Remote Sensing Assessment of Small Dam Sites in Swat District, Pakistan: Inferences from Water Resource Scenarios

Sumaira Kousar[1], Saira Batool[2], Syed Amer Mahmood[3], Faiza Sarwar[1], Zainab Tahir[3], Samreen Javed[3]

[1] Institute of Geography, University of the Punjab, Lahore

[2] Centre for Integrated Mountain Research

[3] Department of Space Science, University of the Punjab, Lahore

Correspondence: Sumaira Kousar (sumaira.geog@gmail.com)

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In a world where water is indispensable, Pakistan grapples with the challenge of ensuring its availability. Freshwater demand from domestic, industrial, and agricultural uses has strained the country's reservoirs. Financial and political barriers have hindered the construction of large dams, making it imperative to seek alternative solutions. However, small dams have the potential to address Pakistan's water security concerns. This study uses advanced technology, engineering expertise, socioeconomic factors, and environmental awareness to find multi-purpose small dam sites in Swat District, Pakistan. Water storage and community and economic development are goals. This study examines criteria using RS and GIS. Dam site selection considers rainfall patterns, slopes, land use, soil types, and drainage density. The study uses Elevation Area Capacity (EAC) curves to view potential reservoirs. The map divides areas into High, Moderate, and Low suitability. This analysis yields some sites where R4 is impressive for its suitability and storage capacity of 358,237 at 2080 m. R1 and R2 are promising with moderate suitability and large storage capacities of 121,346 and 271,964, respectively. These sites are more than numbers on a map they represent local aspirations. Their benefits include electricity, flood protection, irrigation, and drinking water. Small dams are progress catalysts with low maintenance and political support. This study concludes that socioeconomic and environmental factors should be considered when engineering small dams. This small dam can store water and provide essential services to local communities and economies. These multi-purpose small dams advance water security.

Keywords: Site selection Dam RS/GIS EAC SWAT Pakistan

Introduction:

Having reliable access to clean water is crucial to the health of ecosystems and national economies [1]. Freshwater reserves have been dwindling due to the increasing demand for the resource from households, businesses, and farms. Over-exploitation of groundwater reserves has led to a decrease in water tables and a deterioration in water quality, which in turn has disrupted the delicate balance between rainfall and surface water availability [1]. This isn't a problem unique to any one part of the world rather, it's a worldwide phenomenon that has a disproportionately negative impact on developing nations [2][3]. Building reservoirs on a variety of scales, from the tiny to the massive, is an integral part of a sustainable and decentralized strategy to meet this challenge. However, there is no international agreement on how to categorize dams into either "small" or "large" [4]. Dams over 15m in height are considered "large" by the International Commission on Large Dams, but in the United States and China, dams over 90m in height are considered "large." However, reservoirs with a capacity greater than 1 million m^3 are considered large dams[4].

The selection of sites for small dams demands a customized regional approach that takes into account not only engineering considerations but also vital socioeconomic factors [5] Climate, water availability, topography, and geology all constitute significant considerations in this process [6]. These factors encompass elements such as the frequency and intensity of rain, the rate of runoff, the size of intermittent streams, the density of drainage, the nature of slopes, the distribution of land use, the composition of soils, and the depth of alluvial deposits[7]. What matters is that the prioritized uses for the identified dam sites are in line with the actual needs and desires of the local communities[8]. However, these priorities can vary widely depending on the context. While equitable water distribution, flood mitigation, and the provision of safe drinking water to the local populace may take precedence in some regions, others may require small dams primarily for energy generation, irrigation water supply, and biodiversity conservation[9]. Therefore, the site selection process for these small dams should be nuanced and region-specific, considering the various socio-economic and environmental settings in which they will operate[9].

Appropriate locations for small dams can be located with the help of Remote Sensing (RS) and Geographic Information System (GIS) methods. The hydrological potential of regions can be quickly and easily gathered through the combination of RS and GIS [7][10]. Criteria for locating suitable sites for small dams have been the subject of discussion, with many studies highlighting important factors like rainfall, soil type, slope, drainage density, and land use [11][12][13]. For instance, [6] used the Soil Conservation Service-Curve Number (SCS-CN) method to select potential rainwater harvesting sites based on factors such as rainfall, soil type, slope, Curve Number (CN), alluvial depth, drainage density, runoff depth, and proximity to streams. Numerous studies have shown that the SCS-CN method is commonly used in conjunction with other criteria for small dam site selection, including rainfall, runoff, slope, land use, CN, stream order, drainage density, drainage network, DEM, distributed runoff coefficient, and topographic maps [14] [1] [12][15][16].

Pakistan has a critical need for large-scale dams to efficiently manage its scarce water resources, but their construction has been hampered by several factors, including a lack of funding and political instability, for decades. As a result, the construction of small dams presents a feasible option for storing water for subsequent use in agriculture, industry, and other productive endeavors. In contrast to the complexities of large dam projects, small dams provide communities and governments with affordable and locally manageable solutions. Surface runoff is a major contributor to Pakistan's already severe water shortage problem [17]. According to the International Monetary Fund, Pakistan is the 36th most water-stressed country in the world [18][19][20]. While the projected demand for water in 2025 is staggering, the available water recharge/supply is only 191 MAF. Khyber Pakhtunkhwa (KP) province in Pakistan has its water shortages, which has a negative impact on farmland and orchards. The province's inadequacy in capturing and storing ample water during flood events and monsoon seasons is attributed to the absence of both small and large dams. As a result, dam building at national, state, and regional levels becomes an urgent necessity. The Swat River, a major source of freshwater that could provide water to many parts of KP, flows through the Swat District. Dams built on the river's waters at strategically located, feasible sites would help meet the urgent water needs of the area and the country.

Objectives:

This research makes two major additions to the existing literature: First, it provides a methodical strategy for finding good locations in the Swat District to build small dams that can serve multiple purposes, using a combination of RS-GIS technology and engineering criteria. Second, it prioritizes considering local concerns about the environment and economy when deciding where to build small dams. This study is useful because it provides policymakers with information that will help them build small dams and reservoirs that meet not only engineering standards but also the specific needs and preferences of the local population. The primary goal of this research is to identify the best locations for building flexible small dams, considering relevant socioeconomic and environmental indicators. This all-encompassing method promotes sustainable water resource management in Swat District and similar areas by making sure the resulting dams are not only technically possible but also socially and environmentally responsible.

Novelty Statement:

This study stands out for its global perspective on water scarcity and its nuanced understanding of small dams. It pioneers a comprehensive approach by addressing the lack of international consensus on dam classification. Through regionally tailored methodologies, it integrates engineering factors with socio-economic considerations, ensuring dam sites meet both technical requirements and community needs. The innovative use of RS and GIS methods streamlines site selection, addressing complexities like rainfall and land use. Focusing on Pakistan's Swat District, a region in dire need of water management solutions, this research offers actionable insights. Its adaptability, technological integration, and specific context make it invaluable for policymakers, advancing sustainable water resource management practices.

Materials and Methods:

Study Area:

The Swat district, situated at 34°46'58" N and 72°21'43" E, is in KP, Pakistan. To the north, it shares a border with Chitral, while its western border is adjacent to Dir, and in the northeast, it connects with Gilgit-Baltistan. Nearly 1.26 million people live in the district, which is 5337 km^2 in territory [21][22]. The research area is located in the centre of KP tourist industry and is a mountainous region surrounded by the Hindu Kush Himalayas (HKH) [23]. The climate of Swat ranges from semiarid to subhumid to humid [24][25]. From a geological point of view, the study site is situated within a Suture Zone (SZ) resulting from the convergence of the Indian Plate and the Kohistan Island Arc (KIA). The SZ is situated on the northern side and is the most active tectonic and geomorphic region where the KIA meets the Asian Plate [26][27]. Annual precipitation ranges between 600 and 1200 mm in the research region [28][29]. Most of the population relies on natural assets, including farmland, pasture, cattle, fisheries, vacation spots, and timber, for their livelihoods [30]. Approximately 42% of the local population relies on agriculture for their income [31]. The protected woods and rich soils of Swat have made it famous. Swat's forest cover accounts for around 20% of the district's total area, or 409,591 acres[29][31]. Swat has been densely wooded since prehistoric times, and its cedar forest was formerly considered the best in the world [30]. KP's rural residents rely heavily on the province's forest resources. Most of the populace relies on these materials for shelter, food, and transportation [32].

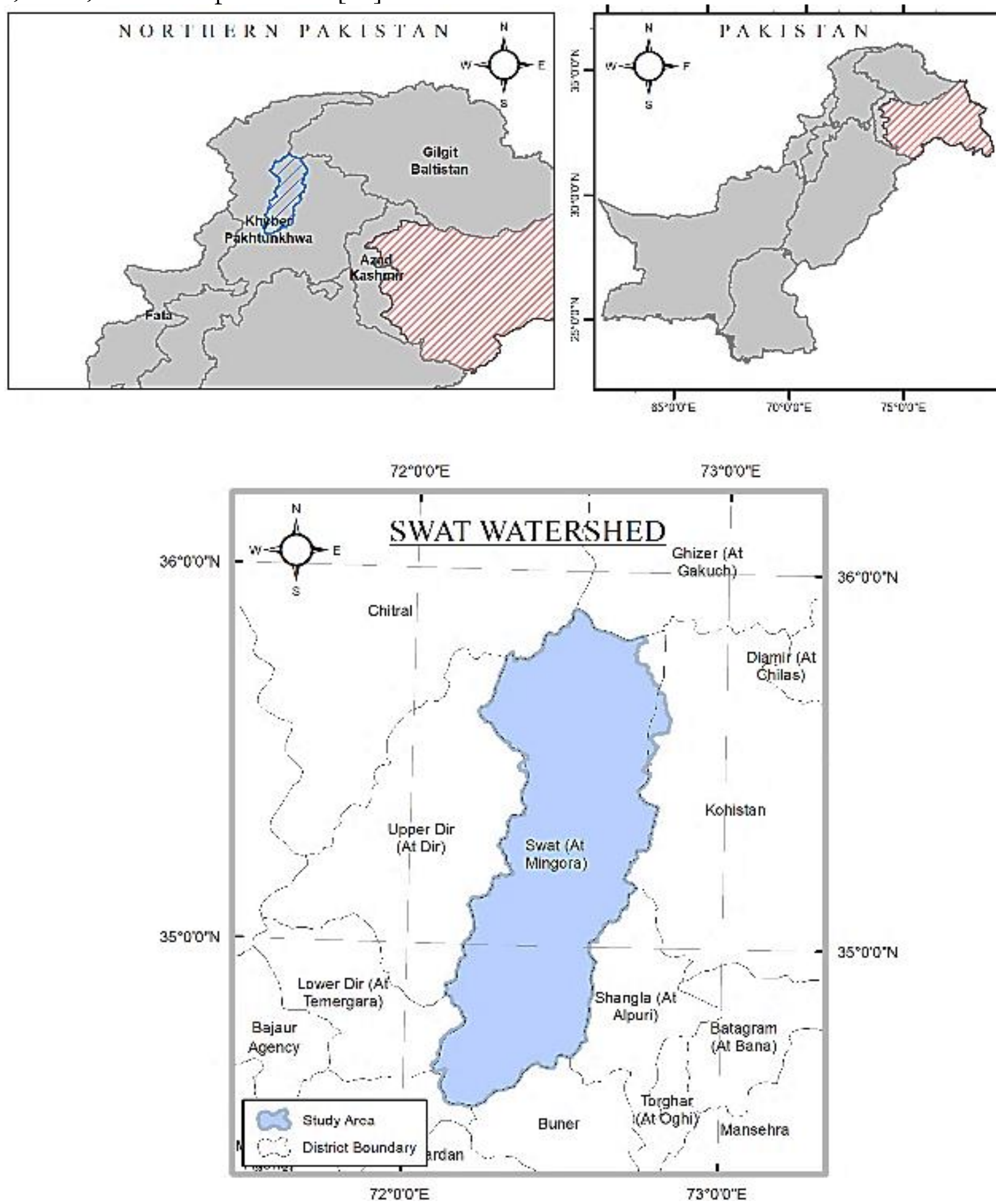


Figure 1. Study area location in Pakistan

- Elevation analysis considers the height or elevation of land or features on the study area. Elevation data is often collected using remote sensing technologies in the form of a Digital Elevation Model (DEM).
- Study site analysis involves measuring the surface area of specific geographic features or land parcels. It is essential for land use planning, resource allocation, and environmental monitoring.
- Volume analysis involves calculating the volume of a specific area or region, often below or above a reference surface. This analysis is particularly important for earthworks, mining, construction, and environmental assessments.

The Swat Valley watershed assessment and location selection of the reservoirs for water storage using the DEM. The topographical maps that are accessible can be used to prepare the initial reservoir elevation-area-capacity curve for a dam location. The incremental volume between any two contour elevations and live capacity of reservoir are calculated using the formulas.

$$\Delta V_i = \Delta h\left(A_i + A_{i+1} + \sqrt{A_i A_{i+1}}\right)/3 \quad (1)$$

$$V_i = \sum_{k=1}^{i} \Delta V_k \quad (2)$$

$$Ya = \sum_{i=1}^{N-1} \Delta V_i \quad (3)$$

ΔV_i = Volume between contour elevations i and $i + 1$,
Δh = Contour interval,
A_i = Area at contour elevation i,
A_{i+1} = Area at contour elevation $1 + i$,
Ya = Live capacity of reservoir, and
N = Number of contour elevations.

Methods:

Analyzing storage capacity at a dam site is crucial for assessing the feasibility and effectiveness of a dam project. This analysis involves calculating the volume of water that can be stored behind the dam, considering various factors such as elevation, topography, and inflow/outflow rates. When choosing a suitable location for a reservoir or assessing the feasibility of building a reservoir, elevation, area, and volume analysis are essential. These analyses assist in determining the site's capacity to preserve and manage water effectively.

Digital Elevation Model (DEM):

The imagery from the Shuttle Radar Topography Mission (SRTM), which has a resolution of 30 meters, was obtained from the website of the United States Geological Survey (USGS) exclusively for the purpose of study. The data provided the basis for the DEM utilized in our research. The DEMs corresponding to these grid segments were downloaded and merged with meticulous attention to detail. Following that, we conducted a clipping procedure using the shapefile of the study area to extract the DEM that is relevant to our research area.

The utilization of high-resolution SRTM imagery facilitated the extraction of essential topographic data, including slope, drainage patterns, and lineaments, within the designated region of our research. The parameters played a crucial role in our evaluation of appropriate sites for dam placement. It is important to highlight that we utilized the SRTM data, which contained voids that were addressed through spatial interpolation algorithms to complete the missing information. This approach ensured a thorough and accurate depiction of the geographical characteristics. The SRTM is a significant international undertaking that enabled the collection of digital elevation models over a wide expanse of the Earth's surface, ranging from 56° S to 60° N. This effort resulted in the creation of a comprehensive database containing detailed geographical information at high resolutions.

Precipitation Data:

The evaluation of yearly precipitation holds significant importance in our dam assessment study, as it plays a crucial role in determining the broader hydrological conditions. To acquire the essential data, we procured monthly records of precipitation covering a period of ten years (2012-2022) from the Pakistan Meteorological Department for each of the five weather stations situated within the designated study area. Nevertheless, the determination of yearly precipitation faced distinct obstacles, predominantly associated with the necessary data prerequisites. To tackle these challenges, we developed streamlined procedures. The collection of yearly precipitation measurements, expressed in millimeters, is a crucial component in our evaluation process.

The data play a critical role in evaluating the appropriateness of the study area for the construction of a dam. Regions characterized by higher annual precipitation typically demonstrate more advantageous circumstances for the selection of dam locations.

This comprehension facilitates our evaluation through the utilization of the mean annual precipitation data. The Inverse Distance Weighting (IDW) method was utilized in our study to spatially map the distribution of rainfall in the research area using ArcMap. The IDW method is widely recognized for its efficacy in forecasting precipitation patterns within a specified geographic region.

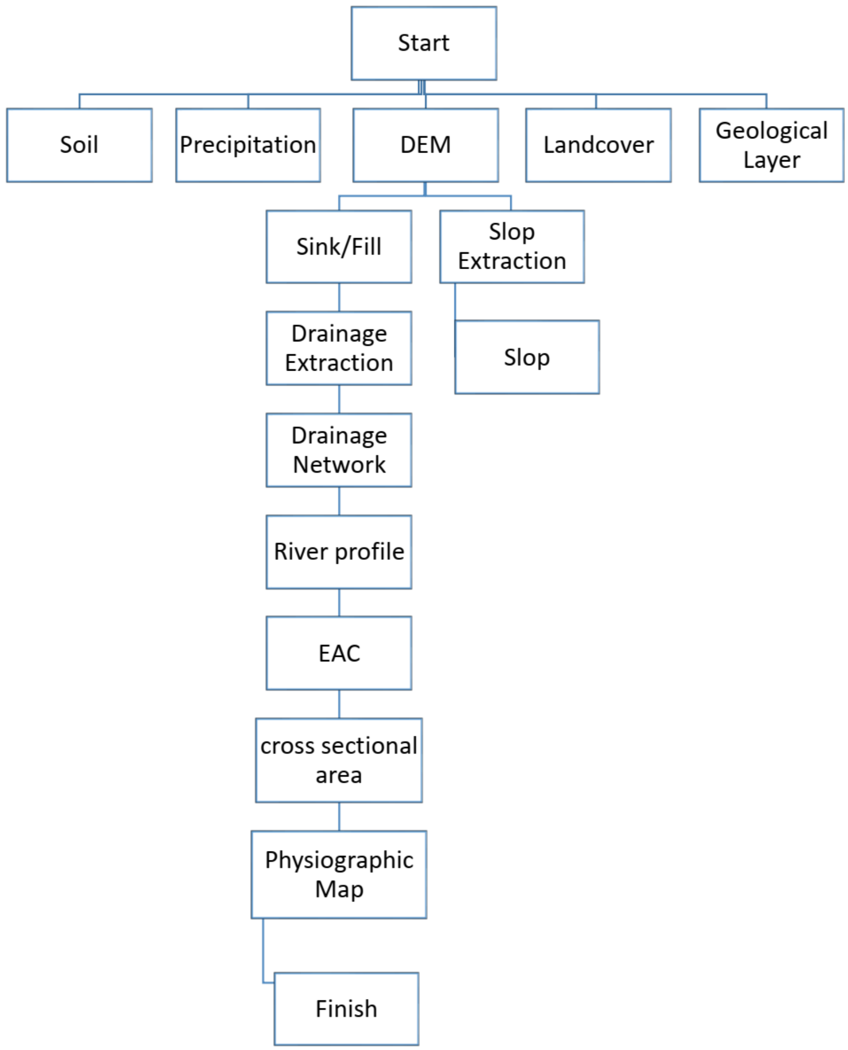


Figure 2. Flow chart of methodology

LULC Data:

The Land Use and Land Cover (LULC) map for the Swat District was generated using Sentinel-2 data processed in ArcGIS. The stacking tool was employed to merge all satellite images, followed by the utilization of the "pan-sharpening tool" to improve the resolution of the image. To establish clear boundaries between different LULC categories, specific training areas were carefully chosen to create hyperplanes. The classification of high-dimensional remote sensing data was performed using machine learning techniques, specifically Support Vector Machines (SVM) [33][34]. The evaluation of the accuracy of the LULC classification is frequently conducted through the utilization of methodologies such as the confusion matrix and kappa coefficient [35][36]. The accuracy and precision of the generated LULC maps were assessed using Kappa analysis, a multivariate and discrete method. The analysis encompassed various measures of accuracy, namely total accuracy, producer accuracy, user accuracy, and the overall kappa coefficient.

The accuracy of the user was assessed by calculating the ratio of the total number of pixels in the image to the number of pixels that were correctly classified for each LULC class. The producer's accuracy was calculated by dividing the count of accurately classified pixels for each LULC class by the total count of pixels in the reference points. The equation used to compute the overall accuracy is as follows:

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixcel}}{\text{Total Number of refferences pixels}} \times 100 \qquad 4$$

The Kappa coefficient was employed to assess the accuracy of the observed image. The Kappa coefficient quantifies the extent to which a classification technique reduces error compared to random categorization. A Kappa coefficient of 1 signifies complete agreement, while a value of 0.811 indicates that the LULC map successfully mitigates 81.1% of errors. The equation provided below was utilized to compute the Kappa coefficient for multiple categorization techniques.

$$\text{Kappa Coefficient (T)} = \frac{(\text{TS} \times \text{TCS}) - \sum(\text{Column total} \times \text{Row total})}{\text{TS2} - \sum(\text{Column total} - \text{Row total})} \times 100 \qquad 5$$

TS= Total samples

TCS= Total corrected samples

Soil Suitability Analysis:

The assessment of soil suitability for the intended purpose was a crucial component in our study. To accomplish this, we obtained relevant soil data from the website of the Food and Agriculture Organization (FAO). The soil dataset presented in this study offers a comprehensive collection of valuable information pertaining to diverse soil types, characteristics, and properties within the designated study area. Utilizing the data, we performed a comprehensive assessment of soil suitability, employing rigorous methodologies to ascertain the compatibility of the soil with our objectives. The analysis undertaken in this study exerted a noteworthy influence on guiding our decision-making and shaping our recommendations. It played a crucial role in ascertaining the compatibility of soil conditions with the intended land use or project specifications.

Longitudinal Profile Analysis of River:

The examination of the Swat district's river's longitudinal profile provides a significant viewpoint on the hydrological dynamics and geomorphic characteristics of the region. The present analysis functions as a graphical depiction illustrating the variations in land elevation along the course of the river within the Swat district. Hydrological investigations greatly benefit from their significant value, as it offers valuable insights into various aspects such as river flow patterns, gradients, and the potential risk of floods. These insights play a crucial role in facilitating effective water resource management and the development of strategies for flood mitigation. In addition, geomorphologists can employ the longitudinal profile as a means of interpreting the geological history of a given region. This analytical approach allows for the identification of various landforms, such as waterfalls, meanders, and rapids, which serve as valuable indicators of the landscape's evolutionary processes. Furthermore, the utilization of this data in environmental assessments provides researchers with the ability to evaluate the influence of the river on its surrounding environment, facilitate habitat conservation initiatives, and make informed decisions regarding ecologically sustainable land-use practices. The longitudinal profile analysis plays a crucial role in informing the design of dams. This analysis ensures that these structures are designed in a manner that prioritizes safety and sustainability, thereby contributing to the overall well-being of this important region.

Interpolation:

In this study, the IDW interpolation technique was exclusively utilized to estimate values between observed data points. IDW ensured accurate spatial representation, facilitating precise analysis of factors like rainfall patterns and soil composition in the selected dam sites.

Elevation Area Capacity Curve:

The Elevation Area Capacity Curve (EAC) is a graphical depiction that elucidates the complex interplay among various crucial variables within a reservoir. The illustration focuses on the relationship between variations in the elevation of a reservoir's water surface and the corresponding changes in the storage volume of water held within the reservoir.

The elevation-area-capacity curve is a valuable tool for gaining insights into the behavior of reservoirs in response to dynamic factors such as inflow, outflow, and operational adjustments. In essence, this technology functions as a crucial tool for the strategic analysis, implementation, and oversight of reservoirs, supporting a wide array of functions including irrigation, flood mitigation, water provisioning, and hydropower production.

This curve is considered a fundamental tool for individuals engaged in reservoir management and engineering. The understanding of the evolution of a reservoir's storage capacity in relation to changes in water level is crucial for making informed decisions regarding reservoir operations, resource allocation, and the optimization of these important water bodies. The EAC curve is a valuable instrument that effectively facilitates the optimization of water resource utilization and management, thereby yielding favorable outcomes for both societal and environmental welfare.

Results and Discussion:

Findings of the DEM analysis conducted in our designated study area indicate a notable variation in elevation, encompassing a range of 677 meters to 6,000 meters above the mean sea level (Figure 2). The considerable range in land elevation plays a pivotal role in the consideration and implementation of dam selection and construction. The DEM data offers valuable insights into the topographical attributes of the area, facilitating a comprehensive evaluation of the appropriateness of potential dam locations.

The comprehension of the elevation profile of the study area is crucial in the process of dam selection. Dams are commonly built in river valleys or canyons, and the utilization of elevation data aids in the identification of appropriate sites where the natural topography aligns with the engineering specifications for dam establishment. The presence of diverse elevation values in the study area enables us to evaluate the viability of various dam types, such as small-scale reservoirs in areas with low elevation or high-head dams in mountainous terrains.

Rainfall Datasets:

In the context of our study on dam selection, we utilized mean annual rainfall data collected from multiple weather stations to create a comprehensive rainfall map for the Swat district. The rainfall values across the entire study area were estimated and interpolated using the IDW interpolation technique. The procedure enabled the development of comprehensive rainfall cartography, which effectively illustrates the geographical dispersion of yearly precipitation. The distribution of annual rainfall values across the Swat district is visually depicted in Figure 3, showcasing a range that extends from a minimum of 690 mm to a maximum of 994 mm. The map successfully conveys the diversity in yearly precipitation, providing valuable insights into the differential rainfall patterns experienced across different locations within the study area. The provided information holds significant importance in our dam selection process, as it aids in the identification of potential dam sites by considering both technical feasibility and the accessibility of water resources. An essential aspect in the optimization of dam design and operation for various purposes, such as water supply, flood control, and hydropower generation, is the comprehension of local rainfall patterns. This understanding ensures that the chosen dam sites are in alignment with the hydrological conditions and land management objectives of the region, thereby promoting harmonious integration.

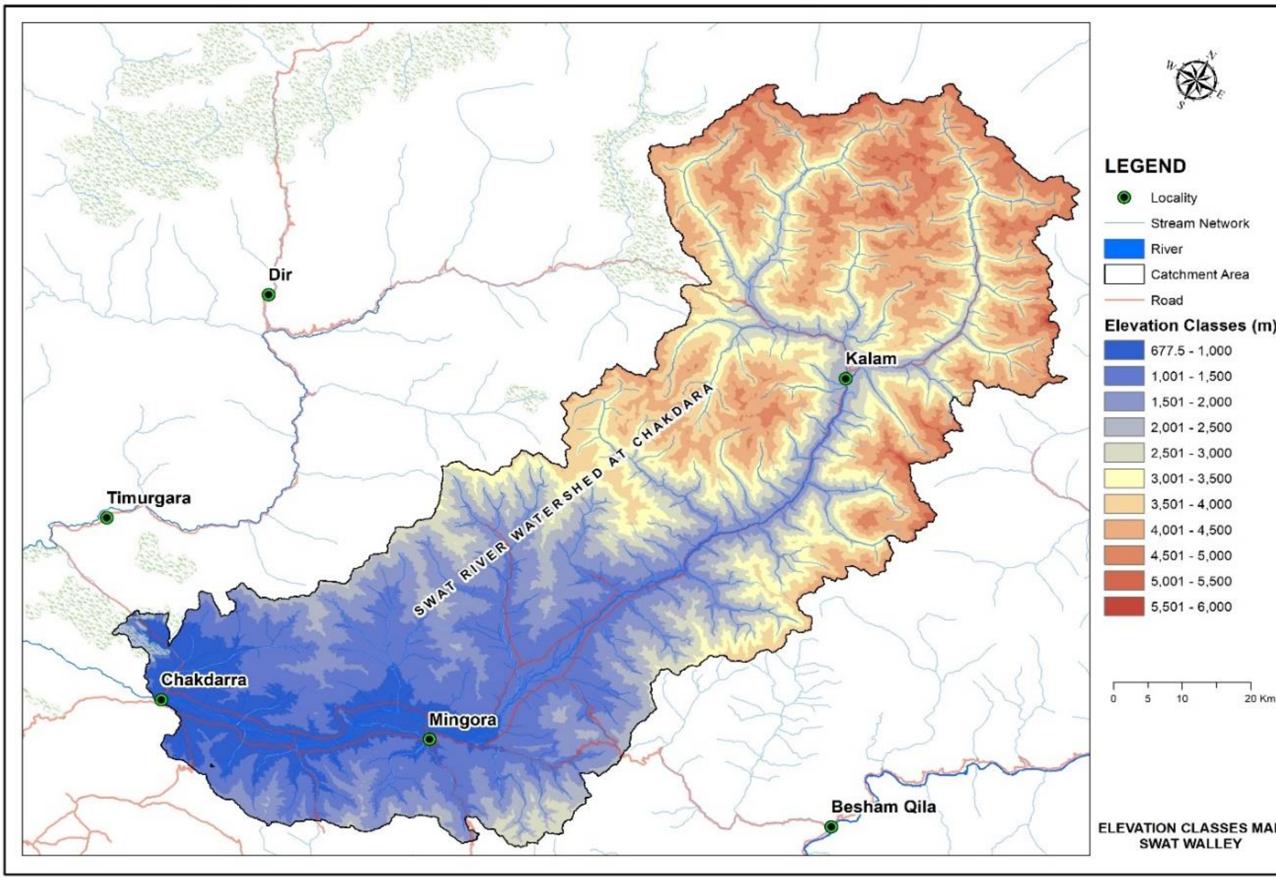


Figure 3. Elevation profile of the study area

Land use Land Cover:

Figure 4 depicts a visual representation of the LULC classification in the Swat region. The classification system demonstrates a high level of efficacy in effectively organizing the landscape into seven discrete categories, each of which provides valuable and distinct perspectives on the land utilization patterns within the given region. The classes that have been identified include bare land, built-up areas, water bodies, natural trees, cropland, snow, and grassland. The presented figure effectively illustrates the spatial distribution of the categories, highlighting their relative proportions within the designated study region. It is worth mentioning that the Swat region consists of various land cover categories. Specifically, bare land accounts for 12% of the region, while built-up areas occupy 11%. Water bodies comprise 1% of the region, while natural trees flourish across 16%. Cropland constitutes 3% of the region, and snow is observed on 1% of the land. Notably, the dominant land cover category in the Swat region is grassland, encompassing a significant 43% of the entire area.

The comprehensive LULC classification holds significant significance in the context of our dam selection process. The utilization of remote sensing techniques facilitates the identification of appropriate dam sites by offering essential information regarding the land cover attributes of the area. Comprehending the distribution of LULC categories holds significant importance in evaluating various factors, including land availability, potential environmental consequences, and the appropriateness of the adjacent topography for the construction and functioning of dams. Furthermore, it aids in the assessment of the prospective consequences on indigenous ecosystems and habitats, guaranteeing that the chosen locations for dam construction are in accordance with sustainable land management goals. The LULC classification plays a fundamental role in the optimization of dam selection, encompassing technical feasibility and environmental factors.

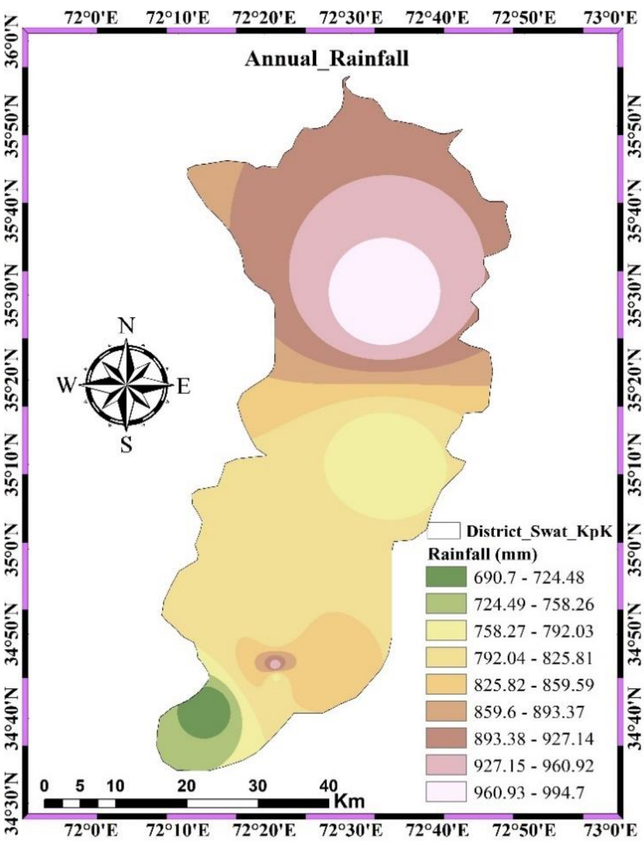


Figure 4. Mean annual rainfall for the study area.

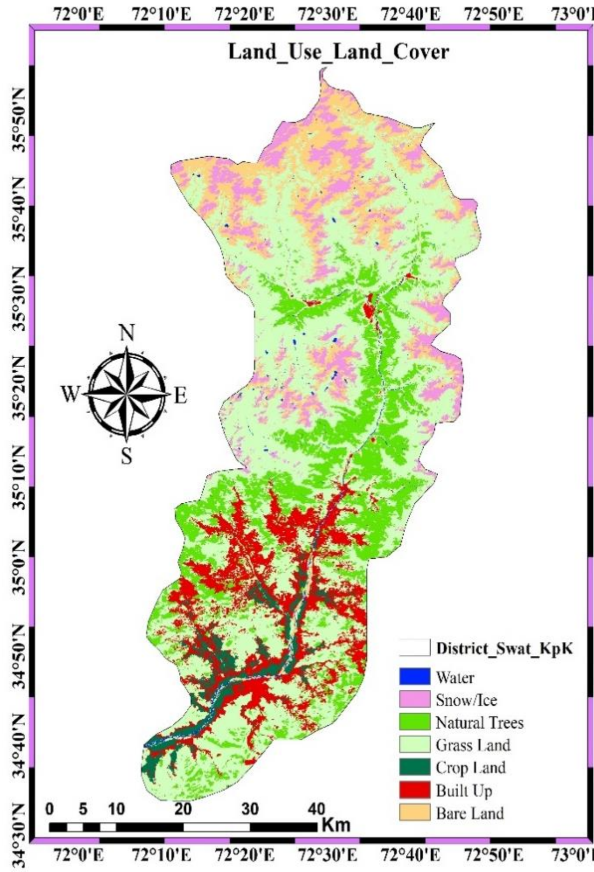


Figure 5. LULC for the study area

The evaluation of the accuracy of the land cover classification was performed by employing the Kappa coefficient as a standard measure. By utilizing the SVM algorithm in the classification procedure, an impressive overall accuracy rate of 89% was attained. The observed high level of accuracy demonstrates a strong concurrence between the classified pixels and the ground truth samples, thereby validating the reliability of our classification outcomes. In addition, it is worth noting that the Kappa coefficient, which goes beyond random agreement, demonstrates a significant value of 0.87. The high value of the Kappa coefficient provides strong support for the accuracy of our classification results and increases confidence in the methodology used.

Soil Analysis:

Distinct colors have been employed in our map to visually depict the various soil types that are prevalent in the Swat district. Gleysol soils are characterized by a black coloration, lithosol soils are distinguished by a red coloration, and eutric cambisol soils are identified by a green coloration. The various soil types are significant in the process of selecting an appropriate dam site. The selection of a dam site is heavily influenced by soil characteristics, as the diverse types of soil possess distinct capacities to sustain dam infrastructure and efficiently regulate water resources. Gleysol soils, characterized by their dark color, frequently signify elevated levels of moisture and necessitate specific precautions during dam construction to ensure structural integrity and mitigate seepage. Lithosol soils, illustrated in red, are commonly characterized by their shallow depth and rocky composition, thereby exerting potential implications on the design of dam foundations and excavation endeavors.

Eutric Cambisol soils, depicted in green, are commonly regarded as highly suitable for the construction of dams owing to their advantageous characteristics that facilitate strong foundation support (Figure 5).

A comprehensive understanding of the distribution and characteristics of these soil types within the Swat district plays a crucial role in the identification of appropriate dam locations that possess both technical viability and enduring stability. A thorough examination of soil properties is imperative for minimizing potential hazards and maximizing the effectiveness of dam design and construction, particularly about water supply, flood management, and hydropower production.

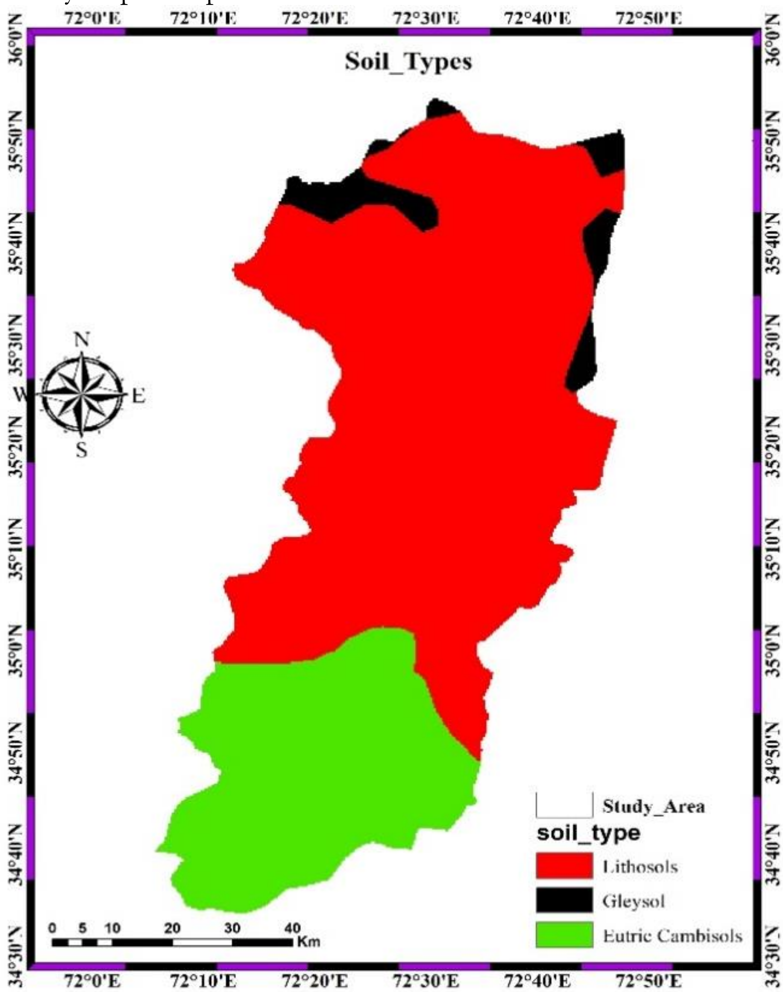


Figure 6. Soil types in SWAT

Elevation Area Capacity Curve:

The EAC Curve is a visual depiction that elucidates the correlation between the elevation of a reservoir's water surface, the corresponding storage volume of water contained in the reservoir, and the area encompassed by the reservoir at that elevation. The curve serves as a pivotal instrument for evaluating the viability of dam locations and comprehending the variations in reservoir storage capacity resulting from fluctuations in water level caused by inflow, outflow, and additional factors. In the present study, a total of five distinct potential dam sites, denoted as R1, R2, R3, R4, and R5, have been identified and are visually represented in Figure 6. The chosen sites within the study area are strategically positioned, with their selection being influenced by a range of factors such as topography, hydrology, geology, and land use. The EAC Curve plays a crucial role in assessing the appropriateness of these locations for the purpose of constructing dams.

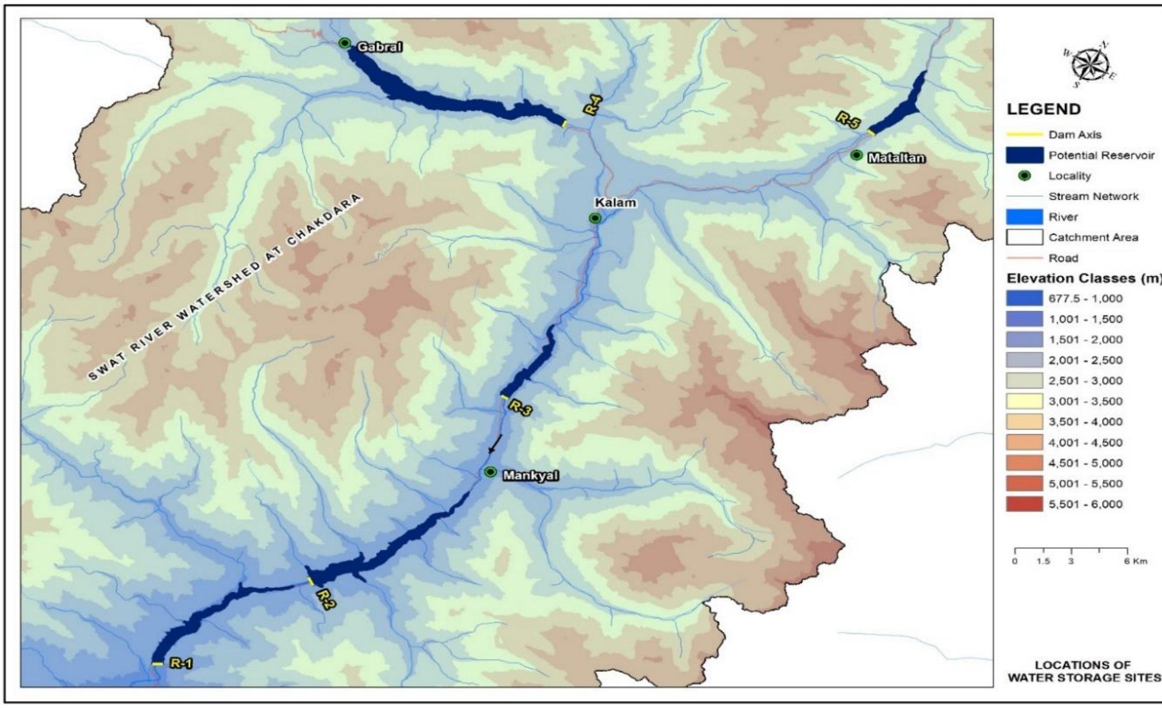


Figure 7. Potential Dam Sites for the study area

Characteristic of Dam Site R1:

Table 1 provides a comprehensive overview of the characteristics of dam reservoirs at different elevations. The data presented in this study was obtained using accurate calculations employing the 3D analyst tool applied to the DEM. The presented table illustrates the relationship between the elevation of a reservoir, measured in meters above sea level, and the corresponding alterations in both surface area and storage capacity. As an illustration, situated at an altitude of 1345m above sea level, the reservoir encompasses an expanse of 9.40 x1000 m² and exhibits a storage capacity of 10.62 m³. Significantly, a rise in altitude from 1345 to 1450ms above sea level results in a considerable enlargement of the reservoir's surface area, which expands to 3271 x 1000m², accompanied by a noteworthy augmentation in storage capacity to 121,346 m³. The dataset presented provides significant insights into the direct influence of various elevations on the physical attributes of the reservoir. These findings can greatly contribute to informed decision-making processes regarding the planning, design, and operation of dams.

Figure 7 visually depicts the significant correlation between elevation and the corresponding area and storage capacity of the dam reservoir. The presented graphical representation offers a conscious and intuitive comprehension of the impact of variations in elevation on the physical characteristics of the reservoir. The provided figure visually illustrates the gradual increase in both the area and capacity of the reservoir as its elevation increases. For example, it demonstrates the substantial increase in both surface area and storage capacity that occurs when raising the reservoir's elevation from 1345 to 1450 m above sea level. This visual aid facilitates the understanding of the direct correlation between elevation and reservoir characteristics, thereby assisting in the decision-making process for dam design and management.

Table 1. Reservoir characteristics at dam site R1 (Elevation vs. Area and Volume)

Sr. No.	Elevation (m asl)	Area (x1000 m²)	Volume (m³)
1	1345	9.40	10.62
2	1350	36.12	121.13

3	1355	69.40	377.91
4	1360	121.00	826.76
5	1365	192.10	1578.61
6	1370	265.30	2678.30
7	1375	365.80	4183.14
8	1380	496.00	6233.96
9	1385	648.00	8976.18
10	1390	824.00	12509.54
11	1395	973.00	16805.45
12	1400	1112.00	21751.89
13	1405	1270.00	27377.69
14	1410	1473.00	33843.68
15	1415	1668.00	41250.41
16	1420	1886.00	49589.53
17	1425	2098.00	58929.12
18	1430	2319.00	69267.24
19	1435	2556.00	80627.30
20	1440	2798.00	93076.11
21	1445	3050.00	106665.36
22	1450	3271.00	121346.31

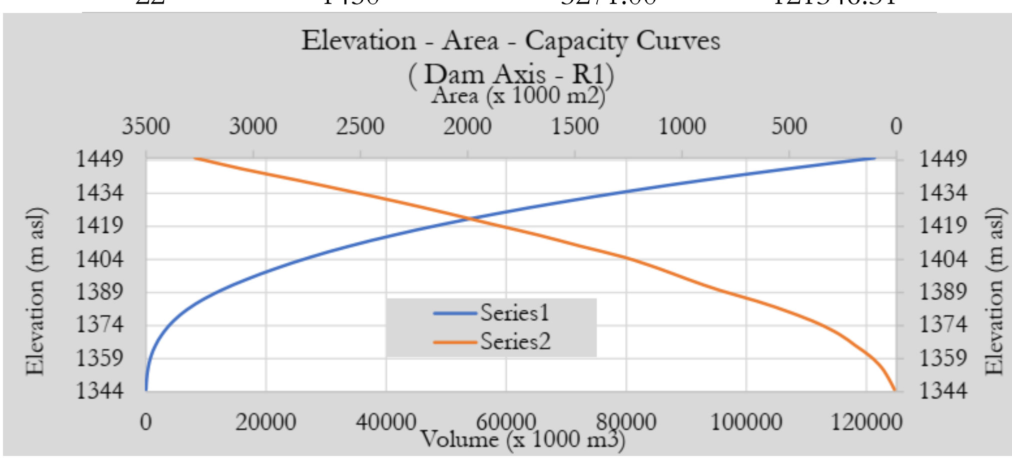


Figure 8. Correlation between elevation, area, and storage capacity for DAM site R1

Characteristic of Dam Site R2:

Table 2 and Figure 8 provide essential data pertaining to the reservoir characteristics of dam site R2 at different elevations. As an illustration, the reservoir demonstrates an elevation of 1455m above sea level, encompassing an area of 2.91 thousand square meters and possessing a storage capacity of 2 m^3. Significantly, when the elevation is raised to 1625m above sea level, there is a noteworthy increase in both the area and storage capacity of the reservoir. Specifically, the reservoir's area expands to 4321x1000 m^2, while its storage capacity experiences a substantial growth to 271,964 m^3. These insights play a crucial role in facilitating well-informed decision-making concerning the planning, design, and management of dam site R2. They emphasize the direct impact of elevation variations on the physical attributes of the reservoir.

Table 2. Reservoir characteristics at dam site R2 (Elevation vs. Area and Volume)

Sr. No.	Elevation (m asl)	Area (x1000 m^2)	Volume (m^3)
1	1455	2.91	2
2	1460	10.86	39
3	1465	32.2	137

4	1470	77.2	412
5	1475	120.5	903
6	1480	173.6	1639
7	1485	246.7	2698
8	1490	323.9	4126
9	1495	402.3	5946
10	1500	476.2	8147
11	1505	559	10738
12	1510	658	13783
13	1515	747	17293
14	1520	838	21260
15	1525	947	25714
16	1530	1055	30714
17	1535	1173	36300
18	1540	1298	42468
19	1545	1424	49280
20	1550	1557	56742
21	1555	1696	64880
22	1560	1859	73765
23	1565	2023	83475
24	1570	2198	94033
25	1575	2384	105496
26	1580	2569	117886
27	1585	2763	131222
28	1590	2949	145497
29	1595	3129	160674
30	1600	3307	176762
31	1605	3495	193773
32	1610	3692	211725
33	1615	3903	230725
34	1620	4129	250814
35	1625	4321	271964

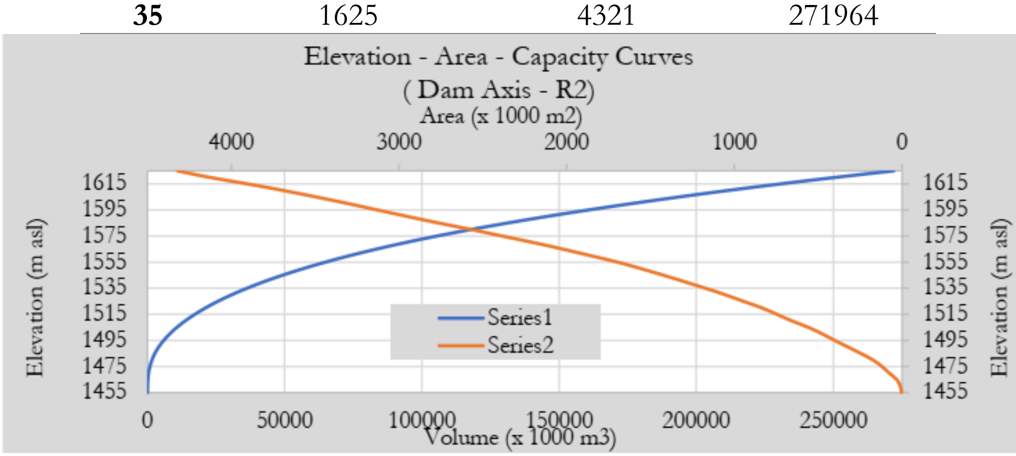


Figure 9. Correlation between elevation, area, and storage capacity for DAM site R2

Characteristics of Dam Site R3:

Table 3 and Figure 9 offer significant insights pertaining to the reservoir characteristics of dam site R3 across various elevations. The data play a crucial role in facilitating well-informed decision-making processes pertaining to the planning, design, and management of the site in question. The reservoir, situated at an altitude of 1740m above sea level, demonstrates an area of 1.08 x 1000 m^2 and a storage capacity, suggesting a restricted ability to retain water at this elevation. Nevertheless, when the elevation is raised to 1745m, a significant transformation occurs. The area of the reservoir experiences a substantial increase, reaching 17.27 x 1000 m^2, while its storage capacity also undergoes growth, reaching 35 m^3. Notably, situated at an altitude of 1850 m above sea level, the reservoir exhibits a vast expanse spanning 1565 x 1000 m^2, accompanied by a noteworthy storage capacity of around 65,989 m^3.

Table 3. Reservoir characteristics at dam site R3 (Elevation vs. Area and Volume)

Sr. No.	Elevation (m asl)	Area (x1000 m^2)	Volume (m^3)
1	1740	1.08	0
2	1745	17.27	35
3	1750	52.4	202
4	1755	100.3	589
5	1760	142.3	1192
6	1765	181.4	2000
7	1770	222.1	3006
8	1775	272.1	4237
9	1780	327	5727
10	1785	383.2	7504
11	1790	449.6	9585
12	1795	524	12024
13	1800	592	14811
14	1805	666	17947
15	1810	746	21474
16	1815	824	25397
17	1820	907	29730
18	1825	992	34471
19	1830	1081	39651
20	1835	1186	45306
21	1840	1317	51552
22	1845	1443	58455
23	1850	1565	65989

Characteristics of Dam Site R4:

The role of elevation variations at dam site R4 is of great significance in determining the characteristics of the reservoir, as demonstrated in Table 4 and Figure 10. The comprehensive records offer a dynamic viewpoint on the reservoir's response to changes in elevation. Beginning at an elevation of 2080m above sea level, the reservoir does not possess any surface area or capacity for storing water. Nevertheless, as the altitude gradually increases to 2085 m, a significant alteration takes place, characterized by the expansion of the reservoir's surface area to 6.98 x 1000 m^2 and an augmented storage capacity of 10 m^3. Upon reaching an elevation of 2200 m above sea level, the reservoir experiences an expansion in its surface area, reaching a total of 1611 x 1000 m^2. This expansion is accompanied by a significant increase in the reservoir's storage capacity, which now amounts to 67,807 m^3. The culmination of this metamorphosis is witnessed at an altitude of 2275 m above the Earth's sea level, where the dam site R4 reaches its utmost characteristics a substantial expanse of 7510 x 1000m^2 and a remarkable capacity for storing 358,237 m^3.

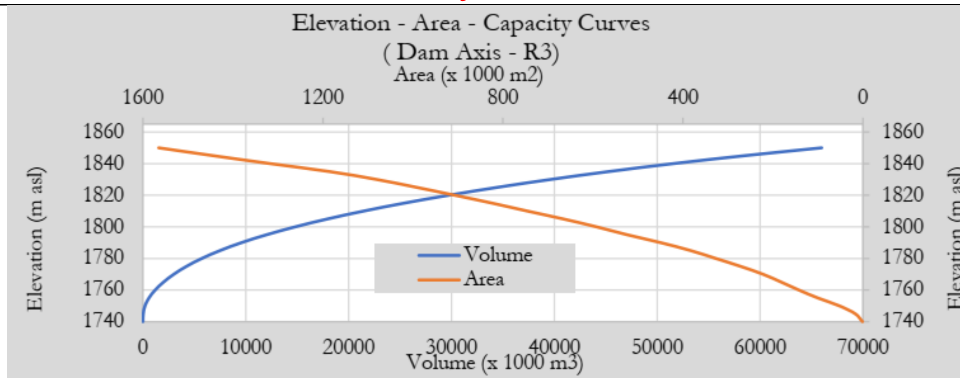


Figure 2. Correlation between elevation, area, and storage capacity for DAM site R3

The results of this study emphasize the significant impact of changes in elevation on the physical characteristics of the reservoir, highlighting the crucial significance of this information in making well-informed decisions regarding the planning and management of dam site R4.

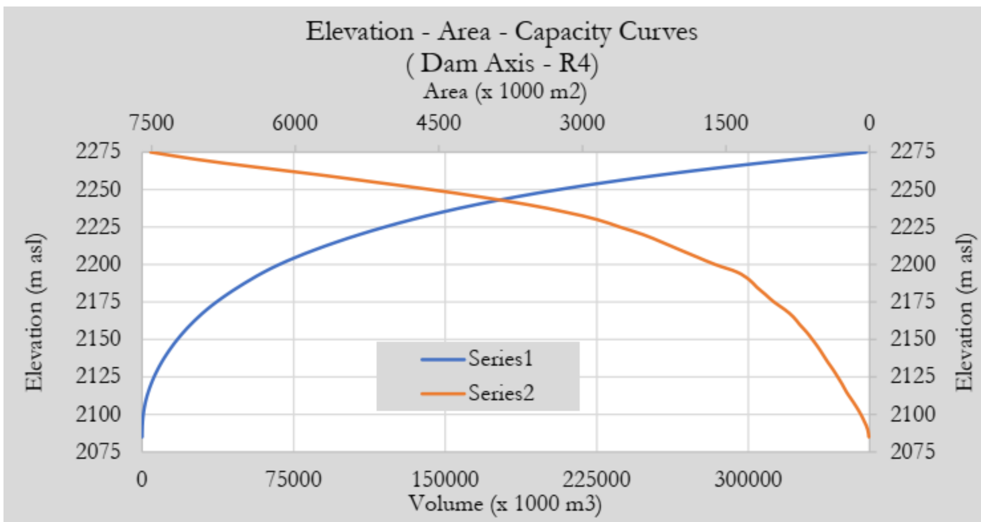


Figure 3. Correlation between elevation, area, and storage capacity for DAM site R4

Table 4. Reservoir characteristics at dam site R4 (Elevation vs. Area and Volume)

Sr. No.	Elevation (m asl)	Area (x1000 m^2)	Volume (m^3)
1	2080	0	0
2	2085	6.98	10
3	2090	19.78	74
4	2095	52	250
5	2100	90.8	608
6	2105	136.5	1176
7	2110	188.3	1990
8	2115	240.9	3061
9	2120	284.1	4374
10	2125	332.2	5910
11	2130	381.7	7703
12	2135	437	9736
13	2140	487.4	12053
14	2145	539	14616
15	2150	597	17444
16	2155	658	20582

17	2160	730	24044
18	2165	795	27858
19	2170	886	32047
20	2175	998	36779
21	2180	1087	41993
22	2185	1179	47655
23	2190	1259	53754
24	2195	1385	60304
25	2200	1611	67807
26	2205	1801	76352
27	2210	1988	85829
28	2215	2172	96222
29	2220	2365	107548
30	2225	2607	119976
31	2230	2846	133579
32	2235	3178	148587
33	2240	3574	165495
34	2245	4054	184525
35	2250	4584	206104
36	2255	5173	230516
37	2260	5766	257804
38	2265	6412	288243
39	2270	7015	321829
40	2275	7510	358237

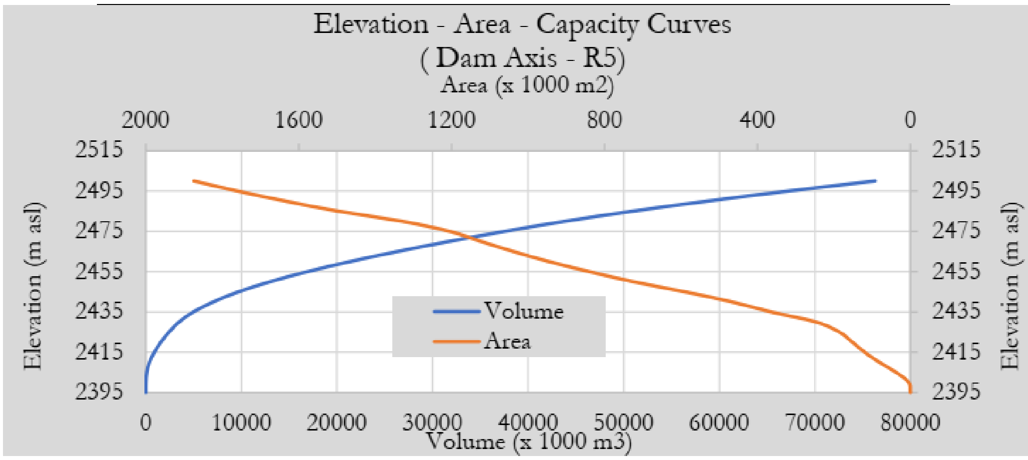
Characteristics of Dam Site R4:

Dam site R5, with an elevation of 2395m above sea level, at first appears to have neither an area coverage nor a capacity indicated by Figure 11 and Table 5. On the other hand, significant shifts take place when it reaches its highest elevation of 2500m above sea level. The storage capacity of the reservoir reaches 76,313 m^3, and the area of the reservoir grows to be 1874 x 10000 m^2. These data highlight the direct relationship between elevation and the physical attributes of the reservoir at dam site R5, providing essential insights for the decisions regarding site planning and management.

Table 5 Reservoir characteristics at dam site R5(Elevation vs. Area and Volume)

Sr. No.	Elevation (m asl)	Area (x1000 m^2)	Volume (m^3)
1	2395	0	0
2	2400	4.119	2
3	2405	36.96	96
4	2410	81	383
5	2415	119.5	894
6	2420	151.7	1574
7	2425	185.7	2423
8	2430	246.3	3474
9	2435	363.5	4970
10	2440	466.6	7061
11	2445	590	9692
12	2450	724	12991
13	2455	839	16894
14	2460	945	21356
15	2465	1038	26315

16	2470	1123	31719
17	2475	1205	37540
18	2480	1329	43831
19	2485	1496	50899
20	2490	1634	58728
21	2495	1760	67216
22	2500	1874	76313



b

Figure 4. Correlation between elevation, area, and storage capacity for DAM site R5

Comparison of Potential Dam Sites:

The comparison table (Table 6) offers a detailed assessment of five distinct dam sites (R-1 through R-5), highlighting their suitability and potential for dam construction. Among these sites, R-4 stands out as the most promising option. It boasts a wide elevation range from 2080 to 2275 m, resulting in a substantial dam height potential. What sets R-4 apart is its remarkable storage capacity of 358,237,000 m^3, categorizing it as having a "High" suitability level. This site is exceptionally well-suited for multiple water resource management objectives, including hydropower generation and flood control, making it the preferred choice among the options presented. In contrast, the other sites (R-1, R-2, R-3, and R-5) exhibit narrower elevation ranges and comparatively lower storage capacities, indicating varying degrees of suitability for specific purposes.

Table 6. Comparison of dam sites (R-1 to R-5) based on elevation, dam Height, storage capacity, and suitability levels

Dam Site	Minimum Elevation	Maximum Elevation	Dam Height	Storage (x 1000 m^3)	Suitability Level
R-1	1345	1450	105	121,346	Medium
R-2	1455	1625	170	271,964	Medium
R-3	1740	1850	110	65,989	Low
R-4	2080	2275	195	358,237	High
R-5	2395	2500	105	76,313	Low

Discussion:

The strategic placement of small dams in the Swat District, Pakistan, as identified in this study, signifies a pivotal step toward addressing the region's pressing water and energy challenges. The comprehensive analysis undertaken here melds technical precision, societal considerations, and environmental consciousness to chart a course for sustainable resource management. By leveraging advanced technologies such as RS and GIS, and combining these with expert knowledge, we meticulously examined the region's land use, soil profiles, and precipitation trends.

The foundation of our analysis rested on the adept integration of diverse datasets, meticulously woven together to create a robust decision-making framework. Through the application of the priority index statistical method, we identified five distinct locations, each varying in suitability, for the construction of small dams. Among these, R-1 and R-2 emerged as sites with medium suitability, holding promise for meeting local water and energy demands efficiently. R-4, characterized by its high suitability, stands out as a leading candidate for optimized water resource utilization.

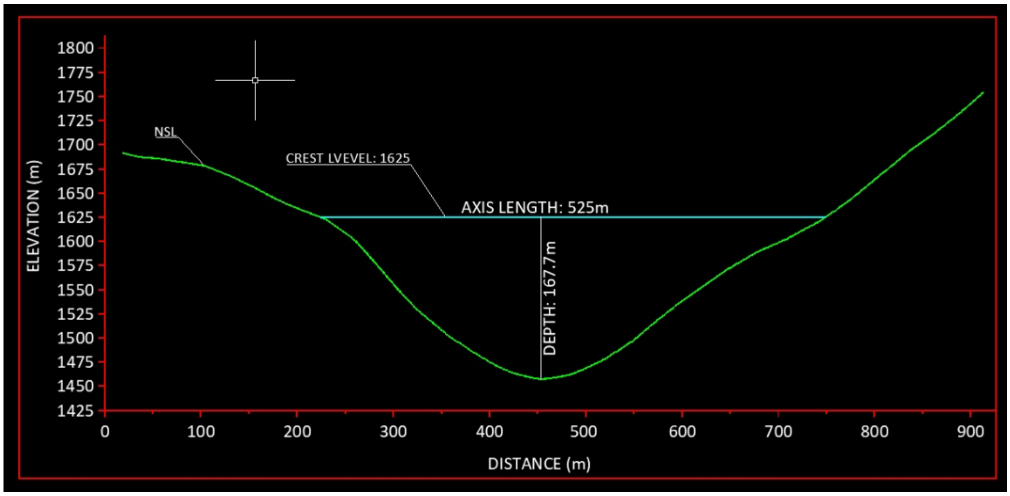


Figure 13. Dam axis profile showing crest level at 1625 m ASL.

The significance of these findings is underscored by the visual representation provided in Figure 6, which serves as a guiding map for efficient water management in the region. This map, highlighting top locations for small dam construction, offers clear directives for future endeavors in water resource management. Looking forward, the implementation of these identified sites bears the potential to usher in a new era for the Swat District. Through the amalgamation of engineering expertise, active community involvement, and ecological sensitivity, these small dams are poised not only to fulfill their immediate purpose but also to foster regional growth and resilience. By empowering local communities and promoting sustainable change, the construction of small dams in Pakistan's Swat District emerges as a catalyst for transformative progress.

In light of these results, it is imperative for government bodies and policymakers to heed the insights provided by this study. The identified sites offer a tangible course of action, balancing the necessities of water and energy demands with the inherent opportunities present in the region. The successful realization of these small dams hinges not only on their construction but also on the ongoing commitment to ecological preservation and community engagement. Therefore, it is recommended that future initiatives prioritize these aspects, ensuring that the potential benefits of these small dams are maximized for the betterment of the Swat District and its inhabitants.

Conclusion:

The strategic placement of small dams offers a glimmer of hope for our region to meet the evolving demands of our water and energy systems as we stand at the crossroads of escalating water and energy challenges. The beautiful landscape of Swat District, Pakistan is ripe with potential sites for multi-purpose small dams, and this study has been instrumental in charting the course, identifying, and assessing those sites. We take a comprehensive view of resource management by carefully balancing technical requirements, societal and economic factors, and a firm dedication to protecting the natural world. The wise application of a diverse array of data sources formed the basis of our decision-making process. To decipher the complexities of the Swat District's land use and land cover map, soil profiles, and precipitation trends, we employed cutting-edge technology and expert knowledge. These masterfully woven datasets were the bedrock upon which we based our site selection voyage. We used the precision of a statistical method called the priority index to guide the use of RS and GIS technologies to uncover these promising locations. Because of this method, water resource managers and decision-makers now have a detailed suitability map at their disposal. Based on the outcomes of this exhaustive assessment, five distinct geographical sites displaying diverse levels of suitability have surfaced. Notably, locations R-1 and R-2 exhibit a moderate level of appropriateness, suggesting their potential efficacy in satisfying local water and energy requisites. Due to its high suitability, R-4 is a leading candidate for efficient use of water resources. Low suitability, on the other hand, creates opportunities that strike a fine balance between protecting the environment and making the most of the resources at hand in regions R-3 and R-5.

Figure 6 map serves as a visual record of our efforts that highlights the top and topnotch locations to build small dams, providing clear instructions for efficient water management. Concluding our research, these five small dams, characterized by their individual suitability profiles, hold the promise of efficiently mitigating the water and energy challenges confronting the Swat District. The future is bright, thanks to engineering prowess, community participation, and ecological sensitivity, and it will guarantee that these small dams not only serve their immediate purpose but also contribute to the growth and resilience of the region. Building small dams in Pakistan's Swat District is central to empowering local communities and facilitating change. The findings of the study illuminate the path forward for government officials and policymakers, providing a roadmap that strikes a balance between essential requirements and available opportunities.

Conflicts of Interest: The authors declare no conflict of interest.

Ethical approval: All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted

Competing interests: The authors declare no competing interests.

References:

[1] T. Kumar and D. Jhariya, "Identification of Rainwater Harvesting Sites using SCS-CN Methodology, Remote Sensing and Geographical Information System Techniques," Geocarto Int., vol. 32, pp. 1–43, 2016, doi: 10.1080/10106049.2016.1213772.

[2] R. Agarwal, P. Garg, and R. Garg, "Remote Sensing and GIS Based Approach for Identification of Artificial Recharge Sites," Water Resour. Manag., vol. 27, 2013, doi: 10.1007/s11269-013-0310-7.

[3] J. Krois and A. Schulte, "GIS-based multi-criteria evaluation to identify potential sites for soil and water conservation techniques in the Ronquillo watershed, northern Peru," Appl. Geogr., vol. 51, pp. 131–142, 2014, doi: https://doi.org/10.1016/j.apgeog.2014.04.006.

[4] E. Blanc and E. Strobl, "Is Small Better? A Comparison of the Effect of Large and Small Dams on Cropland Productivity in South Africa," World Bank Econ. Rev., vol. 28, no. 3, pp. 545–576, 2014, doi: 10.1093/wber/lht026.

[5] G. Mugo and P. Odera, "Site selection for rainwater harvesting structures in Kiambu County-Kenya," Egypt. J. Remote Sens. Sp. Sci., vol. 22, pp. 155–164, 2019, doi: 10.1016/j.ejrs.2018.05.003.

[6] K. Balkhair and K. Rahman, "Development and assessment of rainwater harvesting suitability map using Analytical Hierarchy Process, GIS, and RS techniques," Geocarto Int., vol. 36, pp. 1–19, 2019, doi: 10.1080/10106049.2019.1608591.

[7] A. Adham, M. Riksen, R. Abed, S. Shadeed, and C. Ritsema, "Assessing Suitable Techniques for Rainwater Harvesting Using Analytical Hierarchy Process (AHP) Methods and GIS Techniques," 2022.
[8] D. Khan, A. Raziq, H. V. Young, T. Sardar, and Y. Liou, "Identifying Potential Sites for Rainwater Harvesting Structures in Ghazi Tehsil , Khyber Pakhtunkhwa , Pakistan , Using," 2022.
[9] A. Hussain, "Investigating feasible sites for multi _ purpose small dams in Swat District of Khyber Pakhtunkhwa Province , Pakistan : socioeconomic and environmental considerations," pp. 10852–10875, 2022, doi: 10.1007/s10668-021-01886-z.
[10] M. Kumar, A. Agarwal, and R. Bali, "Delineation of potential sites for water harvesting structures using remote sensing and GIS," J. Indian Soc. Remote Sens., vol. 36, pp. 323–334, 2008, doi: 10.1007/s12524-008-0033-z.
[11] T. Naseef and R. Thomas, "Identification of Suitable Sites for Water Harvesting Structures in Kecheri River Basin," Procedia Technol., vol. 24, pp. 7–14, 2016, doi: 10.1016/j.protcy.2016.05.003.
[12] S. Mahmoud and P. Alazba, "The potential of in situ rainwater harvesting in arid regions: developing a methodology to identify suitable areas using GIS-based decision support system," Arab. J. Geosci., 2014, doi: 10.1007/s12517-014-1535-3.
[13] S. H. Mahmoud and A. A. Alazba, "The potential of in situ rainwater harvesting in arid regions: developing a methodology to identify suitable areas using GIS-based decision support system," Arab. J. Geosci., vol. 8, no. 7, pp. 5167–5179, 2015, doi: 10.1007/s12517-014-1535-3.
[14] A. Adham et al., "International Soil and Water Conservation Research A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq," Int. Soil Water Conserv. Res., vol. 6, no. 4, pp. 297–304, 2018, doi: 10.1016/j.iswcr.2018.07.003.
[15] S. H. M. X. Tang, "Monitoring prospective sites for rainwater harvesting and stormwater management in the United Kingdom using a GIS-based decision support system," Environ. Earth Sci., pp. 8621–8638, 2015, doi: 10.1007/s12665-015-4026-2.
[16] A. Ochir, D. Boldbaatar, M. Zorigt, T. Solongo, and J. van Genderen, "Site selection for water harvesting ponds using spatial multi criteria analysis in a region with fluctuating climate," Geocarto Int., vol. 33, pp. 1–33, 2017, doi: 10.1080/10106049.2017.1289563.
[17] M. Shahid, K. Rahman, K. Balkhair, and D. Nabi, "Impact assessment of land use and climate changes on the variation of runoff in Margalla Hills watersheds, Pakistan," Arab. J. Geosci., vol. 13, 2020, doi: 10.1007/s12517-020-5231-1.
[18] K. Kochhar et al., "Is the Glass Half Empty or Half Full ? Issues in Managing Water Challenges and Policy Instruments," 2015.
[19] A. Hussain et al., "Observed trends and variability of seasonal and annual precipitation in Pakistan during 1960–2016," Int. J. Climatol., 2022, doi: 10.1002/joc.7709.
[20] M. Shahid and K. U. Rahman, "Identifying the Annual and Seasonal Trends of Hydrological and Climatic Variables in the Indus Basin Pakistan," Asia-Pacific J. Atmos. Sci., vol. 57, no. 2, pp. 191–205, 2021, doi: 10.1007/s13143-020-00194-2.
[21] S. Bangash, "Socio-Economic Conditions of Post-Conflict Swat: A Critical Appraisal," Tigah A J. Peace Dev., vol. 2, no. December, pp. 66–79, 2012.
[22] Atta-ur-Rahman and A. N. Khan, "Analysis of flood causes and associated socio-economic damages in the Hindukush region," Nat. Hazards, vol. 59, no. 3, pp. 1239–1260, Dec. 2011, doi: 10.1007/S11069-011-9830-8/METRICS.
[23] M. Qasim, K. Hubacek, M. Termansen, and L. Fleskens, "Modelling land use change

across elevation gradients in district Swat, Pakistan," Reg. Environ. Chang., vol. 13, no. 3, pp. 567–581, 2013, doi: 10.1007/s10113-012-0395-1.

[24] A. Zamani, A. Sharifi, S. Felegari, A. Tariq, and N. Zhao, "Agro Climatic Zoning of Saffron Culture in Miyaneh City by Using WLC Method and Remote Sensing Data," Agric. 2022, Vol. 12, Page 118, vol. 12, no. 1, p. 118, Jan. 2022, doi: 10.3390/AGRICULTURE12010118.

[25] A. S. A.-A. S. A.-H. M. A.-E. M. A.-A. Tariq, "Agricultural Field Extraction with Deep Learning Algorithm and Satellite Imagery," J. Indian Soc. Remote Sens., vol. v. 50, no. 2, pp. 417-423–2022 v.50 no.2, 2022, doi: 10.1007/s12524-021-01475-7.

[26] H. Waqas et al., "Flash Flood Susceptibility Assessment and Zonation Using an Integrating Analytic Hierarchy Process and Frequency Ratio Model for the Chitral District, Khyber Pakhtunkhwa, Pakistan," Water 2021, Vol. 13, Page 1650, vol. 13, no. 12, p. 1650, Jun. 2021, doi: 10.3390/W13121650.

[27] F. Islam et al., "Landslide susceptibility mapping (LSM) of Swat District, Hindu Kush Himalayan region of Pakistan, using GIS-based bivariate modeling," Front. Environ. Sci., vol. 10, no. October, pp. 1–18, 2022, doi: 10.3389/fenvs.2022.1027423.

[28] Z. H. Dahri, B. Ahmad, J. H. Leach, and S. Ahmad, "Satellite-based snowcover distribution and associated snowmelt runoff modeling in Swat River Basin of Pakistan," Proc. Pakistan Acad. Sci., vol. 48, no. 1, pp. 19–32, 2011.

[29] F. Bazzani, "Atlas of the Natural Resources Evaluation in Swat Valley , Khyber Pakhtunkhwa , Islamic Republic of Pakistan," no. May, 2013.

[30] S. R. Khan and S. R. Khan, "Assessing poverty-deforestation links: Evidence from Swat, Pakistan," Ecol. Econ., vol. 68, no. 10, pp. 2607–2618, 2009, doi: 10.1016/j.ecolecon.2009.04.018.

[31] M. S. Bacha, M. Muhammad, Z. Kılıç, and M. Nafees, "The dynamics of public perceptions and climate change in swat valley, khyber pakhtunkhwa, Pakistan," Sustain., vol. 13, no. 8, pp. 1–22, 2021, doi: 10.3390/su13084464.

[32] A. Sajjad et al., "Application of Remote Sensing and GIS in Forest Cover Change in Tehsil Barawal, District Dir, Pakistan," Am. J. Plant Sci., vol. 06, no. 09, pp. 1501–1508, 2015, doi: 10.4236/ajps.2015.69149.

[33] T. Adugna, W. Xu, and J. Fan, "Comparison of Random Forest and Support Vector Machine Classifiers for Regional Land Cover Mapping Using Coarse Resolution FY-3C Images," Remote Sens., vol. 14, no. 3, pp. 1–22, 2022, doi: 10.3390/rs14030574.

[34] K. S. Balkhair and K. Ur Rahman, "Development and assessment of rainwater harvesting suitability map using analytical hierarchy process, GIS and RS techniques," Geocarto Int., vol. 36, no. 4, pp. 421–448, 2021, doi: 10.1080/10106049.2019.1608591.

[35] Z. K. Motlagh, A. Lotfi, S. Pourmanafi, S. Ahmadizadeh, and A. Soffianian, "Spatial modeling of land-use change in a rapidly urbanizing landscape in central Iran: integration of remote sensing, CA-Markov, and landscape metrics," Environ. Monit. Assess., vol. 192, no. 11, 2020, doi: 10.1007/s10661-020-08647-x.

[36] B. R. Parida and S. P. Mandal, "Polarimetric decomposition methods for LULC mapping using ALOS L-band PolSAR data in Western parts of Mizoram, Northeast India," SN Appl. Sci., vol. 2, no. 6, pp. 1–15, 2020, doi: 10.1007/s42452-020-2866-1.