Geospatial Analysis for the Identification of Rainwater Harvesting Sites Using the SCS-CN Technique in the Swat Basin, Pakistan

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Abstract

Rainwater Harvesting (RWH) is a coherent approach to conserving abundant rainwater in a basin, combating water scarcity and reducing pressure on water resources. This study adopts a basin-wide strategy to identify specific locations for RWH in the Swat Basin, Khyber Pakhtunkhwa, Pakistan. The analysis involved different thematic layers, including runoff depth, land use/land cover, slope, drainage density, etc. The land cover data were obtained from the European Space Agency's global land cover and were reclassified in the GIS environment. Drainage density and slope were calculated using the digital elevation model. Rainfall data from the past 30 years were utilized to calculate the average annual rainfall at 12 weather stations across the Swat Basin. By measuring rainfall runoff depth, the prospective RWH sites were identified using the Soil Conservation Service Curve Number (SCS-CN) technique. The SCS-CN technique estimated surface runoff by integrating soil type and land-use patterns to derive a uniform curve number for each area. The thematic layers were assigned weights based on their relative importance to produce a potential RWH map of the study area. The resulting suitability map showed four potential zones, with 23%, 25%, 29%, and 23% of the area in the high, moderate, low, and not suitable classes, respectively. The analysis revealed that the identified potential locations were distributed randomly throughout the study area, primarily in the southern parts of the Swat Basin. The derived suitability map will help decision-makers quickly identify potential locations to develop RWH structures to store water and address the water shortage in the study area. The methodology adopted in this study can also assist the concerned departments with flood mitigation in mountainous areas.

Keywords: Rainwater harvesting, SCS-CN, land cover, soil, GIS, water conservation, sustainable development, drainage density

Introduction

A secure water supply has become one of the most critical issues globally, driven by overpopulation, urbanization and industrial growth that increase water demand. Urban and industrial development has severely contaminated water, resulting in a major decline in existing water resources [1]. Recent findings show that over 2.3 billion people worldwide currently suffer from water stress; the situation is even worse in underdeveloped countries [2]. In 2013, the United Nations predicted a global population of over 9.5 billion by 2050, with over 65% expected to live in urban areas. Studies predict that global water demand will surpass 50% by 2050, further depleting existing resources [3]. Climate change is another major factor shaping water demand and supply [4]. Global warming can significantly affect water resources and future rainfall patterns by changing atmospheric water storage and evapotranspiration, altering the magnitude, frequency, and severity of these events [5, 6]. Balancing water demand and supply often involves considering substitutes such as source reduction and identifying advanced water supply units for optimized water management [7]. In this regard, Rainwater Harvesting (RWH) has proven useful for collecting and storing monsoon rainwater for drinking and irrigation, reducing water supply strain and ensuring clean water for global communities [8]. Global water regulation organizations are earnestly managing water resources and exploring efficient water conservation methods, particularly through RWH systems [9]. RWH is a sustainable, low-cost, and minimally maintained alternative to traditional water supplies in commercial and densely populated areas [10, 11]. This technique can efficiently reduce the risks and impacts of flood disasters [12]. This approach can be easily applied and regulated in regions with sufficient rainfall, ensuring minimal cost and ease of implementation [13]. RWH systems are being promoted in numerous cities as a climate change mitigation measure to reduce water strain in urban settlements [14]. For precise system design, consider the environmental impacts and lifespan of RWH structures to reduce capital costs, raw material use and resource consumption [15,16]. Regional modifications such as tank sizes, water demand rates, and catchment areas are needed for sustainable RWH systems while keeping water conservation in view [17, 18]. Geographic Information Systems (GIS) are widely used to identify RWH sites [19].

The Analytical Hierarchy Process combined with GIS is a reliable decision-making tool for identifying RWH sites because it supports multi-criteria decision analysis and appropriate weighting of input layers [20]. Input parameters such as precipitation, runoff depth, soil types, topographic slope, drainage density, and land use/land cover (LULC) effectively identify potential RWH sites [21].

Surface water is a major source of drinking water in the Upper Indus Basin, Pakistan [22]. The mega-floods of 2022 in northern Pakistan resulted from extreme precipitation in the Indus River catchments and its tributaries. The 2022 flood was declared one of the world's deadliest disasters, claiming more than 1700 lives [23]. Moreover, the lack of potable water has severely affected residents across Swat, including Mingora, Saidu Sharif, Guld Kada, Manyar, Khwaza Khela, Barikot, Matta, Kabal, etc. [24]. The Swat River, a major source of freshwater in Khyber Pakhtunkhwa, faces pollution from urban development, population growth, and unhygienic practices, posing a significant threat to groundwater supplies

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and highlighting the need to install RWH systems. In addition to combating water shortages, installing RWH structures can help mitigate the impacts of recent flood disasters in the study area.

This study emphasizes the foundational hydrological role of the SCS-CN method in directly linking spatial land characteristics to the final suitability assessment. A highly precise and spatially specific estimated runoff map is produced by the model after the quantification of rainfall-runoff across the area. These parameters, including runoff values, are not only separate hydrological data but also an essential thematic layer in the subsequent weighted overlay analysis. Ultimately, combining SCS-CN-based runoff values in the final suitability analysis ensures that water availability and hydrological risk are considered to determine potential RWH sites. Several studies investigating the RWH potential at the provincial level [25], tehsil level [26], and institutional level [27] have been published in recent years. However, to our knowledge, no study in the Swat Basin has identified potential RWH sites based on runoff estimation using the SCS-CN technique in a GIS environment and recommended suitable RWH structures. Moreover, this research involves geospatial analysis to identify suitable RWH sites both in the highlands and plains of the Swat Basin, aiming to achieve the 6th Sustainable Development Goal regarding the provision of clean water and sanitation, and providing a potential route to address the increasing water shortage in one of the colder mountainous regions of Pakistan. The objectives of the study were: 1) to estimate spatial runoff depth using the SCS-CN method, 2) to identify general RWH suitability zones using the selected thematic criteria, and 3) to delineate preliminary candidate areas for farm ponds, check dams, and percolation tanks.

Materials and Methods

Study Area

The Swat Basin, as shown in Figure 1, has longitudinal boundaries between 34.57° and 35.9° and latitudinal boundaries between 71.9° and 72.8°. Spatially, it covers about 5,746.6 km2. Swat Basin is located in the extravagant Hindu Kush Himalayan region. Swat District, located in the Swat Basin, is ranked as the 15th largest district of Khyber Pakhtunkhwa Province, corresponding to its huge population of more than 2.3 million, as reported in the national census of 2017. The regions situated in the north of Swat Basin have an elevation range of 2000 to 5808 meters above mean sea level (a.m.s.l.). In contrast, areas in the south of the study area have a comparatively low gradient, with an elevation range of 686 to 2000 meters a.m.s.l. [28]. These areas are characterized by rocky, uneven mountainous topography, with maximum temperatures exceeding 35 °C in June and lows as low as -18 °C in January. Saidu Sharif, Chakdara and surrounding areas are located in the southeastern region of the district and are more uniform in topography, with temperatures rising to 45 °C in June and dropping to -2 °C in January. The Swat River originates in the Hindu Kush Mountains, where the Usho and Utror rivers intersect in the Kalam Valley, and it joins the Kabul River in the Peshawar Valley. Temperature, wind patterns and precipitation are the main factors influencing snowmelt that floods the Swat River. The study area is a Cenozoic-era aeolian formation and has widespread colluvium deposits throughout the Swat River [29].

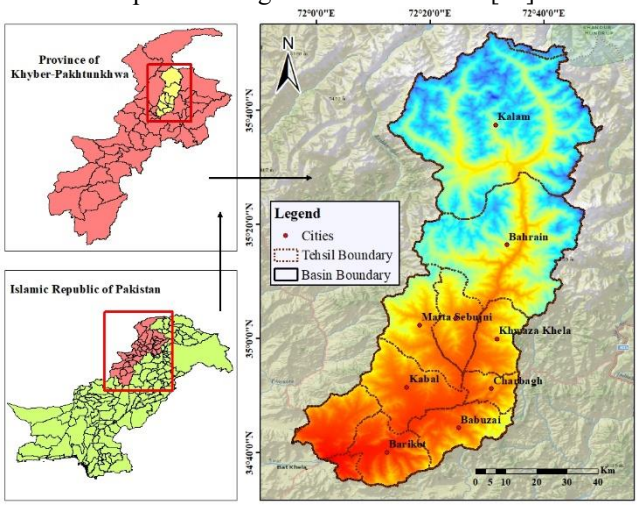


Figure 1: Study area map showing the Swat Basin in the Khyber Pakhtunkhwa Province, Pakistan

Datasets Acquisition

The LULC data of Pakistan was acquired from the European Space Agency's website. We used the 30m digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM) to calculate the slope of the Swat Basin. The data regarding soil series of the Swat Basin were acquired from the Soil Survey of Pakistan. Finally, precipitation data for the region were obtained from the Water and Power Development Authority and the Pakistan Meteorological Department.

Datasets preparation

The LULC thematic layer was prepared by reclassifying the raster in ArcMap and creating 7 land-cover classes. Table 1 shows the dataset sources and their subsequent usage for map creation. The georeferencing and digitization of the soil series data of the Swat Basin were done in ArcGIS software to prepare the Hydrological Soil Groups (HSG) map of the study area. Table 2 shows the soil classes and their runoff potential. The SWAT Basin's 30-year precipitation data were used to calculate average annual rainfall at 12 weather stations, as shown in Figure 2. Figure 3 presents the study's methodological flowchart. The LULC thematic layer was prepared by reclassifying the data into seven classes, including agriculture, water bodies, bare areas, grasslands, built-up areas, forests and permanent snow and glaciers.

Drainage density is described as "the total length of streams per unit area of the catchment", and mathematically it is described as follows [30]:

$$DD = \frac{\sum_{i=1}^{n} L}{A} \quad (1)$$

Where the number of streams is represented by n, the length of streams in kilometers is represented by L and the corresponding drainage area is represented by A.

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Table 1: Sources and resolution of the geospatial datasets used in the study

	Primary Data	Spatial Resolution	Format	Source	Map Derived
1	Digital Elevation Model	30 m	Raster	Shuttle Radar Topography Mission (SRTM)	Slope, watershed, Drainage density, stream network
2	Land Use/ Land Cover	300 m	Raster	European Space Agency's website	Land Use/ Land Cover map
3	Rainfall Data	-	Point data	Water and Power Development Authority and Pakistan Meteorological Department.	Rainfall pattern, Runoff map
4	Soil Map	-	Vector	Digital Soil Map of Pakistan by Soil Survey of Pakistan	Soil texture and HSG maps

Table 2: The soil classes and their runoff potential according to the Soil Conservation Service classification

Hydrological Soil Groups	Soil Texture	Potential of Runoff
Group A	gentle slope, deep, non-calcareous, medium textured, coarse textured, excessively drained soils	Moderate
Group B	shallow, non-calcareous, acid/slightly alkaline, excessively drained	High
Group C	gentle slope, calcareous, moderately fine textured soils	High
Group D	glacier/snow	Moderate

SCS-CN Technique

The SCS-CN method was used to determine surface runoff. This method was created by the United States Department of Agriculture's (USDA) Soil Conservation Service (SCS). The SCS-CN technique is successful mainly because it combines factors affecting runoff generation into a single variable, CN. The parameters include soil type, LULC, moisture conditions, and topographic conditions.

Water balance is calculated based on the following method:

$$P = Ia + Q + F \quad (2)$$

$$\frac{Q}{P-Ia} = \frac{F}{S} \quad (3)$$

where total rainfall in mm is represented by P, initial abstraction (mm) is represented by *Ia*, cumulative infiltration without including *Ia* is represented by *F*, potential maximum retention (mm) and direct runoff (mm) are represented by *Q*.

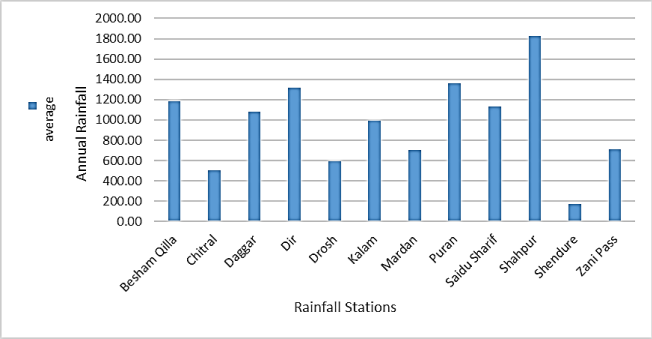


Figure 2: Average Annual Rainfall at different stations that were used in the study

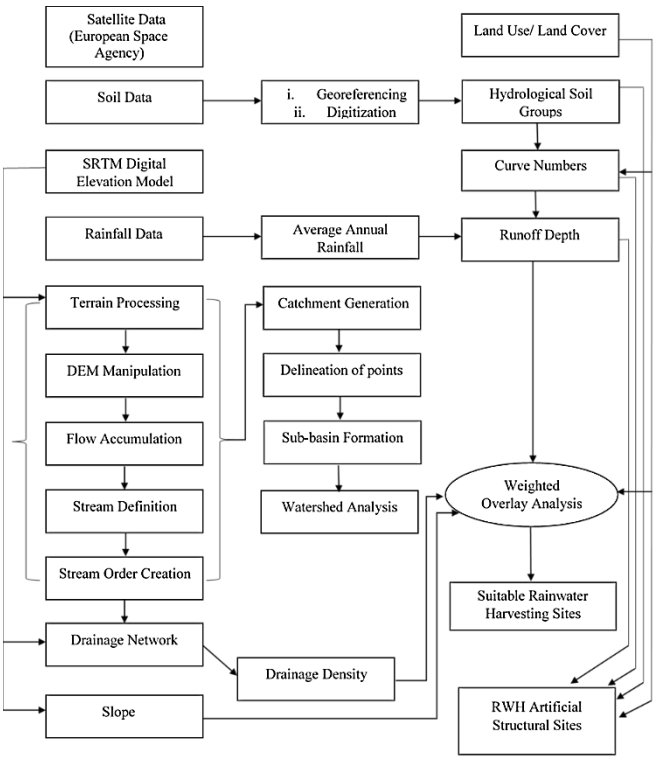


Figure 3: The methodological flowchart to identify suitable rainwater harvesting sites using SCS-CN technique

By combining the two equations, i.e., Eq. (2) & (3), the SCS-CN technique in its standard form yields the following equation.

$$Q = \frac{(P-Ia)^2}{P-Ia+S} \quad (4)$$

This is practical when rainfall exceeds the initial abstraction (P≥Ia); otherwise, Q =0. Since the annual rainfall of the sampled stations has been used, a raster depicting the estimated values was created after carrying out inverse distance weighted interpolation. Point delineation was carried out to divide the Swat Basin into sub-basins. For each sub-basin, rainfall (P) was calculated as the mean pixel value in the raster. This method is dependent on 2 vital assumptions. The first assumption states that the ratio of maximum possible runoff to actual rainfall equals the ratio of actual infiltration to maximum possible retention. According to the second

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assumption, the volume of initial abstraction (Ia) is the portion of maximum possible retention, i.e., Ia = 0.2S [31, 32, 33].

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad (5)$$

Calculation of S is done using a mathematical equation as described below:

$$S = \frac{25400}{CN} - 254$$

where the curve number is represented by CN, which depends on LULC and HSGs; these CN values can be obtained from the fourth section of the SCS Handbook of Hydrology (NEH-4) [31, 33]. In ideal cases, non-permeable surfaces, such as water surfaces where all rainfall becomes runoff, have a CN value of 100. In contrast, surfaces in which all rainfall is absorbed have a CN value of 0 [31, 34]. If the CN value is known, runoff can be calculated using Eq. (5). For this research, CN values were estimated manually by intersecting LULC and HSG (Table 3). The outcome was generated in the form of a polygon, which was further converted into a raster showing a map of CN values in the study area. Thematic layers of all contributing parameters were reclassified, and weighted overlay analysis was performed by assigning weights to each parameter based on its significance. The Arc Hydro extension of ArcGIS software was used to generate the hydrological DEM.

Table 3: The curve numbers assigned to each LULC-HSG combination.

LULC	HSG	CN
Bare areas	B, D	88
Grasslands	A	49
	B	69
	C	79
	D	84
Agriculture	A	67
	B	78
	C	85
	D	89
Forest	A	25
	B	55
Permanent snow/ glacier	A, B, C, D	0
Water bodies	A, B, C, D	100
Built-up areas	B	85
	D	92
	C	90
	A	77

Table 4: Criteria for the selection of artificial structures for rainwater harvesting

Artificial RWH Structure	Slope (%)	Land Cover Type	Soil Type
Farm ponds	< 5	Agriculture	C & D
Check Dams	< 15	Bare areas	C
Percolation Tanks	< 10	Bare areas	B

The specific suitability of individual RWH storage structures

In order to identify the suitable sites for individual RWH storage structures, the generated thematic layers of LULC, slope, HSG and runoff were considered. The relative weights were assigned to each parameter used for RWH potential assessment so that their contributing factors could be controlled. The published literature provided the basis for assigning these weights to each contributing factor [31, 35, 36, 37]. The layers were overlaid, and suitable sites for RWH structures such as farm ponds, check dams and percolation tanks were identified. Table 4 shows the characteristics of each criterion on the basis of which the suitable sites for each structure type were identified. All variables used as input and their assigned weights are provided in Table 5.

Table 5: Factors and scale values of different factors used in the analysis

Factor	Class Weight (Pi) (%)	Classes	Class Rank (Wi)
Land use	7	Bare areas	9
		Grasslands	7
		Agriculture	3
		Forest	2
		Permanent snow/ glacier	2
		Water bodies	1
		Built-up areas	1
Slope	30	0 – 5	1
		5.1 – 11	9
		11.1 – 17	7
		17.1 – 27	5
		27. 1 – 79	1
Runoff Depth	48	670 – 800	1
		801 – 1000	3
		1001 – 1200	5
		1201 – 1400	7
		1400 – 1600	9
Drainage Density	15	< 0.015	1
		0.16 – 0.029	3
		0.030 – 0.054	5
		0.055 – 0.12	7
		0.12 – 0.36	9

Results and Discussion

Slope

Slope is vital for identifying suitable RWH sites and selecting water storage structures. A slope range of 0- 8% is appropriate to prevent soil erosion from uneven runoff patterns and high earthwork ratios, ensuring suitable sites for RWH [38]. The slope in the study area ranged from 0% to 79% and was classified into five classes, as shown in Figure 4. The study area, predominantly in the southwestern region and with an irregular distribution in the northern part, falls within the 0%-11% slope range suitable for RWH sites. However, most of the study area, especially in the northern part, has slope values above 11%, which are not suitable for RWH. Most RWH

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studies in arid and semi-arid regions report suitable slope values [39].

Land Use/ Land Cover

The land cover of Swat was categorized as cropland, forest, grassland, bare land, water bodies, built-up areas, and permanent snow. Water bodies, primarily along the western boundary of the northern region, make up only 0.04% of the total area and are unsuitable for RWH system implementation. Grasslands, mainly in the southern semi-arid parts of the Swat Basin, cover 11.3% of the total area. Swat has experienced rapid urbanization in recent decades, leading to a significant portion, about 27.42%, of the study area being built up, so it was excluded from potential RWH systems. The remaining 6.5% of the land cover is occupied by forests, 12.1% is dominated by snow, 13.4% is bare land, and 29.34% area falls into the category of cropland and agriculture. The spatial arrangement of these land covers is depicted in Figure 5.

Bare land and grasslands have high potential for water retention because they reduce primary abstraction and infiltration losses from vegetation, site clearance or land improvements [40]. RWH sites are not beneficial in built-up areas, water bodies and agricultural lands, whereas forests and snow cover are moderately suitable. The results revealed that over 31% of the study area is moderately suitable for RWH system installation, with 34% being marginally suitable and over 22% being least suitable due to built-up land or water bodies, making them economically unfeasible and difficult to operate and maintain [41]. Satellite data provides a basic foundation for efficient land use/land cover mosaics, with LULC as a critical parameter influencing surface runoff and rainwater-harvesting potential.

Hydrological Soil Groups (HSG)

The surface is crucial for water retention. Higher clay and silt concentrations have a greater potential to hold water. The soil types are classified into four groups, i.e., A, B, C, and D, by the US Soil Conservation Service using the hydrological soil grouping (HSG) scheme. Similarly, the Swat Basin's soils are classified into four hydrological groups (A, B, C, and D). Type A soil covers 7.3% of the study area, primarily in the southern parts. Type B soil covers 77.8% of the area, extending from north to south. Type C and D soils cover 3.04% and 11.9% of the study area, respectively. Type B soil, with high runoff potential and low infiltration rate, is ideal for installing RWH structures. Figure 6 depicts the spatial distribution of these four hydrological soil categories.

Curve Number (CN)

The study examined curve number values in the Swat Basin, focusing on land-use classification and runoff depth.

The CN values were generated in ArcGIS 10.3 software by intersecting LULC and HSG values. The spatial distribution of curve number values is presented in Figure 7.

The most frequently observed CN values ranged from 79 to 89, with 36% of the area falling within this range. The study area comprised 36.7% of CN values between 79 and 89, followed by 35.2% values between 71 and 78 and 4.6% values between 90 and 100. The remaining values between 0-25 represented permanent snow, and 26-70 represented forest cover, covering 12.2% and 11.3% of the study area, respectively. Low CN values indicate low surface runoff potential and high infiltration, whereas high CN values indicate high runoff potential and low infiltration [42]. Evapotranspiration and surface conditions influence the LULC, which is crucial for identifying RWH sites. The highest runoff values occur in water bodies, agricultural lands, and urban areas, highlighting the importance of rainwater collection structures to address flood concerns. The lowest values occur in forested regions, suggesting avoiding artificial structures. Low-CN areas have a long precipitation retention time and may be used as recharge locations [43]. The curve number links HSG, LULC, and antecedent moisture conditions, indicating that much of the study area is available for artificial recharge. Another study used the SCS-CN technique with the Analytical Hierarchy Process in the Kirthar mountain range to identify suitable sites for RWH structures and found five suitable sites that could store and supply rainwater to local communities and mitigate flood risks in that rugged topographic region [44].

Drainage Density

The suitability of a farmed area for RWH depends on the drainage density. The drainage density was calculated based on the stream network using the hydro DEM as shown in Figure 8. Figure 9 illustrates the drainage densities ranging from 0.015 to 0.36 (km/km^2). The results revealed that high, moderate and low drainage densities exist in 2.64%, 52% and 44% of the study area, respectively. Areas with low drainage density are less favorable for rainwater collection, whereas areas with high drainage density are more favorable. The study area has a sixth-order stream network, with geology, slope, and structures controlling drainage-density patterns. High drainage density and the highest-order drainage network are directly correlated. It can be inferenced from Fig. 9 that moderate to high drainage densities are best for rainwater collection in the Swat Basin. Overall, the study area's drainage density values indicate the potential for rainwater harvesting.

Runoff Depth

The SCS-CN method was used to identify probable runoff sites in the study area. The spatial distribution of runoff depth in the study area was classified into five classes (Figure 10).

Relatively higher runoff depth values (above 1200 mm) were found mostly in the central and southern parts of the study area, whereas lower values were found mostly in the northern parts. Runoff depth is a crucial factor in determining optimal RWH locations, as it estimates the potential water supply from surface runoff during the rainy season [45].

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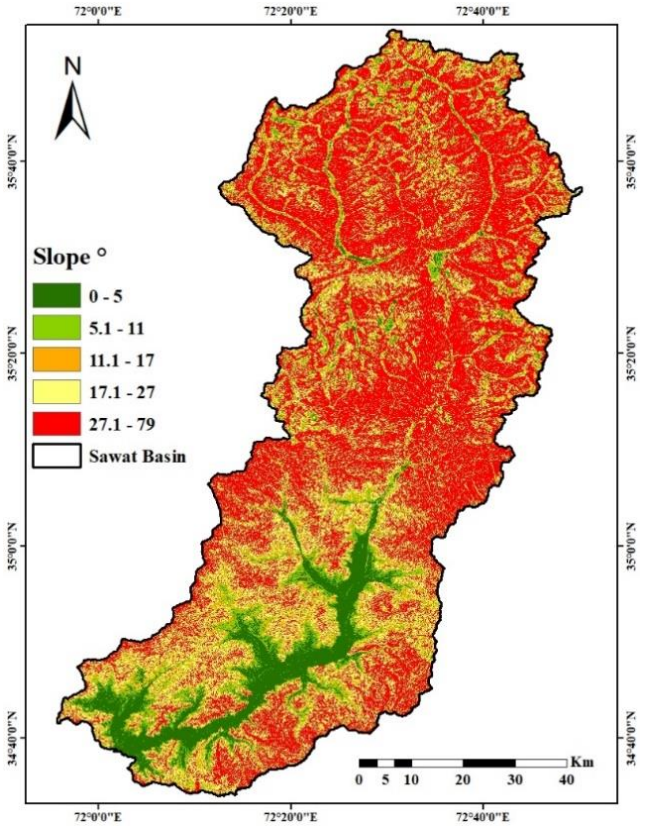


Figure 4: Map showing percentage slope of the Swat Basin

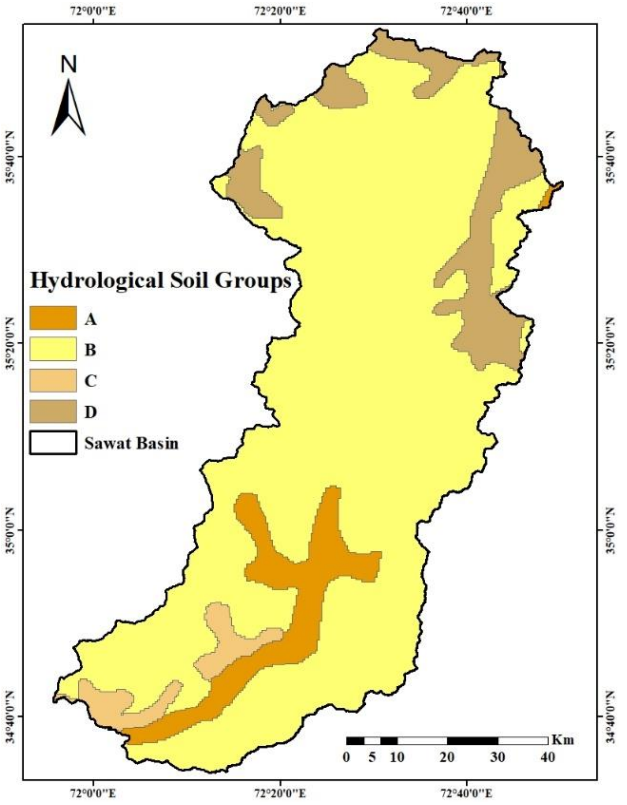


Figure 6: Map showing Hydrological Soil Groups of the Swat Basin

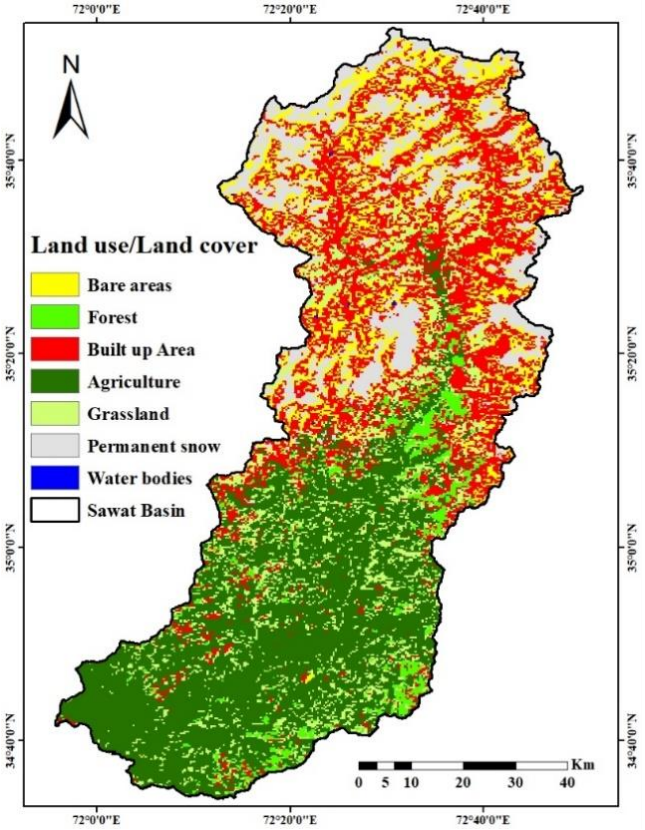


Figure 5: Map showing land cover of the Swat Basin

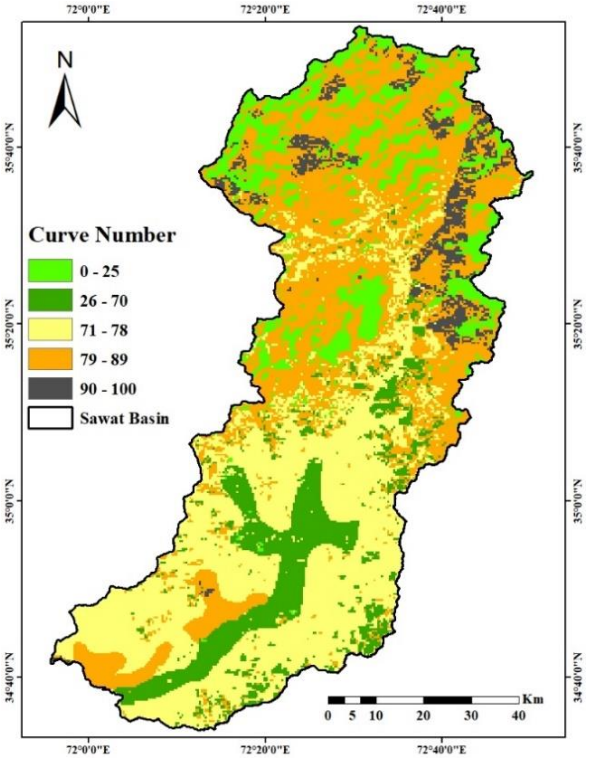


Figure 7: Map showing the Curve Number of the Swat Basin

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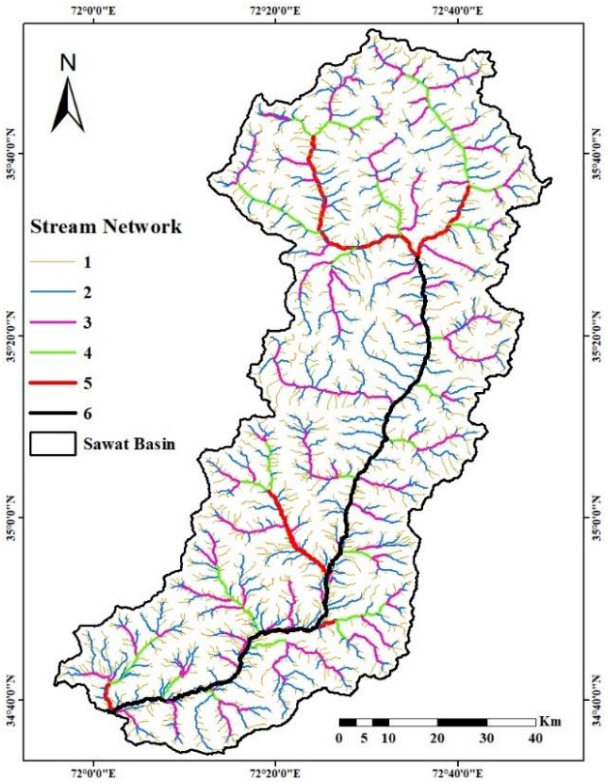


Figure 8: Map showing the Stream Network of the Swat Basin

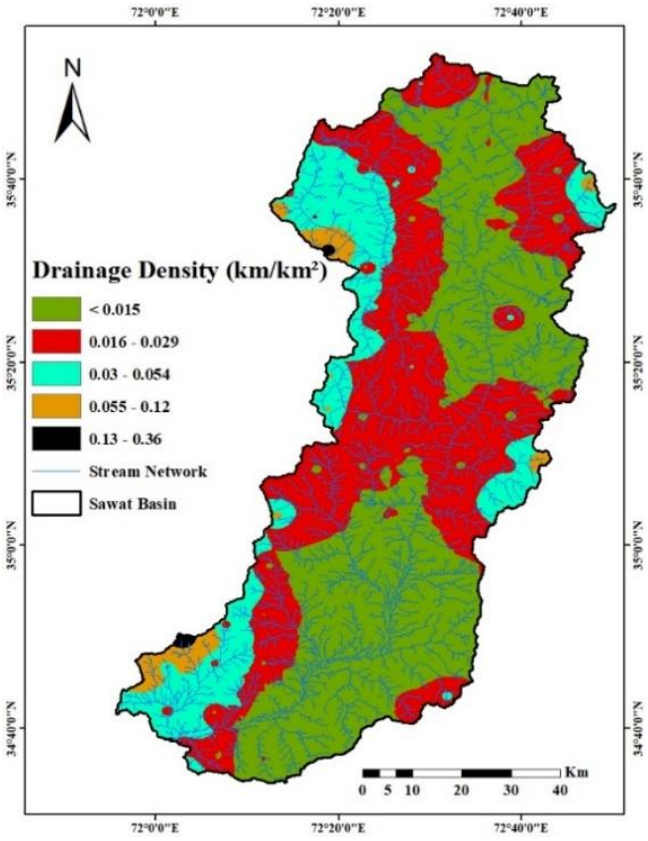


Figure 9: Map showing drainage density of the Swat Basin

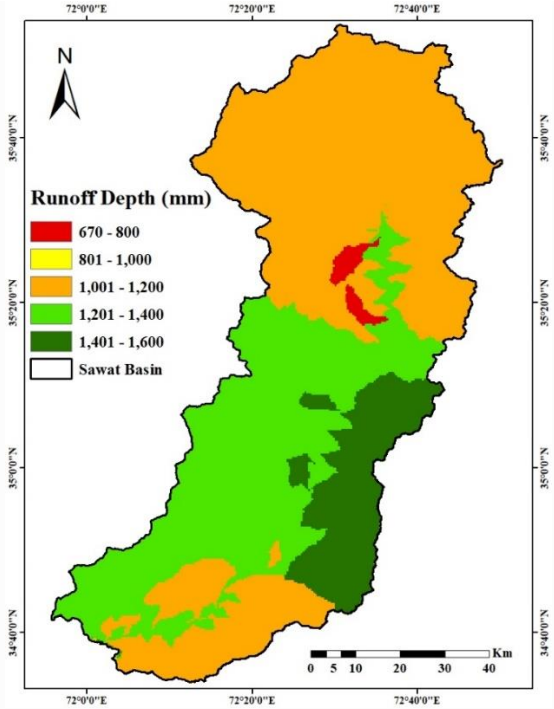


Figure 10: Map showing Runoff Depth of the Swat Basin

Rainwater Harvesting Site Suitability

The current study evaluated RWH potential in the Swat Basin and divided the region into three suitability classes. The equal interval classification method was used to calculate the percentage area of each class. The results showed that 22.9%, 25.24% and 28.6% of the study area had high, moderate and low RWH potential in the Swat basin, respectively (Figure 11).

Whereas 23.2% of the study area was found unsuitable for RWH. Urban areas and aquatic bodies dominate the area, hence making it unsuitable for RWH setups. Most of the study area is arid, with higher runoff values and lower infiltration rates. Although suitable areas for RWH are scattered throughout the Swat Basin, they are mostly clustered in the southern part of the basin. This distribution of suitable locations could support a highly effective RWH system for water storage and usage management in the Swat Basin. Another study in Ghazi Tehsil, Khyber Pakhtunkhwa, also found similar results for suitable RWH area (28.73%) due to the dominance of moderate slopes and high runoff potential [26].

Artificial Structures Storage

This study also evaluated the sites for artificial RWH storage facilities, such as farm ponds, percolation tanks, and check dams, in addition to the general suitability of RWH sites, as shown in Figure 12. Farm ponds require a slope range of 0-5%, moderate to high runoff depth, and sandy clay loam. The results showed that only 2.75% of the Swat Basin is suitable for developing farm ponds.

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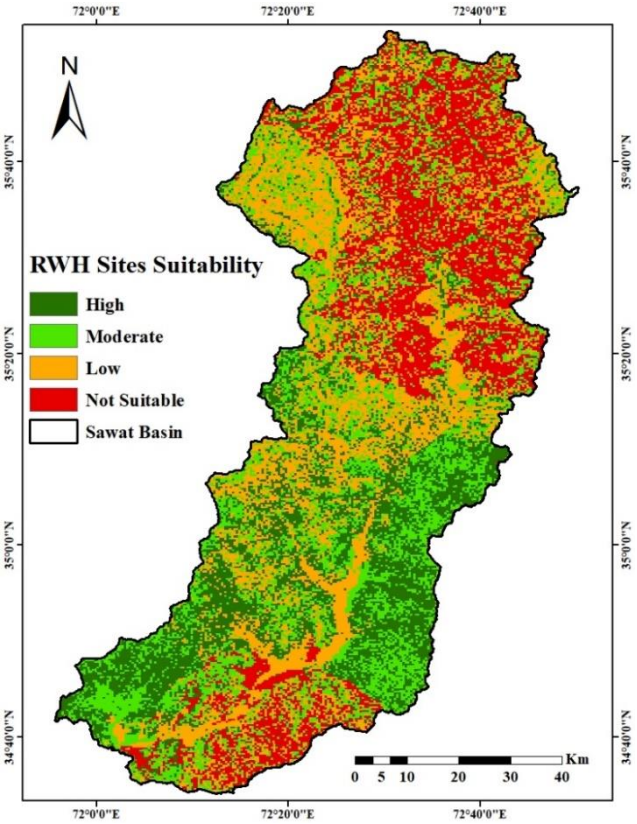


Figure 11: Map showing suitable sites for Rainwater Harvesting in the Swat Basin

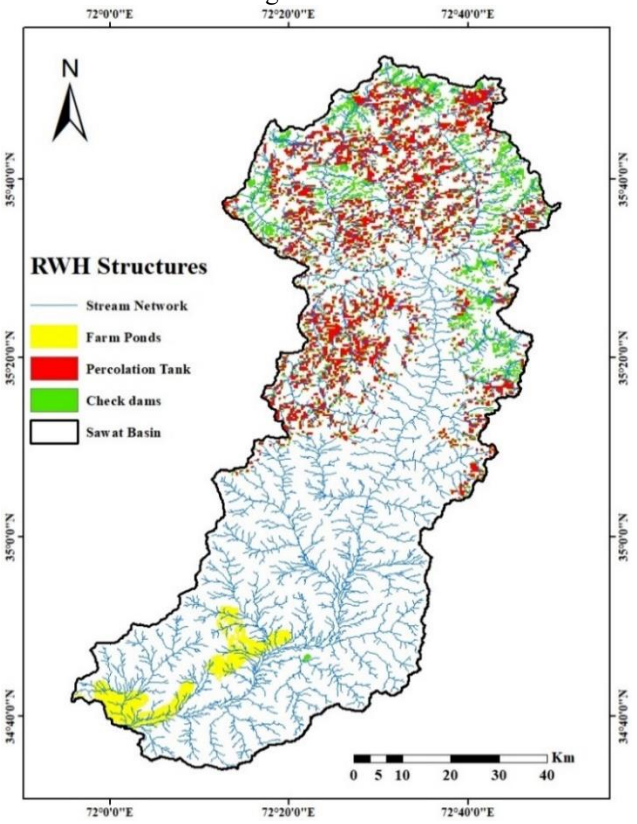


Figure 12: Map showing structures suitable for rainwater harvesting in the Swat Basin

Check dams also have similar requirements for runoff depth and soil type, but they can accommodate slopes up to 15% [46]. About 13.3% of the study area was found suitable for check dam construction.

Installing a percolation tank requires a slope of less than 10%, lower runoff, and clay-containing soil. About 10.8% of the study area was found suitable for percolation tank construction. As this study was based on the SCS-CN technique, another study conducted in China reported that the SCS-CN technique is an effective tool for precise prediction of runoff in the ridge-furrow RWH systems [47].

The Swat Basin includes individually owned private and state-owned properties. Shared communal properties are also widely distributed in the study area, which hinders RWH structure installation due to social and political constraints. Land encroachment conflicts and conventional tenure planning pose a major threat to large-scale water conservation projects and often require substantial compensation [48]. Community-based alliances and public-private partnerships are crucial to future water infrastructure planning, helping avoid displacement costs and community conflicts [49]. The rugged, steep topography of the Swat Basin poses a major barrier to accessibility. Deploying heavy construction machinery in secluded or high-altitude catchments becomes impossible because fragmented road networks create persistent vulnerability to mountain hazards [50]. Instead of starting macro-level projects, regional planning authorities should prioritize RWH systems or localized micro-level dams, as these smaller structures can be built and maintained without heavy vehicular intervention [51].

Rigorous Monsoon seasons induced by climate change have significantly escalated the environmental constraints in the study area. Because of steep, rugged topography, the region is highly vulnerable to landslides, glacial thaws, and debris flows of catastrophic magnitude that can destroy RWH structures [52]. Moreover, escalating deforestation and grassland decline have caused a reduction in natural water recharge, resulting in rapid siltation of reservoirs. Therefore, any proposed infrastructure must incorporate protective bunds, filter strips, and local bioengineering to endure the area's severe flash floods.

The feasibility of implementing RWH systems in the study area depends heavily on local technical capacity, government support and sustained financial stability. Climate-induced disasters make high-budget water infrastructure significantly impractical in mountainous regions [53]. Feasibility planning must focus on low-cost, flood-adaptive, and practical structural designs. Regional integration of water resource management with these systems must also be considered to ensure long-term functionality [54]. Overall, selecting suitable locations for installing RWH structures paves the way for pilot projects in the Swat basin. Locally available raw materials can lower the expected high cost of constructing the proposed RWH structures. Furthermore, ground truthing, while considering local socioeconomic factors, is needed to identify potentially suitable RWH sites and is the need of the hour for sustainable rainwater resource management in the Swat Basin.

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Conclusion

The study was conducted to find suitable locations in the Swat Basin for collecting rainwater. The region's natural configuration supports RWH as an alternative for meeting water demand. Proper collection, filtering, storage, and management can reduce water scarcity. Site suitability was assessed using a geographic multi-criteria evaluation method, incorporating slope, LULC, runoff depth, and drainage density. The study highlights the importance of understanding soil types and their impact on water management. The region has suitable hydrological soil types (B, D, and C), with runoff above 1400 mm and a slope of 0-10%. However, geographic mismatches in these parameters have reduced the suitability of certain areas for RWH systems. Almost half of the Swat basin (48%) has medium to high suitability for RWH system development. In order to save precious time and money, these areas should be taken as primary areas for further investigation by the concerned departments for RWH system installation in the basin. The study proposes a methodology to promote groundwater resource conservation and development in regions with similar topography and climate characteristics. It is recommended that the concerned authorities benefit from this study and consider site characterization, socio-economic activity analyses, and in-depth audits at suitable locations to catalyze overdue RWH pilot projects in the Swat Basin.

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Competing Interests

None.

Authors' Contribution

Conceptualization and methodology, F.M. and S.U.S.; formal analysis, investigation, resources, data curation, F.M. and M.K.; software, F.M.; visualization, F.M. and M.K.; writing-original draft preparation, F.M.; writing-review and editing, F.M., M.K. and S.U.S.; supervision, S.U.S. All authors have read and agreed to the published version of the manuscript.

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