



Research Paper

Assessment of water shortage in Zhemgang town and potential for rooftop rainwater harvesting in RDTC, Zhemgang

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ABSTRACT

Rainwater harvesting is one of the promising alternatives to supplement the surface water resources in areas where existing water supply is inadequate to meet the demand. The residents of Zhemgang town currently face shortage of potable water, but so far the potential of Rainwater Harvesting (RWH) to supplement the existing water supply system has not been assessed. This study was conducted to assess the water shortage problem in Zhemgang town and potential for Rainwater Harvesting (RWH) in the Rural Development Training Centre (RDTC). A total of 318 households were interviewed to assess the water shortage problems and knowledge, attitude and practices on RWH. Data were collected once in 24 h every rainfall during the entire rainy season from five rooftop structures in RDTC premises to determine the potential for RWH and its usage. The study showed that the Zhemgang Municipal Office supplies 469.02 L of water per day per household resulting in residents facing potable drinking water deficit of about 54.48 liter/day/household as the average requirement is 523.50 ± 110.48 L/day/household. Zhemgang town receives a mean annual rainfall of 1412.50 ± 208.90 mm with an intra-annual variability range of 0.95 and 0.97 mm and inter annual variability of 0.15 mm. The low variability in rainfall, which ranges between 0.29 mm and 0.41 mm during the wet seasons, suggests a reliable condition for RWH and a guarantee for 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 showed an overall collection of 633,000 L of rainwater during the wet season (June-September 2019) from rooftop catchment area of 91 m². The study thus identifies a huge potential for RWH as an alternative means to supplement the water supply scheme. The quality of RWH from CGI roofing after first flush is fit for drinking as all physical parameters were within permissible limit.

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Key words: Water quality, water shortage, rooftop rainwater harvesting, 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 social and economic development of all countries (Aladenola and Adeboye, 2010; Che-Ani, 2009). However, available water

supply sources are diminishing due 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 next several decades, two-thirds of the world's

population may face water shortage (Rijsberman, 2006).

This situation calls for alternative water supply sources and Rainwater Harvesting (RWH) has been increasingly used as an alternative source of water, 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 potable demand, as well as for reducing storm water runoff (Park and Um, 2018). The study on rain water harvesting system for communities in developing countries by Charles(2007) presents rainwater harvesting 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. With rooftop harvesting, most of the roof surfaces can be used to intercept the flow of rainwater and provide a household with drinking water as well as for other uses like water for gardening, livestock, agriculture and other purposes. Because rainwater is usually free from physical and chemical contaminants such as pesticides, Lead and Arsenic, color and suspended materials, it is low in salt and hardness (Sendanayake, 2016).

Zhemgang District has eight Gewogs (Block) and the seat of district administration falls under Zhemgang municipality. The town has a capacity to distribute 507.0m³ water during peak season with an average consumption of 176.3 liters/day/person. While during lean season, 253.3 m³ of water is available with an average consumption of 88.2 L/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 1412.50 mm±208.90 with a mean monthly rainfall of 117.71±113.02 mm (NCHM, 2019). The mean average monthly rainfall during the rainy season in Zhemgang town is 255.48±59.09 mm (NCHM, 2019). Thus rain water harvesting can be one of the measures to supplement the existing water supply to decrease the pressure on stream source in Zhemgang town. In this regard, the study was carried out with an objective to assess water shortage problem in Zhemgang town and the potentiality of RWH as an alternative to supplement the use in other areas excluding the usage for drinking purpose.

MATERIALS AND METHODS

Study site

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 (National Centre for Hydrology and Meteorology [NCHM], 2019). Zhemgang town covers a total area of 274.54 acres, which is approximately 1.66 sq.km (NCHM, 2019). The town includes RDTC, two schools, different regional offices, monastic bodies, Dzongkhag administration office complex and town area shopping complex (Figure 1) The town has 462 households, 246 building structure and a population of 2,732 people (District Municipal Office, 2019). The water is supplied from a source located 2.5 km above Zhemgang town and is stored in the reservoirs. Of the three water reservoirs, one with a capacity of 253.0 m³ is for home use while the other two with the capacity of 60.0 m³ each are meant for fire hydrants (District Municipal Office, 2019).

The Rural Development Training Centre (27°12'59.49"N, 90°39'45.35"E) in Trong Gewog 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 and store and food processing units (Figure 2).

Study design and data collection approach

The study was conducted from May to November 2019. The study to assess the potential for RWH in RDTC, Zhemgang was conducted during 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, 318 households in Zhemgang town and RDTC were interviewed using pretested semi-structured questionnaires. The households were selected through convenient sampling to obtain basic data and trends of the study population by including maximum numbers of households based on their availability.

The data on distribution capacity for drinking water by the District Municipal Office in Zhemgang was collected in order to assess the water consumption rate, supplying capacity, seasonal shortage and potential for RWH in Zhemgang town.

The rainfall data for 20 years from 1997 to 2017 were collected from the National Centre for Hydro Meteorology (NCHM) under the Ministry of Economic Affairs. It was then analyzed in order to determine the potential of rainwater,

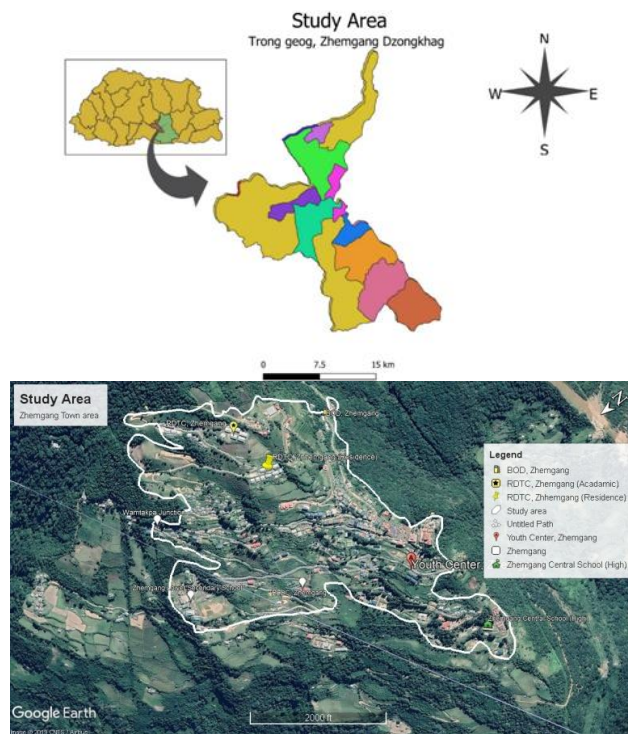


Figure 1: Map showing study area in Zhemgang town.

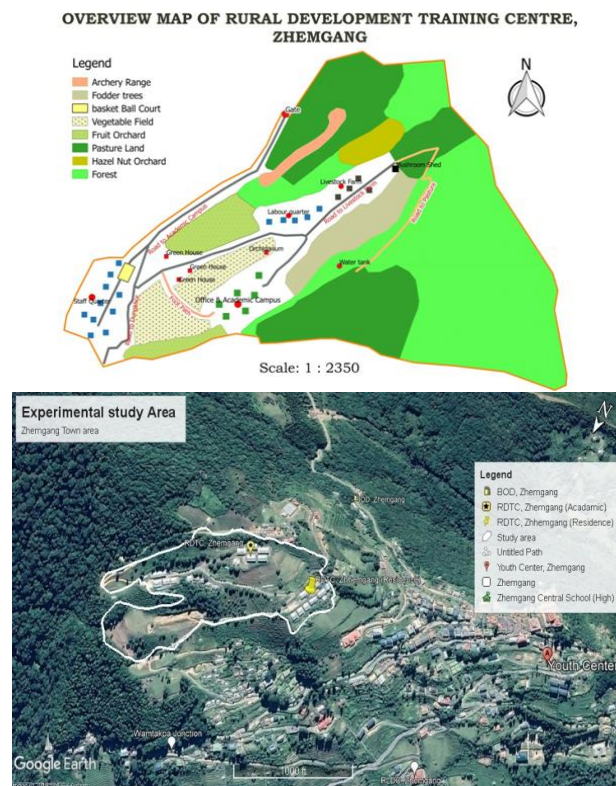


Figure 2: Map showing study area in RDTC.

rainfall pattern, average monthly and annual rainfall to correlate with the potential for RWH in Zhemgang town.

Runoff collection from rainfall can be classified into two broad categories (a) land-based and (b) roof-based. The emphasis of this study was on roof-based rainwater harvesting potential at RDTC. The amount of rainwater harvested was based on 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 collected during the entire wet season from five structures in RDTC premises. The five rooftops (CGI roofing) were measured manually with the help of a water technician in RDTC (Figure 3).

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

$$\text{RWH Potential} = \text{Catchment area (m}^2\text{)} \times \text{Coefficient Variation (CV)} \times \text{Average Annual Rainfall (mm)}$$

Five water meters were installed at the end of the water gutter outlets along with gutter pipes to measure the daily rainwater runoff during the rainfall period. Rain water samples were also collected and quality testing was done to analyze physical parameters such as color, odor, thermo-tolerant, pH, turbidity and chlorine content using Delux water testing kit, Turbidimeter AB Standard 0-100 NTU and pH meter. The samples were collected three times from six sites over the period of four months of wet season. The quality testing of the rainwater was done by a technician working in the Basic Health Unit, Zhemgang.

Data analysis

Data analysis was done using Statistical Package for the Social Sciences (SPSS) version 23 and PHStat2 software. 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 significance testing using *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 60.38% male and 39.62% female respondents (*n*=318). About 24% of the study population had no education while about 76% had some level of education including university degree with 26.73%. Table 1 shows that majority of the study population (*n*=318) were employees of government and corporate agencies comprising 66.98% followed by agriculture and livestock farming at 12.89%.

About 51% of the study population has 4-6 family members while less than 10% 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 (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% out of which 21.70% owned backyard kitchen garden, while 7.23% both dry and wet land. Less than 2% of the respondents had all three types of land (kitchen garden, wetland and dry land). About 55.97% of the respondents do not own land as they are mainly civil servants and corporate staff working under Zhemgang district. They require use water mainly for drinking, cooking and household chores. The percentage of respondents owning land, land types and acreage is shown in Table 2.

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

Water usage, water supply capacity and water 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 drinking, cooking, bathing, flushing toilets, laundry, dish washing and kitchen gardening.

The data on average daily water requirement per household for drinking and cooking, dish washing, flushing toilets, gardening, laundry and bathing were collected and analyzed. The result showed that the overall mean water requirement for the above purposes in the study area was 523.50±110.48 L/day/household. The mean total water

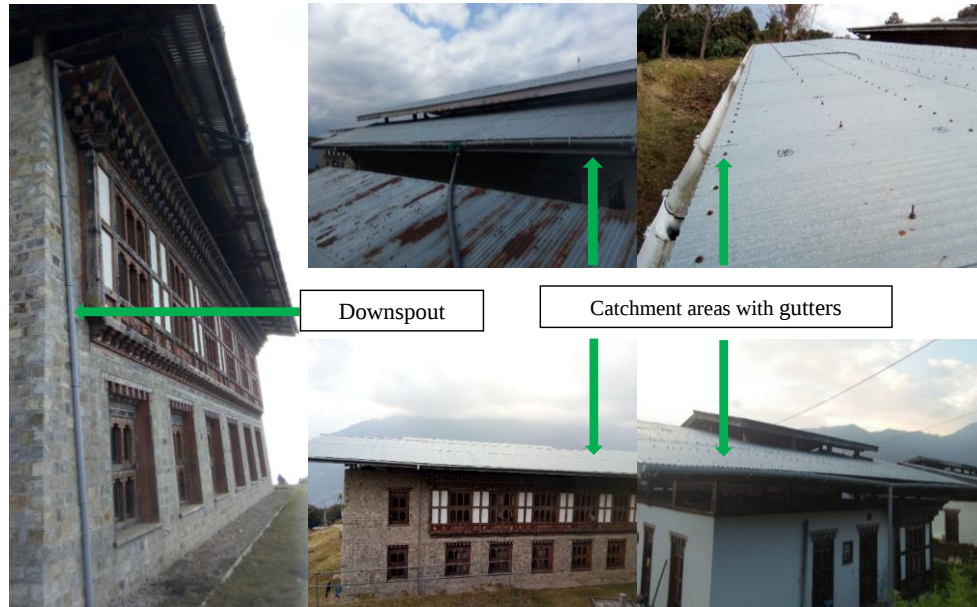


Figure 3: Rooftop structures in RDTC for experimental RWH.

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	23.90
	Non-Formal Education	3.06	0.00	2.83
	Primary Education	10.54	4.17	10.06
	Secondary Education	36.39	37.50	36.48
	Degree	27.55	16.67	26.73
Occupation (%)	Business	13.27	0.00	12.26
	Employed	64.29	100.00	66.98
	Farming	13.95	0.00	12.89
	Others*	8.50	0.00	7.86
Household members (%)	≤3	40.14	29.17	39.31
	4-6	50.34	58.33	50.94
	≥7	9.52	12.50	9.75

*Others comprise house wives, ex-civil servants and religious persons.

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	25.00	16.98

Table 1: cont

	Wet Land	3.06	0.00	2.83
	Dry & Wet Land	7.48	4.17	7.23
	Backyard Kitchen Garden	20.41	37.50	21.70
	All Three Types	1.36	0.00	1.26
	None	51.36	33.33	50.00
Land acreage (%)	0 acre	56.12	41.67	55.03
	0-1.0acre	24.15	20.83	23.90
	1.0-5.0 acre	14.97	37.50	16.67
	5.0-10.0 acre	4.08	0.00	3.77
	10.0-20.0 acre	0.68	0.00	0.63
	>20.0 acre	0.00	0.00	0.00

Table 3: Actual land size owned by the respondents.

Land type	Zhemgang town (In acre)			RDTC (In acre)			Overall (In acre)		
	Acreage	Mean	SD	Acreage	Mean	SD	Acreage	Mean	SD
All	30.00	7.50	5.21				30.00	7.50	5.21
BKG	25.50	0.43	0.65	3.50	0.39	0.33	29.00	0.42	0.62
D&WL	93.50	4.25	3.25	3.00			96.50	4.20	3.18
DL	103.96	2.17	2.11	9.00	1.50	1.38	112.96	2.09	2.04
WL	12.50	1.39	1.54				12.50	1.39	1.54

All = Backyard kitchen garden, Dry land and Wet land.

BKG = Backyard kitchen garden, D&WL = Dry and wet land; DL = Dry land; WL = Wet land.

requirement in Zhemgang town was 522.88 ± 112.27 L/day/household ($n=294$), while it was 531.08 ± 87.14 L/day/household for RDTC ($n=24$). The mean daily requirement of potable water for various purposes described is shown in Table 4.

The *t*-test for differences in two means of total water requirements was compared for Zhemgang town and RDTC. The result showed no statistical difference ($p=0.73$ which is >0.05 at 95% confidence level), indicating that the water requirements is same for the two areas irrespective of sample sizes.

The mean water requirement for all purposes was higher for Zhemgang town as compared with RDTC. This was because the households having more than four members were 10 times higher in Zhemgang town compared to RDTC. However, the significance testing using *t*-test for differences in two means for water requirement in each purpose for the two study areas showed no statistical significance ($p>0.05$), as shown in Table 5.

As per the records available in Zhemgang Municipal Office, the annual consumption of water was 79,091.00 m³, which works out to a consumption rate of 79.31 L/day/person. The daily availability of potable water that can be supplied by the Municipal Office to the residents was 469.02 L/day/household (District Municipal Office, 2019). The average overall requirement of potable water as per the study was 523.50 ± 110.48 and hence there is an expected shortage of about 54.48 ± 110.48 L/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 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. The difference in the mean distance of water source

Table 4: Mean daily water requirements (in liters/day/household) for different purposes in the study areas.

Purpose of Water Usage	Mean daily water requirement (l/day/hh)		
	Zhemgang Town	RDTC	Overall
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Drinking & Cooking ($n=316$)	62.81 $\pm$ 17.62	62.50 $\pm$ 18.71	62.78 $\pm$ 17.67
Dish Washing ($n=311$)	49.27 $\pm$ 17.50	48.48 $\pm$ 20.14	49.21 $\pm$ 17.67
Flushing toilets ($n=304$)	199.61 $\pm$ 17.92	197.08 $\pm$ 15.87	199.41 $\pm$ 17.75
Gardening ($n=264$)	103.58 $\pm$ 21.55	96.57 $\pm$ 16.92	102.97 $\pm$ 21.25
Laundry ($n=313$)	88.13 $\pm$ 20.72	82.92 $\pm$ 17.32	87.73 $\pm$ 20.50
Bathing ($n=311$)	51.83 $\pm$ 18.11	49.58 $\pm$ 17.69	51.66 $\pm$ 18.06

Table 5: t-Test for mean water requirements for different purposes in two study areas.

t-Test for differences in two means	Drinking and cooking	Dish washing	Flushing toilet	Gardening	Laundry	Bathing
Hypothesized difference	0	0	0	0	0	0
Level of significance	0.05	0.05	0.05	0.05	0.05	0.05
Population Sample 1 (Zhemgang Town)						
Sample size (n)	292	288	280	241	289	287
Sample mean	62.81	49.27	199.61	103.58	88.13	51.83
Sample standard deviation	17.62	17.5	17.92	21.55	20.72	18.11
Population Sample 2 (RDTC)						
Sample size (n)	24	23	24	23	24	24
Sample mean	62.5	48.48	197.08	96.57	82.92	49.58
Sample standard deviation	18.71	20.14	15.87	16.92	17.32	17.69
t-Test statistic	0.08	0.21	0.67	1.52	1.20	0.59
p-value	0.93	0.84	0.50	0.13	0.23	0.56

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. Thus, the disruption occurs about 38 days in summer 10 days in winter (District Municipal Office, 2019).

The CI (Confidence Interval) at 95% confidence level 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 with 0.43, 0.82. About 42.81% respondents identified water shortage during winter season and 27.70% 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.

Besides, the water shortage was also attributed to coping mechanisms implemented by the municipal authority wherein the water supply is usually controlled and timed, biased channeling and damages to water lines during implementation of development activities. This study however, is limited due to lack of data on water shortage in terms of number of shortage days in a year/season, shortage severity and concrete evidences for causes of shortage.

Chi-square tests for independence (Table 6) were used to compare baseline characteristics such as gender, occupation, household size, education level and land availability to water shortage recognition by the respondents and the result is shown in Table 6.

The result of the present study showed a significant relationship between water shortage and household members ($p < 0.05$ at 95% confidence level). 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

Table 6: 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= 0.65
Occupation - n (%)				
Employed	213 (67.0)	54	159	$\chi^2(3) = 1.57$
Business	39 (12.2)	9	30	p= 0.67
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= 0.02
≥ 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= 0.05
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= 0.17

possible combinations, the Bonferroni adjusted *p*-value for significance was $0.05/3 = 0.02$ (Table 7). The result indicated that the water shortage problem was significantly more in households having more family members ($p < 0.02$).

Water shortage coping mechanism

To solve the water shortage problems, 62.58% of the respondents store water and use during the scarcity, followed by 14.78% managing from neighbors, 11.95% through 'other' means such as fetching from nearby source in private vehicles, repairing source and buying. Only 4.40% of the respondents use rainwater harvesting as an alternative means to source of water (Table 8).

Rainfall variability

Rainfall pattern

Rainfall data were collected from the NCHM for the period

1998 to 2017 and were analyzed in order to determine rainfall pattern, average monthly and annual rainfall, wet and dry months under investigation. The rainfall statistics for the 20-year were also analyzed to provide basis for assessing the RWH potential in the study area. The mean annual rainfall recorded by NCHM for the last 20 years (1998 to 2017) was 1412.50 ± 208.90 mm (Figure 4).

The lowest annual rainfall recorded during the 20-year period (1998-2017) was 757.40 mm in the year 2010 and the highest annual rainfall recorded was 1805.80 mm in the year 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 ± 113.02 mm. The variation in rainfall between months is significant, with CV 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 shown in Figure 5.

If considering only the four wet season months (June to

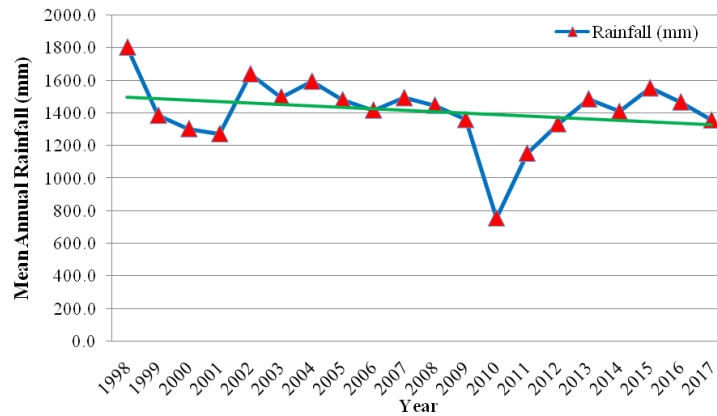
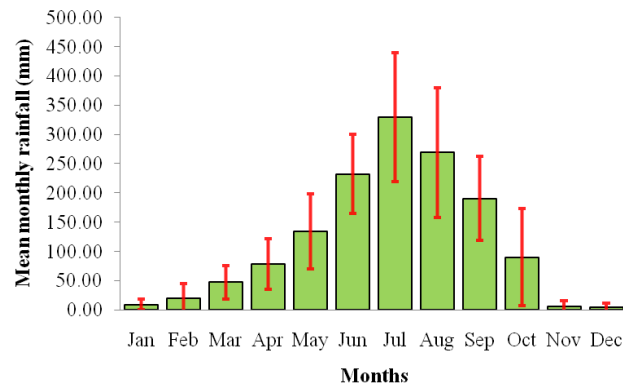
Table 7: Pair-wise comparison of household members for relationship.

Comparisons	Chi-square Tests $\chi^2(df)$	pValue	N
≤ 3 Vs 4-6 members	0.04 (1)	0.84	287
≤ 3 Vs ≥ 7 members	6.00 (1)	0.01*	156
4-6 Vs ≥ 7 members	7.13 (1)	0.008*	193

*Shows pValue < 0.02

Table 8: 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%)

**Figure 4:** Annual rainfall depth (mm) for twenty years from 1998 till 2017.**Figure 5:** Monthly rainfall depth (mm) for twenty years from 1997 till 2017.

September), the mean rainfall during the wet season for 20 years (1998-2017) was 255.48 ± 59.09 mm 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 ± 7.22 mm followed by November with 5.98 ± 9.37 mm.

Rainfall distribution

A three- year monthly rainfall data of 10 years interval, that is, 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 ± 116.96 mm with a maximum rainfall of 379.20 mm in July and no rainfall recorded during November and December months. Similarly, the mean monthly rainfall in 2017 was 113.23 ± 128.54 mm with maximum recorded rainfall of 354.80 mm in August and no rainfall recorded during November and December months. For 2007, the mean monthly rainfall recorded was 124.64 ± 133.35 mm with maximum recorded rainfall of 427.60 mm in July and no recorded rainfall in December.

Rainfall variability

The intra annual variability ranges between 0.95 and 0.97, while inter annual variability was 0.15. These show that there was high variability in the rainfall distributions and 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 (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 with 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 fresh water sources, which may be stored using even a small storage tank.

Potential of rooftop RWH from RDTC, Zhemgang

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 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% of the respondents perceived RWH as very important means to supplement potable water supply while about 6% said it is not important. About 16% of the respondents were neutral.

About 64% of the respondents (205 respondents) indicated interest in adopting RWH in future while about 28% of respondents were still unsure about RWH. The lack of knowledge and idea (12.58%), fund support (8.18%) and proper sanitation measures (1.57%) were mainly attributed for the mediocre interests on RWH at present.

The study showed that 59.75% of the respondents prefer rooftop RWH, followed by open space collection (8.18%), drain collection (5.35%) and through terracing (1.89%).

The simple ranking test showed that RWH can be of importance in flushing toilets (82.70%) followed by dish washing (77.67%), kitchen gardening (77.36%), laundry (77.04%), bathing (59.75%) and drinking purpose (49.37%). However, the key challenges foreseen by the respondents with regard to 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 $6,128 \text{ m}^2$ 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 $7,790,220.00 \text{ m}^3$, which is about $7790.22 \times 10^6 \text{ L}$.

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 $579,867.98 \text{ m}^3$ ($579.87 \times 10^6 \text{ L}$). The RWH potential from the five study sites is shown in Table 9.

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

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 $89.56 \times 10^6 \text{ L}$ 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.

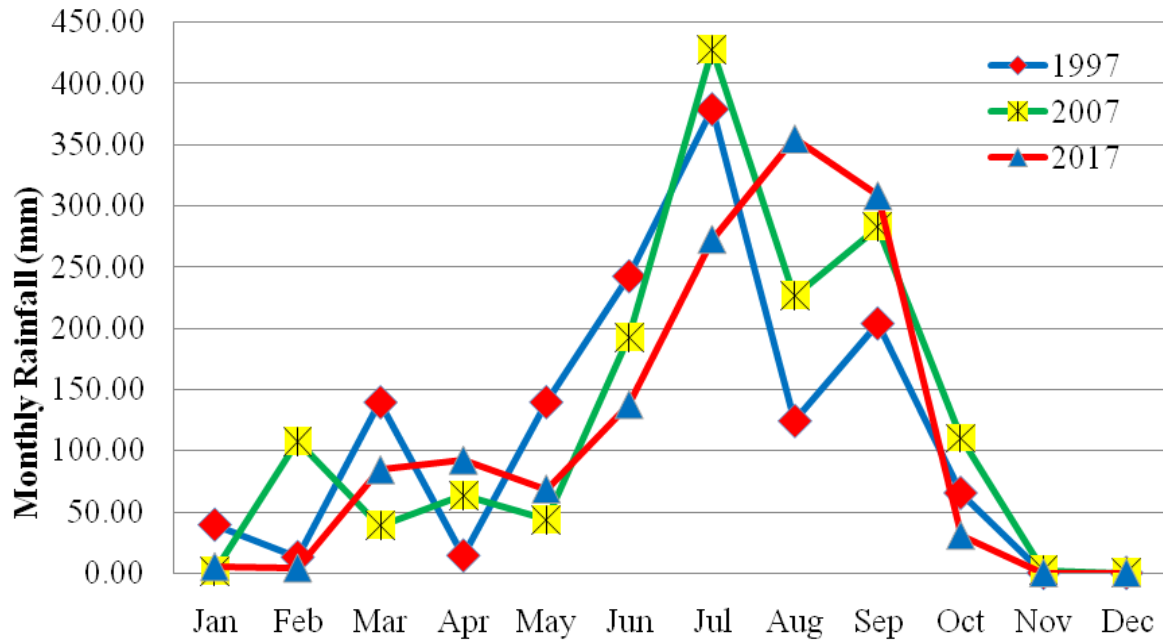


Figure 6: Rainfall Distributions in Zhemgang town during 1997, 2007 and 2017.

Table 9: RWH potential for RDTC and experimental sites.

Locations	Catchment area (m ²)	CV	Average Annual Rainfall (mm)	Potential for RWH (m ³)	Potential for RWH (Liters)
MPH	55.25	0.9	1412.50	70236.56	70236562.50
Dormitory	83.44	0.9	1412.50	106073.10	106073100.00
Class	112.45	0.9	1412.50	142952.06	142952062.50
Dung shed	100.00	0.9	1412.50	127125.00	127125000.00
Resident	105.00	0.9	1412.50	133481.25	133481250.00
Total for 5 Sites	456.14	0.9	1412.50	579867.98	579867975.00
Entire RDTC	6128.00	0.9	1412.50	7790220.00	7790220000.00

Studies conducted elsewhere 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).

Determination of 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 91 m². The average monthly rainwater collected from the five experimental sites (in thousand liters) is shown in Figure 7.

Rainwater quality testing results

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 (NEC, 2016). The average results of rainwater

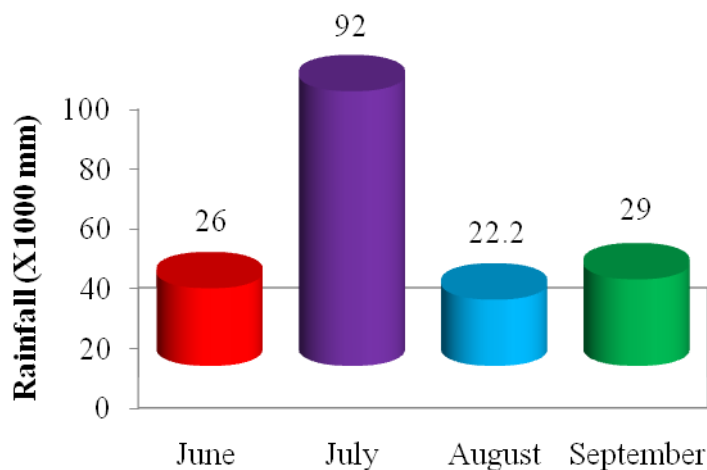


Figure 7: Average rainwater runoff collected from average rooftop catchment area of 91.00 m² (In 1000 L).

Table 10: 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

*Figures in red and italics and in parenthesis show acceptable limits.

quality testing are shown in Table 10.

The rainwater runoff collected and analyzed for water quality showed normal values for all physical parameters from all sites except from dining hall rooftop which was slightly acidic (pH 6.0) and turbid (>5.0).

CONCLUSION

The study shows that rainwater collection systems can provide alternatives to potable water shortage and for use in purpose other than drinking. The study shows that only 4.40% of the study population had practiced RWH till date and around 53.46% of the respondents still lack knowledge on RWH system. As such, through awareness and education programs and proper harnessing of rainwater during the wet seasons, rainwater usage can promote significant potable water savings in Zhemgang, which has been facing water shortage.

It is recommended that rooftop RWH in Zhemgang should be considered as one of the alternative sources of the municipal's water supply scheme. The excess rainwater

obtained during the rainy season could be sufficient to supplement the water shortage in the lean season, providing 313 L/head/day if there is proper storage system. In addition, the introduction of cheap storage tanks, optimal storage tank sizes, cost effective rooftop gutters should be emphasized for cost-benefit balance. RWH can also replace the potable water supply to fire hydrants with 60 m³ capacity. The present study is limited to RDTC only and recommends further studies on assessing the potential for rooftop rainwater harvesting from large public institutions in and around Zhemgang town and if feasible, practice RWH so that the existing water supply system is adequate throughout the year. The quality aspects of RWH from CGI roofing after first flush is fit for drinking with all physical parameters.

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