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Application of GIS & RS in Rainwater Harvesting for an Arid Region

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Abstract: In dry areas with variable rainfall, water shortages severely affect the livelihoods of local populations. Rainwater harvesting from land sites and roof-tops is a readily available solution to this problem. This study presents a GIS & RS-based methodology to identify potential land sites and roof-top rainwater harvesting potential using easily obtainable and freely available data. Slope, land cover, soil, and drainage maps were used to identify suitable rainwater harvesting land sites, which were further analyzed for surface runoff using the curve number method. This research also incorporated obtainable socio-economic factors in identifying the suitable locations of dams considering the implementation stage. Based on the proposed criteria, 44 suitable locations for dams were identified and validated using a validation map and Google Earth images. CROPWAT model analysis revealed that paddy water demand in Batticaloa would increase threefold if all available land for paddy cultivation was utilized. Therefore, abandoned lands can be utilized by erecting dams at those identified locations. Analysis of Google Earth images also revealed that roof rainwater harvesting would be sufficient to meet the basic water demand in the area. This study demonstrates that rainwater harvesting can be an effective strategy for addressing water scarcity in dry areas.

Keywords: Rainwater harvesting, Roof-top, CROPWAT, Batticaloa, Socio-economic factors

1. Introduction

Per capita water resources in Sri Lanka amount to approximately 2400 m^3, whereas the average annual rainfall in the country is estimated to be around 2000 mm [1]. Drought is a recurring phenomenon that commonly occurs in the arid region of Sri Lanka, particularly during the Yala season spanning from May to September. Batticaloa is an arid district that has frequent occurrences of both drought and flooding during the North East monsoonal rain [2]. The exploitation of rainfall in Sri Lanka is characterized by inefficiency, with over 50% of the collected rainwater ultimately being lost to the sea [4]. Rainwater Harvesting (RWH) has emerged as a notable and efficient approach for optimizing water usage in arid regions. This study investigated the extent to which RWH can be utilized as a solution to address water scarcity issues in Batticaloa. Implementation of strategically located reservoirs within these river basins has the potential to effectively address the issues of drought and flooding [4]. Batticaloa experiences a significant issue of water scarcity throughout the Yala season, despite receiving an average annual rainfall of around 1800 mm [5]. The issue of water scarcity significantly impacts agricultural cultivation, while extreme weather conditions contribute to the occurrence of floods and droughts, resulting in substantial harm to both human life and property. RWH has emerged as a viable water supply option, aiming to decrease reliance on centralized water supply networks. The process of identifying appropriate locations for RWH is a crucial task to optimize water accessibility and enhance land production in arid regions [6]. The successful identification of suitable locations for RWH has been achieved through the integration of studies on runoff modelling and GIS & RS techniques [7]. While several studies have been conducted on this topic, there is a notable absence of studies conducted in the dry zone of Sri Lanka. Hence, this study was conducted to determine the viability of Rainwater Harvesting Structures (RWHS) and Roof-top Rainwater Harvesting (RTRWH) in Batticaloa, using GIS & RS techniques. In a review about the identification of appropriate locations for water storage in arid and semi-arid regions, it was determined that the predominant biophysical factors considered were slope, land cover and soil type [8].

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The assessment of sites for soil water conservation involves considering various aspects, as outlined by the Food and Agriculture Organization (FAO). A GIS-based approach was employed to classify criteria and to produce a suitability map for RWHS in a specific case study conducted in western Iraq [9]. Another study centered on the utilization of a GIS-based model to devise a comprehensive approach for evaluating water management [10]. In this study, the integration of GIS with hydrological models and multi-criteria analysis was employed to assess the appropriateness of RWH locations. The model identified suitable locations for RWH and storage, intending to promote water storage and soil-moisture conservation practices on agricultural lands. A distinct technique was employed, whereby the relationship between depression volume and the presence of surface runoff was examined [11]. This investigation was conducted utilizing the Soil Conservation Service (SCS) - Curve Number (CN) method, which is commonly employed in RWH strategies.

A convenience model was employed to generate compatibility maps for RWH by integrating many criteria through weighted linear combination procedure [12]. It is worth noting that this approach is a commonly utilized method in multi-criteria evaluation for conducting suitable site analysis [13]. Applicability of GIS in modelling RWH systems was also examined [14]. The researchers also employed the mass balance method to calculate the volume of runoff available, taking into account factors such as water supply reliability, water quality, and cost-benefit analysis. This approach was utilized to determine suitable RWH sites [15]. This method allows individual households to collect and regulate the water, ensuring that it remains exclusive to their use. The use of the RTRWH technique has primarily been observed as a pragmatic approach, particularly in regions characterized by little precipitation [16]. A streamlined approach for assessing the possibility of RWH on digitized rooftops within the designated study region was also proposed [17]. The utilization of projected roof rainwater can mitigate the disparity between the drinking water demand and supply of water in the domestic sector. However, it is worth noting that excess harvested rainwater can also be directed towards addressing the needs of home gardens. The effectiveness of this approach hinges on factors such as tank sizing and water treatment processes. Properly sized tanks ensure adequate storage capacity to meet both drinking water and gardening needs, while efficient water treatment processes guarantee the safety and quality of the water supply for consumption. The scope of this research will be limited to evaluating the total harvestable rainwater only. Evaluating the capacities of reservoirs for RWHS, tank sizing and water treatment processes will not be covered within this scope, acknowledging the limitations of the study focus.

2. Methods

2.1 Study Area

Batticaloa is situated in the eastern region of Sri Lanka and it covers a total land area of 2,854 km^2 [18]. The mean annual precipitation measures approximately 1860 mm, primarily resulting from the northeast monsoon [5]. The rainy season in Batticaloa spans from October to January. Additionally, the average temperature in Batticaloa is recorded to be 27.4 °C [5]. Batticaloa is characterized by a significant proportion of its land area being occupied by forested and cultivable terrain, while the urbanized area is predominantly centered along the coast. Moreover, the prevailing soil group in the district is alluvial soil and it is located inside the arid region of Sri Lanka, where the occurrence of drought is a common phenomenon observed between April and September [5]. The issue of water scarcity in Batticaloa has a significant impact on both crop production and meeting essential water needs and also has flood events as a consequence of the northeast monsoonal precipitation. Hence, effective implementation of appropriate Rainwater Harvesting (RWH) techniques has the potential to mitigate the adverse impacts of both drought and flood events. Based on the aforementioned information, Batticaloa was chosen as a focal point for this study to evaluate the efficacy of both RWHS and RTRWH techniques.

2.2 Overall Methodology

The primary objective of this study was to generate a suitability map for RWHS using GIS& RS techniques with the incorporation of socio-economic factors. The analysis mainly focused on evaluating the viability of implementing RWH strategies at land sites. This was achieved by quantifying the additional water requirement for paddy cultivation, taking into account the untapped potential of accessible land within the study area. Moreover, this research employed GIS &

RS techniques to compute the maximum RTRWH potential. This research seeks to determine the additional irrigation water requirements for utilizing abandoned paddy lands in Batticaloa to implement RWH strategies at these sites. Furthermore, the study aims to evaluate the suitability of this RTRWH strategy concerning domestic water demand. The comprehensive approach for evaluating the efficacy of the RWH strategy is presented in Figure 1. This framework facilitates decision-making on the deployment and customization of this RWH strategy, guided by the results.

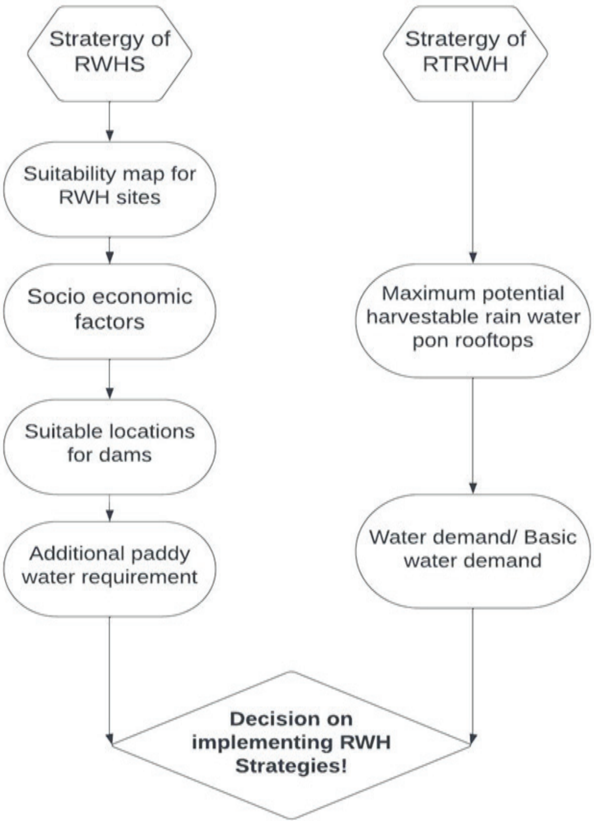


Figure 1 – Overall Methodology for Assessing the RWH Strategies via GIS & RS

2.3 Development of Methodology for Suitable RWH sites

The primary constituents of this RWH system consist of a designated catchment area designed to accumulate surface runoff, as well as a dam intended to create a reservoir to store the collected runoff. The process for identifying appropriate RWHS involves several steps. These steps include selecting appropriate criteria, classifying each criterion, conducting GIS analysis, creating suitability maps, identifying potential sites, and incorporating socio-economic factors. Table 1 presents the criteria suggested by the FAO for evaluating sites for soil water conservation, together with the corresponding values for each criterion as identified by a comprehensive examination of relevant literature.

Table 1 - Criteria and Suitable Parameters for the Assessment of RWHS

Criteria	Suitable parameter
Climate	Runoff depth
Hydrology	Stream order
Topography	Slope
Agronomy	Land cover
Soil	Soil texture
Socioeconomics	Main road and railway network

The rainfall curve was derived using the Inverse Distance Weighting (IDW) method. The CN is determined by the combination of the Hydrologic Soil Group (HSG) and land cover type. The soil is categorized into four HSGs (A, B, C, and D) based on their minimum infiltration rate. The estimation of these CNs can be found in HEC-HMS technical reference tables. The soil within the designated region was determined using the Digital Soil Map of the World (DSMW). In this study, the SCS-CN was utilized to estimate the depth of runoff. This CN value is a numerical representation ranging from 0 to 100, with higher values indicating a greater likelihood of significant rainfall becoming surface runoff. The estimation of the potential maximum retention following the initiation of runoff (S) can be calculated using Equation (1). In this study, the variables "S" and "Precipitation (P)" were utilized as input parameters to determine the Runoff depth (Q) using Equation (2). Moreover, the derivation of the CN grid for Batticaloa involved the utilization of a raster calculator tool to process the reclassified land cover and soil layers. This process of generating the CN grid involved utilizing the Boolean "AND" operation and the conditional query expression.

$$S = (25{,}400/CN) - 254 \quad ...(1)$$

$$Q = (P-0.2S)^2 / (P+0.8S) \quad ...(2)$$

In this study, a DEM with a spatial resolution of 30 m, sourced from the United States Geological Survey's (USGS) website, was utilized to produce slope and stream order maps for Batticaloa. These maps are essential for assessing the suitability of potential RWH sites in Batticaloa. The slope of a land surface is a significant determinant in the production of runoff, exerting impact on sedimentation

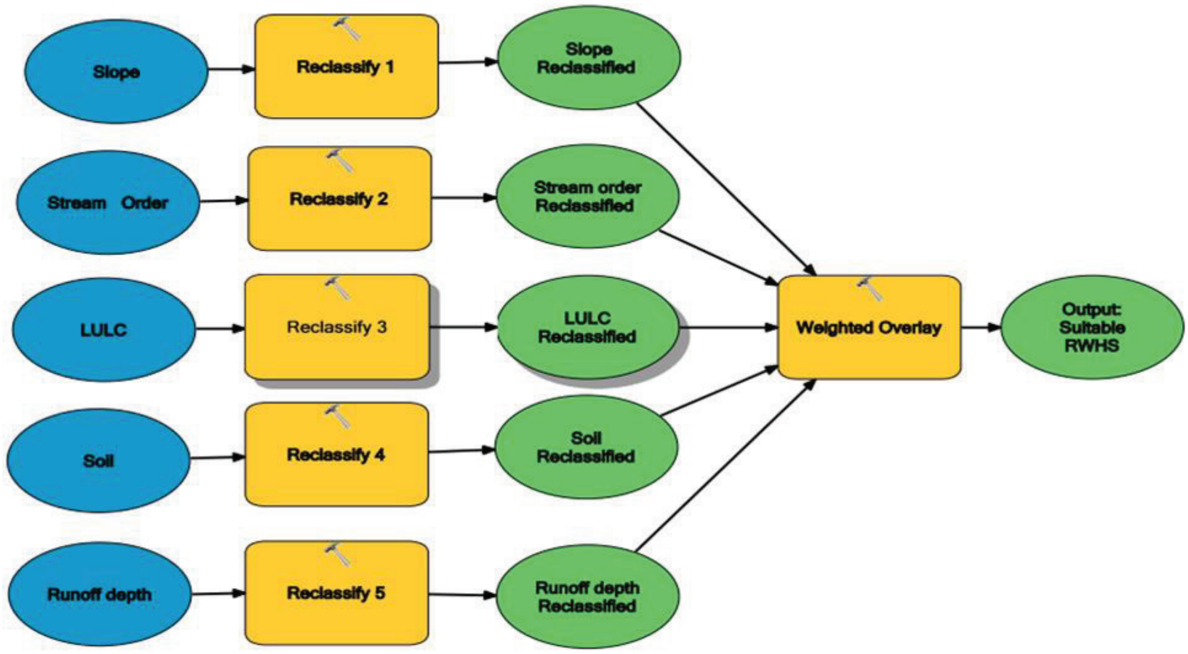


Figure 2 - Flow Chart Methodology for Assessing RWH Sites in the Study Area

processes, the quantity of construction materials necessary for dam construction, and the velocity of water flow. The land cover data used in this study was acquired from Esiri's Sentinel-2 Land Cover dataset, which has a spatial resolution of 10 m. This dataset was then correlated with the runoff data, in addition to the HSG information. The land cover of Batticaloa was classified by supervised classification, utilizing labelled data from Sentinel 2. In this study, a soil map was derived from the DSMW. Here, the textural classification of the soil was calculated based on the proportions of sand, silt, and clay present. Soil with medium and fine textures are considered more favourable for RWH due to their higher water retention capacity [26]. Furthermore, the stream order map for Batticaloa was created through the application of many tools, including Flow direction, Flow accumulation, and Stream order using the STRAHLER approach.

A model builder tool was employed to construct a model aimed at identifying appropriate RWH locations within Batticaloa. The inputs utilized in this study were layers depicting slope, stream order, land cover, soil texture, and runoff depth. The input layers underwent a reclassification process based on a scoring system derived from prior research, relevant literature sources, and recommendations provided by experts in the field of water resources management. The assessment of sites for soil water conservation encompasses several key criteria. This study employed the aforementioned criteria, which were derived from the recommendations of the FAO as shown in Table 1. Rainfall and runoff were utilized as indicators for climate, stream order for hydrology, slope for topography, land cover for agronomy, and soil texture for soil [8]. The process of categorizing the applicability of each criterion involved an initial classification into sub-groups to assign scores, as a result of the diverse range of measurements and scales associated with the different criteria. A comprehensive suitability map can be generated by merging criterion layers within the model builder as shown in Figure 2. The identification of areas suitable for RWH sites involved the reclassification of layers of biophysical criteria and their combination using the "weighted overlay" tool in Arc GIS. Here, these criteria were transformed into numerical values to facilitate their processing in the weighted overlay tool.

The FAO proposed the incorporation of socio-economic parameters for enhancing the efficacy of RWH systems and for strategizing forthcoming infrastructures [8]. These parameters encompass land reservations designated for government development initiatives, archaeological reserves, budgetary limitations, the potential for enhancing water resources, as well as the presence of road and railway networks, etc. In light of the limitations posed by data availability and other constraints, the socio-economic factors were evaluated by focusing on the main road network and railway network. These parameters were selected as key indicators for the implementation of the RWH strategy. Here, appropriate buffers were established surrounding the networks to limit the inclusion of RWH sites within their boundaries.

2.4 Methodology for Assessing Water Demands and RTRWH Potential

The utilization of the CROPWAT model in this investigation was motivated by its straightforward setup procedures and the accessibility of pertinent data (Narmilan, 2018). The CLIMWAT database is designed to be utilized alongside the CROPWAT tool. It enables the computation of agricultural water requirements across various climatological stations globally. The long-term monthly average rainfall data for Batticaloa was obtained from CLIMWAT by specifically selecting Batticaloa station. This data was then integrated with CROPWAT in order to evaluate the water requirement for paddy cultivation. The climatic data results were cross-referenced with the data obtained from the meteorological department and available literature. The predominant type of irrigation channels utilized in minor and medium irrigation schemes is earth channels. The assumption of a 50% field efficiency was made, taking into account the losses due to seepage. Based on the data at hand, it has been determined that the total land area suitable for paddy production in Batticaloa amounts to 84,317 hectares [19]. According to the Department of Census and Statistics, the total area of paddy sown in Batticaloa in 2021 amounts to 28,502 hectares [20]. The water demand for domestic use was determined by considering the greatest population estimate from arithmetic and geometric projections. The estimation of domestic/basic water demand for the construction of a new water supply network was conducted by utilizing the recommendations provided by the WHO and the regulations established by the National Water Supply and Drainage Board (NWS&DB).

The focus of this study revolves around the assessment of aggregated water demands and the issue of water shortage. In the context of the research region, it is important to take into account the availability of water resources when the RTRWH strategy is insufficient to meet the existing demand. The population data for Batticaloa in 2018 was sourced from the Statistical handbook for each divisional secretariat division. To project the population growth, a geometric projection method was employed to forecast the population figures in 2022. Assessing the catchments available for RTRWH is a complex undertaking. Hence, the GIS approach was employed to determine the surface area of different roof types within the designated study area, as seen in Table 3. This was accomplished by treating the rooftops in the Google Earth image as individual catchment areas, as shown in Figure 5(a). In this study, several categories of roof catchments were converted into polygon features using Arc GIS, as seen in Figure 5(b). The RTRWH potential in the designated study area was then assessed by applying the Gould and Nissen formula, as presented in Equation (3).

$$S = R \times A \times Cr \quad ...(3)$$

where,

S = RWH Potential in m^3,
R = Average annual rainfall in m,
A = Roof area in m^2, and
Cr = Coefficient of Runoff [21].

3. Results and Discussion

3.1 Assessing the Potential RWHS

Based on the slope map of Batticaloa, depicted in Figure 3(a), it is evident that the majority of the region exhibits slopes below 5%, and specific elevated regions are observed on the western side of Batticaloa. The implementation of water harvesting techniques may not be advisable in regions characterized by slopes over 5% [9-8]. This recommendation is based on the susceptibility of such locations to elevated erosion rates resulting from irregular runoff distribution, as well as the substantial earthworks that would be necessary for their establishment. This research has placed significant emphasis on the suitability of topography characterized by high stream patterns and sufficient land cover for RWH. Based on the stream order map of Batticaloa depicted in Figure 3(d), it was determined that a significant portion of the central and eastern areas of Batticaloa exhibit favorable conditions for RWH in relation to stream order. These locations exhibit high stream orders, indicating poor permeability and infiltration rates [9]. The stream order results were validated using the shape files of rivers and streams in Batticaloa area. The bulk of river and stream features exhibit a significant degree of overlap with features associated with stream orders greater than three. Based on the land cover analysis of Batticaloa, as depicted in Figure 3(c), it can be

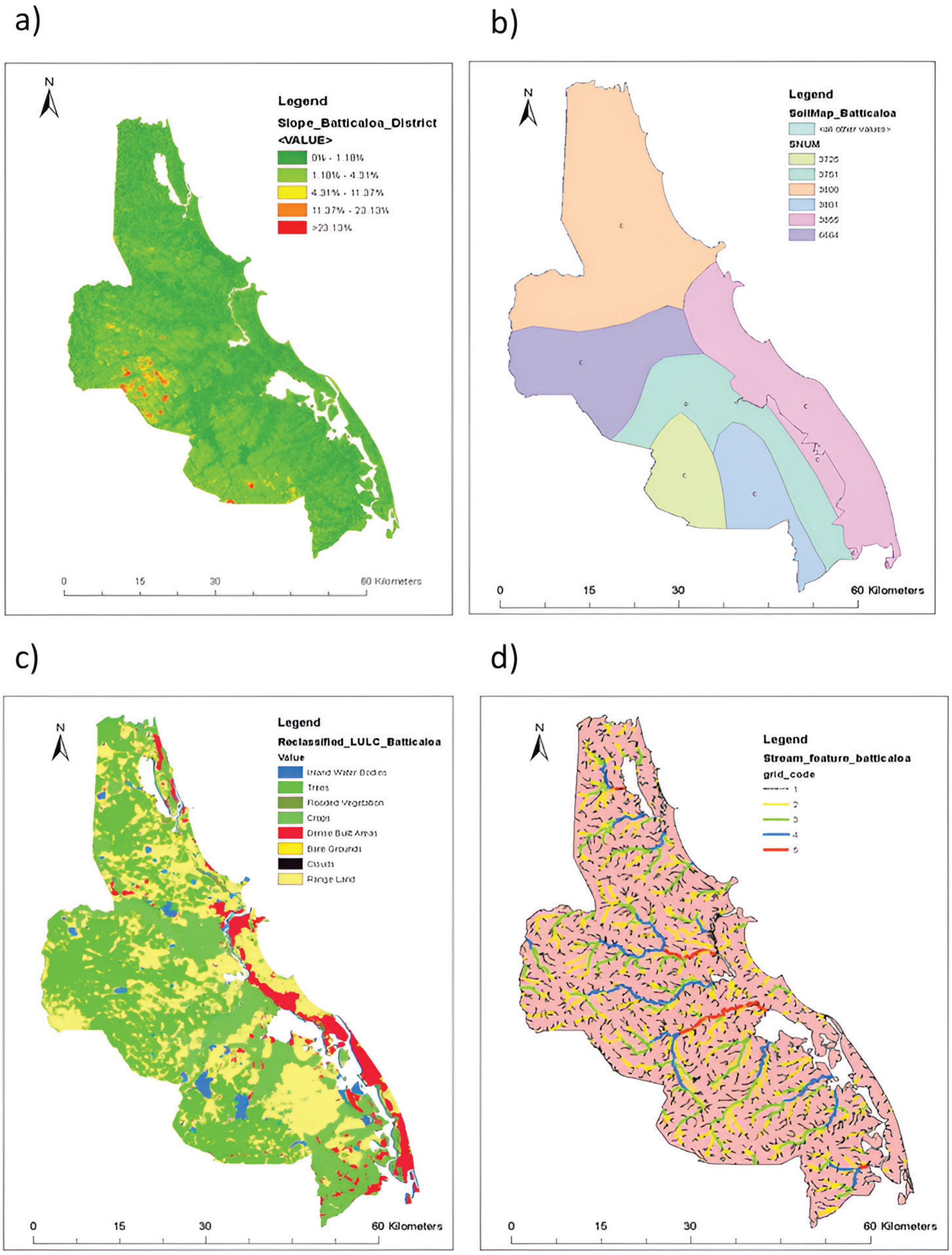


Figure 3 - (a) Classified Slope Map (b) Soil Map (c) Reclassified Land Cover Map (d) Stream Order Map

observed that a significant portion of the region is characterized by vegetation and rangeland, concentrated near the coastal perimeter. The derived land cover was compared to the land cover map published by the Land Use Planning and Policy Department (LUPPD) in 2016 for the Batticaloa region [19]. The comparison revealed a high degree of agreement between the two maps. According to the soil map depicted in Figure 3(b), it has been determined that the prevailing HSG in Batticaloa is classified as "C". According to the results, Batticaloa experiences an average monthly rainfall of over 140 mm, and significant precipitation is observed during the monsoonal period in this region. Hence, implementing appropriate RWHS in this region is a viable approach, particularly in the context of the monsoon season. When examining the runoff depth, it is evident that the western region of Batticaloa exhibits a notable decrease in runoff depth, with values ranging between 70 mm and 102 mm. In contrast, certain regions have a precipitation runoff above 102 mm, rendering them particularly conducive for RWH. In a recent study conducted by Sugirtharan and Pathmaraja (2022), it was determined that the mean monthly runoff depth for Batticaloa during the period of 2005 to 2017 was around 108 mm.

This estimation was obtained through the application of the SCS-CN approach. The aforementioned findings exhibit a resemblance to this study, wherein the mean monthly runoff depth was determined to be 109.7 mm, taking into account the average monthly precipitation over the prior decade. The scores assigned to slope, stream order, and land cover were derived from the recommendations provided from the literatures as presented in Table 2 [9] [10]. Lower stream orders exhibit more permeability and infiltration, while dendritic drainage patterns are characterized by a lack of structural control [8-8]. In this context, inland water bodies have been assigned a high score due to their inherent suitability as RWH sites. Soil with fine and medium textures are often preferred for RWH due to their increased water retention capacity [22]. Soil that possesses a greater capacity to retain water are considered more favourable for RWH [7]. Moreover, it has been found that locations characterized by clay soil exhibit high water storage capabilities owing to the poor permeability of clay and its capacity to retain the collected water [14]. Weights were assigned to each soil type (sand, clay, and silt) based on the aforementioned factors and these weights were multiplied by the corresponding percentages of soil texture in order to calculate appropriate scores.

The resulting runoff depth map of Batticaloa yielded equal ranges of runoff depths, and scores were assigned in ascending order for each respective range. Moreover, it is possible to validate the sensitivity of the marks assigned to each criterion concurrently while validating the suitability of identified RWH sites that have existing inland water bodies. The derived RWH map indicates that a significant portion of Batticaloa exhibits favourable conditions for implementing these RWH strategies. In this study, the suitability of existing inland water bodies for RWH is assessed without taking into account any socio-economic aspects. The subsequent objective of the study entailed the identification of appropriate sites for the placement of dams, with a primary condition being that they should be situated near the main channel of a watercourse. Once the RWH map has been derived, it is imperative to propose appropriate sites for the construction of new dams. In the context of this task, the scoring system was modified to impose restrictions on the scores assigned to inland water bodies and Stream order < 1 in Table 2 during the utilization of the weighted overlay tool.

Table 2 - Value and Score for Each Criterion for Identifying RWH Sites in Batticaloa

No	Criteria	Value	Score
1	Slope (%)	<1.5	1
		1.5-2.5	3
		2.5-4.5	9
		4.5-7.5	5
		>7.5	2
2	Stream Order	<2	1
		2	3
		3	5
		4	7
		5	9
3	Land use/Cover	Inland water	9
		Trees	4
		Flooded Vegetation	9
		Crops	8
		Dense Built Areas	Restricted
		Bare Grounds	5
		Clouds	Restricted
		Range Lands	6
4	Soil Texture	Loam	6
		Clay_Loam	9
		Sandy_Loam_1	4
		Sandy_Loam_2	2
		Sandy_Loam_3	2
		Sandy_Clay_Loam	5
5	Run-off Depth	70.3-86.8	1
		86.8-103.4	2
		103.4-119.9	3
		119.9-136.5	4
		136.5-153.0	5
		153.0-169.5	6
		169.5-186.1	7
		186.1-202.6	8
		202.6-219.2	9

3.2 Validation of the RWHS Map and Assessing the Paddy Water Demand

Figures 4(a) and 4(b) depict the long-awaited maps illustrating the appropriate sites and locations for the establishment of RWHS within Batticaloa. After the incorporation of socio-economic elements, a total of 44 potential places have been identified for the construction of dams. Among these, four locations are deemed moderately acceptable, while the remaining 40 locations are classified as very suitable for the reception of dams as RWHS. In order to propose RWHS for implementation, it is necessary to validate this map with the involvement of irrigation specialists and other relevant stakeholders.

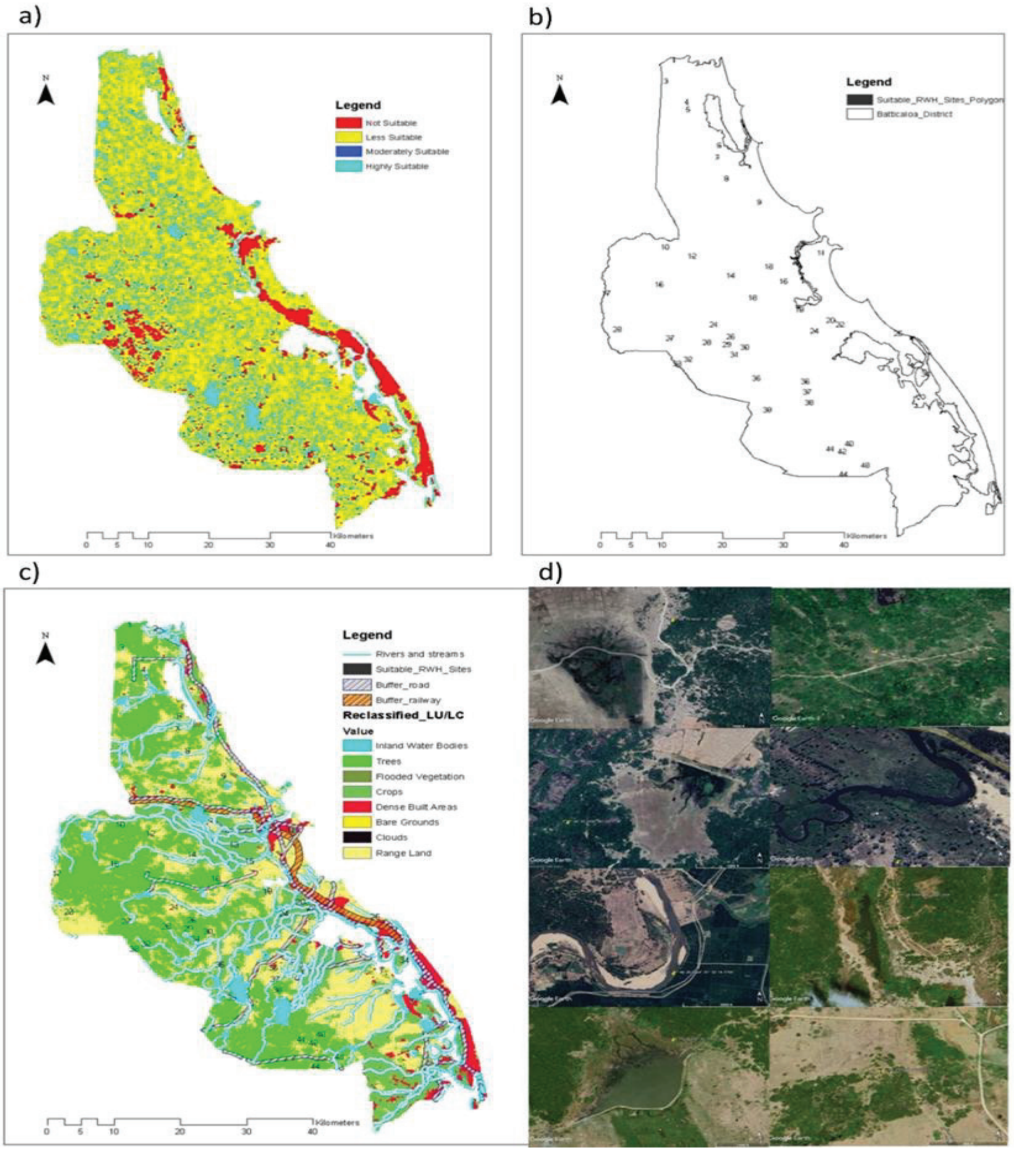
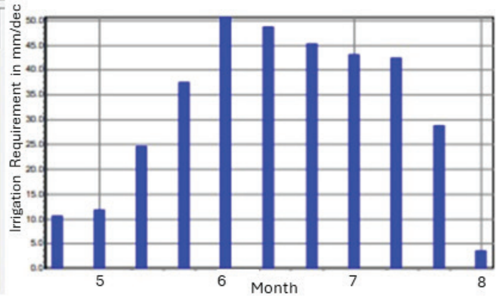


Figure 4 – (a) RWH Site Map. (b) Suitable RWHS Locations. (c) Validation Map for RWHS. (d) Validation by Google Earth Images

The validation of these suitable RWHS can be accomplished by considering their proximity to inland water bodies, ensuring they are situated along the path of existing rivers and streams. One of the simple and cost effective method to identify sites for dams derived from GIS & RS analysis is by the visual interpretation of satellite images [8]. Here, GPS coordinates of the dam locations in the map were found in Arc GIS and these locations were traced in google earth images. Dam locations traced and verified with the google earth images are shown in Figure 4(d). It was found that RWH locations for dams were along the main streams and near the inland water bodies. Therefore, these google images validated the derived RWHS. After analysing the data pertaining to the various water storage strategies, it was seen that the selected locations for these techniques are predominantly influenced by slopes and tributaries with greater stream orders. These streams serve as the primary sources of water for the modelled dams. This validation process should also consider other aforementioned socio-economic factors that may have significant impacts in the implementation stage. The USDA-SC method was utilized to determine the effective rainfall during the Yala season, revealing a measurement of over 100 mm. The precipitation has the potential to significantly decrease the irrigation requirement. Based on the findings derived from irrigation scheduling using CROPWAT, the analysis reveals that the gross irrigation requirement amounts to 808 mm, but the net irrigation requirement stands at 404 mm as depicted in Figure 5. The paddy water requirement for Batticaloa during the Yala season would experience a threefold increase when all available paddy fields are cultivated.

ETo station: BATTICALOA | Crop: Rice
Rain station: BATTICALOA | Planting date: 01/05

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	1	Init	0.50	2.58	25.8	15.1	10.7
May	2	Init	0.50	2.58	25.8	13.9	11.9
May	3	Deve	0.63	3.32	36.6	11.8	24.7
Jun	1	Deve	0.86	4.63	46.3	8.6	37.7
Jun	2	Mid	1.04	5.68	56.8	6.1	50.7
Jun	3	Mid	1.05	5.72	57.2	8.4	48.8
Jul	1	Mid	1.05	5.69	56.9	11.4	45.5
Jul	2	Late	1.05	5.66	56.6	13.3	43.3
Jul	3	Late	0.95	5.18	57.0	14.4	42.7
Aug	1	Late	0.81	4.42	44.2	15.3	28.9
Aug	2	Late	0.71	3.96	11.9	4.9	3.7
					475.0	**123.2**	**348.5**



Totals:

Total gross irrigation	808.1 mm	Total rainfall	135.5 mm
Total net irrigation	404.0 mm	Effective rainfall	67.0 mm
Total irrigation losses	0.0 mm	Total rain loss	68.5 mm
Actual water use by crop	471.0 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	471.0 mm	**Actual Irrigation requirement**	**404.0 mm**
Efficiency Irrigation Schedule	100.0 %	Effective rain	49.4 %
Deficiency Irrigation Schedule	0.0 %		

Yield reductions:

Stage label	**A**	**B**	**C**	**D**	**Season**
Reduction in ETc	0.0	0.0	0.0	0.0	0.0 %
Yield response factor	1.00	1.09	1.32	0.50	1.10
Yield reduction	0.0	0.0	0.0	0.0	0.0 %
Cumulative yield reduction	0.0	0.0	0.0	0.0	

Figure 5 – CROPWAT Modelling Results for Irrigation Water Requirements

Hence, a significant portion of unused land can be effectively repurposed through the implementation of this strategy of RWHS. This research focuses solely on identifying suitable locations for constructing dams to harvest rainwater and aims to produce a suitability map indicating the areas where dams can be effectively implemented for RWH. Therefore, this research does not consider reservoir capacities or feasibility factors related to storing rainwater, such as the area inundated and the range that the water level can fluctuate and reservoir temperature. These aspects are excluded from consideration due to limitations in the scope of this study. However, In the initial implementation stage of a RWHS, capacity, reservoir parameters and financial constraints should be considered.

3.3 Domestic Water Demand for Batticaloa and Assessing the RTRWH Potential in Puliyantivu Central (PC) Grama Niladhari (GN) Division

According to NWS&DB norms, the water requirement for Batticaloa was determined to be 99,393 m^3 per day. According to WHO, a minimum daily water requirement of 20 L per person is necessary to fulfil essential needs [23]. The determined basic water demand for Batticaloa was observed to be 12,048 m^3 per day. In order to evaluate the possibilities of RWH in the PC GN division, an assessment was conducted to compute the water demand in that specific area. In this study, the water demand calculated based on NWS&DB norms and WHO's basic water demand were determined to be 214 m^3 per day and 25 m^3 per day, respectively. Additionally, the proportion of rainfall allocated to meet the water demand was computed for each month based on these criteria. Based on NWS&DB norms, it is evident that the implementation of the RTRWH plan can effectively meet the water demand throughout January, October, November, and December, as illustrated in Table 4. In order to effectively execute the RTRWH approach, it is imperative to appropriately determine the size of the collection tank based on the cumulative RWH potential.

Table 3 - Roof-Top Areas for Each type Derived in Arc GIS

No	Roof Type	Area (m^2)	Percentage distribution
1	Clay tiles	26,101.30	43%
2	Concrete Slab	9,137.23	15%
3	Tin sheet	19,816.44	33%
4	Asbestos	5,087.86	9%

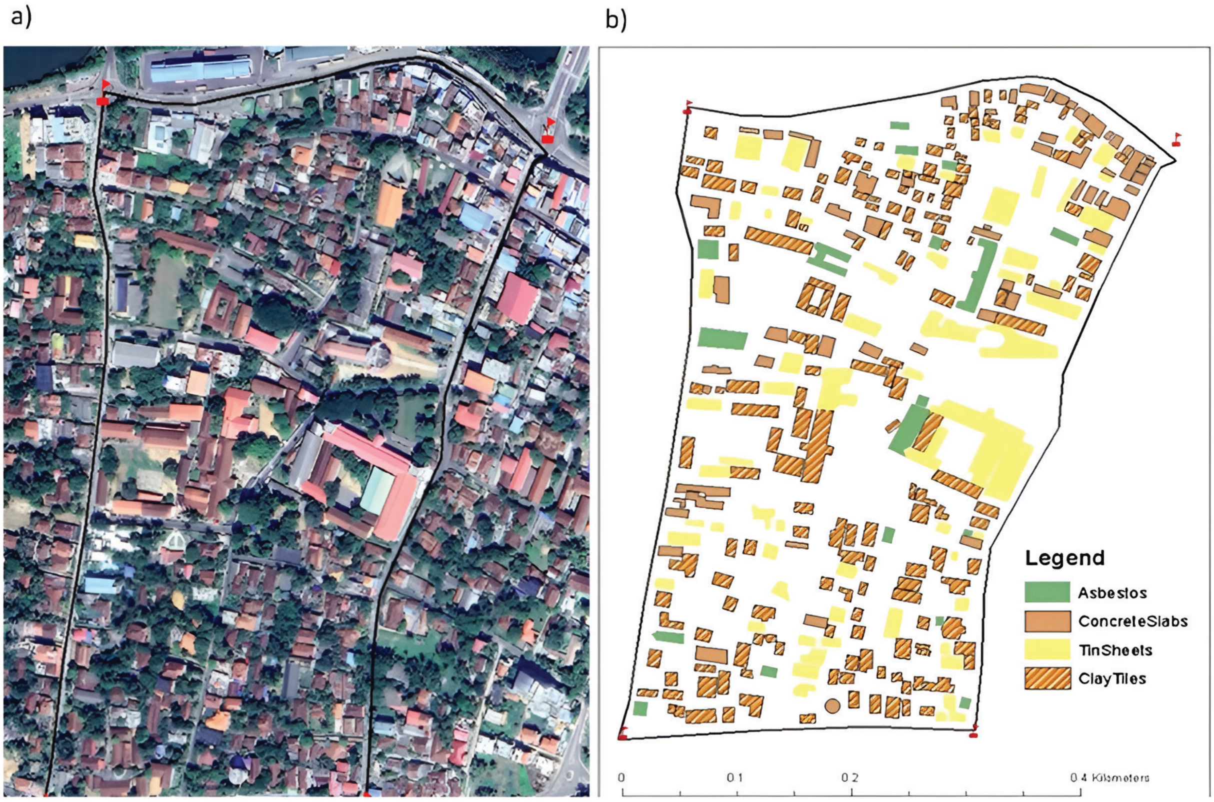


Figure 6 – (a) Google Earth Image of PC GN Division. (b) Digitalization of all Roof Areas in the PC GN division

Upon evaluating the cumulative potential of the RTRWH system concerning the cumulative water demand, the findings indicate that the water demand may be adequately met throughout January, February, March, April, May, November, and December. Based on WHO's minimal water requirements, it is evident that the implementation of the RTRWH strategy has the potential to adequately meet the water demand throughout the entire year.

Table 4 - Percentage of RW catering the NWS&DB water demand in PC GN division

Month	Average monthly rainfall (mm)	Potential Harvestable rainwater (m^3)	Water demand (m^3)	Savings (m^3)	% of rainwater catering water Demand
Jan	226	11,528	6410	5,118	100
Feb	121	6,172	6410		96
Mar	71	3,621	6410		57
Apr	58	2,958.	6410		46
May	44	2,244.	6410		35
Jun	24	1,224.	6410		19
Jul	42	2,142.	6410		33
Aug	54	2,755	6410		43
Sep	69	3,520	6410		55
Oct	182	9,284	6410	2,873	100
Nov	359	18,312	6410	11,902	100
Dec	445	22,699	6410	16,289	100
		86,459	**76,920**		

In order to evaluate the efficacy of the RWH strategy, a specific institution (A school) was chosen within the PC GN division. The purpose of this selection was to conduct an assessment of the potential for rainwater to be harvested and the corresponding water demand. It is recommended that an individual in a daytime school setting should have access to about 15 L to 25 L of water each day [24]. Estimated quantity of around 1.59 L per person per day is recommended for house cleaning and gardening purposes [24]. The calculation of total water consumption for one month is conducted in order to evaluate the efficacy of adopting the RWH approach. In this study, the quantification of water consumption among individuals was conducted over 20 days within a given month, taking into account weekdays.

Additionally, water usage for cleaning and gardening purposes was included in the overall calculation, encompassing all days of the month. It is estimated that the water demand during April, August, and December will be one-third of the regular water demand, taking into account the occurrence of term vacations. Based on the findings, it was seen that the water demand could be adequately met during the majority of the months. Water demand in some months such as March, May, June, and

July may be partially met. When evaluating the cumulative RWH potential in relation to the cumulative water demand, results demonstrate that the water demand might be adequately met during all months of the year. The primary focus of this research is solely on assessing the total amount of RTRWH potential compared to water demands. It is important to note that this study does not delve into aspects such as tank sizing and water treatment processes, which warrant separate investigation. Additionally, the main objective of this research is to evaluate the suitability of this RTRWH strategy for the intended application.

4. Conclusions

4.1 Conclusions for the Approach of RWHS

The following conclusions are made:

•Given the cultivation of paddy in Batticaloa, spanning an area of 28,502 hectares, the total paddy water demand during the Yala season amounts to 230 Mm^3. When evaluating the available land area for paddy cultivation in Batticaloa, which is estimated at 84,317 hectares, it is determined that the entire paddy water demand during the Yala season amounts to 681 Mm^3. Hence, the implementation of this RWHS can effectively utilize a significant portion of unused land.

•Suitable RWH sites are widely scattered throughout Batticaloa area, with the most optimal places being in close proximity to the existing inland water bodies. Based on an analysis of socio-economic characteristics and stream tributaries, a total of 44 viable sites for erecting dams have been identified in Batticaloa region.

•In order to ascertain that the chosen RWH sites do not impede upon any other land uses or reservations that may not be identified by this research, it is imperative to do fieldwork.

•The suitability maps have the potential to be valuable tools for hydrologists, decision-makers, and planners in efficiently identifying potential RWH sites.

•This methodology is efficient in terms of time management and can be employed for the purpose of cost-effective water resource management. Furthermore, it can be implemented in many arid regions and areas of varied sizes, utilizing readily accessible data.

4.2 Conclusions for the approach of RTRWH

The following conclusions are made:

•In the year 2022, it was determined that the water requirement of Batticaloa amounted to around 99,400 m^3 per day. Additionally, the basic water demand, as defined by WHO's minimal standards, was calculated to be 12,050 m^3 per day. In a similar vein, the investigation revealed that the PC GN division (City area) exhibited a water demand of about 214 m^3 per day in the year 2022, with a fundamental water demand of 25 m^3 per day.

•The implementation of the RTRWH Strategy in the PC GN division has the potential to meet the water demand for January, February, March, April, May, October, November, and December. In alternative months, the demand may be partially accommodated. The implementation of the RTRWH Strategy ensures that WHO's basic water requirements are adequately met throughout the entire year, while any surplus water can be effectively utilized for additional purposes.

•The successful implementation of the RTRWH strategy can be achieved in household settings where the average monthly rainfall exceeds 125 mm and the runoff coefficients of the roofs are greater than 0.80.

•The implementation of RTRWH has been demonstrated to significantly reduce water shortages by fully meeting the domestic water demands in metropolitan regions with adequate roof areas.

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