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Estimation of rainwater harvesting potential for emergency water demand in the era of COVID-19. The case of Dilla town, Southern, Ethiopia

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ABSTRACT

Safe and adequate quantity of water is crucial for the implementation of infection prevention and control measures during the prevention of COVID-19. Rainwater harvesting could be an optional water source to fulfill or support the emergency water demand in areas where there is abundant rainfall. The study aimed to assess the rainwater harvesting potential and storage requirements for households and selected institutions and to determine its adequacy to satisfy the emergency water demand for the prevention of COVID-19 in Dilla town, Southern Ethiopia. Rainwater harvesting potential for households and selected institutions were quantified using 17 years’ worth of rainfall data from the Ethiopian Meteorology Agency. To address the rainfall variability, we computed the confidence limits of monthly harvest-able rainwater potential using confidence intervals about the mean as well as confidence intervals using Coefficient of Variation (COV) of monthly rainfall. The storage requirements were also estimated by considering the driest and wet seasons and months. The average annual rainfall in Dilla town was 1464 mm. Households with a roof area of 40 and 100 m² have the potential to harvest 7.2–39.66 m³ and 19.11–105.35 m³ of rainwater respectively. Similarly, the rainwater harvesting potential for the selected institutions was in the range of 34524.5–190374.5, 4070.8–14964.8, 1140.4–6288.6, 4561.7–25154.3, 5605.8–14152.8, and 402.4–2219.1 m³ of rainwater for colleges, vocational schools, secondary schools, primary schools, Dilla University Referral Hospital and health centers respectively. These institutional rainwater harvesting potentials can address, 24–132.2, 222.4–817.8, 59.4–327.3, 34.6–190.9, 94.5–238.5, and 28.2–155.7 % of the colleges, vocational schools, secondary schools, primary schools, Dilla University referral hospital, and, health centers emergency water demand respectively. Rainwater can be an alternative water source for the town in the prevention and control of COVID-19. Further applied researches must be conducted that can address the rainwater quality and treatment for ease of use.

1. Introduction

Public health emergencies arise when an illness, disease, or condition poses an imminent and substantial threat to a population; add a significant risk to overwhelm the existing health services capacity (CDA, 2020). The term ‘emergency’ is used to describe the crisis that arises when a community has great difficulty in coping with a disaster that requires external assistance lasting for months or even for years (House and Reed, 1997). Coronavirus (COVID-19) outbreak was declared as a public health emergency of international concern (PHEIC) by the World Health Organization in January, 2020. It is a viral infection that was first detected and identified in Wuhan, China on 31 December, 2019, and caused by a corona-virus that is novel or new (WHO, 2020). Globally, as of 26 February 2021, there have been 112,456,453 confirmed cases of COVID-19, including 2,497,514 deaths, reported to the

Abbreviations: HAU, African Union; AUST, Adama University of science and technology; AWWA, American water works association; CDC, center for disease control; COV, coefficient of variation; CFR, case fatality rate; CWC, Colombian water center; ENMA, Ethiopian National Meteorology Agency; INEE, Inter-agency network in emergencies; IPC, infection prevention and control; LCL, lower confidence limit; MHRW, monthly harvest-able rainwater; MME, maximum error estimate; PHEIC, public health emergency of international concern; RWH, rainwater harvesting; UCL, upper confidence limit; UNICEF, United Nations international children's emergency fund; UNHCR, United Nations high commissioner for refugees; WHO, World Health Organization; WASH, water sanitation and hygiene.

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World Health Organization (WHO, 2021). According to the Africa Centers for Disease Control and Prevention, as of 23 February, 2021, a total of 3,836,817 COVID-19 cases and 101,629 deaths with a case fatality rate (CFR: 2.6%) have been reported in 55 African Union (AU) Member States which is 3.5% of all cases reported globally and the majority (91%) of Member States continue to report community transmission. With a total of 152,806 cases. Ethiopia is among the fifth most affected country in terms of the number of positive cases reported next to South Africa, Morocco, Tunisia, and Egypt, and the total number of death toll reached 2,279 (Africa CDC, 2021).

The provision of safe and adequate water, sanitation and, hygiene conditions play an essential role in protecting human health and controlling disease outbreaks, including the current COVID-19 outbreak (UN Habitat, 2020). The provision of quick and just-in-time community water access points (including the provision of soap) in urban and rural areas are critical (UN Habitat, 2020; UNHCR, 2020). Different disasters or public health emergency events including, the current pandemic may cause community water system interruptions or may pause additional water requirements than usual which may lead to delivering services below the required amount and quality (CDC and AWWA, 2012).

For example, the prominent recommended prevention measures for COVID-19 in households, schools, and health care settings are good infection prevention and control (IPC) and water, sanitation, and hygiene (WASH) practices, which include hand hygiene, safe cough and sneeze etiquette, environmental cleanliness, and equipment disinfection. These preventive measures must be consistently applied, to serve as barriers to human-to-human transmission of the COVID-19 virus in homes, communities, health care facilities, schools, and other public spaces (WHO, 2020; UNICEF, 2020; World Bank, 2020). These key IPC and WASH practices require not only the availability of a safe and adequate quantity of water (UNICEF, 2020), rather extra water must be available from the normal times. For example, a single 20 s hand wash plus wetting and rinsing uses at least two liters of water, and for a family of five for washing 10 times a day, each would mean 100 l of water is needed only for handwashing (Rohilla, 2020). A global study also indicated that the magnitude of the COVID-19 outbreak was found to be much higher in countries with a lower habit of handwashing (Pogrebna and Kharlamov, 2020), where one of the reasons for the poor habit of handwashing might be a lack of extra water.

To meet these higher water demands a continuous piped water service which is an internationally accepted standard for urban water utilities must be in place, a problem where most urban cities in developing countries are trying to overcome (Kumpel and Nelson, 2016). The water supply service in Dilla town is characterized by intermittent water supply with regular interruption and unfair water distribution just like many cities in developing countries with a water consumption rate of less than 20 l per capita per day (Debela and Muhuye, 2015; Kanno et al., 2020; Kumpel and Nelson, 2016).

Intermittent water supply is mainly caused by a variety of factors, which include inadequate water and energy supplies, pipe breaks and leaks, and municipal rationing in response to water shortages (Kumpel and Nelson, 2016; Van den Berg and Danilenko, 2010). It has many adverse implications for users, including poorer water quality and higher costs (Kaminsky and Kumpel, 2018), increases the risk of contamination, and ultimately the disease burden for water consumers (Kumpel and Nelson, 2016). In the absence of a safely managed and reliable public piped water service, residents in struggling and emerging cities purchase water from private sources or obtain it directly from natural sources (UNESCO, 2019).

Rainwater can be a good water source when emergencies last from mid to longer periods, where there is time to investigate yields, and if appropriate catchment and storage facilities are available (House and Reed, 1997). When compared with surface water, the raw water quality of rainwater is much safer, and less prone to contamination if properly managed and capable of meeting the WHO drinking water standards with no energy requirement in areas where there is an abundant annual rainfall (Parker et al., 2013; Nijhof et al., 2010; Worm and Hattum, 2006; Thomas and Martinson, 2007; Rodrigo et al., 2009; Ndomba and Wambura, 2010; Nguyen et al., 2013; Temesgen et al., 2015). As a result, it has been suggested as an alternative potable water source to the piped system in different setups including during public health emergencies (Kim et al., 2012; House and Reed, 1997). According to the Pan American Health Organization, rainwater harvesting practice at health care facilities can be a resilient approach for the health sector during natural and man-made disasters (PAHO, 2017).

Rainwater harvesting systems have helped and have been suggested in tackling water shortages among schools and universities in different parts of Ethiopia such as in Adama University of Science and Technology (Temesgen et al., 2015), Debretabor University (Andualem et al., 2019), and Addis Ababa University (Adugna et al., 2018). Similar experiences from other teaching institutions such as UK (Lau et al., 2014; Shah et al., 2013), Malaysia (Hamid and Nordin, 2011), and Tanzania (Mwamila et al., 2015) revealed that rainwater harvesting systems help to alleviate water shortages for different hygienic requirements and reduce the usage of treated, piped water for non-consumptive purposes.

Rainwater harvesting can also benefit households. For instance, in Arba Minch, multistory buildings with a roof area of 60 m², and mean annual rainfall of 900 mm, have the potential of producing 46 m³ of rainwater (Feki et al., 2014). In another study conducted in Nigeria, a household with a 100 m² roof size were found to have a potential to generate between 15.23 and 30.40 m³ of rainwater which 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 (Balogun et al., 2016).

A minimum emergency water quantity standard of 15 l of water per person per day (l/p/d) was recommended by the United Nations Higher Commissioner for Refugees and humanitarian assistant agencies (UNHCR, 2015; Sphere, 2020) whereas (WHO, 2002) recommends 15–20 l/c/d and for basic hygiene and infection prevention activities in health centers, the minimum is 10 l/outpatient/day and 40–60 l/inpatient/day and a minimum is 3 l/person/day (WHO, 2013; Sphere, 2018; Sphere, 2020) of water is recommended for schools. There are arguments from scholars that, these minimum emergency water requirements to prevent COVID-19 such as hand hygiene might be modified up to 100–200 l per person per day for a family of five with a daily handwashing frequency increasing from the normal five times to ten 10 times a day (Rohilla, 2020).

However, before the use of rainwater as a source of emergency water supply, access to adequate information is critical. Information may include the amount of monthly and annual rainfall data, rainfall variability, the storage capacity, the emergency water demand, the catchment size, and the local practice of using rainwater harvesting as well as the legal context must be well addressed (House and Reed, 1997). Therefore, our study intends to assess the rainwater harvesting potential, both at the household and institutional level, its adequacy for the emergency water demand for the prevention of COVID-19, and estimation of the size of the required storage tank in Dilla Town, southern Ethiopia.

2. Materials and methods
2.1. Study area and period

The study was conducted in Dilla Town (Fig. 1), 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 m above sea level (Demelash, 2010; Debela and Muhuye, 2015).

According to the data obtained from Ethiopian National Meteorology Agency (ENMA), the 17 years (2002–2018) mean annual rainfall in the area was 1464 mm (ENMA, 2018). The wettest months occur between March and October and the driest months occur from November to February. Precipitation is characterized by a bi-modal 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 groundwater (70 %) and surface water (30%) sources (CWC, 2016; Kanno et al., 2020). However, in recent years, owing to the high rate of urbanization coupled with industrial development and population growth, as well as a change in precipitation patterns, the available water to satisfy the water demand has radically decreased, representing a 38% deficit between 2016–2018 (Debela and Muhye, 2015; Kanno et al., 2020). The use of rainwater harvesting is common in Dilla Town. A simple household level rainwater harvesting system used in the town was shown in Fig. 2 with no first flush diversion and treatment mechanism.

2.2. Data collection methods

Rainfall data were obtained from the Ethiopian Meteorology Agency in digital form and further analyzed in a spreadsheet (ENMA, 2018). According to Shakya and Thanju (2013), rainfall is the most unpredictable variable. Therefore, reliable rainfall data, preferably for at least 15 years is required from the nearest station during calculations to consider the variations. Hence, 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 (Mourad et al., 2017), were corrugated iron sheets, and the average roof size of 60 m² and a runoff coefficient of 0.8 was employed to account for evaporation loss and possible first flush (Thomas and Martinson, 2007). To include households with different ranges of roof sizes, rainwater harvesting potentials for seven typical roof sizes (40, 50, 60, 70, 80, 90, and 100 m²) were calculated.

2.3. Data analysis

2.3.1. Statistical variability (rainfall variability)

In monthly rainfall data (intera annual) and accumulated annual rainfall (mm) inter annual were expressed with coefficients of variation CV, using equation

\[
CV = \frac{S_d}{M_r} \times 100
\]  

(1)

Where CV is monthly/seasonal/annual coefficients of variation

\( S_d \) is the mean monthly/seasonal/annual standard deviation

\( M_r \) is the mean monthly/seasonal/annual rainfall

Seasons were classified based on ENMA, (2018), classification as; Summer (Kiremet) heavy rainfall seasons June, July, August, and September; Winter (Bega) dry season with frost in the morning, which includes October, November, December, and January; and Autumn (Belt) seasons with occasional showers of rain includes February, March, April, and May.

2.3.2. Estimation of the rainwater harvesting potential

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 (Rm), roof area (A), percentage of roof area utilized for rainwater harvesting (\( \beta = 50\% \) (0.5) was utilized), and roof run-off coefficient (C) as given in Eq.(2).

\[
Q_m = (R_m) \times A \times \beta \times C
\]

(2)

According to Balogun et al. (2016), 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 Johnson and Kuby (2012), Bluman (2013) as:

\[
x + Z(a/2)\left(\frac{\sigma}{\sqrt{n}}\right) = Upper\ Confidence\ Limit\ (UCL)
\]

(3)

\[
x - Z(a/2)\left(\frac{\sigma}{\sqrt{n}}\right) = Lower\ Confidence\ Limit\ (LCL)
\]

(4)

\( x \) is where \( \hat{x} = \text{Mean} = \bar{R}_m \); \( Z(\alpha/2) \) =Confidence coefficient; \( \sigma / \sqrt{n} \) = Standard error of mean and Z (\( \alpha/2 \)) \( \sigma / \sqrt{n} \) Maximum error of estimate (MEE), \( \sigma \) = 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 harvest-able 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 Johnson and Kuby (2012), Bluman (2013) as stated in Balogun et al. (2016) were obtained as

\[
Q UCL = [\bar{R}_m + MEE] \times A \times \beta \times C\]

(5)

\[
Q LCL = [\bar{R}_m - MEE] \times A \times \beta \times C
\]

(6)

Finally, for the second approach, harvest-able 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;

\[
Q UCL = \bar{R}_m \times A \times \beta \times C[1 + COV]
\]

(7)

\[
Q LCL = \bar{R}_m \times A \times \beta \times C[1 - COV]
\]

(8)

2.3.3. Proposed basic water requirement for households

For households, emergency water requirement we have used the standard set by Sphere (2020), which is 15 l/c/day, and the standard set by (WHO, 2002) which is (15–20 l/c/day) we take the maximum 20 l/c/day of water for emergency water need at the household level for comparison. From the total daily water requirement, 7.5 l was allocated for drinking and cooking purposes whereas the remaining (7.5 l when using the Sphere standard) and (13.5 l 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 based which is taken from Ethiopian Central Statistical Agency (CSA, 2007).

Table 1

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

| Selected Public Institution in Dilla Town | Total number of institutions | Assumed average roof size in (m²)(Adugna et al., 2018) | Daily water demand | Total number of individuals served per day |
|------------------------------------------|------------------------------|------------------------------------------------------|-------------------|------------------------------------------|
| Hospital (Dilla University Referral Hospital) | 1 | 14273 | 40–60 l/patient/day (World Health Organization, 2013) | 271 patients/day |
| Health centers | 2 | 1119 | 40–60 l/patient/day (World Health Organization, 2013) | 66 patients/day |
| Primary schools | 12 | 2114 | 3 l/person/day for drinking and hand washing (Sphere, 2018; Sphere, 2020; World Health Organization, 2013; INEE, 2012) | 1200 students/day |
| Secondary schools | 3 | 2114 | 3 l/person/day for drinking and hand washing (Sphere, 2018; Sphere, 2020; World Health Organization, 2013; INEE, 2012) | 700 students/day |
| Technical and Vocational schools | 2 | 7546 | 3 l/pupil/day for drinking and hand washing (Sphere, 2018; Sphere, 2020; World Health Organization, 2013; INEE, 2012) | 1500 students/day |
| Colleges | 8 | 23999 | 20 l/person/day for drinking and hand washing for boarding schools and additional 20 l per person per day for conventional flushing toilets (Sphere, 2018; Sphere, 2020; World Health Organization, 2013; INEE, 2012) | 10,000 students/day |
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  | 313.1  | 327.3  |
| SD        | 149.8  | 126.7  | 26.9   |
| COV (%)   | 39.3   | 27.5   | 4.4    |

SD: Standard deviation; COV: Coefficient of Variation.

2.3.4. 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 (Adugna et al., 2018). We took the assumption that the roof sizes of the institutions in the two cities would be proportional. The patient load for the health centers 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 months) during the summertime. However, for Dilla University the calculation takes into consideration all the days (365 days) in the year because the university is giving summer courses.

2.3.5. Storage size determination

To determine the required storage volume at the household level, the maximum rainwater harvesting potential limit was used. For the institutions, the required monthly water demand multiplied by the dry period will give the required storage capacity.

\[
\text{Required storage capacity} = \text{demand} \times \text{dry period} \quad (9)
\]

3. Results

3.1. Annual, seasonal, and monthly rainfall distribution for Dilla town

The average rainfall (for the historical period) was 1464 mm (Fig. 2). According to the data obtained from the Ethiopian Meteorology Agency, out of the total study years, the highest average rainfall in the study area was 2781.1 mm, recorded in 2008 while the lowest average rainfall was 974 mm, recorded in 2003. Besides, a comparison of annual rainfall for the study period as shown in Fig. 2 indicating an 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 (1983) rainfall variability index (which is COV expressed in percentage terms), the seasonal rainfall pattern was less variable with an index of <20% in winter and there is highly variable rainfall in summer with a coefficient of variation index of >30% while rainfall in autumn was moderately variable with an index between 20 and 30%.

Between 2002 and 2009, the highest monthly rainfall occurred in November and June in 2008, while October, 2011 recorded the highest monthly rainfall between the years 2010 and 2018. 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 also indicated that the seasonal changes from summer to winter are accompanied by heavy rainfall patterns in Dilla town.

Dilla town has a bi-modal 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 (Fig. 4). 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 at 983.2 mm in November 2008 followed by 894.2 mm in October, 2011 as shown in (Fig. 3).

The highest variability of monthly rainfall was 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 Hare (1983) rainfall variability index, all the months exhibited high variability with COV (%) >30% except for December, which exhibited moderate variability between 20 and 30%.

3.2. Rainwater harvesting potential for households in Dilla town

In the proposed household roof sizes, June and August recorded the highest and lowest rainwater harvesting potential respectively. Households with a roof size of 40 m² have an average rainwater harvesting potential of 3.63 m³ during June and 0.47 m³ in August. Similarly, a household with a roof size of 100 m² has an average potential to harvest 9.65 m³ of rainwater during June and 1.25 m³ during August (Table 3). The maximum and minimum values (confidence limits) of household-level harvestable rainwater for each month were calculated using the Maximum Error estimate and the Coefficient of variation were indicated in the supplementary materials (SM1).

3.3. Household-level emergency water demand met by rainwater harvesting (RWH)

The estimation of monthly harvest-able rainwater mainly depends on the confidence limits calculated using the coefficient of variation (COV) approach, because it explained the rainfall variability better than the approach used by the maximum error estimate. For example, a household in Dilla town with a roof area of 40 and 100 m² have the potential to harvest 7.2–39.66 and 19.11–105.35 m³ of rainwater respectively. The highest and lowest values were recorded during June and September, respectively as indicated in (SM1).

As indicated in (Fig. 5), rainwater harvesting potential was not adequate to satisfy the emergency water demand during December and January across all kinds of roof sizes whereas higher roof sizes such as 100 m² and above can satisfy the monthly water demand more than 80% during the dry months (December and January) and surplus can be harvested in most of the months when the maximum limit of the rainfall is considered.

Table 3
Monthly average harvest-able rainwater in (m³) with different household roof sizes.

| Month   | Household roof size in m² |
|---------|--------------------------|
|         | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| January | 3.43 | 4.29 | 5.15 | 6.01 | 6.86 | 7.72 | 9.12 |
| February| 1.79 | 2.24 | 2.68 | 3.13 | 3.58 | 4.02 | 4.76 |
| March   | 1.17 | 1.47 | 1.76 | 2.05 | 2.35 | 2.64 | 3.12 |
| April   | 2.15 | 2.68 | 3.22 | 3.76 | 4.29 | 4.83 | 5.70 |
| May     | 2.46 | 3.08 | 3.69 | 4.31 | 4.92 | 5.53 | 6.54 |
| June    | 3.63 | 4.54 | 5.45 | 6.36 | 7.27 | 8.18 | 9.65 |
| July    | 1.36 | 1.69 | 2.04 | 2.39 | 2.71 | 3.06 | 3.61 |
| August  | 0.47 | 0.59 | 0.74 | 0.82 | 0.94 | 1.06 | 1.25 |
| September | 0.49 | 0.61 | 2.04 | 0.86 | 0.98 | 1.11 | 1.31 |
| October | 1.34 | 1.67 | 2.00 | 2.34 | 2.67 | 3.01 | 3.55 |
| November | 2.25 | 2.82 | 3.38 | 3.94 | 4.51 | 5.07 | 6.0 |
| December | 2.87 | 3.59 | 4.31 | 5.03 | 5.75 | 6.47 | 7.64 |

Total | 23.42 | 29.28 | 35.14 | 41.00 | 46.86 | 52.71 | 62.23 |
Fig. 3. Annual rainfall distribution in (mm) from 2002 to 2018 in Dilla town, Southern Ethiopia.

Fig. 4. Mean monthly rainfall pattern in (mm) from 2002 to 2018 for Dilla town, Southern Ethiopia.

Fig. 5. Monthly emergency water demand met in (%) by maximum rainwater harvesting potential among households with different roof sizes in Dilla Town.

Fig. 6. Monthly emergency water demand met in (%) by minimum rainwater harvesting potential among households with different roof sizes in Dilla Town.

3.4. Institutional rainwater harvesting potential in Dilla town

When the lowest limit of the rainwater harvesting potential is considered (determined by using the Coefficient of variation) a household with a roof area of 100 m² could satisfy 6.8 to 145.2% of the emergency water consumption during the wet months and RWH could not supply during the dry months (December, January, February, and March). The wet months could provide the extra volume of rainwater for the dry months by considering the lowest rainwater harvesting potential as indicated in (Fig. 6, Fig. 7).

Average institutional rainwater harvesting was found to be the highest among the colleges in Dilla University where they can produce a total of 112,449.5 m³ of rainwater annually with the highest and the lowest being during October and December respectively as indicated in Table 4. Health centers in Dilla Town were found to be the lowest among the institutions examined for rainwater harvesting potential.
maximum rainwater storage tanker sizes were 1 and 7 m³, respectively, while for a household with 100 m² roof size 1 and 17 m³ storage sizes were the minimum and maximum sizes taking into account the effects of rainfall variability to determine the confidence limits.

For the storage requirements of the institutions, the monthly demand for the dry months was used to determine the storage requirements. Hence, the collages in Dilla town need the largest storage sizes to accommodate the rainwater which is 48,000 m³ which means 6000 m³ each college to store adequate water for the dry seasons (Table 6).

4. Discussion

Access to clean water and sanitation are essential and must be available during normal times and extra must be delivered in emergencies such as the current pandemic (Tortajada, 2020; GRM, 2009). In such critical times, lack of clean and adequate water for drinking and proper hygienic practices become a major concern for most urban utilities in developing countries (Kumpel and Nelson, 2016). Many cities around the world obtain their water from great distances - often over 100 km away. Rainwater harvesting could give a feasible and resilient solution to this practice of increasing dependence on the upper streams of the water resource supply area which is not sustainable (UN-Habitat, 2005).

In this study, the rainwater harvesting potential and the storage sizes among households with different roof sizes and selected key public institutions were estimated using 17 years of rainfall data. The intra-annual variation (CV) for Dilla town ranged between 27.9 and 246% which is an indication of high variability in the rainfall distribution (Aladenola and Adeboye, 2010). This could potentially affect the rainwater harvesting potential at the household and institutional level during the driest months. But since there is adequate harvest-able rainwater during the wet seasons, water-saving practices can compensate for the water shortage during the driest months. The potential to transfer excess water from the wet season to later use in the dry season could be a challenge because it requires higher storage tank installations. Because of the higher rainwater harvesting potential among households and public institutions in the study area, the size of the storage tanks for households and institutions indicated in this study were higher as indicated in Tables 5 and 6. This requires a higher investment power which could be a challenge in low economy institutions, as also reported by Abdulla and Al-Shareef (2006).

The rainwater harvesting potential from the selected public institutions can supplement 30.3% of the water supplied by Dilla Town’s water supply agency in 2018 as reported by Kanno et al. (2020). This supplement could be increased if other public institutions are involved and if improvements will be made to increase the harvest-able roof sizes above 50%.

The institutional rainwater harvesting potential for Dila University dormitory and administration offices was in the range of 345,24.5–190,374.5 m³ (where each college having an average RWH potential of 14,056.2 m³). This was higher than previously reported findings in Ethiopian universities such as Debre Tabor University (Andualem et al., 2019), where the available water to be collected from dormitory buildings were 24,671.43 m³ and lower when compared to a single college rainwater harvesting potential reported by Mishra et al., (2020) in India (Amity University Mumbai campus) which was 25,379.89 m³. This discrepancy might be attributed mainly to the difference in roof sizes and the rainfall variability in the two study areas. Emergencies 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 afterward (World Health Organization, 2003). 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 quality just like in the case of diarrheal diseases.

### Table 4
Average institutional rainwater harvesting potential in Dilla Town.

| Month      | DURH | HC's | PS | SS | VS | Colleges |
|------------|------|------|----|----|----|----------|
| January    | 175.3| 13.7 | 311.5 | 77.9 | 185.3 | 2357.7 |
| February   | 477.4| 37.4 | 848.6 | 212.1 | 504.8 | 6421.6 |
| March      | 804.2| 63.1 | 1429.4 | 357.3 | 850.4 | 10818.0 |
| April      | 1026.1| 80.45 | 1823.8 | 459.9 | 1085.0 | 13803.1 |
| May        | 1224.7| 96.01 | 2176.7 | 544.2 | 1295.0 | 16474.3 |
| June       | 638.9| 50.1 | 1135.5 | 283.9 | 675.5 | 8593.6 |
| July       | 418.8| 32.8 | 744.4 | 186.1 | 442.6 | 5633.7 |
| August     | 765.9| 60.1 | 1361.3 | 340.3 | 809.9 | 10303.9 |
| September  | 878.2| 68.8 | 1560.9 | 390.2 | 928.6 | 11813.6 |
| October    | 1297.1| 101.7 | 2305.3 | 576.3 | 1371.5 | 17447.3 |
| November   | 484.9| 38.01 | 861.8 | 215.5 | 512.7 | 6522.3 |
| December   | 168.1| 13.2 | 298.8 | 74.7 | 177.8 | 2261.4 |
| **Total**  | 8359.7| 1310.8 | 14858 | 3714.5 | 8839.4 | 112449.5 |

DURH= Dilla University Referral Hospital, HC= Health Centers PS= primary Schools, SS= Secondary schools, VS= Vocational schools.

### Table 5
Storage sizes for households with different roof size in Dilla Town.

| Household roof size in m² | Minimum storage size | Maximum storage size in m³ |
|---------------------------|----------------------|---------------------------|
| 40                        | 1                    | 7                         |
| 50                        | 1                    | 8                         |
| 60                        | 1                    | 10                        |
| 70                        | 1                    | 11                        |
| 80                        | 1                    | 13                        |
| 90                        | 1                    | 14                        |
| 100                       | 1                    | 17                        |
Our study showed that Dilla University’s Referral hospital can achieve 35.4–262.3 % of its emergency water supply from rainwater which is very crucial in terms the infection prevention as well as economic terms. For example, hospitals in the US that are among the institutions with high water-usage were estimated to benefit 81–122 million liters of saved water per year if they could use rainwater (Fulton, 2018).

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 (WHO, 2002; World Health Organization, 2003). Therefore, the rainwater can be used for certain infection prevention tasks even with lower water quality levels, whereas care must be taken in using rainwater for medical activities such as hemodialysis, which requires 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 (WHO, 2002; World Health Organization, 2003).

Different studies tried to estimate the rainwater 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 (Balogun et al., 2016), where, using the Maximum error Estimate for calculation, a roof size of 100 m² had a rainwater harvesting potential between 18.16 and 27.45 m³, while 15.23 and 30.40 m³ of water can be harvested using the Coefficient of variation for calculation. Whereas, for Dilla town even smaller roof sizes such as 40 m² gave a higher amount of rainwater (15.71–31.1541.73 m³ using MEE) and (7.2–39.66 m³ using COV) for calculation. But rainwater harvesting potential was found to be lower (35.14 m³ of harvestable rainwater) when compared to the rainwater harvested with a similar finding from Arba Minch (a city also located in southern Ethiopia) 46 m³ using a similar roof size of 60 m² (Feki et al., 2014). Rainwater 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 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 (Adugna et al., 2018).

Different standard-setting and humanitarian agencies such as (WHO, 2020; INEE, 2012; UNICEF, 2020) are stressing that for strong personal prevention practices like hand washing 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, rainwater harvesting can be a valuable source of water supply for the strict hygiene purposes needed during pandemic areas with limited or unreliable water supply (UN Water, 2016; Chubaka, 2018).

Our findings can also imply the water security status of households and the Dilla town in general. In a study done at Addis Ababa city, Ethiopia (Assefa et al., 2019), water security was assessed from three dimensions, namely water supply sanitation, and hygiene. The water supply dimension takes into account different variables for the assessment such as the proportion of the population with piped water supply; water supply service duration; per capita water consumption; the percentage of non-revenue water (NRW); conforming to water quality standards; affordability of domestic water supply tariff. Our finding indicated that rainwater harvesting can contribute directly to 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 the household level and the other is by making water available at an affordable price at the household and institutional level. It can also indirectly enhance the water security problems by reducing the stress on the formal water supply services in such emergencies. Self-help RWH water supply systems can enhance water security through easy access, low cost, and ease of management for households and institutions (Chubaka, 2018).

In Dilla Town, the main sources of water supply are deep boreholes and, Legga Dara River (Debele and Muhye, 2015; World Health Organization, 2013). However, rainwater is mostly an overlooked water source that could easily be an accessible and sustainable source of safe water supply like most countries located in the tropical and subtropical climates (Chubaka, 2018; Ndub and Orisakwe, 2010; World Health Organization, 2003).

Since, the rainwater 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 harvest-able 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.

### 4.1. Strength and limitation of the study

The strength of this study is that it tried to address the rainwater harvesting potential both for households and major public institutions by considering the rainfall variability into consideration during the calculation. Since hand washing is the simplest, cost-effective, and most effective prevention strategy, handwashing frequency is expected to increase both at household and institutional levels. As a result, the water demand is also expected to 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 needed for the increased water demand for hygienic purposes during pandemics like COVID-19 for calculation.

### 5. Conclusions

This study confirms that rainwater harvesting for households with different roof sizes is a viable water source option, with an average annual rainfall of 1464 mm. Households with a roof area of 40 m² and 100 m² have the potential to harvest 7.2–39.66 m³ and 19.11–105.35 m³ of rainwater respectively. This potential can be translated into 19.72–108.66 % and 114.3–170.5% of the household’s emergency water demand for the prevention of COVID-19 for the households with 40 m² and 100 m² roof sizes respectively.
Institutions such as Dilla University Referral Hospital (DURH) can cover 94.5–238.5 % of their emergency water demand needed for the infection prevention tasks using rainwater as the single water source.

Taking the rainfall variability into consideration, the minimum storage size required for all the households with different roof sizes were 1 m³ and the maximum rainwater harvesting storage tanker sizes were 7 m³ for a household with 40 m² roof size and 17 m³ for a house with 100 m² roof size respectively. The storage size estimated for the institutions ranges from 642–48,000 m³. Excluding the rainwater harvested from households, the rainwater harvesting potential from the selected public institutions in Dilla town can supplement 30.3% of the water supplied by Dilla Town’s water supply agency in 2018. We have concluded that rainwater can be one alternative option as a source of water for emergency water demand in Dilla town. Furthermore, observational studies must also be conducted to quantify the actual emergency water demand needed for all the hygiene and infection prevention measures needed to combat the COVID-19 both at the household and institutional level. The priority that must be given to water quantity versus water quality must also be investigated.

Declaration of Competing Interest

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

Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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Author Contributions

Conceptualization, GGG Methodology, GGK and ZAL; Software, GGK; Validation, RVW and MBA; Formal Analysis, GGK and ZAL; Investigation, GGK, ASA and ZGA; Resources, GGK ASA, HT and ZGA; Data Curation, GGK, RVW, and MBA; Writing – Original Draft Preparation, GGK and ZAL; Writing – Review & Editing, GGK, RVW, HT, and MBA; Visualization, GGK, RVW, and MBA; Supervision, ASA, ZGA, RVW and MBA; Project Administration, GGK; Funding Acquisition, GGK, HT.

Ethics Statement

This secondary analysis was exempted from ethical review approval, because it used publicly available, secondary data. However, we have a letter of permission to gather key information used in the calculation.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envrc.2021.100077.

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