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ORIGINAL ARTICLE

Exploring Rainwater Harvesting Potential for Irrigation in Lackatoorah Tea Garden of Sylhet, Bangladesh

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Abstract

Sylhet division is the major tea-producing region of Bangladesh. This study was conducted to explore the potential of rainwater harvesting by a designed model to fulfill the water requirement of the Lackatoorah tea garden during the dry season. Data were collected from both primary and secondary sources, and remote sensing data were analyzed using ArcGIS 10.7 to assess soil texture and slope. Four potential sites of (1.5 m ×1m) area were identified to estimate the volume of runoff water in the study. Four tanks with a capacity of 4000 liters were placed to store water as a reservoir for four sites. This study reveals that the study area received maximum average rainfall during June (742.7 mm - 839.2 mm) and July (667.7 mm - 787.2 mm) and the months from October-March received minimum rainfall (<200 mm) over 30 years. In this research, the rainwater was harvested in 2022 and the yearly harvested water for site 1, site 2, site 3, and site 4 are found as 1.99 m^3/m^2, 1.69 m^3/m^2, 1.99 m^3/m^2, and 2.58 m^3/m^2 respectively. Harvesting the yearly rainfall (5118 mm) in the Sylhet region can meet the net irrigation requirement of 394.48 mm for tea gardens. The catchment area should be taken as (15% - 23%) of a targeted irrigated area with varying runoff coefficients and the total volume of the reservoirs needed for one-hectare tea garden should be made about 3844 m^3 based on the average depth of the reservoirs.

Keywords: Net irrigation requirement, Rainfall, Rainwater harvesting, Runoff co-efficient, Tea garden

1. Introduction

Tea (*Camellia sinensis*) is a high economic beverage crop, almost two-thirds of the people on the planet take it as a morning drink daily (Sumi, 2020). Tea is a cash crop in Bangladesh, contributing significantly to our economy. Tea cultivation is not only for cash earning but also a multidimensional benefit for farmers and industrialists (Qiao et al., 2018). Bangladesh is an important tea-producing country. Bangladesh obtained the 8th position in the production area, the 10th position in production, and the 12th position in exporting (Rahman, 2022). This second cash crop of the country contributes 1% of the GDP and makes up 1.89% of global production. In 2020, 167 tea gardens in Bangladesh produced 86.39 million kg of tea, of which 2.17 million kg were exported (BTB, 2021). Tea production recorded an all-time high in 2021, according to the Bangladesh Tea Board. That year, the 167 tea gardens produced 96.5 million kg of tea, up 11.7% from 86.39 million kg in the previous year 2020. As such, the achievement of several Sustainable Development Goals is associated with the thriving tea industry. It ensures food security (SDG 2), reduces poverty (SDG 1), and generates respectable employment (SDG 8). Equal access to financial resources has been attained for female workers (SDG 5). Green coverage facilitates the reduction of carbon impact. Climate change adaptation strategies are simultaneously promoted by SDG 13 (Islam et al., 2021). Hence, the tea sector of

Bangladesh is essential for providing food security, fostering green space and sustainable land use, producing foreign exchange, and safeguarding biodiversity.

Tea is a type of evergreen shrub with broad leaves that is grown extensively in mountainous regions of tropical and subtropical climates under intense management. The environment has a big impact on the quantity and quality of tea plants that are produced. Rainfall is a key microclimatic factor that influences tea production. Typically, tea plants are grown in highland regions with 2,000–4,000 mm of annual rainfall, with a maximum of two dry months (rainfall of less than 60 mm per month) (Rachmiati et al., 2014). While long-spelt rain decreases tea yield, short-spelt rain is beneficial for the cultivation of tea (Esham and Garforth, 2013; Duncan et al., 2016).

Production can increase with regular rainfall pattern (Ochieng et al., 2016). Similarly, the regions that produce tea ought to experience either a rainy season or a mix of alternate wet and dry seasons. The average annual rainfall of 4000 - 4600 mm is predicted for the excellent tea leaf production in Bangladesh (Ali et al., 2014). The country has been experiencing severe weather and climate phenomena for the past few decades. Tea is considered one of the most vulnerable crops to climate change (Ochieng et al., 2016), which requires a warm and humid climate (Hasimoto, 2001). Its production is severely impacted by the drought (Niinemets, 2015). The pattern of rainfall in tea-producing regions has changed significantly in recent years (Dutta, 2014). Monsoonal rainfall affects both the yield and the quality of the product (Wijeratne et al., 2007). Thus, the timing of rainfall throughout the year is more important to meet the water requirements of tea tree growth (Piyashee and Tuhin, 2021; Chen et al., 2010). Bangladesh achieved a record-breaking yield of 96.5 million kg of tea in the previous calendar year 2021, however, there was still a significant decline in imports due to a shortage of high-quality leaves, as reported in The Business Standard article of 2022 (The Business Standard, 2022).

Since tea is a perennial crop, it needs water throughout the dry season to continue producing and growing vegetatively (Islam et al., 2005; Hossain, 2015). The agriculture specialists say that the first twelve months are crucial for young tea plants. The issue facing the tea business is that the country's current irrigation infrastructure is nearly antiquated, significantly reducing production levels and quality. In this case, irrigation is necessary to ensure that tea plants grow to a healthy stage (Rajakaruna et al., 2021). During the dry season of the year, groundwater is utilized for irrigation purposes in the tea garden. The water table is lowered more quickly when groundwater is continuously pumped. Land subsidence is a result of declining water levels and could have disastrous consequences soon (Ha et al., 2024). In addition, the Sylhet region's groundwater level is trending downward (Hasan et al., 2021) and the region is susceptible to a dropping groundwater table (Zafor et al., 2017), which raises the expense of deep well installation.

The longer the pump runs, the higher the electricity cost. Due to the semi-mountainous area with many tiny and medium-sized hillocks of the tea gardens, there is a lot of runoff, which forms gullies and contributes to erosion. Some crops occasionally use small-scale irrigation with surface water from ponds or streams. High-capacity pumps are required to retrieve groundwater for the vast garden. These issues can be resolved by using the collected rainfall water as an additional irrigation source for the tea gardens. Removing groundwater for irrigation may not be necessary if there is harvested water.

Through a well that has been dug, groundwater can also be replenished. A collection of methods called "rainwater harvesting" was created to collect, store, and use surface runoff of rainfall rather than non-continuous groundwater for agricultural and residential uses (Ertop, 2023). It has been utilized for thousands of years to satisfy the need for water supplies, and in the present day, scientists have repurposed it for the cultivation of crops. Even yet, tea cultivation can adopt climate change adaptation strategies by using rainwater collection to apply irrigation (Baruah and Handique, 2021).

Tea plantations that collect rainfall may be able to keep the moisture content of soil stable during dry spells. The rainwater harvesting technique is suited for a wide range of contexts due to its features of simplicity, efficiency, adaptability, and low implementation cost (Tamagnone et al., 2020). Rainwater harvesting is a pragmatic approach for increasing crop production in dryland areas (Zahra et al., 2021). Large-scale irrigation techniques for tea plantations include flood irrigation, drip irrigation, and sprinkler irrigation (Roy et al., 2020). These techniques can be used to water the tea garden. Several studies have demonstrated that drought changes the concentration of metabolites (Eric et al., 2019; Kfoury et al., 2018; Han et al., 2017). Few studies (Islam et al., 2021; Rahman et al., 2017) examined the effect of rainfall on the yield of one or a small number of tea estates in the Sylhet district. According to published research, a declining water table in 2020 caused a shortage of irrigation water in the Moulvibazar district's Satgaon and Ichamoti tea estates.

A brief period of dryness in January 2020 resulted in somewhat greater acidity in the Surma tea garden in the Hobiganj area. The cost of irrigation was higher for the Lackatoorah gardeners due to short drought in 2020 (Rahman, 2022). There is, however, a dearth of research on the viability of rainwater gathering in tea gardens in Bangladesh. Thus, a study was conducted to first estimate the annual potential for rainwater harvesting and then to store water using a basic rainwater-harvesting model that could be applied to irrigation. In order to determine the net irrigation need for the entire year, the study also aims to analyze meteorological data gathered from secondary sources. It was hypothesized that in a tea garden, collecting rainfall during the monsoon may supply irrigation needs during the dry season.

2. Material and Methods

2.1. Study area

Lackatoorah Tea Estate is one of the oldest tea gardens in Bangladesh, which situated near the Sylhet Agricultural University. This tea garden is among the most exquisite in the nation with a plantation area of 64,74,970 m^2, which is one of the largest tea estates in the country. It produces around 736671 kg of tea every year. It lies between 24.85◦ N and 91.80◦ E and falls within the heavy rainfall zone having 3309 mm annual rainfall in Bangladesh. The experimental site was in a typical subtropical region, with average annual rainfall of 3992 mm and an average annual temperature of 24^0 C, which is favorable for tea plant growth (Yearbook of Agricultural Statistics, 2021). The soil texture of the Lackatoorah garden belonged to loamy sand (Urmi, 2020).

Following the visual identification of a preferred site based on physical attributes and location, four potential sites of (1.5 m×1m) areas are evaluated to estimate the volume of runoff water. This is done by taking into account factors such as soil type, topography, size of the expected irrigated area, and vegetation cover of the area, contributing to surface runoff.

2.2. Data collection

Thirty years (1993 -2022) of the monthly rainfall (mm) data of Sylhet Sadar were collected from the Bangladesh Agricultural Research Center (BARC) and analyzed in Microsoft Excel 2013 version. In our experiment, a rain gauge was used in the study area to record daily rainfall for 2022. Data on soil texture were collected from the Bangladesh Agricultural Research Center (BARC). The Digital Elevation Model (DEM) was collected from the United States Geological Survey (USGS). The required historical data of climatic variables, including temperature, wind speed, and relative humidity, rainfall, sunshine hours etc. was collected with the aid of CLIMWAT 2. Here, runoff loss was taken as a major loss as the study area is in hilly region (Schwyter and Vaughan, 2020). The descriptive summary of rainfall data (1993-2022) was determined and analyzed using SPSS and MS Excel 2013.

2.3. Geographical Information Systems (GIS) applications

ArcGIS 10.7 was employed to extract soil texture and slope information for the designated study locations. Initially, the vector data representing soil texture was converted into raster format. Subsequently, the textural classes were extracted from this raster layer utilizing the extraction tool available in ArcGIS.

To generate the slope map layer, four Digital Elevation Model (DEM) tiles were merged. The slope tool in ArcGIS was then applied to create the slope map. Following this, the slope values for each specific location were extracted and assigned to the corresponding points on the map layer.

The acquired slope and soil texture information were subsequently utilized to calculate the runoff coefficient for the study locations. This methodological approach facilitated the integration of topographical and soil characteristics into the runoff coefficient determination process.

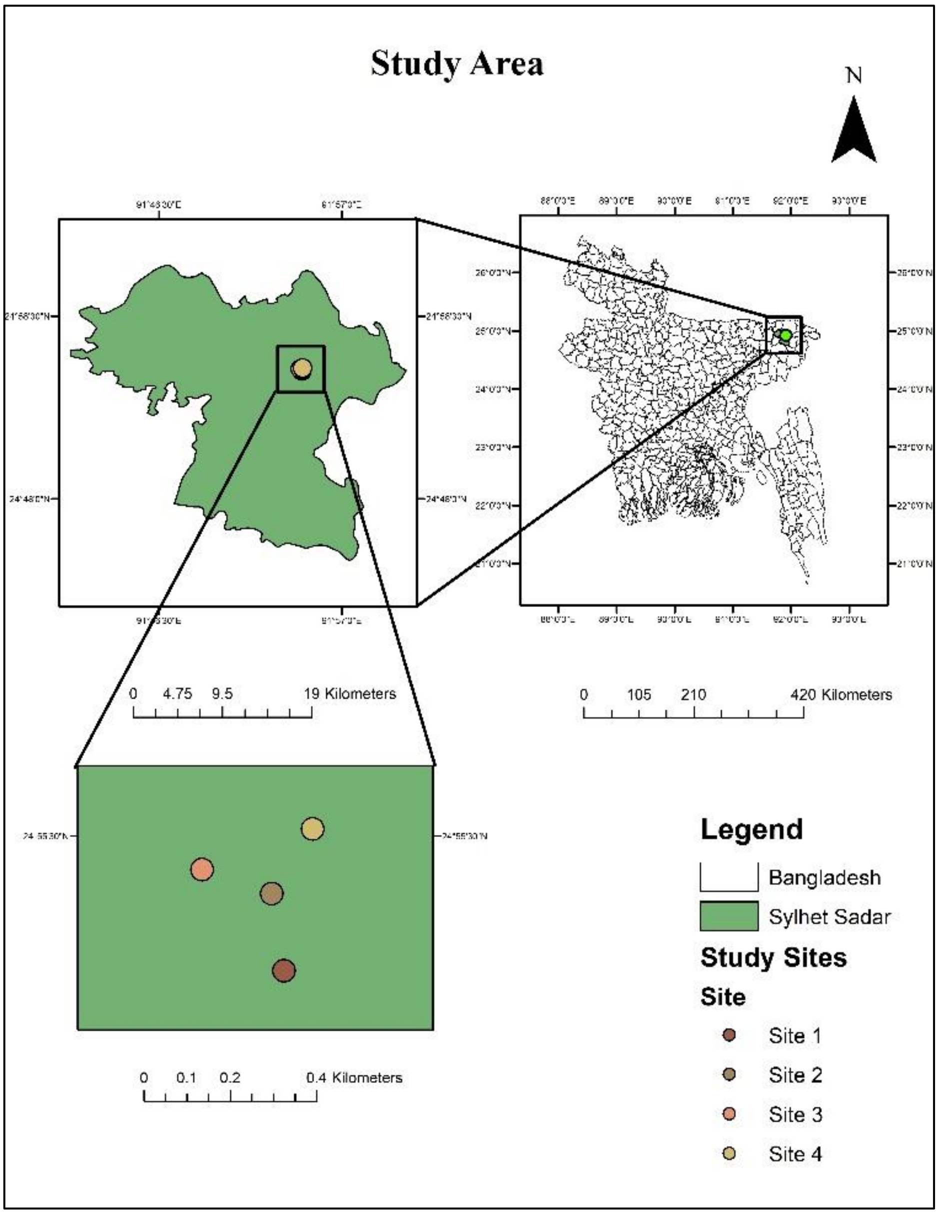

Fig. 1. Map of the Study area (Sylhet)

2.4. Runoff coefficient

The runoff coefficient depends on the soil type, slope, and vegetation of the study area. It represents the portion of accumulated rainfall that turns into direct runoff and is introduced into the drainage system. The runoff coefficient takes into consideration losses from evaporation, leakage, infiltration, spills, and depression storage of the catchment surfaces, all of which help to reduce the amount of runoff. Runoff coefficient varies from 0.1 to 0.82 (Garg, 2019). As per the manual of artificial recharge of groundwater, the “Government of India Ministry of Water Resource Central Ground Water Board” the runoff coefficient in the sloppy natural hilly region is varied from 0.2 to 0.5. The determination of the runoff coefficient for this study was facilitated through the utilization of Geographic Information Systems (GIS).

The slope characteristics of each location were determined by extracting data from the Digital Elevation Model (DEM), while soil texture attributes were identified using the soil raster map. According to the extracted values of the slope and soil texture from GIS, the runoff coefficient values were computed based on the potential runoff coefficient for different land use, soil type, and slope value mentioned in the table 1.

Table 1. Potential runoff coefficient for different land use, soil type, and slope (Liu and De Smedt, 2004)

Land use	Slope (%)	Sand	Loamy Sand	Sandy Loam	Loam	Silt Loam	Silt	Sandy Clay Loam	Clay Loam	Silty Clay Loam	Sandy Clay	Silty Clay	Clay
Forest	<0.5	0.03	0.07	0.10	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40
	0.5-5	0.07	0.11	0.14	0.17	0.21	0.24	0.27	0.31	0.34	0.37	0.41	0.44
	5-10	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50
	>10	0.25	0.29	0.32	0.35	0.39	0.42	0.45	0.49	0.52	0.55	0.59	0.62
Grass	<0.5	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50
	0.5-5	0.17	0.21	0.24	0.27	0.31	0.34	0.37	0.41	0.44	0.47	0.51	0.54
	5-10	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	>10	0.35	0.39	0.42	0.45	0.49	0.52	0.55	0.59	0.62	0.65	0.69	0.72
Crop	<0.5	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	0.5-5	0.27	0.31	**0.34**	0.37	0.41	0.44	0.47	0.51	0.54	0.57	0.61	0.64
	5-10	0.33	0.37	**0.40**	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70
	>10	0.45	0.49	**0.52**	0.55	0.59	0.62	0.65	0.69	0.72	0.75	0.79	0.82
Bare soil	<0.5	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70
	0.5-5	0.37	0.41	0.44	0.47	0.51	0.54	0.57	0.61	0.64	0.67	0.71	0.74
	5-10	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70	0.73	0.77	0.80
	>10	0.55	0.59	0.62	0.65	0.69	0.72	0.75	0.79	0.82	0.85	0.89	0.92
IMP	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

2.5. Model design

For a given climatic condition, the harvested water volume depends on the rainfall characteristics, catchment area, and the storage capacity of the artificial or natural reservoir (Prinz, 1994). Therefore, rainwater harvesting (RWH) systems have three basic elements, which are (i) catchment area, (ii) supporting collection system, and (iii) storage tank. Any sloped surface can yield an approximate estimate of its runoff volume by multiplying the amount of rainfall that falls on it by its runoff coefficient. Using this concept, a model was designed for harvesting rainwater in the selected tea garden for this research (Fig. 2). The research was executed from January 2022 to December 2022.

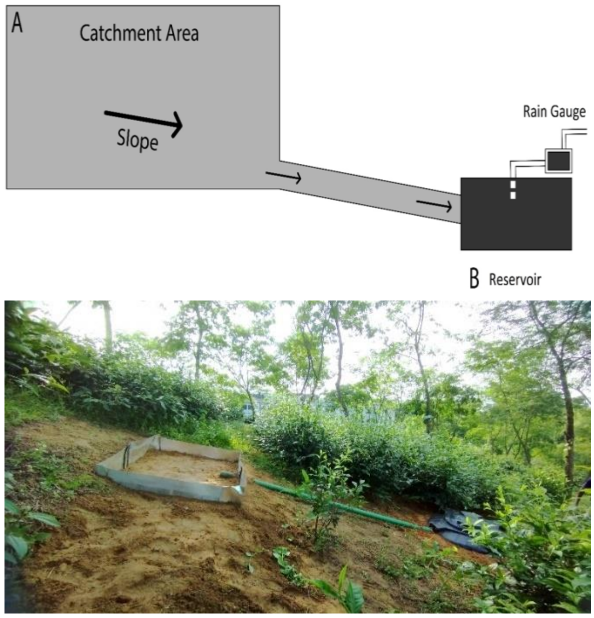

Fig. 2. Model design and Installation

2.6. Selection of catchment area

Here, in the figure (Fig. 2), A is the catchment area. A small catchment area of size 1.5 m × 1 m in a hill of the Lackatoorah tea garden and a model was designed to calculate the runoff that will be collected in a reservoir. The area of the surrounding catchment was protected by a thin steel sheet. The sheet was dug inside the soil so that no water could escape from the catchment. All the runoff water passes through only one outlet to the reservoir.

2.7. Construction of Reservoir

It is essential to consider the demand for water when building a reservoir, that is, the size of the reservoir should be in balance with the needs of the system. A reservoir that captures more water than is required would increase irrigation costs. In contrast, a small structure is limited to an irrigated area of smaller size and whose yields would not justify the investment in the reservoir. There are no pre-established rules to determine the size of a reservoir since the water demands of a crop is highly variable and depend on the duration of the cycle, time of year, and type of irrigation to be used. However, some basic considerations can be followed to determine the amount of water required, which will subsequently determine the necessary size of the reservoir. Here, B is the reservoir shown in the Fig 2.

For four sites, tanks with a capacity of 4000 liters were placed to store water as a reservoir. It was built by digging the soil and placing the tank in the hole. Rainwater was collected in the catchment area and directly stored in these tanks using proper protection. A plastic sheet also was used to prevent the water from being evaporated. A rain gauge was also incorporated in the model design to record rainfall.

2.8. Rainwater harvesting potential

The runoff volume can be estimated from any sloped surface by multiplying the depth of rainfall that falls on that surface with its runoff coefficient and catchment area. Rainwater harvesting potential refers to the amount of water that can be collected from a given surface during a specific period and stored for future use. In this study, the rainwater harvesting potential of four experimental sites was determined by using the following formula:

$$V = K \times I \times A \quad (1)$$

where,

V= Rainwater Harvesting Potential (m^3)

K= Runoff coefficient

I = Rainfall in (m)

A = Catchment area in (m^2)

2.9. Net irrigation requirement

The quantity of water required for a disease-free crop growing in wide fields with unrestrictive soil and water conditions, sufficient fertility, and after any meaningful rainfall is known as the Net Irrigation Requirement (NIR).

$$NIR = ET_c - E_{Rain} \quad (2)$$

where, NIR= net irrigation requirement, ET_c = crop-evapotranspiration, and E_{Rain} = effective rainfall.

The effective monthly rainfall was calculated by substituting runoff loss. Runoff loss was calculated by multiplying the runoff coefficient with rainfall.

$$E_{Rain} = \text{Monthly rainfall} - \text{Runoff loss} \quad (3)$$

$$\text{Runoff loss} = \text{Rainfall} \times \text{Runoff coefficient} \quad (4)$$

Crop evapotranspiration was calculated according to the following formula:

$$ET_c = K_c \times ET_o \quad (5)$$

where, K_c= crop coefficient, ET_o= reference evapotranspiration.

Reference evapotranspiration (ET_o) was calculated using the Penman-monteith method (Allen et al., 1998) by CROPWAT 8.0 software. The Food and Agriculture Organization (FAO) created CROPWAT, a decision support tool mostly used for irrigation planning and management. Climatic data for Sylhet station (minimum and maximum temperature, relative humidity, wind speed and sunshine hours) were obtained from FAO software CLIMWAT 2.0 (CLIMWAT 2.0 for CROPWAT is a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO and it offers observed agroclimatic data of over 5000 stations worldwide distributed).

Penman-monteith method:

$$ET_o = \frac{0.408\Delta\,(R_n - G)}{\Delta + \gamma\,(1 + 0.34u_2)} + \frac{\gamma\left[\frac{900}{T_{mean} + 273}\right]u_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \quad (6)$$

where;

ET_o = Reference evapotranspiration (mm/day),

R_n = Net radiation at the crop surface ($MJ/m^2/day$),

G = Soil heat flux density ($MJ/m^2/day$), which can be neglected (G=0),

T_{mean} = Mean air temperature (°C),

u_2 = Wind speed measured at 2 m height (m/s),

e_s = Saturation vapor pressure (kPa),

e_a = Actual vapor pressure (kPa),

$e_s - e_a$ = Saturation vapor pressure deficit (kPa),

Δ = Slope vapor pressure curve (kPa/°C),

γ = Psychrometric constant (kPa/°C).

For tea cultivation, the entire year was divided into three distinct growth seasons or stages: the initial season (mid-April to the second week of July), the mid-season (third week of July to the first week of November), and the late season (second week of November to mid-April), based on the crop coefficient as influenced by the crop evapotranspiration and climatological parameters (Sikka et al., 2009).

According to FAO (1998), for shaded tea plants, crop coefficients 1.10, 1.15 and 1.15 for $K_{c(initial)}$, $K_{c(mid)}$ and $K_{c(end)}$ respectively were used.

3. Results and Discussion

In this study, a series of steps were completed for estimating the rainwater harvesting potential to improve the irrigation system at a Lackatoorah tea garden. The steps of investigation included rainwater potential, soil texture, slope and runoff coefficient is to determine rainwater for harvesting. All those steps have been discussed in the following sections.

3.1. Descriptive statistics of rainfall data

The fundamental statistics of rainfall records showed that the maximum annual rainfall was 5944.0 mm in the year 2017, and the minimum annual rainfall of 3101.0 mm in the year 2011. Various interpretations were made based on the statistical parameters of the rainfall data from 1993 to 2022 to determine the significance of the findings. According to the descriptive data, there is a significant degree of variability in the mean rainfall of 3963.31 mm, demonstrated by the standard deviation of 658.11 mm. The data distribution is positively skewed and somewhat peaked with a kurtosis of 1.39 and a skewness of 1.14, indicating a tendency toward higher rainfall values. The coefficient of variance at 16.61% reflects the relative variability of rainfall amounts to the mean. Overall, the rainfall data exhibits significant variability, considerable peak values, and a tendency toward higher values in the rainfall data.

A study conducted on rainfall variability for 64 years (1952-2016) for Sylhet found that mean annual rainfall was 3691.62 mm with a standard deviation of 743.13 mm (Noorunnahar and Hossain, 2019). According to this, the value of the coefficient of variance is found to be 20.13%.

3.1.1. Rainwater potential

This Sylhet region experiences high and unpredictable rainfall, with an average annual rainfall of 3992.73 mm. The monthly rainfall (mm) analysis for the Sylhet region from 1993 to 2022 is presented in Fig. 3.

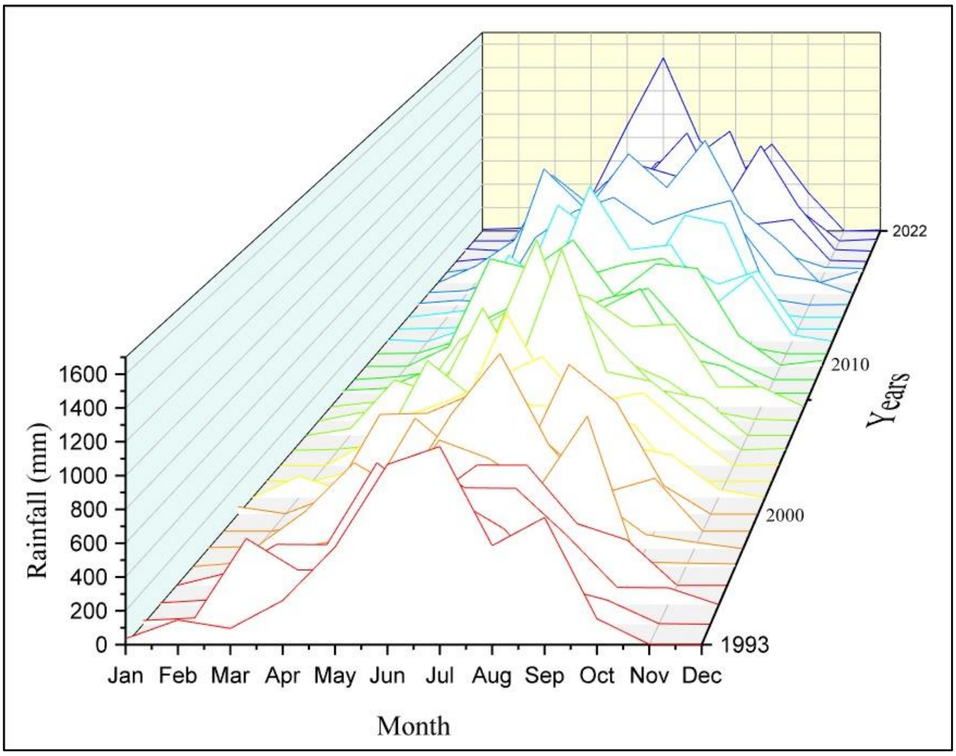

Fig. 3. Rainfall (mm) Pattern of the Study Area for the Last 30 Years

This graph shows a symmetrical average monthly rainfall pattern. Compared to other months of the year, January, February, March, November, and December received the lowest amounts of rainfall, usually falling below 200 mm in five months. On the other hand, there was relatively higher rainfall in May, June, July, and August. There was just 4.85%

rainfall in the arid months of November through March. With sporadic rain of 9.26%, April marked the change from the dry to the rainy season. According to the rainfall data, the months from May through October were considered the rainy season, which contributes the most (85.89%) to annual rainfall (Fig. 3). Tea zones experience a dry season from November to March while the rainy season continues from April to October and above 80% of annual rainfall is obtained during June–September (Rahman et al., 2017; Paul et al., 2017). Therefore, it was possible to collect rainfall in this study area from May to October (Fig. 3), and then utilize it during the dry season that lasted from November to April.

3.1.2. Decade-wise monthly variation of rainfall

The following figure (Fig. 4) shows the average monthly rainfall trend for each decade over thirty years.

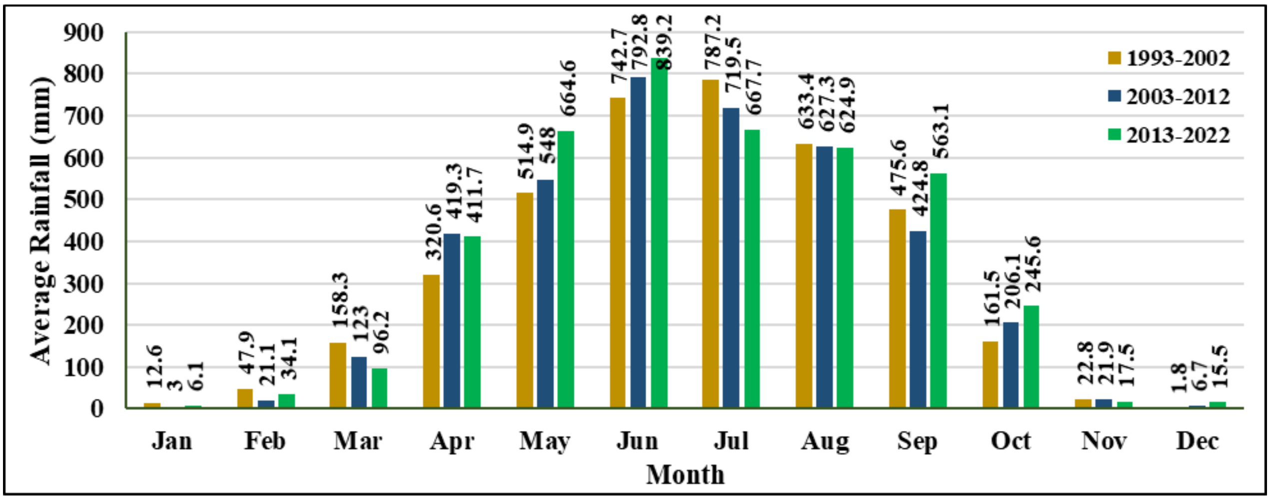

Fig. 4. Average monthly rainfall trend for each decade during 1993-2022

It is important to notice that, in the months that often have considerable rainfall (April to October), the amount of rain is progressively rising (except July) as the days pass. Conversely, the amount of rain that falls during the dry season (November, January, February, March) is diminishing within a decade. Here, some different phenomena are observed. Although June and July receive the highest rainfall than other months, July experiences a declining trend (787.2 mm > 719.5 mm > 667.7 mm) in rainfall over 30 years per decade. In the case of August, August experienced relatively consistent rainfall levels (varying from 633.4 mm to 624.9 mm) during the same period. This observation makes it evident that the water issue is worsening every year during the dry season regarding the availability and sustainability of water resources.

A different study conducted on the Lackatoorah tea estate found that it receives 3764.674 mm of rain on average per year (Islam et al., 2021). The study also reported that over the previous ten years, the Lackatoorah tea estate experienced 3132.24 mm of rainfall at its lowest point and 5523.76 mm at its greatest. In addition, rainfall and tea production at the Lackatoorah tea estate were positively connected.

3.2. Runoff coefficient in the study area

According to the values mentioned in the table 01, the runoff coefficient in response to soil texture, and slope are found as 0.4, 0.34, 0.4 and 0.52 for the study sites 1, 2, 3 and 4 respectively.

3.2.1. Determination of soil texture

Soil is one of the most important criteria that determine the appropriate site for rainwater harvesting, which affects the surface runoff and the rate of infiltration. Medium and fine-textured soils are more desired for the process of rainwater harvesting site selection (Mbilinyi, 2007). Clayey soil can clutch the assembled water and has low permeability. Therefore, sites with this type of soil are superlative for water conservation (Adham et al., 2018). Thus, soil texture is considered the most important criterion for choosing sites for rainwater harvesting. The soil texture map is categorized. Fig. 5 shows the soil texture map of the study sites. All four study sites had found sandy loam texture on the surface.

3.2.2. Determination of slope

In the determination of runoff suitability for a catchment region, the slope map is considered as a crucial map. It has an impact both on infiltration and on recharging (Adham et al., 2018). It is recommended that the areas of rainwater harvesting should be <5% because it needs large earthwork prerequisites, and these areas are liable to extraordinary erosion amounts because of uneven runoff distribution (Critchley and Sieger, 1991). DEM represented as raster elevation data (grids) provides measurements, analysis, and accurate results for slopes (Saeed and Hadi, 2010). In this study, the slope map is generated using DEM with 30 m resolution, which is generated from Shuttle Radar Topographic Mission (SRTM) data after flat areas and sinks are removed via ArcGIS software. The slope map is classified into four classes as shown in Fig. 5, which shows the slopes of the study sites in percentage. Site 1, 2, 3, and 4 had 9%, 3%, 5%, and 11% slope respectively.

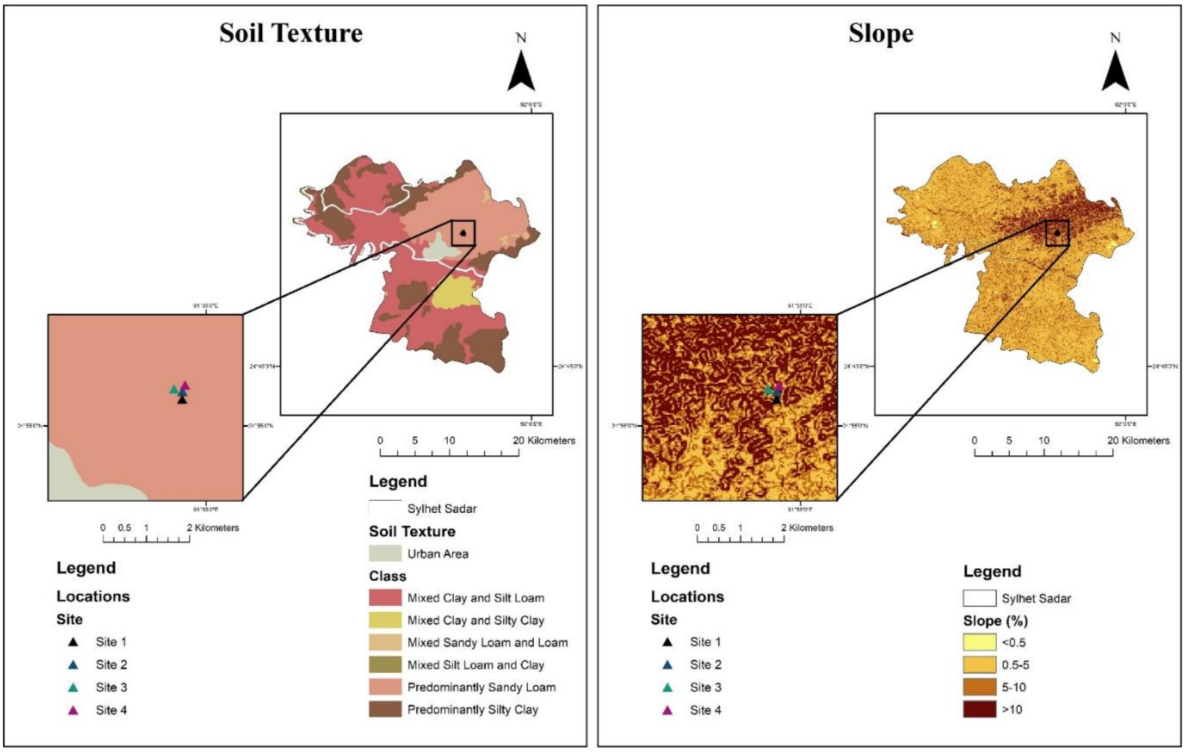

Fig. 5. Soil Texture and Slope of the Study Sites

In our study, the runoff coefficient (k) was found between 0.34 - 0.52. Runoff coefficients for four sites with sandy loam soil and different slopes are displayed in the results. Because of its moderate topography and 3% slope, Site 2 has the lowest coefficient, measuring 0.34, indicating effective water infiltration. On the other, hand, Site 4 has the greatest coefficient of 0.52 and a slope of 11%, indicating significant surface runoff on steeper slopes. The intermediate sites, 1 and 3, have slopes of 9% and 5%, respectively, indicating moderate runoff coefficients of 0.40.

Overall, our results showed that runoff is influenced by slope gradient, with steeper slopes often producing higher surface runoff levels even though all locations have the same sandy loam soil texture.

3.3. Harvested rainwater

For each of the four sites (Sites 01, 02, 03, and 04) during the month of 2022, the volume of collected rainwater (measured in cubic meters) is depicted on the Fig. 6. There is no rainwater is harvested in January, February, March, November, and December, presumably because of the dry spell. Rainwater was collected in April, however not much at any one location. Substantially more rainwater was collected in May, and all four locations contributed significantly to this total. June had the largest received rainwater volume across all sites, measuring 0.89 m^3 at Site 01, 0.76 m^3

at Site 02, 0.89 m³ at Site 03, and 1.16 m³ at Site 04 (the highest volume recorded).

Rainwater harvesting was moderate in July, August, September, and October, with contributions from all sites, though lower than at the peak in June. Overall, the graph indicates rather evident that June was the month with the greatest amounts of rainfall harvested, while January, February, March, November, and December were the months with the lowest amounts. With a rainy season that peaks in June and a dry season that lasts through the early and late months of the year, the seasonal pattern most likely reflects the local climate.

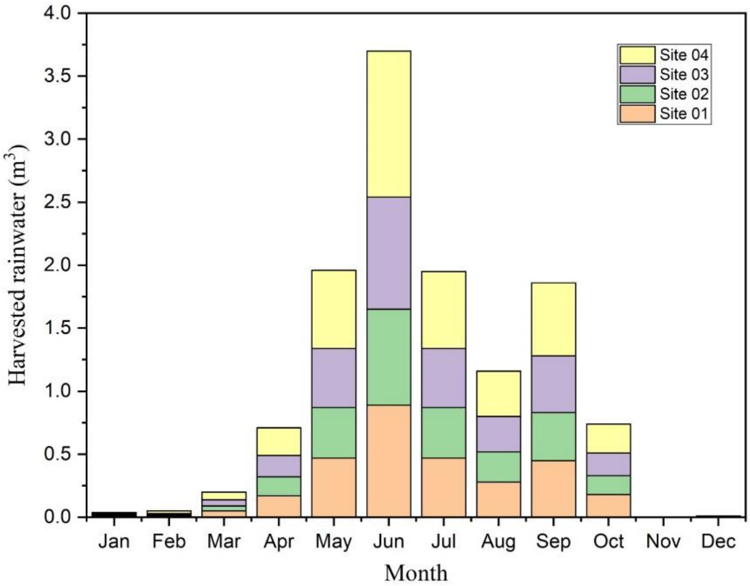

Fig. 6. Harvested Rainwater Volume (m^3) in 2022

3.4. Estimation of area covered by harvested rainwater

From CROPWAT software, it was found that 4.18 mm/day of reference evapotranspiration (ET_o) occurs most frequently in April and May. However, in December and January, this number is substantially lower (2.22 mm/day and 2.18 mm/day respectively). Furthermore, its value is largely dependent on the climatic parameter.

Table 2. ETc and NIR Calculation

Month	ET_o (mm/day)	ET_o (mm/month)	Etc = ET_o *K_c	Rainfall (mm)	Losses (mm)	Effective rainfall (mm)	NIR (mm)
Jan	2.19	67.89	78.07	16	6.72	9.28	68.79
Feb	2.69	75.32	86.61	24	10.08	13.92	72.70
Mar	3.65	113.15	130.12	79	33.18	45.82	84.30
Apr	4.18	125.4	141.08	287	120.54	166.46	0
May	4.18	129.58	142.54	902	378.84	523.16	0
Jun	3.72	111.6	122.76	1485	623.7	861.3	0
Jul	3.71	115.01	125.40	778	326.76	451.24	0
Aug	3.59	111.29	127.98	461	193.62	267.38	0
Sep	3.45	103.5	119.03	744	312.48	431.52	0
Oct	3.34	103.54	119.07	334	140.28	193.72	0
Nov	2.73	81.9	94.19	0	0	0	94.19
Dec	2.22	68.82	79.14	8	3.36	4.64	74.50

The above table demonstrates the monthly net irrigation requirements (NIR) for tea crops. The table shows that the net irrigation needs for January, February, March, November, and

December are 68.79 mm, 72.70 mm, 84.30 mm, 94.19 mm, and 74.50 mm, respectively. There is no need for irrigation from April to October since monthly effective rainfall exceeds crop evapotranspiration. The average monthly rainfall during November to March is less than the evapotranspiration loss causes soil moisture deficit, which affects tea bushes. Even when there is enough rainfall throughout the monsoon season, tea plants suffer greatly and yield decreases if this dry spell lasts longer. Thus, high yield can be achieved with proper irrigation in the winter and early spring.

In this context, the monthly harvested rainfall volume is calculated and shown in table 3. The table provides monthly data on Net Irrigation Requirement (NIR) and Harvested Rainfall Volume for four sites.

Table 3. Annual Targeted Irrigated Area

Month	NIR (m)	Harvested Rainfall Volume (m^3/m^2)			
		Site 01	**Site 02**	**Site 03**	**Site 04**
Jan	0.07	0.01	0.01	0.01	0.01
Feb	0.07	0.01	0.01	0.01	0.01
Mar	0.08	0.03	0.03	0.03	0.04
Apr	0.00	0.11	0.10	0.11	0.15
May	0.00	0.32	0.27	0.32	0.41
Jun	0.00	0.59	0.50	0.59	0.77
Jul	0.00	0.31	0.26	0.31	0.40
Aug	0.00	0.18	0.16	0.18	0.24
Sep	0.00	0.30	0.25	0.30	0.39
Oct	0.00	0.12	0.10	0.12	0.15
Nov	0.09	0.00	0.00	0.00	0.00
Dec	0.07	0.00	0.00	0.00	0.00
Total	0.39	1.99	1.69	1.99	2.58
Total Area covered by harvested water (m^2/m^2)		5.04	4.28	5.04	6.55
Catchment area (%)		20%	23%	20%	15%
Reservoir volume (m^3) needed for 1ha tea farm		3844	3844	3844	3844

Throughout the year, NIR peaked in March (0.08 m) and November (0.09 m) due to lower rainfall, while it was zero from April to October, indicating sufficient rainfall during these months. It is found that the harvested rainwater is adequate for reliable tea production in the Sylhet region based on an analysis of the total rainfall (5118 mm) and the net irrigation requirement (390 mm) of the experimental year (2022). Harvested rainfall volumes were highest in June, with site 01 and site 03 each harvesting 0.59 m^3/m^2, site 02 harvesting 0.50 m^3/m^2, and site 04 harvesting 0.77 m^3/m^2. Annually, site 01 and site 03 each harvested 1.99 m^3/m^2, site 02 harvested 1.69 m^3/m^2, and site 04 harvested 2.58 m^3/m^2 and area covered by harvested water was found 5.04 m², 4.28 m², 5.04 m², and 6.55 m² respectively. It has also been observed that for any tea garden in the Sylhet region, the catchment area should be taken as (15% - 23%) of the total targeted irrigated area with varying runoff coefficients. The total volume of the reservoirs needed for one ha tea farm should be made about 3844 m^3 based on the average depth of the reservoirs. It is calculated based on the months of rainy periods (April to October) as amount of storage water is decreasing with other months. It is also mentioned that, the overall cost of setting up the model was around 10,000 BDT (≅\$84) for each experimental site.

4. Conclusions

The tea sector of Bangladesh has great importance in earning foreign currency, employment generation, food security, green coverage, sustainable land use, and biodiversity conservation, so it must be necessary to ensure sufficient and quality tea production. For this, rainwater harvesting is such an innovative idea to meet the water demand of tea gardens. Analyzing the last thirty years' rainfall data has demonstrated that June topped the list of months with the most rainfall, followed by July, August, May and September and January, February, March, November, and December experience the lowest rainfall level. Annual variations in the average amount of rain were significant and monthly rainfall averages in the Sylhet were almost symmetrical. Sylhet region is blessed with high rainfall, thus, rainwater harvesting for tea gardens can be a great resource. Since tea is produced in the hilly region in Sylhet, it is possible to store rainwater easily by using the rainwater-harvesting model when there is excess rainfall. Therefore, uninterrupted irrigation can be provided throughout the year both during the dry season (January, February, March, November, and December) and at times of uneven intervals of rainfall. This will increase the production of tea as well as save groundwater. The results of this study demonstrate a positive relationship between the amount of rainwater collected and the net irrigation needs of the tea plants in the Lackatoorah Tea Garden. In addition, the size of the catchment area needed to collect the required amount of rainfall as well as the desired irrigation area that can be irrigated using harvested rainwater are also quantified in this study.

Ancient RWH technologies have been revived and new ones developed to increase water availability by using harvested rainwater and thus limiting groundwater abstraction. There are many systems for harvesting rainwater in the mountain regions; a system can be a recommended that will harvest rainwater. As the tea garden are in the hilly areas with small tilas (i.e. hillocks). If this tila are guided by masonry wall of 1-2 feet and with proper drainage system so that all water from each tila are deviated through a common outlet to a reservoir, thus, the water can easily be harvested. Each tilla have a different or a common reservoir for several tilas can be used. The reservoir may be built by brick masonry wall so that no water can be lost by seepage or percolation. Like our designed model, the reservoir could be covered by polythene sheet to save the stored water from evaporation for economic use. The storage capacity of the reservoir should according to the potential storage of the catchment and irrigation requirement. Extra water should be drained from the reservoir. At the times of dry season, the stored water can be easily used by pump and connect to the irrigation system that might be sprinkler or drip. The construction of the system is very simple, easy and economical. Since this study only uses the designed model, further research is needed to determine its applicability and cost-effectiveness. The entire garden was not taken into consideration when conducting the study; only specific portions were. Consequently, more data and large-scale study should be conducted to examine the applicability and verify the efficiency of the suggested RWH system. It is recommended to calculate a cost-benefit analysis of the RWH system prior to implementation. This research could help develop a more advanced rainwater collection system in the hilly area.

5. Disclosure Statement

No potential conflict of interest was reported by the authors

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