BJNRD (2020), 7(1): 26-39
Bhutan Journal of Natural Resources & Development

Article

www.bjnrd.org

Open Access

ISSN 2409–2797 (Print)
ISSN 2409–5273 (Online)

DOI: https://doi.org/10.17102/cnr.2020.43

Assessment of Water Shortage and Potential for Rooftop Rainwater Harvesting in Rural Development Training Centre, Zhemgang Town, Bhutan

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Abstract

Rainwater harvesting is one of the promising alternatives to supplement surface water resources in areas where existing water supply is inadequate to meet the demand. The water shortage in Zhemgang is a recurring problem. This study was conducted to assess the water shortage in Zhemgang town and the potential for Rainwater Harvesting (RWH) in the Rural Development Training Centre (RDTC). A total of 318 households were assessed for the water shortage and knowledge, attitude and practices on RWH. Additionally data were collected once in 24 hours in the rainy season from June through September from five rooftops in RDTC premises. The study revealed that the Zhemgang Municipal supplies 469.02 litres of water per day per household resulting in residents facing potable drinking water deficit of about 54.48 litres/ day/ household as the average requirement is 523.50 ± 110.48 (mean ± SD) litres/day/household. Zhemgang town receives a mean annual rainfall of 1,412.50 ± 208.90 (mean ± SD) mm with an intra-annual variability range of 0.95 and 0.97 mm and interannual variability of 0.15 mm. The low variability in rainfall, ranging from 0.29 mm to 0.41 mm during the rainy season, indicates a reliable condition for RWH and guarantees the return on investment. The RWH potential for RDTC was 7,790,220.00 m3 and the average rainwater runoff collection from the experimental sites was 633,000 L during the rainy season from the rooftop catchment area of 456.14 m2. The daily collections of rainfall in 1,000 L from the month of June through September were 3.4 L, 8.9 L, 3.6 L, and 4.9 L respectively. The water was used to irrigate field crops such as maize, oats, vegetable, pasture field and fruits trees. The study identifies RWH as an alternative means to supplement the water supply scheme. The quality of RWH from CGI roofing after the first flush had all physical parameters within the permissible limit.

Keywords: rooftop rainwater harvesting, water quality, water shortage, Zhemgang

Introduction

Water is a basic human requirement which may be sourced from surface water, groundwater or rainwater (Gleick, 1996). It is essential to life and sets a foundation for the social and economic development of all countries (Che-Ani, 2009: Aladenola and Adeboye, 2010). However, available water supply sources are diminishing owing to population rise, climate change and pollution, causing a globally acknowledged situation of water scarcity, especially in developing countries (Fang *et al.*, 2007). It is reported that in the coming decades, two-thirds of the world's population may face water shortage (Rijsberman, 2006).

Rainwater Harvesting (RWH) has been increasingly used as an alternative source of wa-

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Received: April 9, 2020
Accepted: June 15, 2020
Published online: June 30, 2020

ter, especially in regions where water resources are either scarce or difficult to access (Tidwell *et al.*, 2004). Rainwater harvesting systems (RWHS) use a rain barrel to collect rainwater from the roofs of buildings that can be used for gardening, flushing toilets, car washing, and even meeting potable demand, as well as for reducing storm-water runoff (Park and Um, 2018). The paper on RWHs for communities in developing countries by Charles (2007) presents RWH as “one of the most promising alternatives for supplying freshwater in the face of increasing water scarcity and escalating demand”. In most cases, it was mainly used as an alternative water source in dry periods and it was a survival strategy for ancient civilizations (Hofman and Paalman, 2014).

RWH is a technique of collecting and storing rainwater in natural reservoirs, or the infiltration of surface water into surface aquifers before it is lost as surface runoff (Kumar, 2019). There are several definitions and classifications of water harvesting techniques although the terminology used at the regional and international levels has not been standardized yet (Nasr, 1999). One method of RWH is rooftop harvesting. Most of the roof surfaces can be used to intercept the flow of rainwater and provide a household with drinking water, gardening, livestock, agriculture and other purposes. Rainwater is usually free from physical and chemical contaminants such as pesticides, Lead and Arsenic, color and suspended materials and it is low in salt and hardness (Sendanayake, 2016).

Zhemgang District has eight *Gewogs* (Blocks) and the seat of district administration falls under Zhemgang municipality. The town can distribute 507 m^3 of water during peak season with an average consumption of 176.3 litres/ day/ person. While during the lean season, 253.3 m^3 of water is available with an average consumption of 88.2 litres/ day/ person (District Municipal Office, 2019). The residents in Zhemgang experience an acute shortage of water during the lean season (March-Mid June) by almost 50% (District Municipal Office, 2019).

Zhemgang town receives an average annual rainfall of 1,412.50 mm ± 208.90 *SD* with a mean monthly rainfall of 117.71 mm ± 113.02 *SD* (National Centre for Hydrology and Meteorology [NCHM], 2019). The mean average monthly rainfall during the rainy season in Zhemgang town is 255.48 mm ± 59.09 *SD* (NCHM, 2019). Thus, rainwater harvesting can be one of the measures to supplement the existing water supply in Zhemgang town. In this context, a study was carried out to assess the water shortage problem in Zhemgang town and the potentiality of RWH as an alternative to supplement the existing water supply.

Methodology

Study area

Zhemgang District (27°12’58.53’’N and 90°39’45.30’’E) is 300 km east of Thimphu and lies in a warm temperate region experiencing a maximum temperature of 22 °C and minimum temperature 1 °C with a mean temperature of 13 °C (NCHM, 2019). Zhemgang town covers a total area of 274.54 acres, which is approximately 1.66 km^2. The town includes RDTC, two schools, different regional offices, monastic bodies, Dzongkhag administration office complex and town area shopping complex (See Figure.1) The town has 462 households, 246 building structures and a population of 2,732 people. The water is supplied from a source located 2.5 km above Zhemgang town and is stored in reservoirs. Of the three water reservoirs, one with a capacity of 253 m^3 is for home use while the other two with a capacity of 60 m^3 each are meant for fire hydrants (District Municipal Office, 2019).

The RDTC (27°12’59.49’’N, 90°39’45.35’’E) in Zhemgang was established in 2007. It is located 1 km north of Zhemgang town. With 56.51 acres of land, the Centre has Administration and office units, residential quarters, a training hall, a dining hall with kitchen and two hostels with a capacity for 80 persons, dairy, poultry and piggery blocks, store and food processing units (Figure 2).

The study to assess the potential for RWH in RDTC, Zhemgang was conducted from June to September 2019 and the social survey was done in October and November 2019. To assess the water shortage problems and knowledge, attitude and practices on RWH, a competent member of 318 households each in Zhemgang town and RDTC were interviewed using pretested semi-structured questionnaires. The interviewees were selected through convenient sampling.

The rainfall data available with NCHM from 1997 to 2017 were used to calculate the inter and intra rainfall variability for 20 years. It was then analyzed to determine the potential of rainwater, rainfall pattern, average monthly and annual rainfall to correlate with the potential for RWH in Zhemgang town. The emphasis of this study was on roof-based rainwater harvesting potential at RDTC. The amount of rainwater harvested was based on the roof area, rainfall depth and runoff coefficient which depends on roof material and design (Thomas and Martinson, 2007). To determine the potential for RWH and its usage, rainfall data were col-

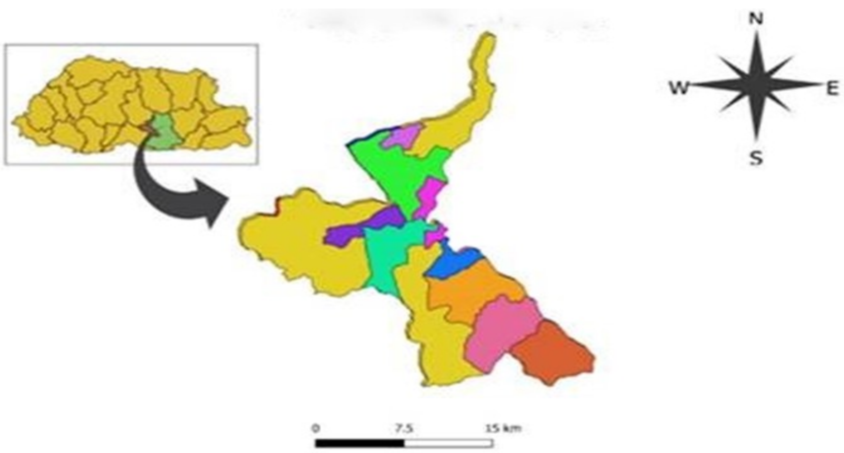

Figure 1: Map showing study area in Zhemgang town

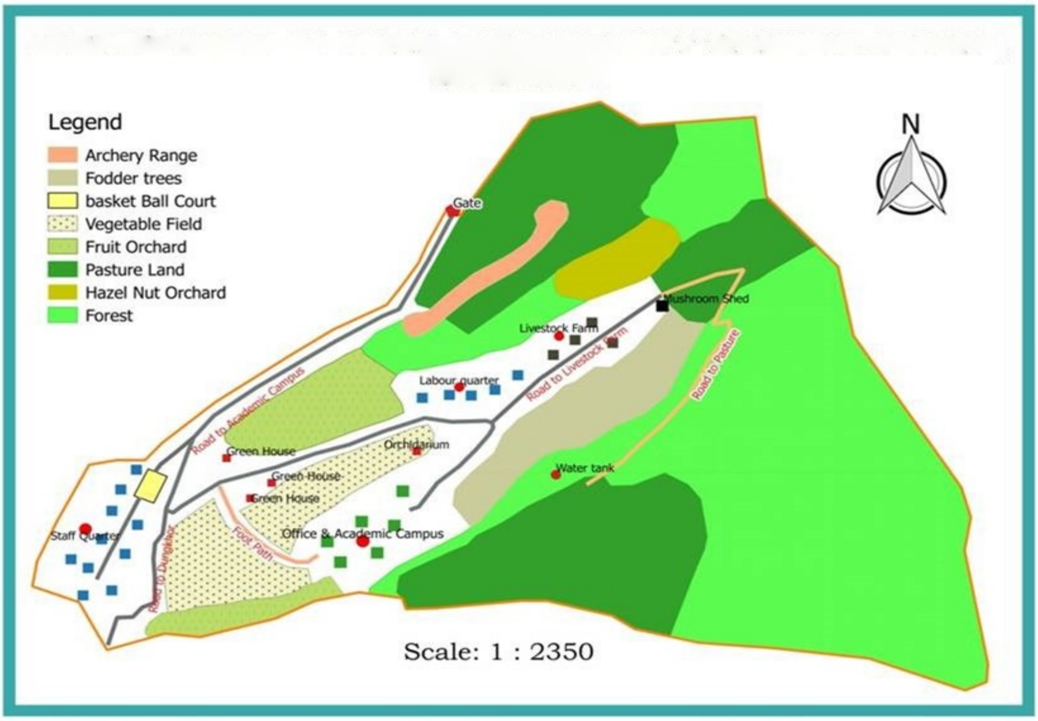

Figure 2: Map showing study area in RDTC

lected during the entire wet season from five structures in RDTC premises.

The rooftop potential for RWH was calculated using the following formula:

RWH potential = Catchment area (m^2) x Coefficient variation (CV) x Average rainfall (mm)

Water metres were installed to measure the daily rainwater runoff. Rainwater samples were also collected and quality testing was done to analyze physical and chemical parameters such as color, odor, thermo-tolerant, pH, turbidity and chlorine content using Delux water testing kit, Turbidometer AB Standard 0 -100 NTU (Nephelometric Turbidity Unit) and pH meter. The samples were collected three times from six sites for four months.

Data analysis

Data analyses were done using IBM.SPSS and PHStat2. Descriptive statistical analysis was used to elaborate the results for demographic characteristics, land holdings, water usage, supply capacity and shortage, rainfall variability and knowledge, attitude and practices on RWH. The statistical tests that were used to analyze data were pair-wise comparisons of household members with Bonferroni correction of *p*-value and chi-square test of independence. The *t*-test for differences in two means for water requirement was also conducted.

Results and Discussion

Demographic characteristics

The social study on potable water supply capacity, distribution, consumption and water shortage in Zhemgang town and RDTC comprised of 62.5% (n = 15) male and 37.5% (n = 9) female from 318 respondents. About 24% (n = 76) of the study population had no education while about 76% (n = 242) had some level of education including 26.73% (n = 85) with university degree. Table 1 shows that majority of the study population (N = 318) were employees of government and corporate agencies comprising 66.98% (n = 213) followed by agriculture and livestock farming at 12.89% (n = 41).

About 51% (n = 162) of the study population has four to six family members while less than 10% (n = 32) has more than seven members in each household. The population growth rate in Zhemgang is 1.5% indicating an annual increase of about 297 persons (Gross National Happiness Commission [GNHC], 2013). This rise in population will lead to increased water demand for domestic, agricultural and municipal needs and hence could impact particularly those areas in Zhemgang where water resources are few and population growth rates are higher.

Land holdings

The overall percentage of respondents holding land was 44.03% (n = 140) out of which 21.70% (n = 69) owned backyard kitchen garden while 7.23% (n = 23) owned both dry and wetland. Less than 2% (n = 7) of the respondents had all three types of land (kitchen garden, wetland and dry land). About 55.97% (n = 178) of the respondents do not own land as they are mainly civil servants and corporate staff working under Zhemgang district. They use water mainly for drinking, cooking and household chores. The percentage of respondents owning land, land types and acreage is given in Table 2.

The overall mean acreage of land owned by the respondents (N = 318) was 0.88 ± 1.96 *SD*. The mean acreage of land owned by the study population in Zhemgang town was 0.90 ± 2.02 *SD* (n = 294) and RDTC was 0.65 ± 1.03 *SD* (n = 24). The actual land size owned by the respondents in each category of land types for the study area is given in Table 3.

Water usage, supply capacity and shortage

The study on water usage, water supply capacity and distribution by Zhemgang Municipal Office and assessment of water shortage in the study areas indicated that the potable water is mainly required for domestic purposes.

The result shows that the overall mean water requirement for the above purposes in the study area was 523.50 ± 110.48 (mean ± *SD*) litres/day/household. The mean total water requirement in Zhemgang town was 522.88 ± 112.27 (mean ± *SD*) litres/day/household (n = 294) while it was 531.08 ± 87.14 (mean ± *SD*) litres/day/household for RDTC (n = 24). The mean daily requirement of potable water for various purposes is given in Table 4.

The mean water requirement for all purposes was higher for Zhemgang town compared to RDTC. This was because the households having more than four members were 10 times higher in Zhemgang town compared to that in RDTC. However, the independent samples t-test for differences in two means for water requirement in each purpose for the two study areas showed

Table 1: Demographic characteristics of study population

Demographic Characters		**Zhemgang town** (n=294)	**RDTC** (n=24)	**Total** (n=318)
Gender (%)	Male	60.54	58.33	60.38
	Female	39.46	41.67	39.62
Education level (%)	None	22.45	41.67	23.9
	Non-formal Education	3.06	0	2.83
	Primary Education	10.54	4.17	10.06
	Secondary Education	36.39	37.5	36.48
	Degree	27.55	16.67	26.73
Occupation (%)	Business	13.27	0	12.26
	Employed	64.29	100	66.98
	Farming	13.95	0	12.89
	Others*	8.5	0	7.86
Household members (%)	≤3	40.14	29.17	39.31
	4-6	50.34	58.33	50.94
	≥7	9.52	12.5	9.75

Table 2: Land holding, land types and acreage

Land Holding and Land Type		**Zhemgang town** (n=294)	**RDTC** (n=24)	**Overall** (n=318)
Land holding (%)	Yes	43.88	45.83	44.03
	No	56.12	54.17	55.97
Land type (%)	Dry Land	16.33	25	16.98
	Wetland	3.06	0	2.83
	Dry & Wetland	7.48	4.17	7.23
	Backyard Kitchen Garden	20.41	37.5	21.7
	All Three Types	1.36	0	1.26
	None	51.36	33.33	50
Land acreage (%)	0 acre	56.12	41.67	55.03
	0-1.0acre	24.15	20.83	23.9
	1.0-5.0 acre	14.97	37.5	16.67
	5.0-10.0 acre	4.08	0	3.77
	10.0-20.0 acre	0.68	0	0.63
	>20.0 acre	0	0	0

Table 3: Actual land size owned by the respondents

Land type	Zhemgang town (in acre)			RDTC (in acre)			Overall (in acre)		
	Total	Mean	SD	Total	Mean	SD	Total	Mean	SD
BDW	30 (n=4)	7.5	5.21				30 (n=3)	7.5	5.21
BKG	25.5 (n=60)	0.43	0.65	3.5 (n=9)	0.39	0.33	29 (n=50)	0.42	0.62
D&WL	93.5 (n=22)	4.25	3.25	3 (n=1)			96.5 (n=20)	4.2	3.18
DL	103.96 (n=48)	2.17	2.11	9 (n=6)	1.5	1.38	112.96 (n=36)	2.09	2.04
WL	12.5 (n=9)	1.39	1.54				12.5 (n=6)	1.39	1.54

BDW = Backyard kitchen garden, Dry land, and Wetland; SD=Standard Deviation; BKG = Backyard kitchen garden; D&WL = Dry and wetland; DL = Dry land; WL = Wetland

Table 4: Independent samples *t*-test for water requirements for different purposes in two study areas

t-tests	Drinking & cooking	Dish washing	Flushing toilet	Gardening	Laundry	Bathing
Zhemgang town (group statistics)						
N	292	288	280	241	289	287
M	62.81	49.27	199.61	103.58	88.13	51.83
SD	17.62	17.5	17.92	21.55	20.72	18.11
RDTC (group statistics)						
N	24	23	24	23	24	24
M	62.5	48.48	197.08	96.57	82.92	49.58
SD	18.71	20.14	15.87	16.92	17.32	17.69
Independent Samples t-test						
t-test Statistic	0.08	0.21	0.67	1.52	1.2	0.59
p	0.93	0.84	0.5	0.13	0.23	0.56
df	314	312	311	293	313	313

no significant difference ($p > .05$) as shown in Table 4.

As per the records available in Zhemgang Municipal Office, the annual consumption of water was 79,091.00 m^3, which works out to a consumption rate of 79.31 litres/ day/ person. The daily availability of potable water that can be supplied by the Municipal Office to the residents was 469.02 (mean ± *SD*) litres/day/ household (District Municipal Office, 2019). The average overall requirement of potable water as per the study was 523.50 ± 110.48 (mean ± *SD*) and hence there is an expected shortage of about 54.48 ± 110.48 (mean ± *SD*) litres/day/ household which is especially so during the winter and rainy seasons.

Overall, 239 respondents (75.16%) identified the presence of water shortage in the study areas. In Zhemgang town area, 224 participants (76.19%) agreed that there is water shortage while 15 participants (62.50%) in RDTC did so. This difference was because the water sources for Zhemgang town and RDTC were completely different and the distance of the water source also varied. The overall mean distance of water source for the study areas was 8.96 km. The difference in the mean distance of water source between Zhemgang town and RDTC was 2.62 km. Because of different source, greater distance and more households to be covered in Zhemgang town, there is intermittent disruption including controlled water supply by the municipal. However, in RDTC, the supply is continuous; disruption happens only during breakage in water supply lines during monsoon due to landslides and drying up of source during winter. The disruption occurs for about 38 days in summer and, 10 days in winter (District Municipal Office, 2019).

The CI (Confidence Interval) at 95% was calculated for the water shortage in the study area. The CI for overall water shortage in the study area was 0.70, 0.79. The CI for Zhemgang town was 0.71, 0.81 and similarly for RDTC was 0.43, 0.82. About 42.81% (n = 136) respondents identified water shortage during winter season and 27.70% (n = 88) respondents agreed there is water shortage during summer season (n = 278). This was mainly attributed to drying up of water sources during winter season and destruction of waterlines due to rainwater flooding in summer season (Dorji, 2016). Besides the disruption of pipelines in summer and drying up of sources in winter, the water shortage was also attributed to coping mechanisms implemented by the municipal authority wherein the water supply is usually controlled and timed, improper alignment and damages to water lines during implementation of development activities.

The result showed that there is a significant relationship between water shortage and household members ($p < .05$ at 95% CI) (Table 5). To investigate further, pair-wise comparisons of household members with Bonferroni correction of p-value was done and chi-square test of independence carried out. Since there were three possible combinations, the Bonferroni adjusted p-value for significance was 0.05/3 = .02 (Table 6). The result indicated that the water shortage problem was significantly more in households having more family members. This was because the households having more than four members were 10 times higher in Zhemgang town compared to RDTC ($p < .02$).

Table 5: Comparison of baseline characteristics by water shortage recognition

Characteristics	**Overall sample**	**No water shortage identified**	**Water shortage identified**	**Chi-square tests (*df*)**
Gender - n (%)				
Male	192 (60.4)	46	146	$\chi^2_{(1)} = 0.20$
Female	126 (39.6)	33	93	$p = .65$
Occupation – n (%)				
Employed	213 (67.0)	54	159	$\chi^2_{(3)} = 1.57$
Business	39 (12.2)	9	30	$p = .67$
Farming	41 (12.9)	12	29	
Others	25 (7.9)	4	21	
H/H size – n (%)				
≤ 3	125 (39.3)	29	96	$\chi^2_{(2)} = 7.63$
4-6	162 (50.9)	36	126	$p = .02$
≥ 7	31 (9.8)	14	17	
Education level – n (%)				
None	76 (23.9)	22	54	$\chi^2_{(4)} = 9.42$
NFE	9 (2.8)	3	6	$p = .05$
Primary	32 (10.1)	8	24	
Secondary	116 (36.5)	18	98	
Degree	85 (26.7)	28	57	
Land availability – n (%)				
Yes	140 (44.0)	40	100	$\chi^2_{(1)} = 1.86$
No	178 (56.0)	39	139	$p = .17$

Water shortage coping mechanism

To solve the water shortage problems, 62.58% (*n* = 199) of the respondents store water and use during water scarce period followed by 14.78% (*n* = 47) managing from neighbors, 11.95% (*n* = 38) through 'other' means like fetching from nearby source and buying. Only 4.40% (*n* = 14) of the respondents use rainwater harvesting as an alternative means of water source (Table 7, 8 and 9).

Rainfall pattern

The rainfall statistics for the 20-years were also analyzed to provide the basis for assessing the RWH potential in the study area. The mean annual rainfall for the last 20 years (1998 to 2017) was 1,412.50 mm ± 208.90 *SD* (Figure 3).

The lowest annual rainfall recorded during the 20 years (1998-2017) was 757.40 mm in the year 2010 and the highest annual rainfall recorded was 1,805.80 mm in 1998. Generally, there is a decreasing trend in the rainfall depths over the last 20-years, indicating a possible reduced rainfall and the need for increasing resilience in the water supply system.

Similarly, the monthly mean rainfall recorded for 20-year period (1998-2017) was 117.71 mm ± 113.02 *SD*. The variation in rainfall between months was significant, with CV (Coefficient Variation) of 96.00% while the variation in total rainfall between years was modest with CV of 14.79%, reflecting a rather stable rainfall pattern. The 20-year (1998-2017) mean monthly rainfall with standard deviation is illustrated in Figure 4.

Table 6: Pair-wise comparison of household members for relationship

Household members (%)		Water shortage (%)	Comparison	χ^2 tests (*df*)	*p*
≤ 3	39.30% (125)	39.31% (49)	≤ 3 Vs 4-6	0.04 (1)	.84
4-6	50.94% (162)	50.94% (83)	≤ 3 Vs ≥ 7	6.00 (1)	.01*
≥ 7	9.75% (31)	9.75% (3)	4-6 Vs ≥ 7	7.13 (1)	.008*

* shows p value < 0.01, N (sample) = 318

Table 7: Water shortage coping mechanism in the study areas

Coping mechanism	Zhemgang town (%)	RDTC (%)	Overall (%)
Storing	182 (61.90%)	17 (70.83%)	199 (62.58%)
Managing from others	46 (15.65%)	1 (4.17%)	47 (14.78%)
RWH	13 (4.42%)	1 (4.17%)	14 (4.40%)
Others	34 (11.56%)	4 (16.67%)	38 (11.95%)
No solution	19 (6.46%)	1 (4.17%)	20 (6.29%)

If only the four wet season months (June to September) are considered, the mean rainfall during the wet season for 20 years (1998-2017) was 255.48 mm ± 59.09 *SD* with monthly variation of CVs ranging between 29.02% and 41.09%. The driest season with least rainfall was December with a mean rainfall of 4.33 mm ± 7.22 *SD* followed by November with 5.98 mm ± 9.37 *SD*.

Rainfall distribution

A three-year monthly rainfall data of 10 years interval i.e., 1997, 2007 and 2017 were plotted against their respective months to show the bimodal nature of rainfall distribution in the study area (Figure 6). In 1997, the mean monthly rainfall was 113.42 mm ± 116.96 *SD* with a maximum rainfall of 379.20 mm in July

Table 8: Perception of respondents to participate in rain water harvesting

Sites	Willingness to participate in rain water harvesting (%)		
	Yes	**No**	**Not sure**
Zhemgang town	64.63	7.82	27.55
RDTC, Zhemgang	62.5	8.33	29.17

Table 9: Perception of respondents to use rain water harvesting

Sites	Willingness to use rain water harvesting (%)			
	Very important	**Important**	**Not at all important**	**Not important**
Zhemgang town	45.92	31.29	17.01	5.78
RDTC, Zhemgang	54.17	29.17	8.33	8.33

and no rainfall in November and December months. Similarly, the mean monthly rainfall in 2017 was 113.23 mm ± 128.54 *SD* with maximum recorded rainfall of 354.80 mm in August and no rainfall in November and December months. For 2007, the mean monthly rainfall recorded was 124.64 mm ± 133.35 *SD* with maximum recorded rainfall of 427.60 mm in July and no recorded rainfall in December.

Rainfall variability

Standard Deviation (SD) and mean (M) were used to calculate both the intra and interannual rainfall variability of the past 20 years. The intra annual variability ranges between 0.95 and 0.97, while interannual variability was 0.15. These show that there was high variability in the rainfall distributions which is similar to the findings of Aladenola and Adeboye (2010). With the climate change, the high seasonal variations and changes in future rainfall patterns and distribution are expected and RWH can help to reduce the burden of water supply in the vulnerable areas

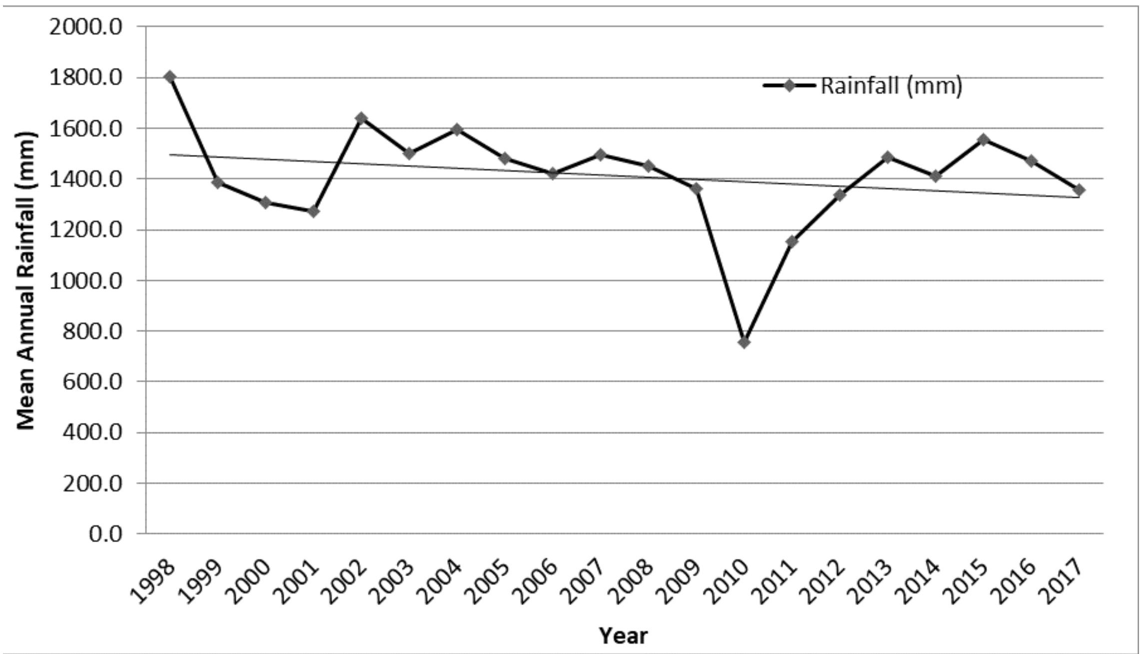

Figure 3: Annual rainfall depth (mm) decreasing trend for twenty years from 1998 till 2017

(Intergovernmental Panel for Climate Change [IPCC], 2007).

The low variability in rainfall which ranges from 0.29 and 0.41 during the wet seasons from June to September between different years agrees to the findings of Engida (1999). This suggests a reliable condition for RWH and a guarantee for the return of investment. The steady rainfall patterns in the rainy seasons allow for an efficient alternative for freshwater sources, which may be stored using even a small storage tank.

Knowledge, attitude and practices on RWH

The result showed that only 4.40% (14 households out of 318 respondents) had previously practiced RWH through some basic harvesting techniques as a means to meet water scarcity

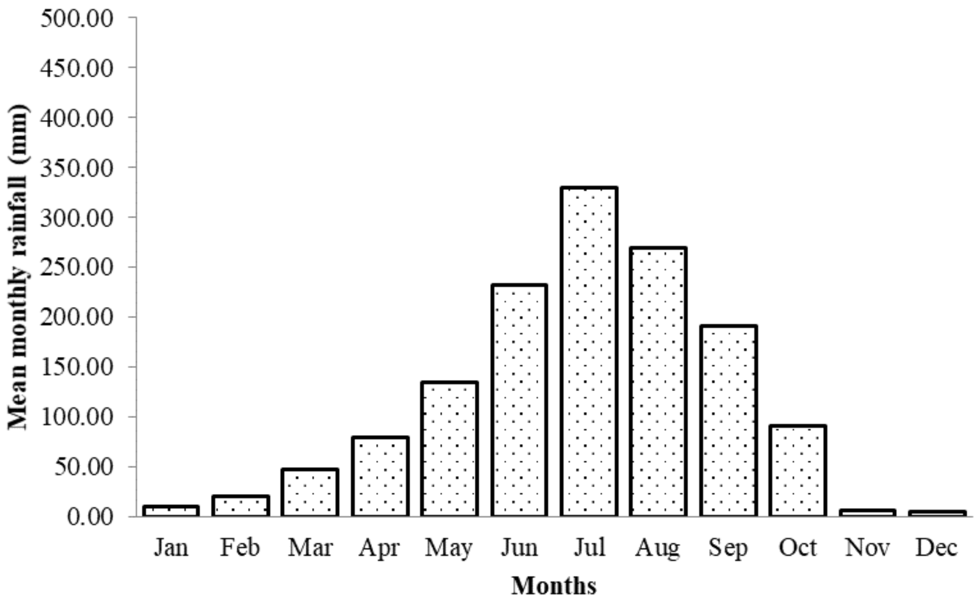

Figure 4: Monthly rainfall depth (mm) for twenty years from 1997 till 2017

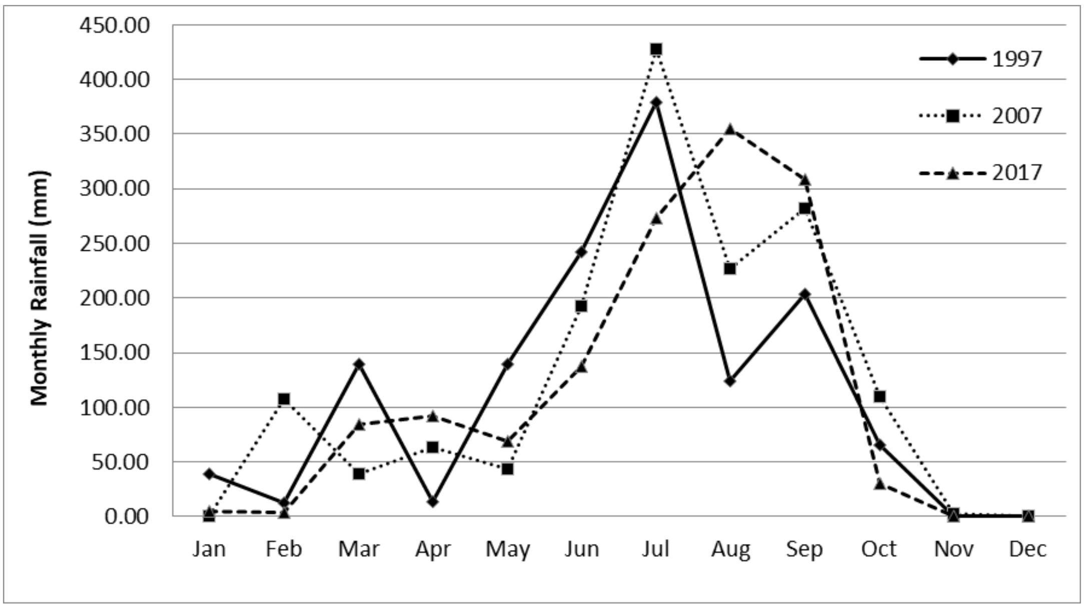

Figure 5: Rainfall distributions in Zhemgang town during 1997, 2007 and 2017

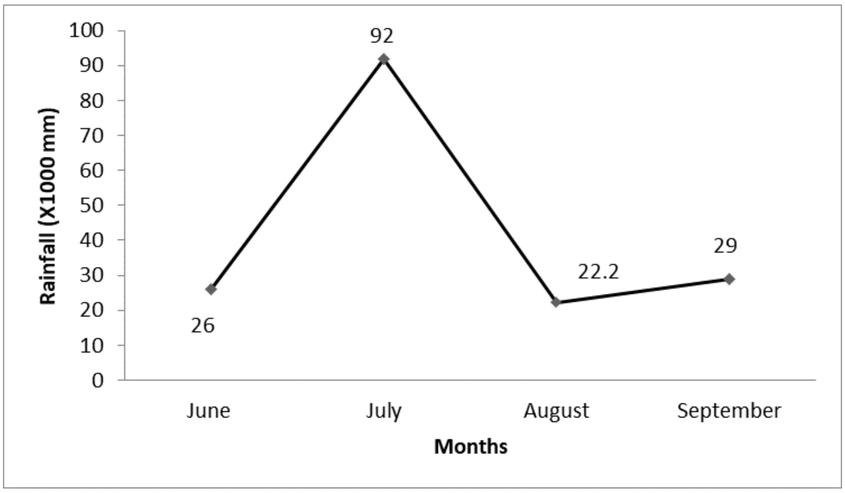

Figure 6: Average rainwater runoff collected from average rooftop catchment area of 456.14 m^2 (in 1,000 L)

in Zhemgang town. About 46.54% of the respondents (148 out of 318) had limited knowledge about RWH and 29.25% (93 respondents) had used rainwater collected directly to flush toilets, kitchen gardening and washing clothes. About 47% (n = 149) of the respondents perceived RWH as very important means to supplement potable water supply while about 6% (n = 19) said it is not important. About 16% (n = 51) of the respondents were neutral.

About 64% of the respondents (205 respondents) indicated interest in adopting RWH in future while about 28% (n = 89) of respondents were still unsure about RWH. The lack of knowledge and idea (12.58% [n = 40]), fund support (8.18% [n = 26]) and proper sanitation measures (1.57% [n = 5]) were mainly attributed for the mediocre interests on RWH at present. The study revealed that 59.75% (n = 190) of the respondents prefer rooftop RWH followed by open space collection (8.18% [n = 26]), drain collection (5.35% [n = 17]) and through terracing (1.89% [n = 6]).

A simple ranking test showed that RWH can be of importance in flushing toilets (82.70% [n = 263]) followed by dishwashing (77.67% [n = 247]), kitchen gardening (77.36% [n = 246]), laundry (77.04% [n = 245]), bathing (59.75% [n = 190]) and drinking purpose (49.37% [n = 157]). However, the key challenges foreseen by the respondents concerning RWH were its limited usage during wet seasons, lack of technical knowledge, dependency on rainfall conditions and its economic feasibility.

Potential contribution of RWH from RDTC, Zhemgang

The RWH potential from all existing structures in RDTC premises was calculated using the formula given in the study design. The total catchment area for all the structures was 6,128 m^2 and CV was fixed at 0.9 as per the literature review for CGI rooftops. The average annual rainfall for the study area was 1,412.50 mm. Thus, the total RWH potential for RDTC was 7,790,220.00 m^3, which is about 7790.22 x 10^6 litres.

In the five study sites which were used to measure rainfall-runoff, the total catchment area was 456.14 m^2 and its potential for RWH is 579,867.98 m^3 (579.87 x 10^6 litres). The RWH potential from the five study sites is illustrated in Table 10.

Zhemgang Municipal Office supplies about 79,091 m^3 (79.09 x 10^6 litres) of potable water to the residents of Zhemgang town. Though the annual requirement of water for the study area is 88,277.81 m^3 (88.28 x 10^6 litres), it is deficit by about 9,186.81 m^3. Thus, there is a water shortage of about 54.48 litres/day/household which requires some kind of intervention to meet the deficit.

The RWH from RDTC indicated that there is potential to meet water supply capacity in Zhemgang town by an excess of 99.0% and can also meet the water requirement of 89.56 x 10^6 litres for RDTC. If all the public institutions in Zhemgang were to be involved in rooftop RWH, the potential would be 10 times larger since rooftops in this study make up approximately 10% of the total structures currently available in the town.

The study conducted in Addis Ababa, Ethiopia found that the rooftop RWH from large public institutions can replace water supply by a minimum of 0.9% in January to a maximum of 649% in July, indicating that the excess rainwater can be stored for later uses (Adugna *et al.*, 2018). This implies that if each of the large public institution is involved in rooftop RWH, it could supplement the potable water supply to a great extent (Adugna *et al.*, 2018).

The existing water supply sources are vulnerable to extended dry months and climate change as is being observed from the decreasing rainfall patterns over the last twenty years in the country. Thus, the rooftop RWH could contribute to minimizing the shortage of water supply in Zhemgang town too. Consistent with this, similar study indicates that RWH could minimize the vulnerability of the water supply in urban areas (Kucezera, 2007).

Runoff collection of rainfall in experimental sites in RDTC

The determination of rainwater runoff collection from five experimental sites in RDTC showed an overall collection of 633,000 L of rainwater during the wet season (June-September) from an average rooftop catchment area of 456.14 m^2. The average monthly rainwater collected from the five experimental sites (in 1,000 L) is illustrated in Figure 6.

Rainwater quality

The rainwater samples collected were analyzed for physical parameters such as color, odor, thermo-tolerant, pH, turbidity and chlorine content as a part of verification and monitoring (National Environment Commission [NEC], 2016). The average result of rainwater quality test is illustrated in Table 11. The rainwater runoff collected and analyzed for water quality showed normal values for all physical parameters from all sites except from dining hall roof-

Table 10: RWH potential for RDTC and experimental sites

Locations	**Catchment area** (m^2)	**Potential for RWH** (m^3)	**Potential for RWH** (L)
MPH	55.25	70,236.56	70,236,562.50
Dormitory	83.44	106,073.10	106,073,100.00
Class	112.45	142,952.06	142,952,062.50
Dung shed	100.00	127,125.00	127,125,000.00
Resident	105.00	133,481.25	133,481,250.00
Total	*456.14*	*579,867.98*	*579,867,975.00*
Entire RDTC	6,128.00	7,790,220.00	7,790,220,000.00

CV = 0.9; Average Annual Rainfall (mm) = 1,412.50

Table 11: Rainwater quality test results for the study areas

Sites	**Thermo-tolerant bacteria** (10-20)	**pH** (6.5-8.5)	**Turbidity** (<5.0)	**Chlorine** (*Zero*)	**Odor & Color** (*Acceptable*)
Dining hall roof	2.0	6.0	10.0	0.0	Acceptable
Dung shed	0.0	6.8	0.61	0.0	Acceptable
Class roof	0.0	6.9	1.8	0.0	Acceptable
Hostel roof	3.0	6.9	0.42	0.0	Acceptable
Residential	0.0	7.0	1.46	0.0	Acceptable
Tap water	1.0	7.0	0.22	0.0	Acceptable

top which was slightly acidic (pH 6.0) and turbid (> 5.0).

Conclusions

The aims of this study were to determine the potential of rainwater to supplement the existing water supply for domestic use in RDTC, Zhemgang, analyze the quality of rainwater, and to assess the perception of the communities on RWH and their willingness to participate in RWH. The findings of this study revealed that the physical parameters of rainwater harvested from the study area were within the standard set for potable use. Therefore, RWHs could be implemented in the region to supplement the water for potable use to minimize the water shortage in wet season as the RWHs were used informally by the residents in the past to supplement potable water. Only a small portion (4.40% [n = 14]) of the study population practices RWH while the majority (53.46% [n = 170]) of the respondents still lack knowledge on RWH system. As such, thorough awareness and education programmes and proper harnessing of rainwater during the rainy seasons, rainwater usage can promote significant potable water savings in RDTC and Zhemgang town, which have been facing water shortages.

Acknowledgement

The authors would like to extend appreciation to the Regional Director, RLDC for assisting us in in conducting the research. We are grateful to Dasho Dzongdag, Zhemgang for approving us to do the research and supporting to get information from District Municipal Office. Thanks to the Director, RDTC, for allowing the authors to conduct the study at office premises and for equipment support. Our heartfelt gratitude goes to the NORHED project for providing fund for the study through the College of Natural Resources.

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