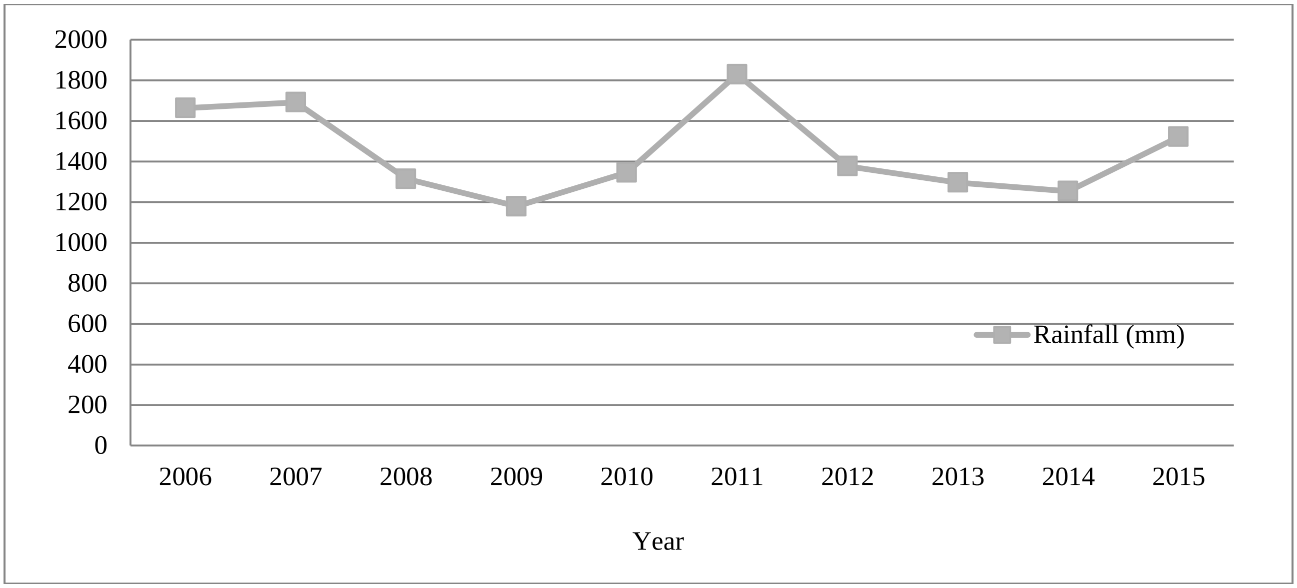

Figure-2: Mean annual rainfall of 10 years.

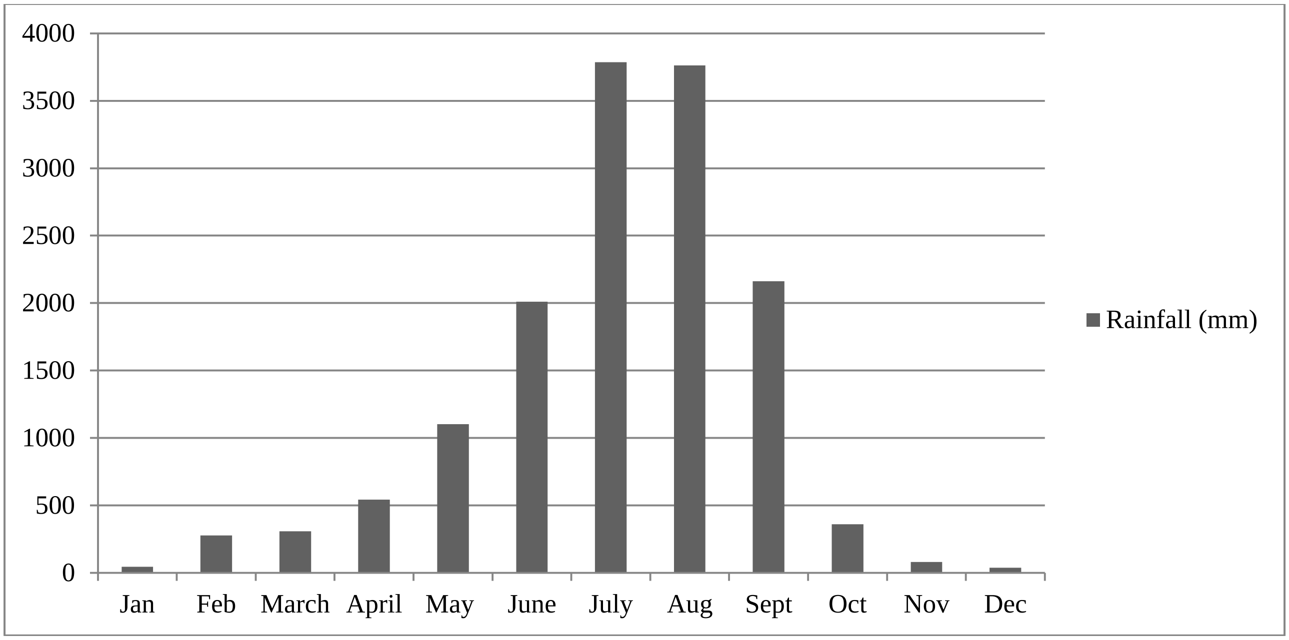

Figure-3: Mean monthly rainfall of 10 years.

In hospitals, water is used for multiple purposes such as dishwashing, landscaping, cooling and heating, restroom, medical equipment, restroom, and laundry. The water demand of the hospital is 180m^3/month as shown in Table-5. This indicates that hospitals require a large volume of water. The RWH system cannot completely fulfill water demand in hospitals but it can be used as an additional source of water. The total volume of harvested rainwater in the hospitals is 314.62m^3/year.

Analyses of rainwater quality: Table-6 shows physico-chemical and microbial characterizations of the collected rainwater samples from three cluster sampling areas *viz.*, residential, school, and hospital. The mean values of all tested water quality parameters are given and the values compared against NDWQS and WHO guideline values for water quality assessment.

Temperature: The study area showed no thermal variation among three cluster study sites *viz.*, residential, school and hospital, all recording almost the same temperature of 18^{0}C. Water having temperature range of 7^0-11^{0}C has a pleasant test according to WHO[26]. The biological activity of aquatic organisms is often affected by water temperature[37].

Table-3: Potential for monthly harvested rainwater and water balance at households.

Month	Rainfall (mm)	Mean rainfall	Volume of harvested rainwater (m^3 /month)	Water demand (m^3)	Monthly balance (m^3) = Volume of harvested rainwater - demand
Jan	44.3	4.43	0.28	21.6	-21.32
Feb	278.4	27.84	1.74	21.6	-19.86
March	307.4	30.74	1.92	21.6	-19.68
April	543	54.3	3.39	21.6	-18.21
May	1101.8	110.18	6.88	21.6	-14.72
June	2010.9	201.09	12.55	21.6	-9.05
July	3785.8	378.58	23.62	21.6	2.02
Aug	3763.3	376.33	23.63	21.6	1.88
Sept	2161.6	216.16	13.49	21.6	-8.11
Oct	359.7	35.97	2.24	21.6	-19.36
Nov	81.7	8.17	0.51	21.6	-21.09
Dec	37.4	3.74	0.23	21.6	-21.37
Total	14475.3	1447.53	90.33	259.2	-168.87
Average	1206.275	120.6275	7.527	21.6	- 14.07

Table-4: Potential for monthly harvested rainwater and water balance at schools.

Month	Rainfall (mm)	Mean rainfall (mm)	Volume of harvested rainwater (m^3/month)	Water demand (m^3)	Monthly balance = Volume of harvested rainwater-water demand
Jan	44.3	4.43	0.89	104	-103.11
Feb	278.4	27.84	5.57	104	-98.43
March	307.4	30.74	6.15	104	-97.85
April	543	54.3	10.86	104	-93.14
May	1101.8	110.18	22.04	104	-81.96
June	2010.9	201.09	40.22	104	-63.78
July	3785.8	378.58	75.72	104	-28.28
Aug	3763.3	376.33	75.27	104	-28.73
Sept	2161.6	216.16	43.23	104	-60.77
Oct	359.7	35.97	7.19	104	-96.81
Nov	81.7	8.17	1.63	104	-102.37
Dec	37.4	3.74	0.75	104	-103.25
Total	14475.3	1447.53	289.51	1248	-958.49
Average	1206.275	120.6275	24.13	104	-79.87

Table-5: Potential for monthly harvested rainwater and water balance at hospitals.

Month	Rainfall (mm)	Mean rainfall (mm)	Volume of rainwater (m^3/month)	Water demand (m^3/month)	Monthly balance = Volume of harvested rainwater - water demand
Jan	44.3	4.43	0.96	180	-179.04
Feb	278.4	27.84	6.05	180	-173.95
March	307.4	30.74	6.68	180	-173.32
April	543	54.3	11.80	180	-168.20
May	1101.8	110.18	23.95	180	-156.05
June	2010.9	201.09	43.71	180	-136.29
July	3785.8	378.58	82.28	180	-97.72
Aug	3763.3	376.33	81.80	180	-98.20
Sept	2161.6	216.16	46.98	180	-133.02
Oct	359.7	35.97	7.82	180	-172.18
Nov	81.7	8.17	1.78	180	-178.22
Dec	37.4	3.74	0.81	180	-179.19
Total	14475.3	1447.53	314.62	2160	-1845.38
Average	1206.275	120.6275	26.22	180	-153.78

Table-6: Mean values of physico-chemical and microbial parameters in rainwater samples (Mean ± SD).

Parameters	Unit	Residential (n = 15)	School (n = 7)	Hospital (n = 5)	NDWQS	WHO
Temperature	^{0}C	18.0±0.8	18.0±0.9	18.0±0.9	-	-
Turbidity	NTU	< 5	< 5	< 5	5 (10)	5.0
EC	(µS/cm)	220±15	225±26	221±12	1500	1000
pH	-	6.7±0.5	6.9±0.8	6.5±0.4	6.5-8.5	6.5-8.5
Total hardness	(mg/L)	16.5±3.4	16.9±5.0	15.1±4.2	500	80 - 120
Ca hardness	(mg/L)	13±3.8	13.7±3.6	11.9±4.8	-	200
Mg hardness	(mg/L)	3.5±0.9	3.2±0.6	3.2±0.9	-	150
Total alkalinity	(mg/L)	60±8	63±10	65±12	-	200
Chloride	(mg/L)	26.6±12.4	27.2±8.5	30.0±10.4	250	250
Sulphate	(mg/L)	14.5±7.2	20.0±9.5	18.5±8.0	250	250
NO_3^--N	(mg/L)	2.5±0.4	4.0±0.8	3.5±0.9	50	50
NH_4^+-N	(mg/L)	0.20±0.04	0.25±0.07	0.30±0.08	1.5	1.5
Fe	(mg/L)	0.08±0.02	0.05±0.01	0.07±0.01	0.3(3)	0.3
Mn	(mg/L)	BDL	BDL	BDL	0.2	0.2
Pb	(mg/L)	BDL	BDL	BDL	0.01	0.01
Zn	(mg/L)	0.7±0.2	0.6±0.1	0.4±0.1	3.0	3.0
Total coliforms	MPN/100 ml	0	0	0	0 (95% samples)	0

Turbidity: Turbidity is one of the commonly used water quality parameters. Turbidity values less than 5.0 NTU were found in all the sampling sites and within the guideline limits of NDWQS and WHO. Our findings are in contradiction with the study conducted by Naddeo *et al.*[38] who reported 25.88 NTU in the harvested rainwater. Turbidity in water is an important indication of particulate matters present either in suspended or dissolved form. They can retard biological activity including photosynthesis thereby scattering light and making water body appear cloudy[39]. Revivable bacteria may also cause rainwater turbidity. Besides, the roughness of the roof-covering material and its' capacity to hold dirt is also attributable for turbidity value which is in consistent with the findings of Leong *et al.*[40]. They reported 92.9, 57.1, and 10.1 NTU for glass, metal, and ceramic roof surfaces respectively.

Electrical conductivity (EC): The mean EC values of rainwater from three sampling zones only marginally fluctuated between 220 and 225µS/cm. These values did not cross the maximum permissible limits of NDWQS and WHO guidelines. The presence of positive or negative ions conducts electricity in water. Presence of heavy metal ions may also indicate pollution. Further, the types of rooftop materials and land-use zones may affect the level of EC in rainwater. Zhang *et al.*[6] reported variable levels of EC for rainwater based on the roof materials. They obtained significantly high EC values in rainwater from the green roof and low EC from roofs covered with roof sheets and tiles.

pH: pH is another important rainwater quality parameter. In the present study, pH values were recorded between 6.5 and 6.9 among the sampling sites. The obtained values are slightly acidic but lie within NDWQS and WHO guideline values. Zdeb *et al.*[41] also reported pH values in acidic range in rainwater samples collected directly from atmospheric precipitation than roof-harvested. The rainfall water with low pH values may result from fuel combustion leading to the formation of oxides of nitrogen (NO_x) and SO_2. Studies revealed such a feature of acidic precipitation in large urban agglomerations[42]. Bai and Wang[43] also found significantly low pH (4.4) in rainwater collected from highly urbanized zones. Similar to turbidity and EC, pH values of rainwater may also be affected by types of roof surface. For instance, cement tiles are mainly composed of sand, portland cement, iron oxide pigments, and water. They also consist of calcium and magnesium carbonate which increase the pH value to some extent[40].

Total hardness: Total hardness in rainwater samples from all sampling sites were found practically the same. The values of total hardness including Ca and Mg hardness did not cross the safe limits described by NDWQS and WHO guidelines. Presence of calcium and magnesium ions increase hardness of water. Rainwater is naturally soft but its hardness increases as it passes through the ground. High deposition of salt in drinking water may cause osteoporosis, hypertrophy, renal stones, asthma, and risk of stroke[44]. The concentration of magnesium hardness is generally lower than calcium hardness in natural water system[45]; however a high concentration of calcium is often undesirable for washing, bathing, laundry etc.,[39]. Human diets also need the same elements which may be fulfilled to extent by drinking hard water.

Total alkalinity: Phenolphthalein alkalinity was detected in none of rainwater samples from the study area. So, total alkalinity for the rainwater samples at Dallu Awas area is mainly due to carbonates and bicarbonates[46]. The values were found marginally different among the sites with 60mgL^{-1} at residential and 65mg/L at hospital areas indicating that they lie well below NDWQS and WHO guideline values.

Chloride: The mean concentrations of chloride in rainwater samples collected from residential, school and hospital zones were found to be 26.6, 27.2 and 30.0mg/L respectively. None of the tested samples crossed the guideline values for chloride described by NDWQS and WHO. Chlorides occur in natural water system in the form of salts such as NaCl, KCl and $CaCl_2$ in varying concentrations and also act as an important indicator of pollution. The concentration of chloride ions exceeding 200 mg/L may raise human health risk as well as loss of pleasant taste of water[47].

Sulphate: Sulphate levels were found to be 14.5, 20.0 and 18.5 mg/L in the tested rainwater samples from residential, school and hospital zones respectively. None of the samples tested contained sulphate content above NDWQS and WHO guideline values. Significant amount of sulphate are present in natural water in completely oxidized form of sulfur and the anions are more stable in aqueous form. Sulphate mineral dissolution, sulphide mineral oxidation and atmospheric deposition are some of the primary sources of sulphate[48].

Nitrogen compounds (NO_3^--N and NH_4^+-N): The levels of nitrogen compounds were almost equal in the tested samples of harvested rainwater. The concentrations of NO_3^--N measured in rainwater samples ranged between 2.5 (residential) and 4.0 mg/L (school). The NO_3^--N value amounted to 3.5mg/L in rainwater collected from hospital area. Similarly, the NH_4^+-N values were in the range from 0.20 (residential) to 0.30mg /L (hospital). The values comprising both the nitrogen compounds were far below the guideline limits according to NDWQS and WHO for the respective parameters (Table-6).

The level of nitrogen compounds in rainwater is an indicative of the conditions promoting the survival and growth of bacteria. Rainwater may contain nutrients such as fungal spores, plant pollen, bacterial spores and bacterial cells from atmospheric precipitation. Besides, lichens, bryophytes and bird droppings are some of the natural sources that pollute roof runoff[49]. Although, rainwater samples were collected directly from atmospheric precipitation, the level of nitrogen compound in the analyzed rainwater samples ranged from 2.5 to 4.0mg/L for NO_3^-N. Low levels of nitrate in rainwater of the urbanized areas may be attributed to the limited share of agricultural areas. However, the concentration may vary depending upon types of roofing used for harvesting rainwater[49]. Similarly, Zdeb *et al.*[41] found significantly low levels of NH_4^+-N ranging between 0.2 and 0.4mg /L in urbanized areas in consistent with the present study. Further, their study indicated higher levels of turbidity, NO_3^--N, PO_4^{3-}P and TOC in rainwater harvested from the roof covered with epoxy resin inclined to a minimum angle stating that roof surface inclination can significantly affect rainwater water. Besides, the differences in the concentrations of nitrogen and other nutrient compounds in harvested rainwater may be attributed to difference in roof structures and also the possibility of washing out dry deposition pollutants.

Heavy Metals in Rainwater: Heavy metals present in rainwater samples from all sampling sites are displayed in Table-6. The concentration of Fe in rainwater ranged between 0.05 (school) and 0.08mg/L (residential) while that of Zn between 0.4 (hospital) and 0.7mg/L (residential). The values were found well below the NDWQS and WHO guidelines values for the respective heavy metals (Table-6). Both Mn and Pb were found below detection level.

Studies revealed that virtually all types of rainwater contain heavy metals whether it is natural water[50] or water from strongly urbanized and rural areas[43], as well as in stored rainwater[22]. In addition, dry deposition of pollutants over roof surfaces are the points of heavy metals contamination in rooftop rainwater samples. As the solubility of heavy metals in rainwater depend on its pH level, Zn, Cd and Cu are readily soluble than Pb, Cr and Ni in wet as well as dry deposits[51]. As of other parameters, materials used for roofing purpose also determine the contamination of heavy metals in rainwater[50,52].

Microbiological quality of rainwater: Microbiological analysis of rainwater samples are presented in Table-6. Results showed no microbial contamination in the samples collected from all sampling sites. All the tested rainwater samples showed 0 cfu/100mL without violating NDWQS and WHO guidelines.

Normally, sanitary quality of water is defined by two types of microorganisms *viz.*, *Escherichia coli* and *Enterococcus*. Human and animal feces contain both the microorganisms are at very high numbers. Deposition of feces by small mammals and birds on the rooftops is the prime source of bacterial contamination in roof-harvested rainwater[53]. Likewise, wind carrying soil particles from the fertilized agricultural lands tend to cause bacterial contamination rainwater.

Although rainwater is microbiologically stable, its stability may be decreased by some factors such as rainwater collection techniques and the structure and types of roofs. Upon contact with roof surfaces, the microbiological quality of rainfall undergoes deterioration. At the same time, the quality may improve or undergo deterioration depending on the frequency of rainfall and materials used for roofing. A study by Llopart-Mascaróetal *et al*.[54] detected *E. coli* in 36% of cases in rainwater collected directly from precipitation while they found 100% contamination in the samples from roof drainage. Similarly, Lee *et al.*[51] obtained 0, 1 and 2cfu/100mL of *E.coli* counts in rainwater samples from roofs covered with zinc-coated metal sheets, ceramic and concrete tiles respectively. Study also proved galvanized steel roof coverings as the most effective material to prevent the growth of microorganisms[55]. This disinfection property may have resulted from the synergetic effect of solar radiation[50].

Correlations among physico-chemical parameters: Table-7 shows correlation coefficients among some physico-chemical parameters used in this study.

Table-7: Pearson's correlations among some physico-chemical parameters of rainwater.

	EC	pH	TH	TA	Cl^-	SO_4^{2-}	NO_3^-N	NH_4^+N	Fe	Zn
EC	1.000									
pH	0.259	1.000								
TH	0.262	0.411(*)	1.000							
TA	0.510(*)	0.572(**)	0.654(**)	1.000						
Cl^-	0.912(**)	0.499(**)	0.362(*)	0.188	1.000					
SO_4^{2-}	0.854(**)	0.210	0.766(**)	-0.088	0.265	1.000				
NO_3^-N	0.798(**)	0.198	0.642(**)	0.079	0.186	0.244	1.000			
NH_4^+N	-0.078	-0.148(*)	0.078	0.576(**)	0.178	0.166	0.442(*)	1.000		
Fe	0.149	0.188	0.198	-0.078	0.098	0.194	0.068	-0.108	1.000	
Zn	0.228	0.210	0.166	-0.086	0.122	0.244	0.110	-0.088	0.084	1.000

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level, TH= Total Hardness; TA= Total Alkalinity.

Potential common sources of components are defined by their correlations which are frequently expressed by Pearson's correlation coefficient[56]. Accordingly, pH of rainwater was found significantly correlated with TA ($r = 0.572, p<0.01$), Cl^- ($r = 0.499, p<0.01$) and TH ($r = 0.411, p<0.05$) respectively while a negative correlation was found between pH and NH_4^+-N ($r = -0.148, p<0.05$).

The analysis also revealed significant correlations between EC-Cl^- ($r= 0.912, p<0.01$), EC-TA ($r= 0.510, p<0.05$), EC-SO_4^{2-} ($r= 0.854, p<0.01$), TH-TA ($r= 0.654, p<0.01$), TH-Cl^- ($r= 0.362, p<0.05$), TH-SO_4^{2-} ($r= 0.766, p<0.01$), TH-NO_3^--N ($r= 0.642, p<0.01$) and NH_4^+-N- NO_3^--N ($r= 0.442, p<0.05$), indicating that they have common sources of origin.

Conclusion

The present study was related with analyses of rainwater quality and potential for rainwater harvesting at Dallu Awas, Kathmandu, Nepal. The mean monthly rainfall and mean annual rainfall from 2006 to 2015 AD was analyzed. The mean annual rainfall value of 1447.53mm shows that maximum amount of rainfall occurs in Kathmandu valley. Monthly and annual household water demand were also determined. It shows that rainwater can fulfill 87.36% of water demand.

To assess rainwater quality, some physico-chemical and microbial parameters were tested in the rainwater collected directly from atmospheric precipitation taking appropriate measures. Among the water quality parameters, temperature, turbidity and EC as physical parameters; pH, total hardness, total alkalinity, chloride, sulphate, nitrate, ammonia, Fe, Mn, Pb and Zn as chemical parameters and total colifrms as microbial parameter.

All the values revealed by the studied parameters meet the requirements set out by the NDWQS and WHO and hence may be used for drinking purpose following proper disinfection process, preferably chlorination. The present study suggests that water scarcity in Kathmandu valley may be solved to some extent if proper rainwater harvesting system is adopted.

Studies reveal that water demand at a particular region can be solved to some extent through rainwater harvesting and be used for various domestic purposes. In general, physico-chemical and microbiological quality of rainwater are deteriorated after contact with a roof surface.

It has been reported that the type of materials from which the roofing is made, can alter physico-chemical as well as bacteriological quality of the water. The retention of dust impurities carrying both promoters (C, N, P) and inhibitors (metal ions) of microbial development is affected by porosity of the roofing. This suggests use of appropriate roofing materials during construction of houses so as to harvest rainwater in proper way for solving water demand. Therefore, further researches are necessary in the pertinent area.

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