Journal of Applied Science, Engineering, Technology and Management
Vol. 02, Issue 02, December 2024 pp. 15 - 24

A survey on the need to incorporate rainwater harvesting systems as an alternative domestic water source in Ghana

Duke Mensah Bonsu ANTWI (PE, GHIE)
Chemical Engineering dept.
Kumasi Technical University
Kumasi-Ashanti, Ghana
damb397@yahoo.com
duke.mbantwi@kstu.edu.gh

Isaac Kwadwo AMANKWAA
Mechanical Engineering dept.
Kumasi Technical University
Kumasi-Ashanti, Ghana
isaacamankwaa@gmail.com
isaac.kamankwaa@kstu.edu.gh

Ami Johannes
Department of Chemical and Petrochemical Engineering
University of Mines and Technology,
Tarkwa, Ghana.
jami@umat.edu.gh

Emmanuel Agyekum
Chemical Engineering dept.
Kumasi Technical University
Kumasi-Ashanti, Ghana
agyekum124@gmail.com

Daniel AMANIAMPONG
Chemical Engineering dept.
Kumasi Technical university
Kumasi-Ashanti, Ghana
danielamaniampong106@gmail.com

Theophilus Ofori AGYEKUM
Chemical Engineering dept.
Kumasi Technical university
Kumasi-Ashanti, Ghana
theophylls80@gmail.com

Harriet Kwakye BOATENG
Chemical Engineering dept.
Kumasi Technical university
Kumasi-Ashanti, Ghana
kwakyeboatenharriet@gmail.com

Abstract*—This research survey seeks to gather responses in rainwater gathering and storage using harvesting systems as a key alternative. About 502 responses were gathered. Averaging 8 persons per household and 6 rooms per household. 73.1 % of males and 26.9 females. The main source of water includes GWCL (37.8 %), Borehole/groundwater (59.6 %), both GWCL & Borehole (1 %), Both Rainwater & GWCL (1 %), other unspecified sources (0.6 %). 58.2 % responded 'Yes' to the collection of rainwater to 41.8 'No' responses. Methods for collecting rainwater includes roof gutter & drain spouts (37.8 %), open containers (40.8 %), other unspecified means (14.7 %). 56.8 % said 'YES', with about 2 % saying 'IF THE NEED BE' and 41.2 % responding 'NO' to the need to collect rainwater for future use. Roofs age also contribute to water quality, 45.2 % were above 10 years, 30.7 % between 7-10 years, 14.3 % between 4-6 years and 9.8 % between 1-3 years. Furthermore, 65.3 % respondents had heard of rainwater harvester systems. About 75.7 % responded to 'NO' for not having rainwater systems installed. About 83.3 % responded 'NO' to treating the collected water before use. About 64.1% are willing to treat the harvested rainwater. About 61.4 % respondents indicated the reduction in their water bill. The t-statistic and P-value results suggested collecting rainwater does not appear to be associated with a difference in the number of rooms in a household. The Chi-square statistic of 14.394 and a P-value of 0.000148 establishes a strong association between collecting rainwater at the household during the rainy seasons and seeing a reduction in water bills during the rainy season compared to reliance on traditional water supplies alone. Households that collect rainwater are significantly more likely to see a reduction in their water bills. There is a growing interest in the gathering, harvesting and the purification of rainwater for domestic use as a great alternative.

***Keywords*—Rainwater harvest system, gutter systems, downspouts, drainage pipes, Below-ground systems.**

I. Introduction

The provision of clean potable drinking water for domestic use has become a major problem for developing countries which Ghana is not an exception. Despite water being the most available resource on earth, just a small percentage of it is wholesome for domestic use [1]. The continuous growth in population has created an increasing demand for potable water, prolonged periods of droughts and the distraction of our water bodies via pollution from industrial generated waste [2, 3]. Rainwater harvesting is defined as the gathering and storing of rainwater for several usages including irrigation, landscaping, domestic duties, and, in certain circumstances, for drinking water. It is a long-standing custom that has regained popularity in recent years as people become more concerned about water scarcity and environmental sustainability [4].

The basic concept behind rain harvesting is simple: rainwater that falls on roofs, pavements, and other surfaces is collected and directed into storage tanks or reservoirs for later use [5]. This can be done through various methods, including gutter systems, downspouts, and drainage pipes. We have two main types of rain harvesting systems. Above-ground

eISSN 2584-0371

Received for review: 04-06-2024
Accepted for publication: 08-07-2024
Published: 19-07-2024

systems; these typically involve collecting rainwater from rooftops and storing it in tanks or barrels located above ground [6]. These systems are easy to install and maintain, making them popular for residential use. Below-ground systems involve collecting rainwater in underground tanks or cisterns. While more complex to install, below-ground systems offer the advantage of saving space and protecting the stored water from evaporation and contamination [7].

In Rain harvesting, we explore the significance of rain harvesting, its benefits, and considerations for its implementation. Rain harvesting traces its roots back to ancient civilizations like the Romans and Greeks, who ingeniously captured rainwater for agricultural and domestic use [8]. Over time, as urbanization and industrialization accelerated, this practice waned. However, recent concerns over water scarcity and sustainability have reignited interest in rain harvesting, one of the primary benefits of rain harvesting is its contribution to environmental conservation [9]. By capturing rainwater, we reduce the strain on traditional water sources such as rivers and reservoirs, preserving these ecosystems and their biodiversity.

Moreover, rain harvesting helps mitigate the adverse effects of stormwater runoff, such as soil erosion and water pollution. Rain harvesting offers substantial economic advantages, both at the individual and community levels. Utilizing harvested rainwater for non-potable purposes like irrigation and sanitation can lead to significant cost savings on water bills [10].

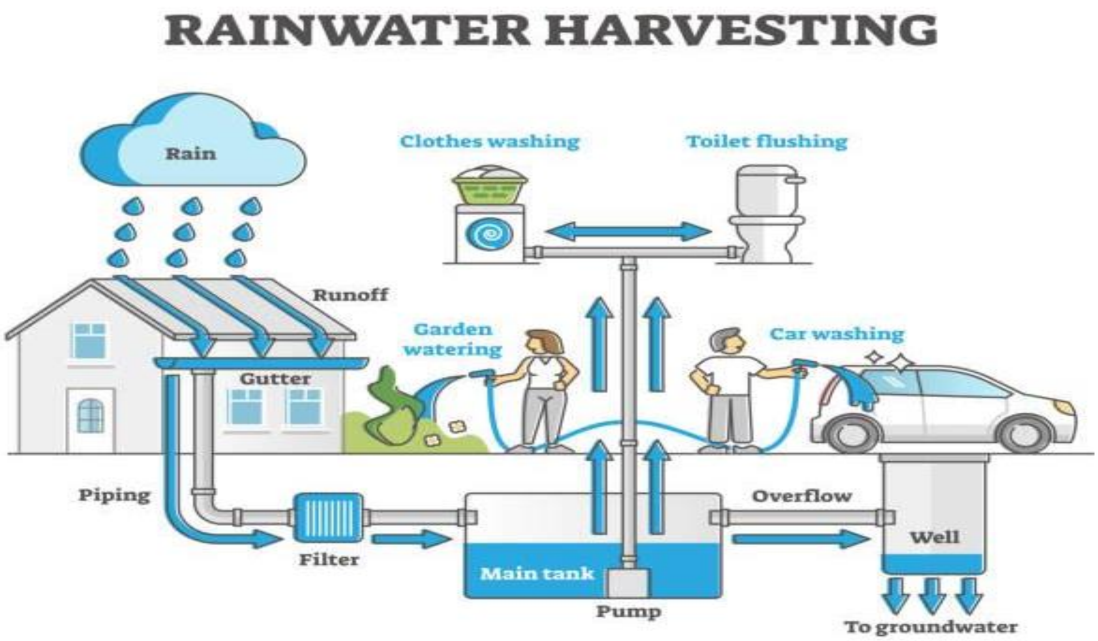

Figure 1: schematic representation of the Rainwater harvesting system

Furthermore, in regions where water is scarce or expensive, rain harvesting provides a reliable and cost-effective alternative. In an era characterized by climate uncertainty, rain harvesting enhances community resilience against droughts and water shortages [11]. By decentralizing water supply systems and empowering individuals and communities to manage their water resources, rain harvesting fosters self-reliance and reduces dependence on centralized infrastructure. Despite its numerous benefits, rain harvesting is not without challenges. Factors such as local regulations, water quality concerns, and initial investment costs must be carefully considered before implementing a rain harvesting system [12].

Additionally, proper maintenance and treatment of harvested rainwater are essential to ensure its safety and suitability for various uses. Rain harvesting embodies the harmonious relationship between humans and nature, offering a sustainable solution to pressing water challenges [13]. By harnessing the power of rainfall, we do not only conserve water resources but also promote environmental stewardship and community resilience. As we navigate an increasingly uncertain future, embracing rain harvesting is not just a choice but a necessity for building a more sustainable and resilient world [14].

In Ghana, the genesis of RWH at household levels began with the use of small storage containers for the collection and storage of rainwater during the rainy seasons but currently employed the use of large concrete reservoirs for larger communities [15]. An average of 16-liter containers are placed beneath roof edges to gather water during rainfall. The collected water is then transferred into main storage containers in different households by women and children as these buckets become full [16].

In other communities, residents rely on unprotected streams, dams, rivers, dug outs and impounded reservoirs that are restocked during the rainy seasons for their domestic water. These same water sources also serve as drinking places for animals and irrigation of farm lands [17]. Harvesting of rainwater with rooftops has proven to be among the most growing domestic water resources.

Table 1: Average Rainwater Precipitation in Ghana from 1901-2022 [1]

Actual	Previous	Highest	Lowest	Dates	Unit	Frequency
1230.61	1262.45	1775.89	849.69	1901 – 2022	mm	Yearly

Table 2: Average Rainwater Precipitation in Ghana for 2022 [1]

Related	Last	Previous	Unit	Reference
Precipitation	1230.61	1262.45	mm	Dec 2022
Temperature	27.73	28.30	Celsius	Dec 2022

Precipitation in Ghana decreased to 1230.61 mm in 2022 from 1262.45 mm in 2021. Precipitation in Ghana averaged 1236.00 mm from 1901 until 2022, reaching an all-time high of 1775.89 mm in 1968 and a record low of 849.69 mm in 1983 [18].

II. Methodology

A. Data Collection

a) Instrument: Google Forms was utilized as the primary tool for data collection due to its accessibility, user-friendly interface, and ability to seamlessly gather responses in a structured format.

b) Form Design: The Google Form was carefully crafted to extract specific information relevant to the research objectives. This included a variety of question types (e.g., multiple-choice, open-ended) to capture both quantitative and qualitative data.

c) Data Validation: Measures were integrated within the form to ensure data validity, such as setting response constraints, utilizing dropdown menus for specific choices, and including mandatory questions.

d) Distribution: The Google Form was disseminated to the target participants through various channels (e.g., email, social media, direct link) with clear instructions on how to access and complete it.

B. Data Analysis

a) Export and Organization: Responses collected via Google Forms were automatically compiled into a Google Sheets spreadsheet for convenient data management and analysis.

b) Data Cleaning: The dataset was meticulously scrubbed to address any inconsistencies, errors, or missing values. This process involved eliminating duplicate entries, correcting typos, and standardizing responses as needed.

c) Quantitative Analysis: Quantitative data gathered from the multiple-choice and Likert scale questions were examined using descriptive statistics (e.g., frequencies, percentages, means) and inferential statistics (e.g., t-tests, chi-square tests) based on the research questions and hypotheses.

d) Qualitative Analysis: Open-ended responses underwent thematic analysis, identifying recurring patterns, themes, and key insights relevant to the research questions. This included coding, categorization, and interpretation of qualitative data.

C. The 't-test' analysis

To conduct a t-test analysis on this dataset in Python, we needed to identify a specific hypothesis to test. We compared the average number of rooms between households that collect rainwater and those that do not. Here's a step-by-step guide:

1. First, the dataset was loaded into python.
2. The relevant columns 'Number of rooms in your household:', 'Do you collect rainwater at your household during the rainy seasons?' from the dataset were selected.
3. All the null values in the selected columns were dropped.
4. We converted the categorical column 'Do you collect rainwater to your household during the rainy seasons?' to numerical values for the t-test.

   data['Do you collect rainwater at your household during the rainy seasons?'] = data['Do you collect rainwater at your household during the rainy seasons?'].apply(lambda x: 1 if x == 'Yes' else 0)
5. We splitted the data into two groups in python:
   rainwater_collectors = data[data['Do you collect rainwater at your household during the rainy seasons?'] == 1] ['Number of rooms in your household:']
   non_collectors = data[data['Do you collect rainwater at your household during the rainy seasons?'] == 0]['Number of rooms in your household:']

   We performed the t-test:
   from scipy.stats import ttest_ind
   t_stat,p_value = ttest_ind(rainwater_collectors, non_collectors)
   # Output the results
   print(f"T-statistic: {t_stat}")
   print(f"P-value: {p_value}")

D. Chi-square tests analysis

The chi-square test is typically used to determine if there is a significant association between two categorical variables. A contingency table is created from these two categorical variables before performing the chi-square test.

For this analysis, we examined if there is an association between **"Do you collect rainwater at your household during the rainy seasons?"** and **"Do you see a reduction in your water bills during the rainy season as compared to reliance on traditional water supplies alone?"**

a) from scipy.stats import chi2_contingency

A contingency table was created using the pd.crosstab function to summarize the frequencies of responses for the two categorical variables. The chi2_contingency function from the scipy.stats module was used to perform the chi-square test.

contingency_table = pd.crosstab(df['Do you collect rainwater at your household during the rainy seasons?'], df['Do you see a reduction in your water bills during the rainy season as compared to the reliance on the traditional ghana water supplies alone?'])

This function returned the chi-square statistic, P-value, degrees of freedom, and the expected frequencies.

chi2, p, dof, expected =
chi2_contingency(contingency_table)

b) Results: The chi-square statistic, p-value, degrees of freedom, and expected frequencies are printed.

```
# Output the results
print(f"Chi-square statistic: {chi2}")
print(f"P-value: {p}")
print(f"Degrees of freedom: {dof}")
print("Expected frequencies:")
print(expected)
```

III. RESULTS AND DISCUSSIONS

Figure 2 displays the percentage distribution of the number of individuals occupying households of the survey respondents. An average of 8 people per household was evident from the responses gathered.

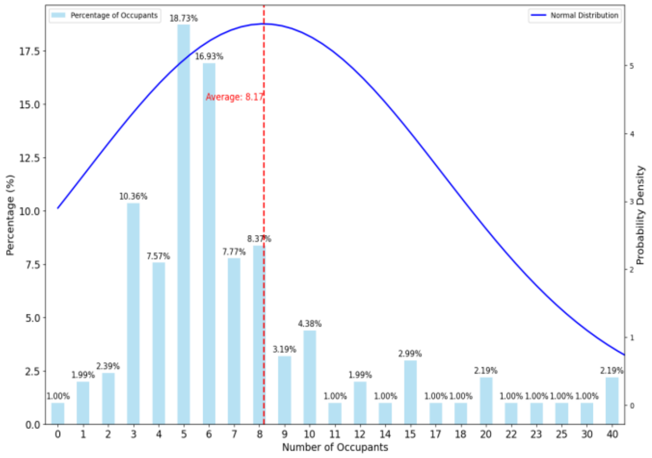

Figure 2: Percentage distribution of the number of occupants per household of respondents.

Figure 3 presents the distribution for the number of rooms in households of the survey participants. An average of about 6 rooms per household was evident per the responses gathered.

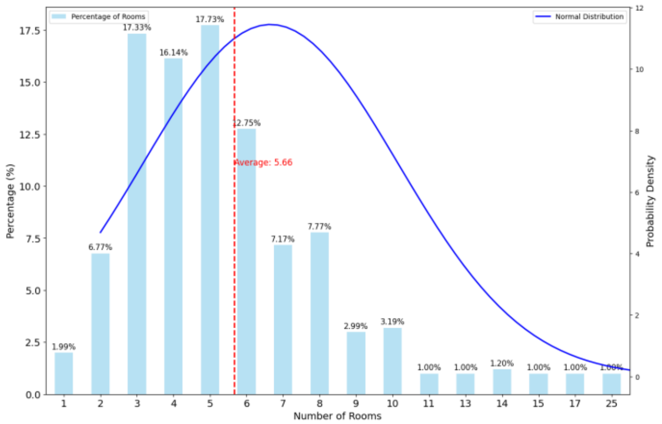

Figure 3: Percentage distribution of number of rooms per household of respondents.

Based on the data presented in Figure 4 below, 26.9% of the respondents in the survey were females as compared to 73.1% males.

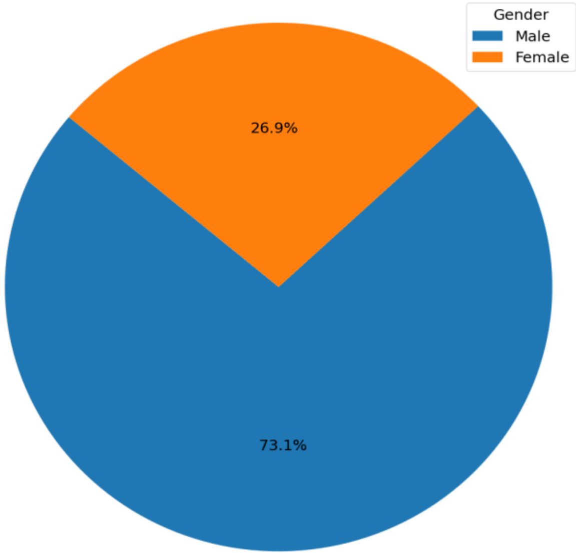

Figure 4: Gender distribution of respondents

Figure 5 below is a representation of the various sources of water as indicated by the respondents. Based on the survey findings on whether respondents collect and use rainwater during the dry season, the results indicated in Figure 6 shows that 58.2 % of households collect rainwater for domestic use as compared to 41.8 % of 'NO' responses.

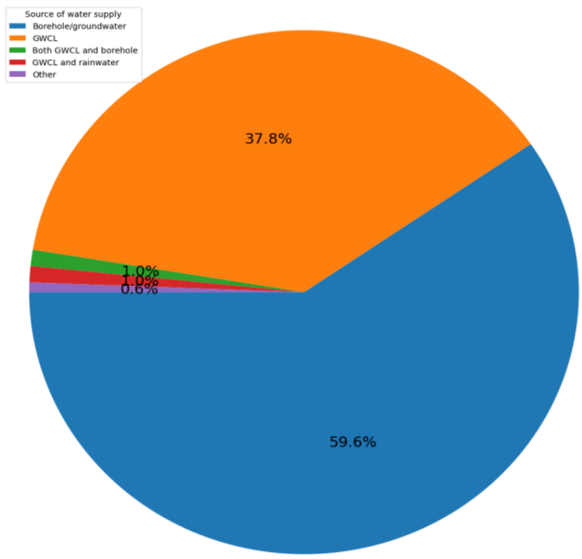

Figure 5: Distribution on the sources of domestic water supply to the households of respondents.

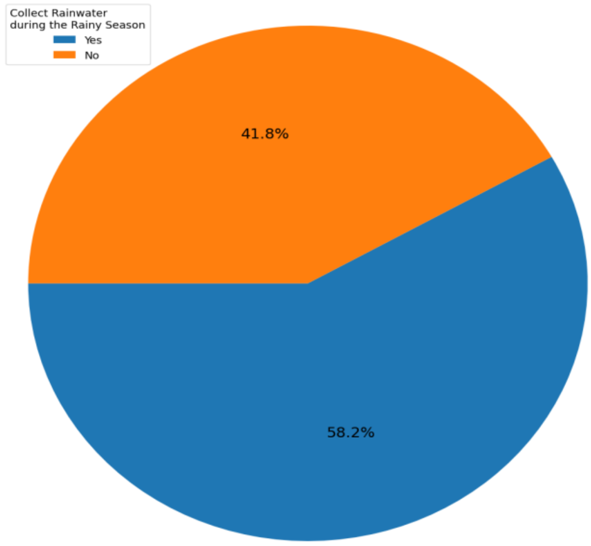

Figure 6: distribution on the rainwater collection by respondents during the rainy season.

In Figure 7, the data shows the various methods used by households to collect rainwater. The data shows that 40.8% of the respondents collect rainwater using open containers, and 37.8% of the respondent's collect rainwater through roof gutters. Other unspecified methods were also employed as shown in figure 7.

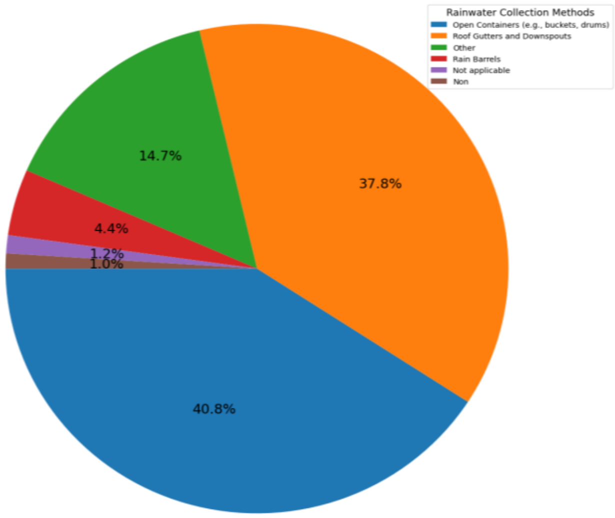

Figure 7: Distribution showing the primary methods of rainwater collection by respondents.

The figure below (Figure 8) shows the interest of respondents in collecting rainwater for future use. 56.8% of respondents would like to collect rainwater for future use while 41.2% showed no interest in collecting rainwater for future purposes. 2% of respondents would like to collect water depending on possible circumstances.

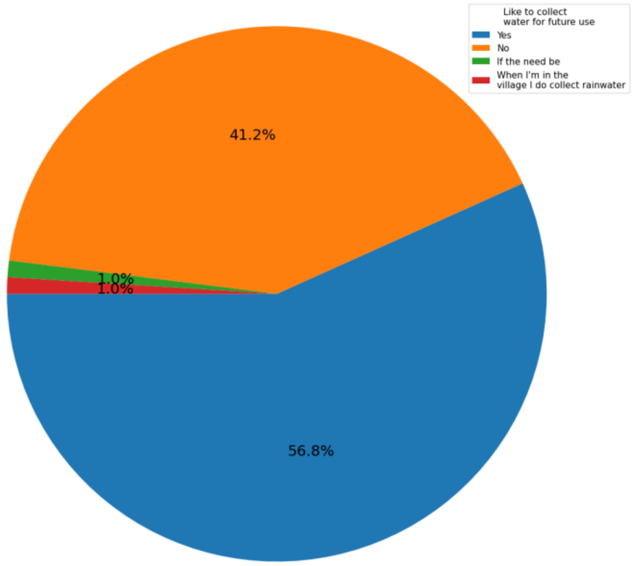

Figure 8: Distribution showing respondents' interest in the collection and storing of rainwater for future use.

Figure 9 below shows a plot of the ages of roofs in the households of respondents, various years were recorded ranging from 1 to 10 years and above. Out of the responses, 45.2% of the survey respondents have roofing installed over 10 years, 30.7% have roofing installed over a 7 to 10 year period, 14.3% and 9.8% have roofing installed over 4 to 6 years and 1 to 3 years, respectively.

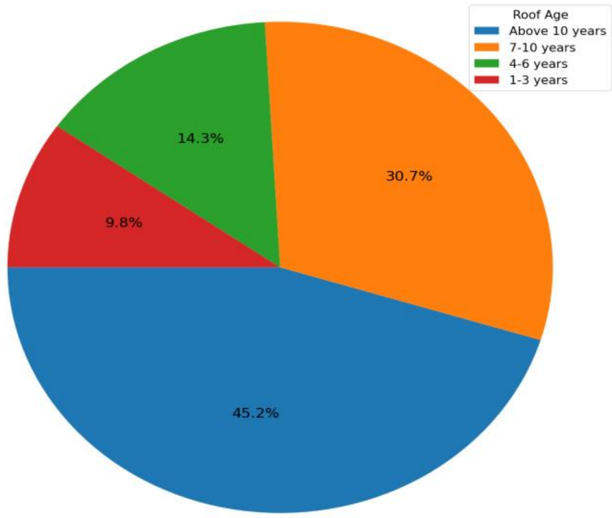

Figure 9: Distribution of roofing sheets duration (age) after installation.

Figure 10 also represents a plot of respondent's knowledge in rainwater harvester systems, 65.3% of respondents responded 'YES' to having heard of rainwater harvesting, while the remaining 34.7% have no knowledge of it.

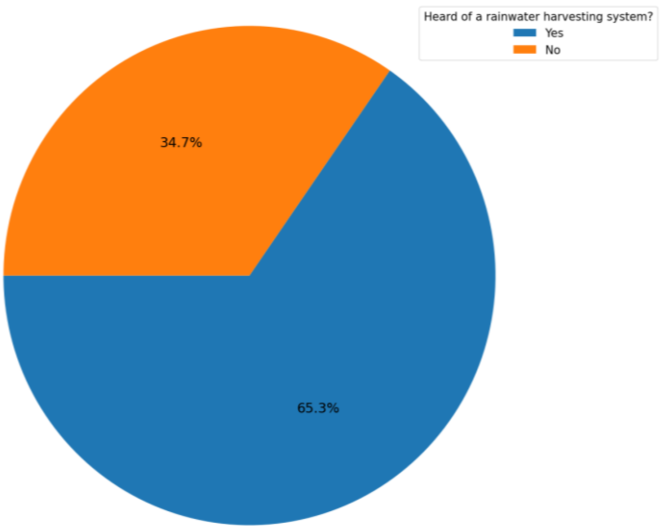

Figure 10: Distribution of respondents' knowledge on rainwater harvesting systems

Figure 11 illustrates a distribution indicating only 24.3% of respondents have rainwater harvesting systems installed in their households, as per the survey findings.

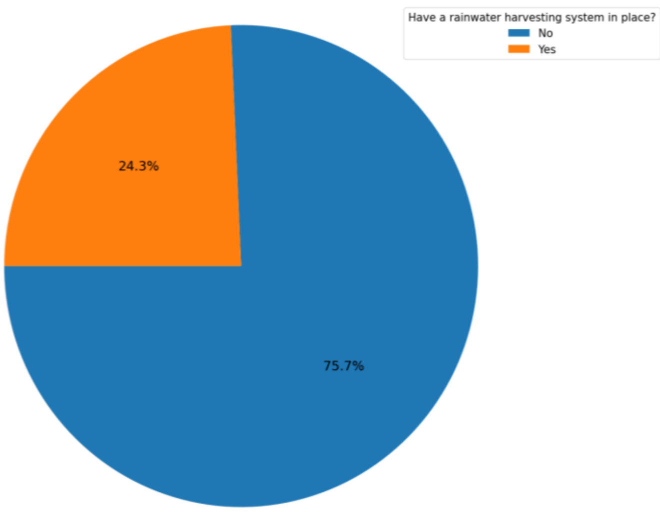

Figure 11: Distribution showing respondents having rainwater harvesting systems installed in their households.

Figure 12 provides a detailed breakdown of how rainwater is utilized for various purposes such as irrigation, domestic use, and other applications by respondents.

In Figure 13, the data shows the various percentages of rainwater that is used together with the main source of domestic water of households during the rainy seasons.

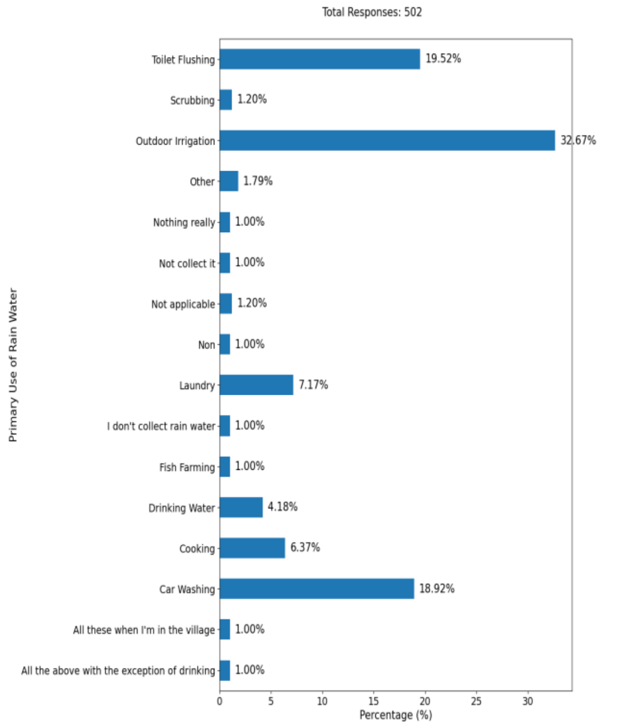

Figure 12: Percentage distribution of the primary use of rainwater usage by respondents.

The data shows that about 75.5 % of the respondents use less than 25% rainwater as part of total domestic water during this season. This clearly shows that most households do not utilize more rainwater as part of their source of water domestically.

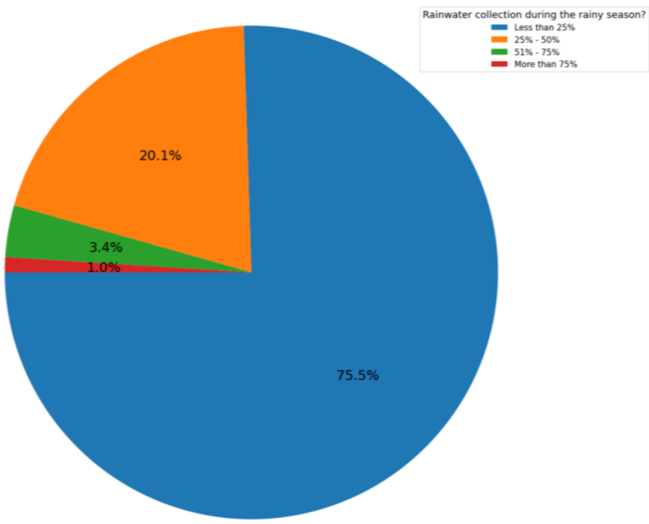

Figure 13: Distribution of the percentage of rainwater versus total water consumption by respondents.

From the results collected from the survey, Figure 14 shows that only 16.7% of households treat the collected rainwater before domestic use as compared to 83.3 % that do not treat the collected rainwater before use.

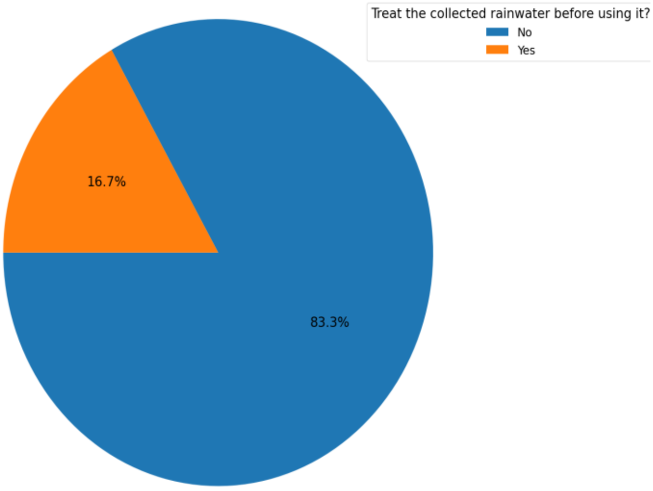

Figure 14: Distribution on responses on pretreatment of collected rainwater before use.

The information illustrated in Figure 15 is a distribution that shows 64.1% of participants expressing their willingness to purify rainwater before using it in their homes.

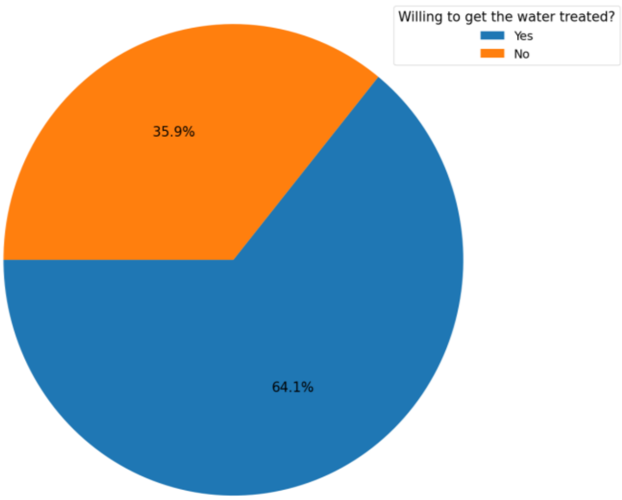

Figure 15: Distribution of respondents' willingness to treat collected rainwater before use.

Figure 16 provides a detailed breakdown of some of the primary benefits of rainwater collection. A higher percentage of respondents (63.55%) collect rainwater to cut the cost of purchasing water from other means.

Figure 17 explores the key advantages of rainwater collection compared to the challenges associated with collection methods.

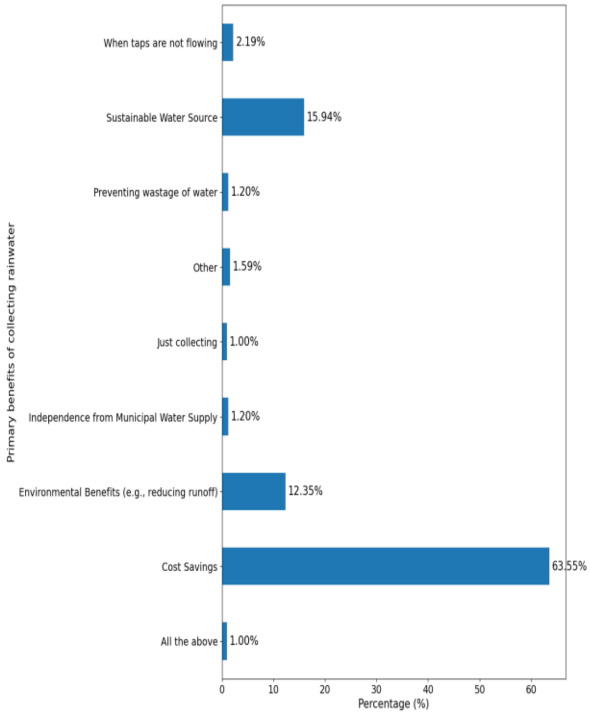

Figure 16: Distribution on the primary benefits of rainwater collection.

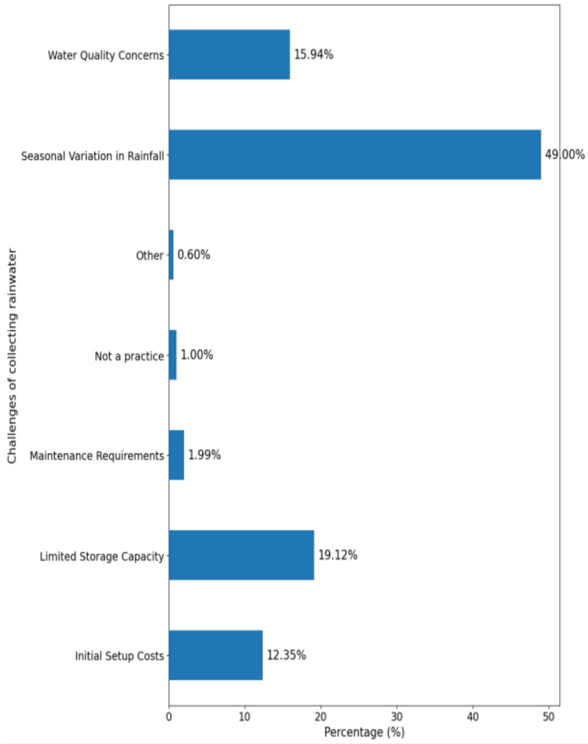

Figure 17: Distribution of the primary benefits of rainwater collection versus collection challenges.

The figure below (Figure 18) illustrates a variation in water bills paid by respondents during the rainy season. 62.7% of respondents reported paying lower bills during this season.

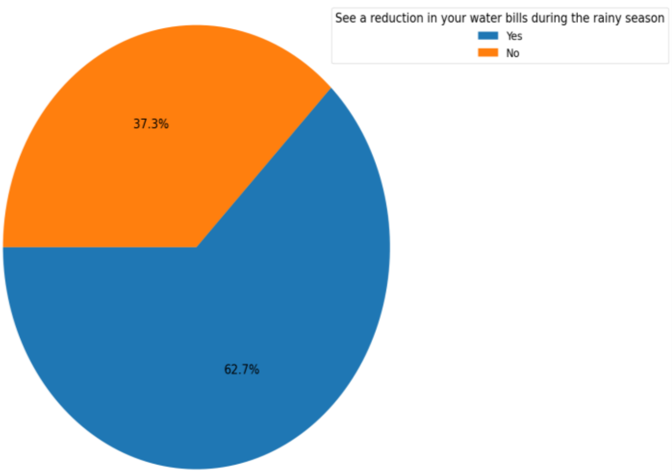

Figure 18: Distribution of the primary benefits of rainwater collection versus collection challenges.

The visual representation in Figure 19 indicates that a significant majority, specifically 61.6% of the total respondents, experience benefits from the incorporation of rainwater collection alongside traditional sources of domestic water.

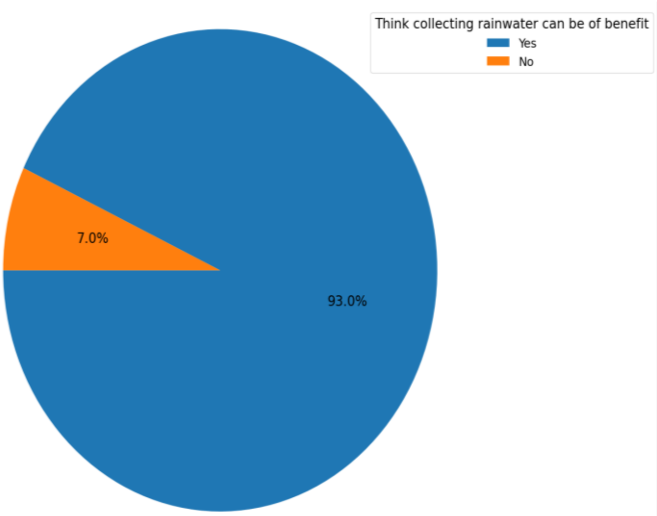

Figure 19: Distribution showing benefits of the addition of rainwater collection to the traditional sources of domestic water.

Figure 20 illustrates that storing rainwater reduces reliance on main water supply systems and lowers water bills. 61.4% of respondents don't depend solely on traditional water supply methods, saving a significant amount of money.

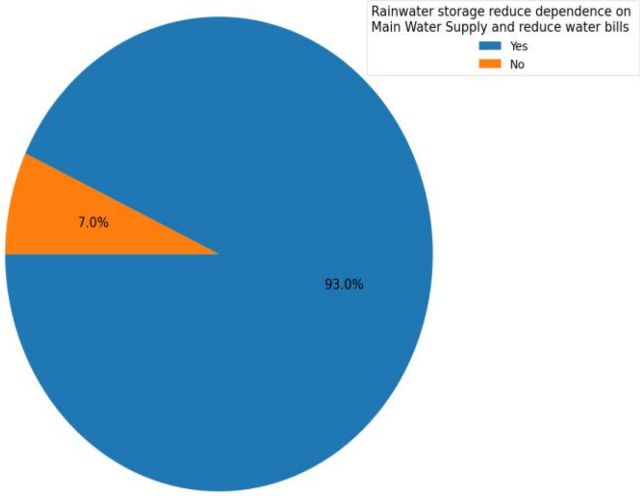

Figure 20: Distribution of response to the reduction of the dependence on traditional means of domestic water on proper rainwater collection and storage.

IV. INFERENCES

A. The 't-test'

We had a t-statistic value of -1.1416165810840224 and a P-value of 0.25415986697590753.

B. Interpretation:

t-statistic: This value indicates the difference between the two groups in terms of standard errors. A higher absolute value suggests a greater difference.

The t-statistic is a measure of the difference between the means of the two groups (households that collect rainwater and those that do not), relative to the variability in the data.

Negative value: The negative t-statistic indicates that the mean number of rooms in households that collect rainwater is lower than in those that do not.

Magnitude: The absolute value (1.142) is not very large, suggesting that the difference between the groups is relatively small when compared to the variability in the data.

P-value: This value tells us whether the observed difference is statistically significant. Typically, a *P-value* less than 0.05 indicates statistical significance. The *P-value* indicates the probability of observing a *t-statistic* as extreme as the one calculated, assuming the null hypothesis is true. The null hypothesis typically states that there is no difference between the means of the two groups.

P-value: 0.254: This value is higher than the conventional threshold of 0.05 (or 5%).

Interpretation: A *P-value* of 0.254 means there is a 25.4% probability that the observed difference (or a more extreme one) could occur by random chance if there were no real difference between the groups.

Statistical significance: Since the *P-value* is much higher than 0.05, we fail to reject the null hypothesis. This means that the data does not provide sufficient evidence to conclude that there is a statistically significant difference in the number of rooms between households that collect rainwater and those that do not.

C. Chi-square results

Chi-square statistic: 14.394247295708105
P-value: 0.0001482545292704976
Degrees of freedom: 1
Expected frequencies: [[78.22709163 131.77290837]
[108.77290837 183.22709163]]

D. Interpretation:

Chi-square statistic: Measures the difference between the observed and expected frequencies.
P-value: Indicates the probability that the observed association is due to chance. A *P-value* less than 0.05 typically suggests a statistically significant association.
Degrees of freedom: The number of independent values or quantities that can be assigned to a statistical distribution.
Expected frequencies: The frequencies expected if there were no association between the variables.

1. Chi-square statistic: The chi-square statistic of 14.394 is a measure of how much the observed counts deviate from the expected counts. A higher value indicates a greater deviation and suggests a stronger association between the variables.
2. P-value: The p-value of 0.000148 is very small, much less than the commonly used significance level of 0.05. This indicates that the probability of observing such a deviation (or a more extreme one) by chance alone is very low. Therefore, we reject the null hypothesis, which posits that there is no association between the variables.
3. Degrees of freedom: The degree of freedom (df) is calculated based on the number of categories in each variable (df = (number of rows - 1) * (number of columns - 1)). In this case, both variables have two categories, leading to df = (2-1) * (2-1) = 1.
4. Expected frequencies: These are the frequencies that would be expected if there were no association between the variables:
   - For "No" rainwater collection and "No" reduction in water bills: 78.23
   - For "No" rainwater collection and "Yes" reduction in water bills: 131.77
   - For "Yes" rainwater collection and "No" reduction in water bills: 108.77
   - For "Yes" rainwater collection and "Yes" reduction in water bills: 183.23

V. Conclusion

Rainwater collection, storage and usage as an alternative source of domestic water is highly recommended based on the responses gathered from this survey. The data collected indicated respondents' willingness to accept this means as an alternative source of domestic water for all household use.

Respondents also indicated their willingness to have rainwater harvesting systems incorporated in their houses to enable them to benefit fully from it.

The *t-statistic* and *P-value* helps to determine if there is a significant difference in the number of rooms between households that collect rainwater and those that do not. Based on the *t-test* results, there is no statistically significant difference in the mean number of rooms between households that collect rainwater and those that do not. The observed difference (if any) could easily be due to random variation in the sample data. These results suggest that, with the given dataset, collecting rainwater does not appear to be associated with a difference in the number of rooms in a household.

Given the chi-square statistic of 14.394 and a p-value of 0.000148, we have strong evidence to reject the null hypothesis. This means there is a significant association between collecting rainwater at the household during the rainy seasons and seeing a reduction in water bills during the rainy season compared to reliance on traditional water supplies alone. Households that collect rainwater are significantly more likely to see a reduction in their water bills.

References

[1] M.A. Tofighy *et al.*Adsorption of divalent heavy metal ions from water using carbon nanotube sheets J. Hazard. Mater. (2011)

[2] World Health Organization, 1996. Guidelines for drinking-water quality. Geneva: WHO, Vol:

[3] US Environmental Protection Agency, 1998b. Microbial and disinfection byproduct rules. Federal Register, 63: 69389-69476.

[4] Mohammed, T.A., Noor, M.J.M.M. and Ghazali, A.H., 2007. Study on potential uses of rainwater harvesting in urban areas. Putrajaya *Malaysia*.

[5] Sivanappan, R.K., 2006, November. Rainwater harvesting, conservation and management strategies for urban and rural sectors. In *National Seminar on Rainwater Harvesting and Water Management* (Vol. 11, No. 12, p. 1). New Delhi, India: Institution of Engineers (India), Nagpur Local Centre, Nagpur in association with UNESCO.

[6] Abdulla, F.A. and Al-Shareef, A.W., 2009. Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*, *243*(1-3), pp.195-207.

[7] Nazif, S., Tavakolifar, H., Abbasizadeh, H. and Eslamian, S., 2021. Comparing Rainwater Storage Options. *Handbook of Water Harvesting and Conservation: Basic Concepts and Fundamentals*, pp.385-399.

[8] Ghimire, S.R. and Johnston, J.M., 2015. Traditional knowledge of rainwater harvesting compared to five modern case studies. In *World Environmental and Water Resources Congress 2015* (pp. 182-193).

[9] Critchley, W. and Gowing, J.W. eds., 2012. *Water Harvesting in Sub-Saharan Africa* (pp. 224-pp). London: Routledge.

[10] Jing, X., Zhang, S., Zhang, J., Wang, Y. and Wang, Y., 2017. Assessing efficiency and economic viability of rainwater harvesting systems for meeting non-potable water demands in four climatic zones of China. *Resources, Conservation and Recycling*, *126*, pp.74-85.

[11] Boelee, E., Yohannes, M., Poda, J.N., McCartney, M., Cecchi, P., Kibret, S., Hagos, F. and Laamrani, H., 2013. Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa. *Regional Environmental Change*, *13*, pp.509-519.

[12] Campisano, A., Butler, D., Ward, S., Burns, M.J., Friedler, E., DeBusk, K., Fisher-Jeffes, L.N., Ghisi, E., Rahman, A., Furumai, H. and Han, M., 2017. Urban rainwater harvesting systems:

Research, implementation and future perspectives. *Water research*, *115*, pp.195-209.

[13] Scott, C.A., Kurian, M. and Wescoat, J.L., 2015. The water-energy-food nexus: Enhancing adaptive capacity to complex global challenges. *Governing the nexus: Water, soil and waste resources considering global change*, pp.15-38.

[14] Karpouzoglou, T. and Barron, J., 2014. A global and regional perspective of rainwater harvesting in sub-Saharan Africa's rainfed farming systems. *Physics and Chemistry of the Earth, Parts A/B/C*, *72*, pp.43-53.

[15] Owusu, S. and Asante, R., 2020. Rainwater harvesting and primary uses among rural communities in Ghana. *Journal of Water, Sanitation and Hygiene for Development*, *10*(3), pp.502-511.

[16] Andoh, C., Gupta, S. and Khare, D., 2018. Status of rainwater harvesting (RWH) in Ghana. *Current World Environment*, *13*(1), p.172.

[17] Ritter, Keith Solomon, Paul Sibley, Ken Hall, Patricia Keen, Gevan Mattu, Beth Linton, L., 2002. Sources, pathways, and relative risks of contaminants in surface water and groundwater: a perspective prepared for the Walkerton inquiry. *Journal of Toxicology and Environmental Health Part A*, *65*(1), pp.1-142.

[18] Asante, F.A. and Amuakwa-Mensah, F., 2014. Climate change and variability in Ghana: Stocktaking. *Climate*, *3*(1), pp.78-101.

[19] "Ghana Average Precipitation." Accessed: May 21, 2024. [Online]. Available: https://tradingeconomics.com/ghana/precipitation