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Is rainwater harvesting sufficient to satisfy the emergency water demand for the prevention of COVID-19? The case of Dilla town, Southern, Ethiopia

Girum Gebremeskel Kanno[1*], Zemachu Ashuro Lagiso[1], Zeleke Girma Abate[1] Abereham Shiferaw Areba[1] Renay Van Wyk[2] Mekonnen Birhanie Aregu[1]

[1] College of Health and Medical Science, School of Public Health, Dilla University

[2] Department of Environmental Health, Faculty of Health Science, University of Johannesburg

[*]**Corresponding Author:** Girum Gebremeskel Kanno

E-mail:girummeskell@gmail.com/girumg@du.edu.et

Author's email address: zemash65@gmail.com, zelekegirma4@gmail.com, Abriamshiferaw@gmail.com, renayvw@uj.ac.za, mokebir16@gmail.com

Abstract

Rainwater harvesting could be an optional water source to fulfil the emergency water demand in different setups. The aim was to assess if the rainwater harvesting potential for households and selected institutions were sufficient to satisfy the emergency water demand for the prevention of COVID-19 in Dilla town, Southern, Ethiopia. Rain water harvesting potential for households and selected institutions were quantified using 17 years' worth of rainfall data from Ethiopian Metrology Agency. With an average annual rainfall of 1464 mm, households with 40 and 100 m^2 roof sizes have a potential to harvest between 15.71-31.15 m^3 and 41.73-82.73 m^3 of water using Maximum Error Estimate. Meanwhile 7.2-39.7 m^3 and 19.11-105.35 m^3 of water can be harvested from the same roof sizes using Coefficient of Variation for calculation. Considering mean monthly rainfall, the health centres and Dilla University can attain 45.7% and 77% of their emergency water demand, while the rest of the selected institutions in Dilla Town can attain more than 100 % of their demand using only rainwater. Rainwater can be an alternative water source for the town in the fight against COVID-19.

Keywords: COVID-19, Dilla, Emergency water demand, Ethiopia, Rainwater Harvesting

Highlights

- Adequate water supply is one of the key components in combating pandemics.
- In Dilla Town, almost two third of the inhabitants are served by the town water supply service. However, the water supply system with regular interruption and unfair water distribution poses a serious challenge.
- Rainwater harvesting can be used as an alternative water source in the town to tackle the emergency water shortage in the era of COVID-19.

Introduction

COVID-19 is a viral infection caused by a coronavirus which is novel (new) and identified in Wuhan, China [1]. As of 4 October 2020, the pandemic globally affects more than 34.8 million cases and nearly 1.6 billion learners in more than 190 countries and all continents, with over 1 million deaths [2, 3]. In African Region the number of cases reached 1 201 111 with 26 475 deaths as of 6 October 2020. The cumulative total of COVID-19 cases reported in Ethiopia was 80 0031, with 1,238 deaths, which makes it one of the top ten countries with highest cases in Africa. The number of health workers infections continues to increase gradually with 1506 cases until 6 October 2020 [4].

According to the technical brief on Water, sanitation, hygiene (WASH) and waste management for COVID-19, provision of safe water, sanitation and hygienic conditions play an essential role in protecting human health during all infectious disease outbreaks, including the current COVID-

19 outbreak [5]. UN Habitat also stressed that, vulnerable people, mainly those who live in informal settlements and rural community settings will be the world's most affected by COVID-19. Providing quick and just-in-time community water access points (including provision of soap) in unserved urban and rural areas are critical [6].

In many countries found in sub-Saharan Africa, water demand surpasses available resources with water stress (<1700 m^3 per capita per annum) or water scarcity (less than 1000 m^3 per capita per annum), and nearly half of all people using unimproved water sources live in this region, calling for alternative water supply sources [7].

However, available water supply sources are diminishing owing to the poor water governance, extreme social inequality, population rise, climate change, and pollution, causing a globally acknowledged situation of water scarcity, especially in developing countries mainly in Sub-Saharan Africa [8, 9]. To make things worse the situation posed by COVID-19 response affects the capacity of the water and sanitation utilities to operate normally, when staffing is not optimal, financial resources not met, and energy supply disrupted. In such emergency times technical, material and financial resources can be provided on a temporary basis to restore the problem [5].

Preventing or combating potential pandemics such as COVID-19, is likely to increase water demand for domestic and health uses. Supply and storage solutions are needed to ensure there is adequate water available. Ensuring sustainable access to adequate amounts of potable water and resilience will require strengthening water resources management so that water is available where and when it is needed to combat the current and future pandemics [10].

Rainwater harvesting is a widely used term covering all those techniques whereby rain is intercepted and used “close” to where it first reaches the earth, and it has been proposed as one of the options to improve water supply especially in rural and peri-urban areas of low-income countries. It plays a critical role in the mitigation of water-scarcity and water crisis problems, and support when existing water supply systems are inadequate in areas where there is an abundant annual rainfall [11, 12].

As international aid budgets might be reduced due to the economic effects of Covid-19, there is a small but growing body of evidence that Nature based solutions (NBS) such as Rain water harvesting systems are cost-effective, efficient, and adaptable compared to gray infrastructure, and they also offer co-benefits. Rainwater harvesting can improve water storage and supply, thereby increasing water availability and potentially reducing competition between different water users and uses [13, 14].

For instance, Feki *et al*. 2014 [15], studied the potential of rainwater harvesting in multi-story buildings in southern Ethiopia, by which they found that with an average family members of 4, roof area of 60 m^2 and mean annual rainfall of 900 mm, 46 m^3 of rain water can be harvested, which can cover all potable and non-potable water needs at a family level. In another study conducted in Nigeria, using the maximum error estimate approach, the rainwater harvesting potential can generate between 18.16 and 27.45 m^3, while applying the coefficient of variation approach, it can yield between 15.23 and 30.40 m^3 of rainwater. The finding also showed that domestic rainwater harvesting has the potential to meet 27.51– 54.91% of non-potable household water demand as well as 78.34–156.38% of household potable water demand for a six-member household [16].

As part of the COVID-19 response, ‘stay at home’ measures has been encouraged, wearing mask was mandated and efforts to implement social distancing in communal places have been in progress [17]. Besides, there is a national plan to reopening schools and universities at national level [18]. All these measures require minimum WASH infection prevention and control standards to prevent and control the spread of the disease and the provision of safe and adequate water supply is at the heart of one of implementing this standard during COVID-19 response at household and at institutional level [5, 6]. For example Sphere set the emergency water needed for an individual to be 15 l/c/d [19], whereas WHO recommends 15-20 l/c/d. similar water demand requirements were set for schools by different organizations [20] and for health facilities in emergency times like this to maintain the required infection prevention for emergency situation like the current pandemic.

Previous assessment conducted in Dilla Town showed a number of challenges such as; delivering an average per capita consumption less than 20 Liter person/day, frequent complaints by water customers, regular interruption of water supply and unfair water distribution which clearly indicate that there is a huge gap between the water supply and demand in Dilla town [21, 22]. Therefore, our study intends to assess if the rainwater harvesting both at household and at the institutional level is adequate and can supplement the water supply system to fulfill the emergency water needed for the prevention of COVID-19 in Dilla Town, southern Ethiopia.

Materials and Methods

Study Area

The study was conducted in Dilla Town, which is located in Southern Ethiopia at a distance of 359 km from the capital city, Addis Ababa, on the way from Addis Ababa to Moyale. It is located at 6° 22´ to 6° 42´ N and 38° 21´ to 38° 41´ E longitude with an altitude of about 1476 meters above sea level [23]. The 17 years (2002-2018) mean annual rainfall in the area is 1464 mm. The wettest months occur between March and October and the driest months occur during November to February. Precipitation is characterized by a bimodal pattern with maximum peaks during April and May (“small rainy” season) and during September and October in the “main rainy” season (ENMA 2018). The city’s water supply represents an annual consumption of 494,164 $m^{3,}$ in 2018, which is abstracted from ground water (70 %) and surface water (30%) sources [22, 24]. However, in recent years, owing to the high rate of urbanization coupled with industrial development and population growth, as well as change in precipitation patterns, the available water to satisfy the water demand has radically decreased, representing a 38% deficit between 2016-2018 [21, 22].

Data collection, methods and analysis

Rainfall data was obtained from Ethiopian Meteorology Agency in digital form and further analysed in a spreadsheet [25]. According to [26], rainfall is the most unpredictable variable. Therefore, a reliable rainfall data, preferably for a period of at least 15 years is required from the nearest station during calculations to consider the variations. Hence, a monthly rainfall data for Dilla town for the recent 17 years (2002-2018) was utilized for this analysis. Taking the assumption that most household’s roof material in Ethiopian Towns [27], were corrugated iron sheets, and the average roof size of 60 m^2 and a runoff coefficient of 0.8 was employed to account for evaporation loss and possible first flush [28]. To include households with different range of roof sizes, rainwater harvesting potentials for seven typical roof sizes (40, 50, 60, 70, 80, 90, and 100 m^2) were calculated.

Statistical variability (Rainfall Variability) in monthly rainfall data (intra annual) and accumulated annual rainfall (mm) inter annual were expressed with coefficients of variation CV, using equation

$$CV = \frac{Sd}{Mr} * 100 \ldots\ldots\ldots \quad (1)$$

Where *CV* is monthly/seasonal/annual coefficients of variation

Sd: is mean monthly/seasonal/annual standard deviation

Mr: is mean monthly/seasonal/annual rainfall

Seasons were classified based on [25], classification as; **Summer** (Kiremet) heavy rain fall seasons June, July, August and September; **Winter** (Bega) dry season with frost in the morning, which includes October, November, December, and January; and **Autumn** (Belg) seasons with occasional showers of rain includes February, March, April and May.

Estimation of the Rain Water harvesting potential and storage requirements

Rainwater harvesting potential for our study was calculated using the monthly balance approach. The monthly harvestable rainwater (*Qm*) was calculated as a function of the product of mean monthly rainfall ($\bar{R}_m$), roof area (*A*), percentage of roof area utilized for rainwater harvesting (β=50% (0.5) was utilized)) and roof run-off coefficient (*C*) as given in Equation 1.

$$Q\,m = (\bar{R}_m) \times A \times \beta \times C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

According to [16], using only monthly rainfall for the estimation of rainwater harvesting potential could be misleading since it can hide rainfall variability which occurs in real-life scenarios. Therefore, they have suggested the use of two approaches to be utilized in computing the confidence limits, namely: confidence interval about the mean monthly rainfall as well as confidence interval using Coefficient of Variation (COV) of monthly rainfall as described by [29, 30] as:

$$\bar{x} + Z(\alpha/2)\left(\frac{\sigma}{\sqrt{n}}\right) = Upper\ Confidence\ Limit\ (UCL)$$

$$\bar{x} - Z(\alpha/2)\left(\frac{\sigma}{\sqrt{n}}\right) = Lower\ Confidence\ Limit\ (LCL)$$

x = where $\bar{X}$= Mean = $\bar{R}_m$; Z (α/2) =Confidence coefficient; $\sigma/\sqrt{n}$= Standard error of mean and Z (α/2) $\sigma/\sqrt{n}$Maximum error of estimate (MEE), σ = Standard deviation of monthly rainfall for each month and n = sample size = 17. The confidence interval adopted in our study was 0.95 which gave a confidence coefficient of 1.96.

The harvestable rainwater equations for the scenarios of upper confidence limit (UCL) of monthly mean rainfall and lower confidence limit (LCL) of monthly mean rainfall according to [29, 30] as stated in [16] were obtained as

$$Q\ UCL = [\bar{R}m + MEE] \times A \times \beta \times C \text{...4}$$

$$Q\ LCL = [\bar{R}m - MEE] \times A \times \beta \times C \text{...5}$$

Finally for the second approach, harvestable rainwater equations for the upper confidence limit (UCL) of monthly mean rainfall and lower confidence limit (LCL) of monthly mean rainfall were also calculated as;

$$Q\ UCL = \bar{R}m \times A \times \beta \times C[1 + COV] \text{...6}$$

$$Q\ UCL = \bar{R}m \times A \times \beta \times C[1 - COV] \text{...7}$$

Proposed Basic Water Requirement for households

For households emergency water requirement we have used the standard set by [19], which is 15 l/c/day and the standard set by [20] which is (15-20 l/c/day) we take the maximum 20 l/c/day of water for emergency water need at household level for comparison. From the total daily water requirement, 7.5 liter was allocated for drinking and cooking purpose whereas the remaining (7.5 when using the Sphere standard) and (13.5 liter per capita per day when using the WHO standard) were allocated for hygienic purposes in the fight against the COVID-19 such as frequent hand washing and other personal hygienic purposes. The average family size of five was utilized for the water demand calculation.

Proposed Basic Water Requirement for health facilities and schools

To assess rainwater harvesting potential in the selected institutions in Dilla Town the average roof size was adopted from similar institutions in Addis Ababa [31]. We took the assumption that the roof sizes of the institutions in the two cities would be proportional. The patient load for the health centres and the hospitals as well as the number of students in the schools and colleges were directly taken from the institutions and were utilized for the water demand calculation as indicated in (Table 1). A total of 305 school days were utilized for the calculation because most schools are closed (for two month) during the summer time. However, for Dilla University the calculation takes into consideration all the days (365 days) in the year because the university is giving summer courses.

Table 1 Assumed average roof sizes and water demand for selected institutions in Dilla Town.

Selected Large Public Institution in Dilla Town	Total number of institutions	Assumed average roof size in (m^2) [31]	Daily water demand	Total number of individuals served per day
Hospital (Dilla University referral Hospital)	1	14273	40-60 liters /Patient/day [32]	271 patients/day
Health centers	2	1119	40-60 liters/patient/day [32]	66 patients/day
Primary schools	12	2114	3 liters/person/day for drinking and hand washing [19, 32,33,34]	1200 students/day

Secondary schools	3	2114	3 liters/person/day for drinking and hand washing [19, 32,33,34]	700 students/day
Technical and Vocational schools	2	7546	3 liters/pupil/day for drinking and hand washing [19, 32]	1500 students/day
Colleges	8	23999	20 liters liters/person/day for drinking and hand washing for boarding schools and additional 20 liters per person per day for conventional flushing toilets [19,32]	10,000 students/day

Results

Annual, seasonal and monthly rainfall distribution

The average rainfall (for the historical period) was 1464mm (Figure 1). According to the data obtained from Ethiopian Meteorology Agency, out of the total study years, the highest average rainfall in the study area was 2781.1mm, recorded in 2008 while the lowest average rainfall was 974 mm, recorded in 2003. In addition, comparison of annual rainfall for the study period as shown in (Figure 2) indicating increment in yearly rainfall between 2003 and 2008. The seasonal variation of rainfall for Dilla town is described in (Table 2), where winter recorded the highest seasonal rainfall followed by autumn and summer respectively. The maximum seasonal rainfall of 1400.1 mm occurred in winter, while the minimum seasonal rainfall of 250.1 mm occurred in the summer. The season with the lowest coefficient of variation (COV) of 4.45% was winter, while summer had the highest Coefficient of Variation, which was 39.3% as shown in (Table 2). Based on Hare's (1983) rainfall variability index (which is COV expressed in percentage terms), the seasonal rainfall pattern was less variable with index of <20% in winter and there is highly variable rainfall in summer with coefficient of variation index of >30% while rainfall in autumn was moderately variable with index between 20 and 30%.

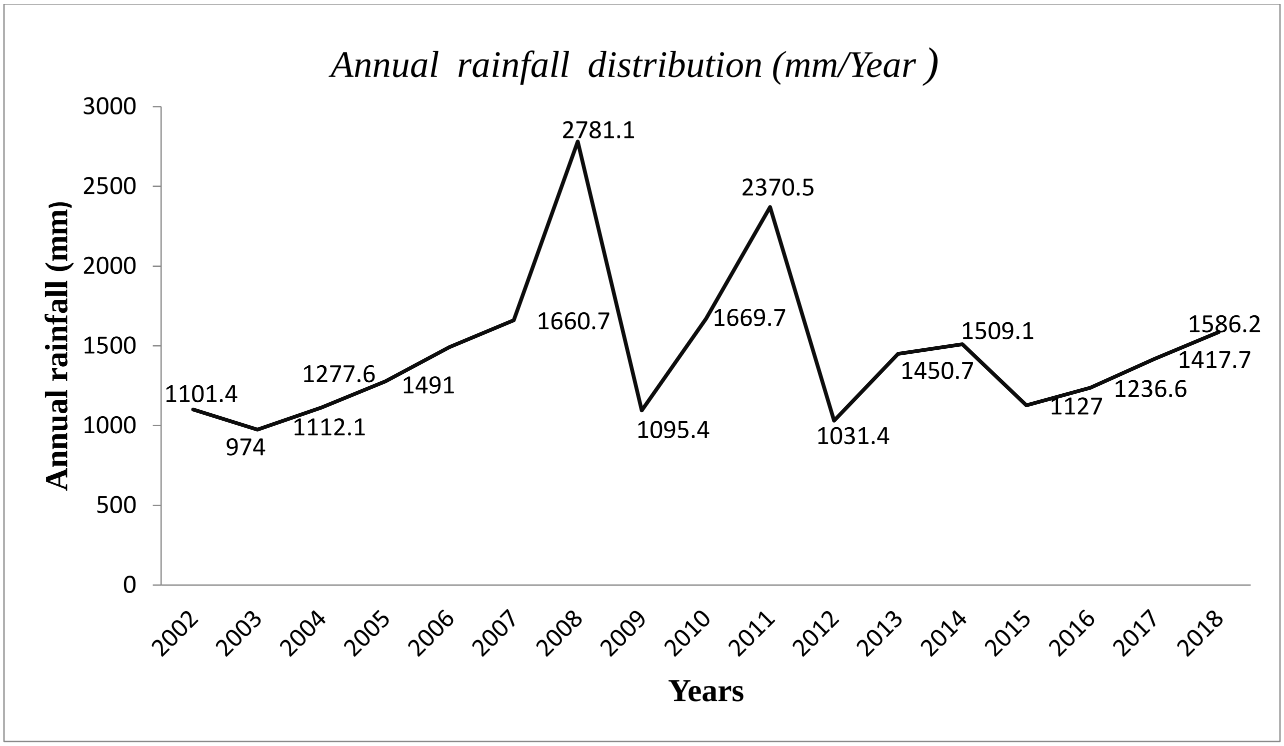

Figure 1: Annual rainfall distribution from 2002 to 2018 in Dilla town, Southern Ethiopia

Between 2002 and 2009, highest monthly rainfall occurred in November and June in 2008, while October 2011 recorded the highest monthly rainfall between the years 2010 and 2018. Besides the fact that this indicates a progressive shift in maximum rainfall from November and June in the pre-2009 period to October in the post-2010 period, it clearly indicates that the seasonal changes from summer to winter are accompanied by heavy rainfall patterns in Dilla town.

Table 2**: Seasonal rainfall distribution pattern of Dilla town, southern Ethiopia**

Parameters	Summer	Autumn	Winter
Mean	381.5	461.1	613.6
Maximum	901.4	735.9	1400.1
Minimum	250.1	313.3	327.3
SD	149.8	126.7	26.9
COV (%)	39.3	27.5	4.4

SD: Standard deviation; COV: Coefficient of Variation

Dilla town has a bimodal rainfall distribution with maximum monthly rainfall was recorded in June and January of 227.2 mm in June and 214.5 mm in January respectively. The minimum monthly average rainfall for the study period (17 years) was 0 mm in (March, 2012, August, 2007 and November , 2013), while the maximum rainfall was recorded 983.2 mm in November, 2008 followed by 894.2 mm in October, 2011 as shown in (Figure 3).

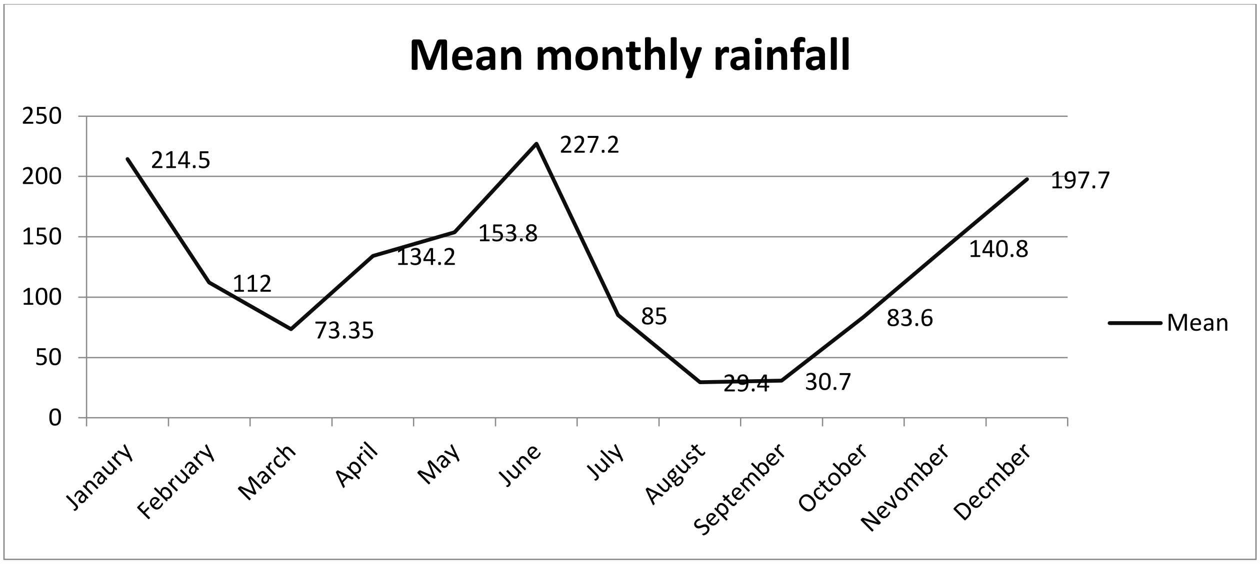

Figure 3: Mean monthly rainfall pattern from 2002 to 2018 for Dilla town, Southern Ethiopia

The highest variability of monthly rainfall were recorded during October and November with COV of 246% and 154.8%, marking the beginning of intense rainfall during the rainy season, while the month with the lowest monthly rainfall variability took place during December with COV of 28%. Based on the Hare's rainfall variability index (1993), all the months exhibited high variability with COV (%) >30% with the exception of December, which exhibited moderate variability between 20 and 30%.

Rainwater harvesting potential for households in Dilla Town

In the proposed household roof sizes, June and August recorded the highest and lowest rain water harvesting potential respectively. This result was obtained by considering the maximum error estimate for the calculation of monthly harvestable rainwater (MHRW) in the three scenarios of upper confidence limit (UCL), Mean and lower confidence limit (LCL) at household level (Table 3). Households with minimum roof size of 40 m^2 have the maximum rain water harvesting potential of 4.86 m^3 during June and minimum water harvesting potential of 0.18 m^3 in August. A household with a roof size 100 m^2 have a maximum potential to harvest 12.91m^3 of rain during June and a minimum of 0.49 m^3 during August. The second maximum and minimum RWH months were 10.65 m^3 in January and 2.01 m^3 in August respectively (Table 3).

Table 3 Monthly harvestable rain water Data with different assumed household roof sizes using MME approach

Roof size m^2	**Limits**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
40	UCL(m^3)	4.01	2.11	1.47	2.61	2.85	4.86	1.72	0.76	1.47	2.61	3.92	3.23	31.15
	MEAN(m^3)	3.43	1.79	1.17	2.15	2.46	3.63	1.36	0.47	0.49	1.34	2.25	2.87	23.42
	LCL (m^3)	2.85	1.47	0.88	1.68	2.07	2.41	0.99	0.18	0.29	-0.23	0.59	2.49	15.71
50	UCL(m^3)	5.01	2.63	1.83	3.26	3.56	6.07	2.15	0.94	0.86	3.63	4.89	4.07	38.93
	MEAN(m^3)	4.29	2.24	1.47	2.68	3.08	4.54	1.69	0.59	0.61	1.67	2.82	3.59	29.28
	LCL (m^3)	3.57	1.84	1.10	2.11	2.59	3.01	1.24	0.23	0.37	-0.28	0.74	3.12	19.64

	UCL(m^3)	6.02	3.16	2.20	3.91	4.28	7.29	2.58	1.13	1.03	4.35	5.87	4.89	46.72
60	MEAN(m^3)	5..15	2.68	1.76	3.22	3.69	5.45	2.04	0.71	0.74	2.00	3.38	4.31	35.14
	LCL (m^3)	4.28	2.21	1.32	2.52	3.11	3.61	1.49	0.28	0.44	-0.34	0.89	3.74	23.57
	UCL(m^3)	7.11	3.68	2.56	4.56	4.99	8.51	3.01	1.32	1.21	5.08	6.85	5.7	54.5
70	MEAN(m^3)	6.01	3.13	2.05	3.76	4.31	6.36	2.39	0.82	0.86	2.34	3.94	5.03	41.00
	LCL (m^3)	5.00	2.58	1.54	2.94	3.62	4.21	1.74	0.34	0.51	-0.40	1.04	4.36	27.5
	UCL(m^3)	8.02	4.21	2.93	5.21	5.70	9.72	3.45	1.51	1.38	5.80	7.83	6.52	62.3
80	MEAN(m^3)	6.86	3.58	2.35	4.29	4.92	7.27	2.71	0.94	0.98	2.67	4.51	5.75	46.86
	LCL (m^3)	5.71	2.95	1.76	3.37	4.14	4.82	1.99	0.37	0.58	-0.45	1.19	4.98	31.42
	UCL(m^3)	9.02	4.74	3.29	5.86	6.41	10.93	3.88	1.70	1.55	6.53	8.80	7.33	70.08
90	MEAN(m^3)	7.72	4.02	2.64	4.83	5.53	8.18	3.06	1.06	1.11	3.01	5.07	6.47	52.71
	LCL (m^3)	6.42	3.32	1.98	3.79	4.66	5.42	2.23	0.42	0.66	-0.51	1.34	5.16	35.35
	UCL(m^3)	10.65	5.59	3.89	6.93	7.57	12.91	4.58	2.01	1.83	7.71	10.4	8.65	82.73
100	MEAN(m^3)	9.12	4.76	3.12	5.70	6.54	9.65	3.61	1.25	1.31	3.55	6	7.64	62.23
	LCL (m^3)	7.58	3.92	2.34	4.48	5.50	6.40	2.64	0.49	0.77	-0.60	1.58	6.62	41.73

UCL: Upper confidence limit; LCL: Lower confidence lim

Based on coefficient of variation (COV) approach, the monthly HRW for the different scenarios of households with a roof size of 40 m^2 recorded the highest and lowest values of 6.21 m^3 in June and 0.07 m^3 in September, respectively. Similarly, households with a roof size of 100 m^2 had highest and lowest monthly HRW potential of 16.5 m^3 and 0.19 m^3, in the same months respectively as indicated in (Table 4).

Table 4: Monthly harvestable rainwater (HRW) based on (COV) approach

Roof size m^2	**Limits**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
	UCL(m^3)	4.65	2.45	1.79	3.12	3.28	6.21	2.12	1.07	0.91	4.63	5.74	3.68	39.66
40	LCL (m^3)	2.22	1.13	0.56	1.18	1.64	1.06	0.59	-0.13	0.07	-1.95	-1.24	2.07	7.2
	UCL(m^3)	5.81	3.07	2.24	3.9	4.1	7.77	2.66	1.34	1.14	5.79	7.18	4.6	49.58
50	LCL (m^3)	2.77	1.41	0.7	1.47	2.05	1.32	0.74	-0.16	0.09	-2.44	-1.54	2.59	9
	UCL(m3)	6.97	3.68	2.68	4.67	4.92	9.31	3.18	1.61	1.36	6.94	6.61	5.52	59.5
60	LCL (m^3)	3.32	1.69	0.84	1.76	2.46	1.59	0.89	-0.19	0.11	-2.93	-1.85	3.11	10.8
	UCL(m^3)	8.13	4.3	2.13	5.46	5.74	10.87	3.72	1.87	1.59	8.1	10.05	6.44	69.41

70	LCL (m3)	3.87	1.97	1	2.06	2.86	1.85	1.04	-0.02	0.13	-3.42	-2.16	3.62	12.58
80	UCL(m3)	9.3	4.9	3.58	6.23	6.57	12.43	4.25	2.14	1.82	9.26	11.49	7.36	79.32
	LCL (m3)	4.43	2.25	1.12	2.35	3.28	2.11	1.85	-0.26	0.15	-3.91	-2.47	4.14	14.4
90	UCL(m3)	10.46	5.52	4.02	7.01	7.39	13.97	4.78	2.41	2.05	10.42	12.92	8.28	89.24
	LCL (m3)	4.98	2.54	1.26	2.65	3.68	2.38	1.33	-0.29	0.165	-4.4	-2.78	4.66	16.18
100	UCL(m3)	12.35	6.52	4.78	8.28	8.72	16.5	5.64	2.85	2.41	12.3	15.26	9.78	105.35
	LCL (m3)	5.88	3.0	1.48	3.12	4.35	2.81	1.57	-0.34	0.19	-5.18	-3.28	5.50	19.11

UCL: Upper confidence limit; LCL: Lower confidence limit

In the study area of Dilla town, with an average annual rainfall of 1464 mm, the result indicated that 15.71-31.15 m^3 of water can be harvested from a household with a roof size of $40m^2$ and 41.73-82.73 m^3 with a roof size of 100 m^3 by using MEE. On the other hand 7.2-$39.7m^3$ of water can be harvested with a roof size of 40 m^2 and 19.11-105.35 m^3 with a roof size of 100 m^2 by using the coefficient of variation (COV) approach.

RWH for household level emergency water supply (the prevention of COVID-19)

The potable water demand needed for emergency water supply in the prevention of COVID-19 that could be met by domestic RWH potential was between 114.75 and 227.54% of household roof areas of $40m^2$ and between 304.8 and 604.3% of household roof areas of $100m^2$ (Figure 4). Whereas, for annual non-potable water demand met by RWH for household roof size of 40 m^2 and 100 m^2 were between 63.76 and 126.37% and between 169.4 and $335.76m^3$ respectively, using the Maximum Error Estimate approach. As (Figure 4) indicates increment in roof size results in higher harvested rain water. By using, the harvested rainwater with MEE approach, it is possible to achieve the potable water demand in all the roof sizes and only households with a roof size between 70-100 m^2 were able to achieve their non-potable water demand. Only households with roof size of 90 and 100 m^2 can fully satisfy both their potable and non-potable daily water demand which is 20 litre capita per day.

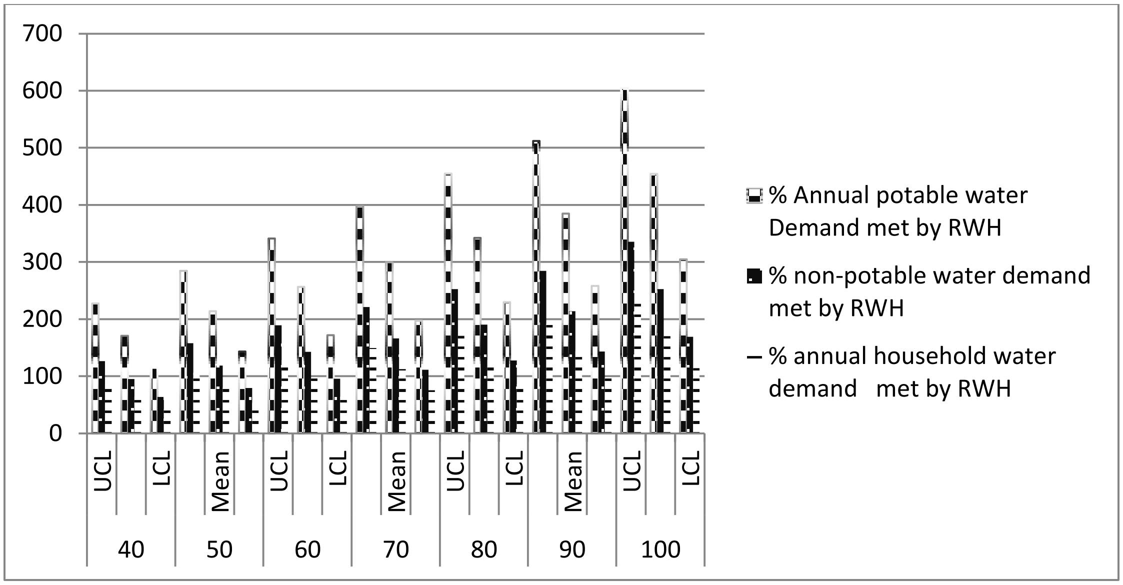

Figure 4: Emergency water demand met by Domestic RWH potential based on (MEE)

This clearly indicates that using the mean and Upper Confidence Limit (UCL) scenarios, potable water demand can be sufficiently met with some excess remaining (63.76%, 79.71% and 95.66%) in the LCL scenario for households with roof size of 40, 50 and 60m^2 respectively. For Households with roof sizes of 70 m^2 and above, the rain water is more than enough to satisfy the emergency water needed for the prevention of the current pandemic.

Table 5: Emergency water demand met by DRWH potential based on (COV) Approach

Roof size	Scenario	Total annual harvested rain water In m^3	%Annual potable water Demand met by RWH	% Non-potable water demand met by RWH	% Annual household emergency water demand met by RWH
40	UCL	39.66	289.7	161	108.66
	LCL	7.2	52.6	29.2	19.72

50	UCL	49.58	362.2	201.2	135.8
	LCL	9	65.7	36.52	24.6
60	UCL	59.5	434.6	241.5	163
	LCL	10.8	79	43.83	29.6
70	UCL	69.41	507	281.7	190.2
	LCL	12.58	92	51.1	34.5
80	UCL	79.32	579.4	322	217.3
	LCL	14.4	105.2	58.44	39.45
90	UCL	89.24	652	362.2	244.5
	LCL	16.18	118.2	65.7	44.3
100	UCL	105.35	769.5	427.6	288.6
	LCL	19.11	139.6	77.5	52.3

UCL: Upper confidence limit; LCL: Lower confidence limit, RWH: Rain Water Harvesting

By using, the harvested rain water with COV approach, it is possible to achieve the potable water demand using the roof sizes of 80-100 m^2 and only households with a roof size of 100 m^2 were able to achieve both the non-potable water demand. But none of the households with a roof size of 40-100 m^2 can fully satisfy both the potable and non-potable daily water demand (20 l/c/d) for a household with a family size of five (Table 5). For the COV approach, DRWH has the potential to meet 29.2-161% and 77.5-427.6% of the NPWD for households with roof area of 40m^2 and 100m^2 respectively.

As indicated in (table 6), all households roof sizes can attain their emergency water demand of (15 l/c/d and 20 l/c/d) when the rainfall pattern is the highest. When the rainfall pattern is the lowest, households with roof sizes between 40-100 m^2 can attain 26.3-69.8% of the water demand based on 15 l/c/c daily requirement and 19.72-52.3% based on 20 l/c/d daily emergency water requirement.

Table 6 comparison of emergency water demand meet by rain water harvesting using the Sphere and the WHO standard

Roof size	Scenario	Total annual harvested rain water in m^3	% Annual emergency water demand met by RWH using Sphere standard (15 l/c/d)	% Annual emergency water demand met by RWH using WHO standard (20 l/c/day)
40	UCL	39.66	144.9	108.66
	LCL	7.2	26.3	19.72
50	UCL	49.58	181.1	135.8
	LCL	9	32.9	24.6
60	UCL	59.5	214.4	163
	LCL	10.8	38	29.6
70	UCL	69.41	253.6	190.2
	LCL	12.58	46	34.5
80	UCL	79.32	289.6	217.3
	LCL	14.4	52.6	39.45

90	UCL	89.24	326	244.5
	LCL	16.18	59.1	44.3
100	UCL	105.35	384.8	288.6
	LCL	19.11	69.8	52.3

RWH for institutional level emergency water supply (the prevention of COVID-19)

Using the maximum error estimate to calculate the rain water harvesting potential Dilla University referral Hospital could satisfy 94.5% of its emergency water supply needs from rain water even in the worst case scenarios (LCL) and it can achieve 140.8% of its needs using average rainfall, which is more than the (WHO 2013) requirement needed for the infection prevention tasks during this pandemic using rain water as the only source.

Using the coefficient of variation (COV), when the rainfall is at its maximum, all the selected institutions can fulfill more than 100% of their demand only from the rain water as the single source, except the health centers in Dilla Town (which can achieve only 77.3% of their emergency water demand). Lower confidence limit using COV, indicate that only the vocational schools in Dilla Town can achieve their demand when the rainfall declines (data regarding institutional rainwater potential can be found on the supplementary material).

Discussion

Provision of Safe and adequate water and access to sanitation are linked with most of the 17 SDGs. Access to clean water and sanitation are essential and must be available during normal times and extra must be delivered in emergency situations such as the current pandemic [35, 36]. In such critical times, lack of clean and adequate water for drinking and proper hygienic practices becomes a major concern for cities in most developing countries, especially in slums and peri-urban areas [36]. To avoid the water demand problem most developed nations such as the US and counties in Europe relay on bottled water mostly out of choice which is not a viable and sustainable option, considering the financial impact the lockdown has brought to the economy where millions are struggling to pay their utility bills, including for water [36]. The provision of adequate water is a resource intensive and a complex issue which requires integrated and multi-sectorial interventions. In Dilla Town, the main sources of water supply are deep boreholes and, Legga Dara River [21, 32]. However, rainwater is mostly an overlooked water source which could easily be accessible and sustainable source of safe water supply like most countries located in the tropical and subtropical climates [37-39].

Besides, emergency situations always put decision makers stuck between fulfilling minimum water quantity versus water quality choices. The priority should be for quantity over quality and all the options available to make the water safer should be applied afterwards [40]. Since, washing hands at critical times together with other hygienic practices is the primary strategy to prevent and control further spread of COVID-19, the impact of water quantity is also expected to have greater influence over water quantity just like in the case of diarrheal diseases.

In health care setups, the water used for infection prevention tasks such as laundry and for cleaning floors and other surfaces need not be of drinking water quality, as long as it is used with a disinfectant or a detergent [40, 41]. Therefore, the rain water can be used for certain infection prevention tasks even with lower rainwater quality levels, whereas care must be taken in using rainwater for medical activities such as haemodialysis, which require higher water quality standards. In situations like this care must be taken and rainwater must be used only after approved and recommended water treatment methods are applied [40, 41].

Different studies tried to estimate the rain water harvesting potential in different countries using rainfall data. Our finding revealed that a higher rainwater harvesting potential when compared with a study conducted in Nigeria [16] where, using the Maximum error Estimate for calculation, a roof size of 100 m^2 had a rainwater harvesting potential between 18.16 and 27.45 m^3, while 15.23 and 30.40 m^3 of water can be harvested using the Coefficient of variation for calculation. Whereas, for Dilla town even smaller roof sizes such as 40 m^2 can be used to harvest higher amount of rainwater (15.71-31.1541.73 m^3 using MEE) and (7.2-39.66 m^3 using COV) for calculation. But rainwater harvesting potential was found to be lower (35.14 m^3 of harvestable rainwater) when compared to the rainwater harvested with similar finding from Arba Minch (a city also located in southern Ethiopia) 46 m^3 using a similar roof size of 60 m^2, average annual rainfall for calculation [15]. Rain water was also found to cover more than half of the water demand for the institutional emergency water demand in Dilla town. This is comparable to findings from Addis Ababa, Ethiopia [31] where, rooftop RWH from large public institutions can replace 0.9-649% of the water supply depending on the season of the year indicating that the importance of storage facilities to use the excess rainwater during the wet season for later uses. Different standard setting and humanitarian agencies such as WHO [4], INEE [33], UNICEF [3, 5] and are stressing for strong personal prevention practices like hand washings and environmental cleaning and disinfection plans to be in place before reopening schools are important precautionary measures that must be taken to lower the risk of COVID-19. Therefore, for institutions like schools and health facilities, Rain water harvesting can be a valuable source of water supply for the strict hygienic purposes needed during pandemic areas with limited or unreliable water supply [34, 37].

Our research can also have an implication on the water security status of households and the Dilla town in general. In a study done at Addis Ababa city, Ethiopia [42], water security was assessed from three dimensions, namely water supply sanitation and hygiene. The water supply dimension take into account different variables for the assessment such as proportion of population with piped water supply; water supply service duration; per capita water consumption; percentage of NRW; conforming to water quality standards; affordability of domestic water supply tariff. Our finding clearly indicated that rainwater harvesting can contribute directly in two critical components of the water security issues by addressing the water supply dimension. The first one is by increasing the Per capita water consumption at household level and the other is by making water available at affordable price at household level. It can also indirectly enhance the water security problems by reducing the stress on the formal water supply services at such emergency situations. Self-help RWH water supply systems can enhance the water security through easy access, low cost, and ease of management for households and institutions [37].

Since, the rain water harvesting potential calculation (for households and institutions) assumes only 50% of the roof size, if a household or the institutions are efficient enough to utilize 100% of the roof area the outcome will be doubled which is very promising. Yet, it should be considered that the upper limit and lower limit calculation of the harvestable water volume, did not take into account the critical real life limitations associated with tank size, water losses, water pollution, or social and cultural issues that are likely to reduce the volume that can be attained in practice. Besides, the water quality issues must be a priority if rainwater has to replace other water sources for the prevention of COVID-19.

Strength and Limitation of the study

The strength of this study is that it tried to address the rain water harvesting potential both for households and major public institutions by considering the rainfall variability into consideration during calculation. Since hand washing is the simplest, cost effective and the most effective prevention strategy, hand washing frequency is expected to increase both at household and institutional levels. As a result the demand for water is also expected increase. This is also true for other hygienic and infection prevention tasks implemented in the fight against COVID-19, which are dependent on water demand for the operation. One limitation was the absence of data regarding the amount of emergency water that is actually needed for the increased water demand for the hygienic purpose during pandemics like COVID-19 for calculation.

Conclusions

Based on this study result, we have concluded that rainwater can be one alternative option as a source of water for emergency water demand in Dilla town. A small household with a roof area of 40m^2 can cover 19.72%-108.66% of the household's emergency water demand for the prevention of COVID-19 whereas a household with a roof area of 100m^2 can cover 114.3-170.5% of the total daily emergency water requirement.

Institutions such as Dilla University referral Hospital (DURH) 43.3-238.5% of their emergency water demand needed for the infection prevention of the current pandemic which can cover from rain water as the single source. Further observational studies must be conducted to actually quantify the actual emergency water demand needed for all the hygienic and infection prevention measures needed to combat the COVID-19 both at household and institutional level. The priority that must be given to water quantity versus water quality must also be investigated.

Conflict of interest

The authors declare no conflict of interest, financial or otherwise.

Data availability statement

All relevant data are included in the paper or it's Supplementary Information.

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Author Contributions

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References

1. World Health Organization 2020 Coronavirus disease 2019 (COVID-19) Situation Report – 94 from national Authorities by April 2020.
2. World Health Organization 2020, COVID-19, WHO COVID-19 Weekly Epidemiological Update

https://www.who.int/docs/default-source/coronaviruse/situation-reports/20201005-weekly-epi-update-8.pdf

3. United Nations 2020, Policy Brief: Education during COVID-19 and beyond.
4. World Health Organization Regional Office for Africa 2020, COVID-19, External Situation Report 32, Health Emergency Information and Risk Assessment.
5. UNICEF 2020 United Nations International Children's Emergency Fund, COVID-19 Emergency Response Monitoring and mitigating the secondary impacts of the COVID19 epidemic on WASH services availability and access, March 2020
6. UN Habitat 2020 UN-Habitat Covid-19 Key messages. Accessed from https://unhabitat.org/sites/default/files/2020/03/covid19_key_messages_eng_1.pdf
7. Ngigi, S.N. 2009. Climate Change Adaptation Strategies: Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa. The MDG Centre for East and Southern Africa, *The Earth Institute at Columbia University*, New York. 189p ISBN 978-92-9059-264-8
8. Bocanegra M. A, Ponce-Ortega J, Nápoles-Rivera F, Serna-González M, Montoya A, El-Halwagi M. 2014 Optimal design of rainwater collecting systems for domestic use into a residential development. *Resources, Conservation and Recycling*, **84**, 44–56. DOI:10.1016/j.resconrec.2014.01.001
9. Fang C., Bao C., & Huang J. 2007 Management Implications to Water Resources Constraint force on Socio-economic System in Rapid Urbanization: A Case Study of the Hexi Corridor, NW China. *Water Recourse Management*, **21**, 1613–1633. DOI 10.1007/s11269-006-9117-0 [CrossRef].

10. Joshi, D. & Nicol, A. 2020 COVID-19 is a deadly reminder that inclusive water supply and sanitation matters for all of us. *Integrated Water Resources Management Institute*
11. Parker, A., Cruddas, P., Rowe, N., Carter, R., & Webster, J. 2013 Tank costs for domestic rainwater harvesting in East Africa. Proceedings of ICE: *Water Management* DOI:10.1680/wama.11.00113, ISSN:17417589
12. Nijhof Saskia, Basja Jantowski, Robert Meerman and Ard Schoemaker (2010) Rainwater harvesting in challenging environments: Towards institutional frameworks for sustainable domestic water supply. *Waterlines*, **29**(3), 209–219 doi: 10.3362/1756-3488.2010.022
13. Liquete, C., Udias, A., Conte, G., Grizzetti, B. & Masi, F. 2016 Integrated Valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. *Ecosystem Services*, **22.B**, *392-401*. https://doi.org/10.1016/j.ecoser.2016.09.011 [Cross referenced]
14. Oral, H.V., Carvalho, P., Gajewska, M., Ursino, N., Masi, F., van Hullebusch, E.D., et al. 2020 A review of nature-based solutions for urban water management in European circular cities: a critical assessment based on case studies and literature. *Blue-Green Systems*, **2**(1), *112–136*. https://doi.org/10.2166/bgs.2020.932
15. Feki F, Weissenbacherb, N., Assefac, E., Oltod, E., Gebremariame, M.K., Dalechac, T., et al. 2014 Rain water harvesting as additional water supply for multi-storey buildings in Arba Minch, Ethiopia. *Desalination and Water Treatment*, **53**
16. Balogun I. I., Adebayo O. S. and Bosede O. O. 2016 Assessment of rainfall variability, rainwater harvesting potential and storage requirements in Odeda Local Government Area of Ogun State in South-western Nigeria. *Cogent Environmental Science*, **2**: 1138597. http://dx.doi.org/10.1080/23311843.2016.1138597

17. Mohammed H, Oljira L, Roba K T, Yimer G, Fekadu A and Manyazewal T. Containment of COVID-19 in Ethiopia and implications for tuberculosis care and research. BMC Infectious Diseases of Poverty 2020, 9:131 (1-8). https://doi.org/10.1186/s40249-020-00753-9

18. UNHCR 2020. COVID-19 AND OPERATIONAL UPDATE, Ethiopia, 07 October 2020. https://reliefweb.int/sites/reliefweb.int/files/resources/UNHCR%20ETHIOPIA%20COVID%20and%20Operational%20Update%2008%20October%202020.pdf

19. Sphere 2020, Applying humanitarian standards to fight COVID-19
World Health Organization 2002 Environmental health in emergencies and disasters: a practical guide. Edited by B. Wisner, J. Adams. ISBN 92 4 154541 0

21. Debela M. C. and Muhye H. K. 2015 Water supply and demand scenario of Dilla Town, Southern Ethiopia. *International Journal of Water Resources and Environmental Engineering*, **9**:12: 270-276. DOI: 10.5897/IJWREE2017.0748

22. Kanno G. G. Lagiso Z. A., Gondol B. N., Alembo A., Abate Z. G, Getahun B., Hussen R, Legesse M. T., Andarge S. D., Korita G. K., Gebeyehu M. Y., Abate M., Ana T. F., Aregu M. B. 2020 Sanitary Survey and Drinking Water Quality Performance of Treatment Plant: The Case of Dilla Town, Ethiopia. *Afri. J. Heal. Sci. Med*, **01**(01). https://doi.org/10.20372/10.20372/duhj001-000002

23. Demelash W (2010). Characterization and Classification of the Soils of Upper Sala Watershed in Dilla Zuria District of Gedeo Zone, Southern Ethiopia. MSc Thesis, *Haramaya University, Haramaya, Ethiopia.*

24. Columbia Water Center. 2016. Policy Implications & Survey Results for Water & Sanitation in Dilla Shumaker A., SNNPR, Ethiopia. Columbia Water Center.
25. Ethiopian National Metrology Agency 2018 Monthly Rainfall Data of Dilla.
26. Shakya B. and Thanju P., 2013 Technical guideline for installation of rainwater harvesting system operation. *Hydro Nepal issue*, **12**
27. Mourad K. A. & Yimer S. M., Yimer. 2017 Socio-economic Potential of Rainwater Harvesting in Ethiopia, Sustainable Agriculture Research, **6**(1).
28. Thomas THM, D.B., 2007 "Roof Water Harvesting: A Handbook for Practitioners," Technical Paper Series,No. 49; *IRC International Water and Sanitation Center: Delft, The Netherlands*, **49**
29. Johnson R, & Kuby, P. 2012 Elementary statistics. New York, NY: Cengage Learning.
30. Bluman AG. 2013 Elementary statistics. A step by step approach (6th ed.). New York, NY: *McGraw-Hill*.
31. Adugna D, Jensen M.B, Lemma B, Gebrie G.S. 2018 Assessing the Potential for Rooftop Rainwater Harvesting from Large Public Institutions. *International Journal of environmental research and public health*, **15**(2). doi:10.3390/ijerph15020336
32. World Health Organization 2013 Technical Notes series on drinking-water, sanitation and hygiene in emergencies. How much water is needed in emergencies? **9**
33. INEE 2012, Minimum Standards For Education: Preparedness, Response, Recovery

35. UN-Water, 2016: Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development. Geneva.
36. Tortajada C and Biswas A K COVID-19 heightens water problems around the world

The Conversation UK. June 8, 2020. https://theconversation.com/covid-19-heightens-water-problems-around-the-world-140167

37. Ministry of Housing Transport and Environment Government of the Republic of Maldives 2009, Guidelines and Manual for Rain Water Harvesting in Maldives
38. Chubaka C. E, "Lead, zinc, copper, and cadmium content of water from south Australian rainwater tanks," International Journal of Environmental Research and Public Health, vol. 15, no. 7, p. 1551, 2018.
39. Nduka J. K and Orisakwe O. E., "Assessment of environmental distribution of lead in some municipalities of southeastern Nigeria," International Journal of Environmental Research and Public Health, vol. 7, no. 6, pp. 2501–2513, 2010
40. World Health Organization 2003, Domestic Water Quantity, Service, Level and Health by Guy Howard and Jamie Bartram. WHO/SDE/WSH/03.02
41. World Health Organization; 2019, Water, sanitation and hygiene in health care facilities: practical steps to achieve universal access. Geneva Licence: CC BY-NC-SA 3.0 IGO.
42. Assefa Y T., Babel M S., Sušnik J. and Shinde V R. Development of a Generic Domestic Water Security Index, and Its Application in Addis Ababa, Ethiopia. J. Water 2019, 11(37) doi:10.3390/w11010037