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Identifying Potential Sites for Rainwater Harvesting Structures in Ghazi Tehsil, Khyber Pakhtunkhwa, Pakistan, Using Geospatial Approach

Dawood Khan [1], Abdur Raziq [2], Hsu-Wen Vincent Young [3], Tariq Sardar [4] and Yuei-An Liou [5,*]

[1] Institute of Geographical Information Systems, School of Civil and Environmental Engineering, National University of Sciences & Technology, Islamabad 44000, Pakistan
[2] Department of Geography, Islamia College University, Peshawar 25120, Pakistan
[3] Department of Electronic Engineering, Chung Yuan Christian University, Taoyuan City 320314, Taiwan
[4] Department of Environmental Science, Kohat University of Science and Technology, Kohat 26000, Pakistan
[5] Center for Space and Remote Sensing Research, National Central University, No. 300, Jhongda Rd., Jhongli District, Taoyuan City 320317, Taiwan
* Correspondence: yueian@csrsr.ncu.edu.tw; Tel.: +886-3-4227151 (ext. 57631)

Abstract: Rainwater harvesting is an important step towards maximizing the water availability and land productivity in arid and semi-arid areas. The present study shows that the area of Ghazi Tehsil within Khyber Pakhtunkhwa Province, Pakistan, has great potential for rainwater harvesting due to its feasible climatic and topographic conditions. This area of 348 km^2 normally receives high rainfall annually, but, due to hilly terrain, the bulk of rainwater is lost in the runoff process. In order to enhance agricultural output for such a large area, the practice of rainwater harvesting is a sustainable and decisive approach. However, the selection of appropriate sites for rainwater harvesting on a large scale presents a critical challenge. In such areas, geospatial technology has proved very decisive in the identification of potential sites. In this study, we have used the HEC-GeoHMS tool (ArcGIS 9.3) to compute a curve number to represent the effects of rainfall against the hydrological soil group and landcover. Subsequently, the curve number was used as an input parameter in the soil conservation service runoff-curve number (SCS-CN) method to estimate surface runoff potential for different combinations of landcover and hydrological soil groups. It was observed that runoff was higher in mountainous areas and relatively low in plain areas. Finally, to identify the potential sites for rainwater harvesting, weighted overlay analysis-based related thematic map layers were further reclassified, and weights were assigned according to the technical guidelines of suggested international standards and under consideration of the study area's topographic, hydrological, and climatic factors. As a result, about 20% of the area was found suitable, 52% less suitable, and 29% as not suitable. Furthermore, relative suitability was assigned to the results of suitable sites as an input for the identification of potential sites for different rainwater harvesting storage structures. These results show that 10% of the area was suitable for farm ponds, 5.74% for check dams, 21.5% for Nigarims, and 8.9% was found to be suitable for gully plugs. The comparison of our GIS-derived and field-based results spatially affirms that the analyzed results were agreeably overlaid in the context of spatial results for check dams, gully plugs, and Nigarims.

Keywords: geospatial technology; SCS-CN method; rainwater harvesting; HEC-Geo-HMS; weighted overlay analysis

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1. Introduction

Rainwater harvesting has been in practice for 4000 years. It is a process consisting of the storage and collection of rainwater from a catchment area during rainy seasons and the preservation of water in a reservoir for drinking and other purposes of its daily consumption. This approach is helpful in the provision of water under the premise that there are water-needed sites in the area [1–3]. Across the world, many water management organizations and related authorities are actively working to manage and explore water resources with a particular focus on rainwater harvesting (hereafter RWH) as a way of obtaining water supply [4]. Particularly in urbanized regions, where the shortage of quality water supply can often occur, this practice offers a sustainable alternative in terms of cost and maintenance [5–7]. It is also one of the simplest and most easily accessible approaches to water management in areas with sufficient rainfall [8,9]. Pertaining to the impacts of growing urban population and urbanization, the Asian Development Bank has placed Pakistan in the red zone in the context of water stress [10]. In addition, Pakistan was declared a water scarce country in 1991 as well as in 2007 and declared as a water stressed country with an availability of 1000 m^3/capita [11].

Pakistan depends on monsoon rainfall, with high seasonal precipitation falling in 90 days, which also makes the country highly susceptible to floods [12]. Additionally, its high susceptibility to climatic change and projected growth of urbanization have added to the causing factors of urban flooding in major cities. Other major factors include soil erosion due to insufficient watershed management, deforestation, and inadequate land-using practices, which have consequently eroded about 65% of potable water structures. As a result, many fertile lands have lost their due deposits in downstream reservoirs such as dams. While aiming to reach a possible solution to this issue on an urban level, it has been observed that Lahore city has an estimated rainwater harvesting potential of 535,756 m^3/year [13]. Particularly, about 22% of domestic water demand within Islamabad (the capital) could be fulfilled with the development of a rainwater harvesting system (hereafter RHS) [14]. However, no detailed study has been carried out using modeling tools and methods on a proper assessment of the efficiency and applicability of RHS in order to enable the related engineers and decision-makers to actualize this system for a sustainable solution to water stresses.

Numerous modeling approaches and tools have been used for the design and evaluation of RHS, which include the design storm approach [15], the linear programming approach [16], a nonlinear metaheuristic algorithm [17], an analytical probabilistic approach [3], a random matrix based non-parametric approach [18], a dimensionless method [19], and continuous simulations [20,21]. In particular, long-term continuous simulations are deemed the most common approach and can be used to evaluate the effectiveness of flood water management and the economic benefit of RHS [22–24], as well as to determine the optimal tank size for water storage [25,26]. However, few of those approaches could be applied for a detailed assessment of the water saving and flood-water control performance and the economic feasibility of the RHS.

For more effective and precise analysis in water management studies, the geographic information system (GIS) and satellite remote sensing (SRS) utilities have been proven to be superior tools [27]. In the context of these applications, various methodologies are being practiced, among which the Analytic Hierarchy Process (AHP) is a method of multi-criteria decision analysis that is relatively reliable as it assigns weights to each of the input criteria, thus making it a better decision support system. Additionally, for the delineation of sites for RWH, the multi-criteria-based GIS-based method is the weighted overlay of the critical input parameters, i.e., drainage density, slope, runoff depth, soil map, and the land-use/land-cover (LULC) map [27,28]. Particularly for surface runoff, the soil conservation service-curve number (SCS-CN) method has been used. It was initially developed by the Soil Conservation Service (SCS-USDA) [29]. With an additional focus on site selection for better potential for RWH, some critical socio-economic factors are considered, such as distance from the road and settlements, physical characteristics such as land use/cover, soil types, slopes, and the watershed zone [30]. While the precipitation factors such as the annual difference of rainfall, daily rainfall depth, and the duration of rainfall also strongly affect RHS performance [31], many related studies on the selection of suitable sites and zones for RWH and related harvesting structures have been conducted [32–37].

In the present study, focusing on the Ghazi Tehsil area in the KP province of Pakistan, using a geospatial approach, we concentrate on investigating the following RWH structures: farm ponds, check dams, gully plugs, and Nigarims. The specifics of these structures can be found in the Integrated Mission for Sustainable Development (IMSD), Indian National Committee for Hydrology (INCOH), and the Food and Agricultural Organization (FAO). Generally speaking, the previous studies on RWH have considered the most common factors for analysis such as land use and land cover, slop, runoff water depth, soil depth, rain excess, lineaments, lithology, and geomorphology [38–41]. However, none of them has examined the overall critical factors. Hence, in the present approach, we have focused on most of these major factors in order to determine the potential RWH sites and related structures. Therefore, the main objective of this study was to explore suitable and potential sites and zones for RWH in the mentioned area through the approach of the runoff estimation SCS-CN method as well as the identification of potential sites and suggestions of RWH structure including farm ponds, check dams, Gully Plugs, and Nigarims. Prospectively, the present approach will also be adopted for other regions with similar topographic and climatic conditions within the country as well as globally.

2. Materials and Methods

2.1. Study Area

The studied area of Ghazi is a tehsil-administrative region in Khyber Pakhtunkhwa district, Pakistan, which lies at 33°52′ to 34°25′ north latitude and 72°30′ to 72°55′ east longitude (Figure 1). Geographically, to its northwest are the Indus River and district Swabi, to the southwest lies the district Attock (Punjab province), and to its southeast are the district Rawalpindi (Punjab) and district Haripur, respectively. The total geographical area of the Ghazi Tehsil is approximately 348 km^2 [42].

In terms of the physical environment, this area is divided into three major physiographic regions: the hilly terrain, piedmont, and plain areas. Photographically, on the western tip of the Hazara division, the Ghadaghar range (elevation 457 up to 1341 m ASL) forms a prominent feature and isolates the Haripur plains from the Khari plain of Ghazi Tehsil. On a structural basis, this mountainous area is part of the Himalayas (northeast to southwest), with the flow of rainwater into down-streams which emerge from hilly terrain. The Piedmont area in this region is a narrow belt on the western side of the Ghandaghar range that consists of numerous streams and torrents (locally known as Dara). Since the land area is generally plain with a relatively steep gradient, it has great potential for water harvesting, as well as the conversion of barren land into agricultural cropland.

The flood plain of the studied area is a relatively fertile region; it is hill-locked by the hilly terrain of Ghandaghar and part of the Indus River. The populated area lies within the flood plain of the Indus River (locally known as Khari Plain), which is further divided into the active flood plain and the old flood plain. The active flood plain lies with part of the Indus River in Ghazi tehsil and remains flooded during every rainy season. Hence, due to seasonal high discharge, the related river processes of erosion and deposition occur simultaneously.

The recorded precipitation data (1981–2002) clearly exhibit two distinct rainfall periods (summer and winter) in the area. Summer rainfall is mainly caused by the monsoon (July, August, and September), whereas the winter (December to March) precipitation is mainly caused by western disturbances (originating from the Mediterranean) (Pakistan Metrological Department). In terms of the climate, this area is relatively semi-arid. During summer time (June and July), the nights remain cool, but day-time temperatures can reach a mean maximum of 44 °C, which is generally moderated by the Tarbela dam in the premises. On the other hand, in winter, which includes the months of December, January, and February, it is relatively cold, with January generally being the coldest month (mean minimum temperature of 4.8 °C). Occasionally, the temperature even falls below the freezing point, with the record low temperature of the area being −0.4 °C (Tarbela Observatory 1960–2000).

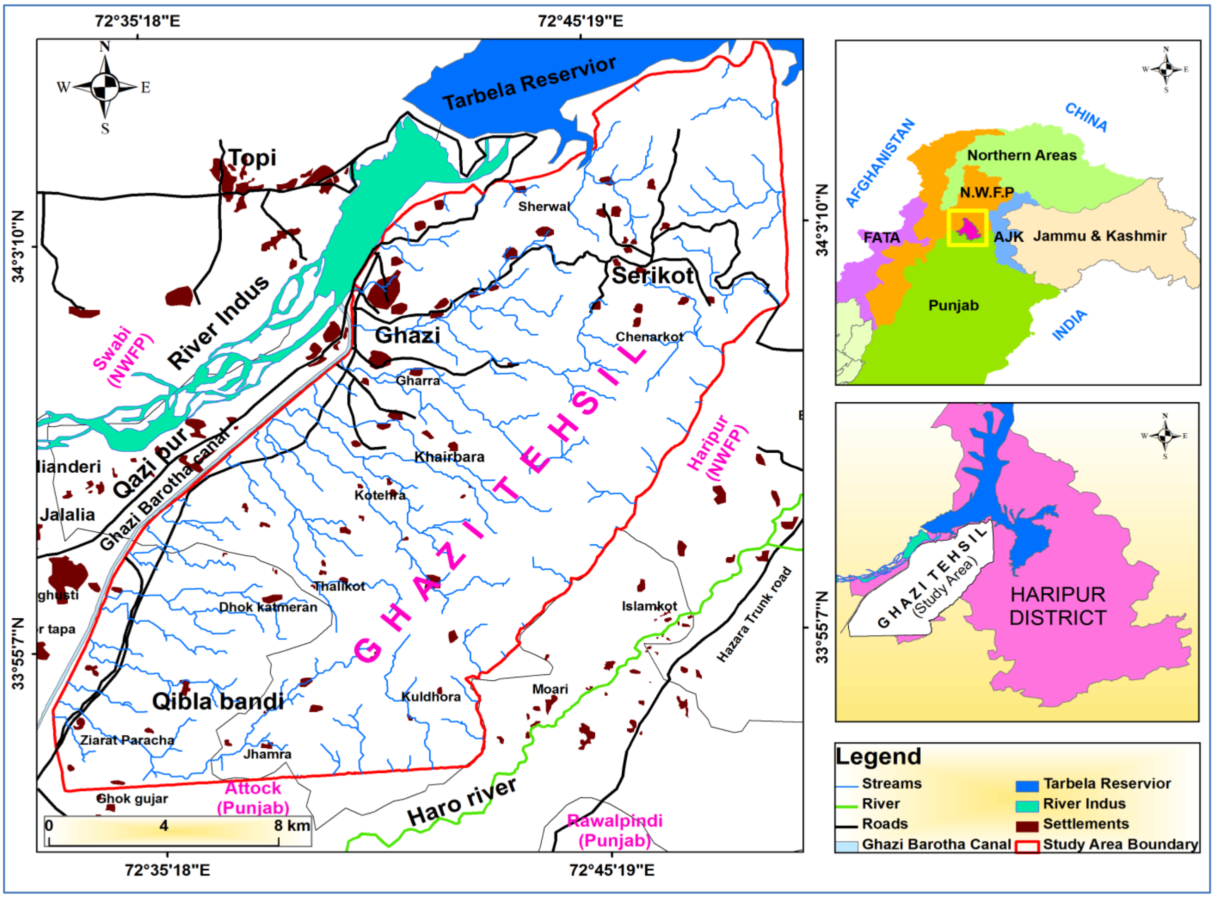

Figure 1. Location map of the study area.

2.2. Datasets

In order to obtain the surface slope and the elevation of the studied area, the Digital Elevation Model (DEM) of 30 m was downloaded from ASTER GDEM website (www.gdem.aster.ersdac.or.jp/search.jsp accessed on 15 January 2011) [43]. In addition, the Arc Hydro tool was used to depict the drainage network of the area. This also requires terrain preprocessing with DEM to identify the pattern of surface drainage of the area. All the steps in the terrain preprocessing were performed in a sequential order, from top to bottom. For this purpose, the data (in ArcGIS environment Arc Hydro Tool) were processed to produce the major water channels of the study area including streams, rivers, the Tarbela reservoir, and river Indus (Figure 1). Soil data play a pivotal role in water resource management, such as in site selection processes for rainwater harvesting. The soil map was constructed based on the soil survey of Pakistan Peshawar regional office, while the soil types were assigned by considering the infiltration assessment according to USDA Natural Resource National Conservation Service (NRCS) soil infiltration values. The geological maps (sheet numbers 43B12 and 43C9) at a scale of 1:50,000 were also acquired from the Geological Survey of Pakistan, Peshawar Regional Office (GSOP) in order to extract the information about the lithology of the concerned area [44]. The landcover information obtained from the satellite image of SPOT [45] (December 2007) had a spatial resolution of 2.5 m after performing the supervised classification with the ERDAS Imagine 9.1 software. The studied area is divided into regions characterized by thin vegetation, thick vegetation, bare rock, barren land, and water, respectively. In addition, certain land use data of roads and settlements were also extracted and compared with toposheets to confirm the exact locations of spatial features. The topographic sheets (sheet numbers 43C13, 43B12, 43B13, and 43B16) at a scale of 1:50,000 were acquired from Soil Survey of Pakistan, Islamabad, and were then used to extract the information about roads and settlements and to delineate the boundary of the area. The detailed methodology flowchart is shown in Figure 2.

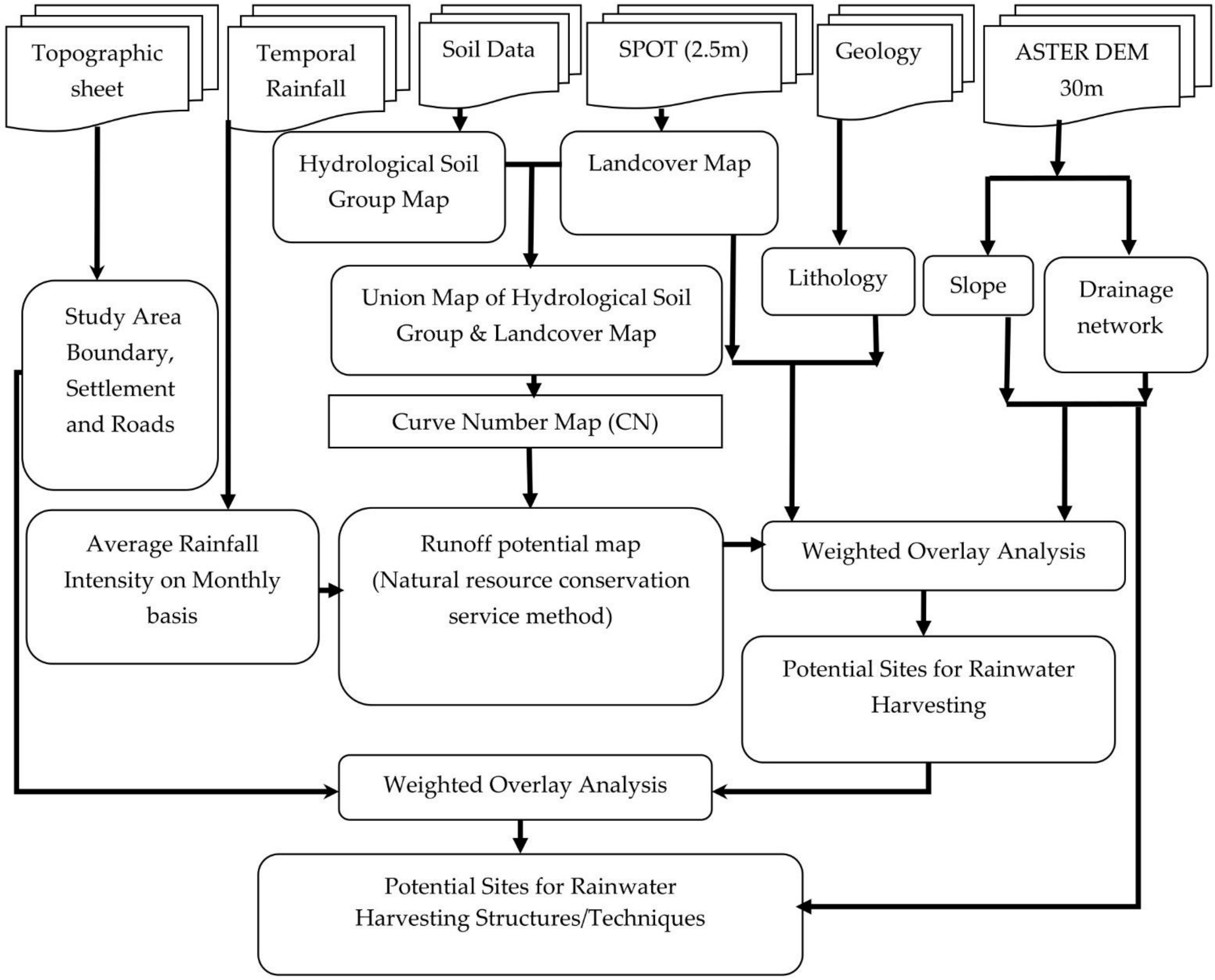

Figure 2. Conceptual methodology framework used to identify RWH potential site selection and potential sites for different RWH structures.

2.3. Data Processing

The agricultural land of the studied area, Ghazi tehsil (KP Province), is considered to be a rainfed area, and its local population mostly relies on agriculture as its main source of income. The area has a good potential for rainwater harvesting. Hence, the methodology adopted in this research aims to ensure that the site selection for RWH has positive and sustainable outcomes for the local people and environment. Earlier, the socio-economic survey conducted by the Irrigation Department of Peshawar concluded that there is a high demand of water for both domestic and agriculture use. In the present study, for the identification of suitable sites for RWH, the parameters used are surface slope, elevation, landcover, rainfall, soil, geology, and proximity maps of drainage and various land uses (such as roads, settlements).

Based on a methodological approach, this study was divided into three phases: first, the soil conservation service method was used to estimate the rainfall runoff relationship; secondly, potential sites were identified for RWH; finally, different techniques, i.e., RWH structures, were suggested for the studied area.

2.4. Runoff Estimation Using Soil Conservation Service Method

Much effort is required to make a quantitatively accurate prediction of the runoff from land surfaces into rivers and streams for ungauged watersheds. However, runoff is essential in dealing with watershed development and management issues. The Soil Conservation Service Curve Number (SCS-CN) method developed by the United States Department of Agriculture (USDA) was used to determine the runoff. The SCS-CN method provides relatively accurate and consistent results of the runoff estimation. This method requires two input parameters: the rainfall data and the SCS curve numbers.

The US soil conservation service curve number method is a widely used technique for estimating runoff for rainfall events from small catchments [46–49]. This method explores and utilizes the relationship between the landcover and the hydrological soil group, which together make up the curve number. The curve number is an index and hydrological parameter used to describe the storm (flood) water runoff potential in a drainage area. Basically, the number shows the runoff response of the catchment to a rainfall event. The curve number values range from 30 to 100, where greater curve number values represent greater proportions of surface runoff [33]. The formula of the curve number is given as follows:

$$S = 25{,}400/CN - 254 \text{ (having water quantity expressed in inches)}$$

The curve number is used as an input to identify the potential maximum retention.

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

where Q = runoff depth; P = rainfall volume; S = potential maximum retention.

2.4.1. Rainfall Data

Rainfall is a main contributor to the generation of surface runoff. For this study, rainfall data of installed stations were acquired from Pakistan Meteorological Department (PMD, Islamabad head office and Peshawar regional office) [50]. The monthly rainfall data of Saidu Sharif, Peshawar, Balakot, Kakol, Murree, Tarbela, Swabi, Kamra, Rawalpindi, and Cherat stations for the last 23 years (1981–2002) were acquired in order to compute the annual-based average rainfall volume for the studied area. The data were separated into four time intervals with lengths from four to six years, i.e., 1981–86, 1987–92, 1993–96, and 1997–2002, respectively. The surface interpolation method (spatial analysis) was performed to obtain the rainfall surface maps for different years on a monthly basis. These surface maps were in turn used as input for the SCS method to compute the runoff of the area. The geographical locations of selected climatic stations are given in Figure 3. However, the averaged annual rainfall is shown in Figure 4.

2.4.2. Curve Number, Grid Map Generation and Curve Number Lookup Table

Another parameter adopted as an input in the SCS method is the curve number (hydrological parameter, function of hydrological soil groups, and landcover), which is used to determine the runoff potential within the drainage area. HEC-GeoHMS is an excellent GIS application that provides engineers and planners with an efficient and useful tool for storm water analysis and management. The HEC-geoHMS tool of ArcGIS 9.3 was used to generate the curve map (used as input in the SCS method). It was downloaded from the following source: ftp://ftp.ecn.purdue.edu accessed on 15 January 2011. The required shapefiles for HEC-GeoHMS to generate the curve number grid map were DEM (Digital Elevation Model), union map hydrological soil groups, and landcover types. The available soil data (soil survey of Pakistan) of the area comprise some physical characteristics. However, in order to determine the curve number, the hydrological soil group is needed, which is based on the soil infiltration rate. There are four hydrological groups: A, B, C, and D (details shown in Figure 5). Landcover information was used for the determination of the curve number for each landcover type. The union map of hydrological soil groups

(HSG) and landcover was constructed in order to evaluate the standard SCS curve number values for each soil and landcover combination. The land use categories were derived from the standard categories typically employed for hydrological analysis using the SCS methodology (SCS, 1986).

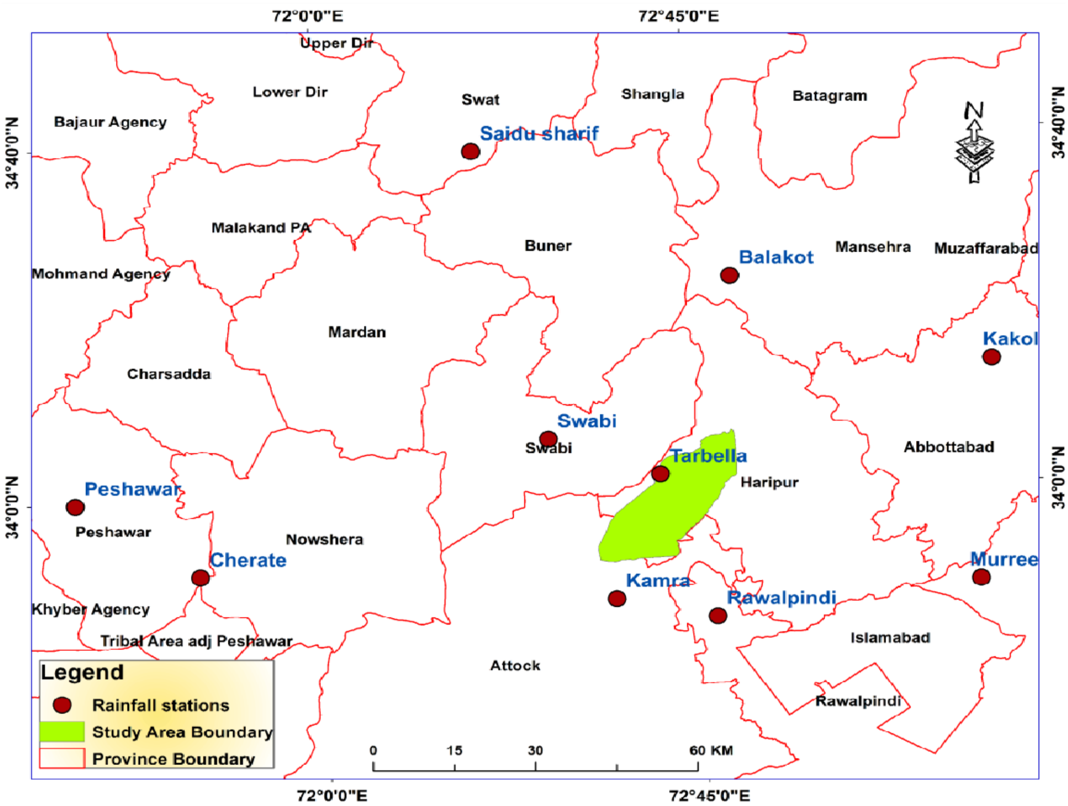

Figure 3. Map showing geographical locations of meteorological stations around Ghazi tehsil in the north central part of Pakistan.

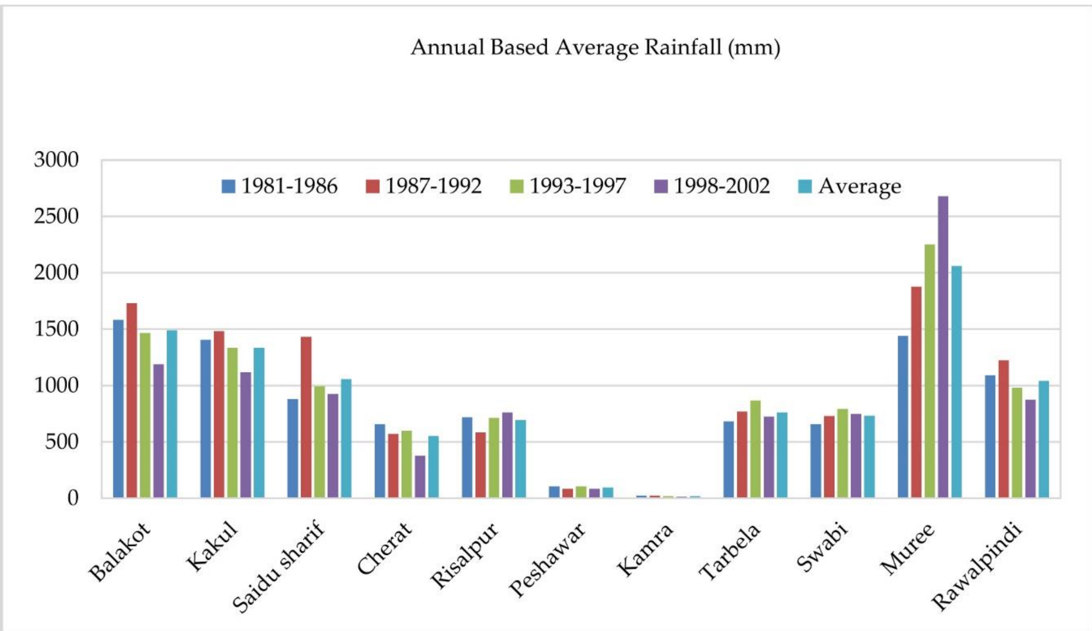

Figure 4. Average annual precipitation data (1981–2002) of different weather stations including Tarbela.

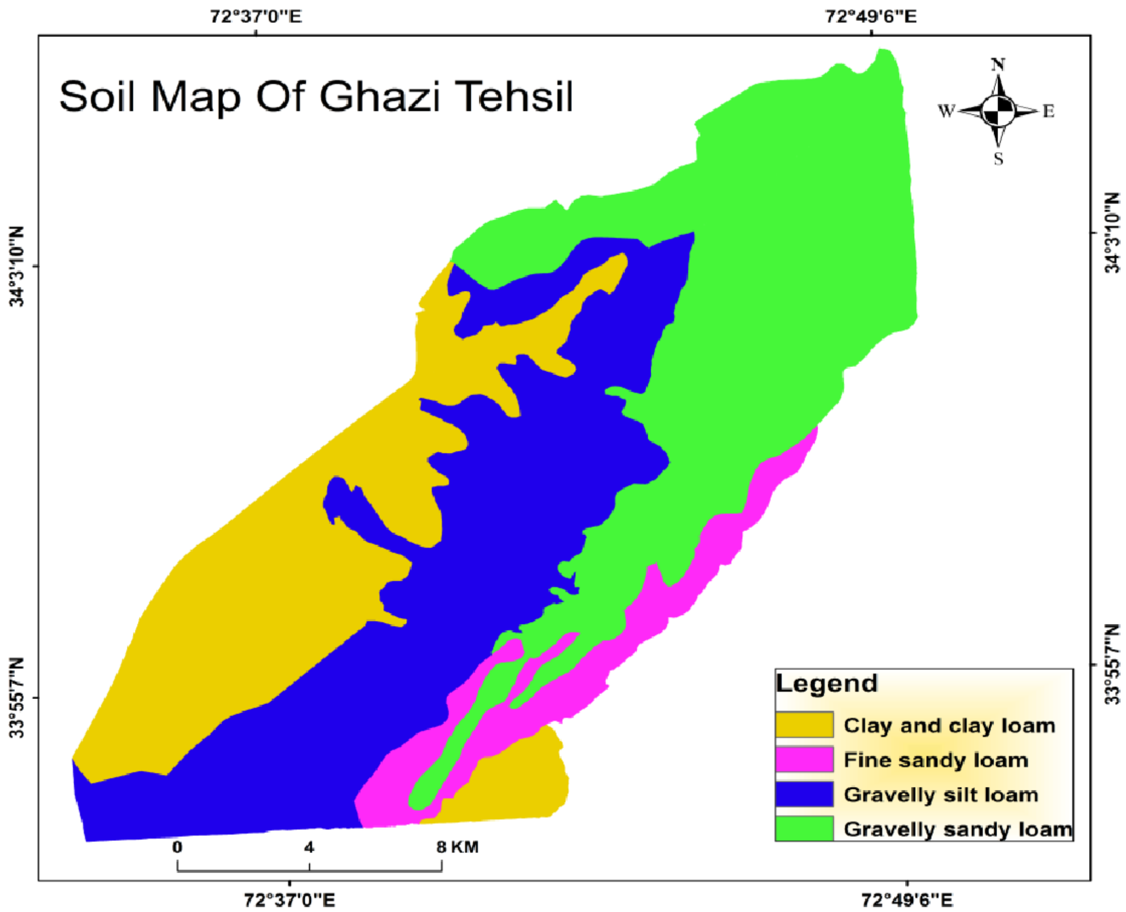

Figure 5. Hydrological soil group (HSG) of the study area showing soils of different major textures.

To generate the curve number grid map of an area, the CN Grid tool of HECgeoHMS is useful. It requires a polygon layer that merges both soil and landcover type data. The CN Grid tool also requires a look-up table. The look-up table comprises a field known as "LUValue" and hydrological soil groups known as "A", "B", "C", and "D". The user is required to enter the appropriate curve number values for the land use and HSG combination. The basic purpose of the lookup table is to combine the HSG and landcover with the curve number and, on the basis of this, to assign the name "LUValue" which refers to the land use type (numbers should correspond to those in the "land use" column from the land use and soil type layer). This tool automatically adds the "CN" field to the land use (soil types) attribute table and fills it with computed curve numbers.

2.5. Potential Sites for Rainwater Harvesting

After the determination of the runoff condition in the area, potential sites for rainwater harvesting were identified. Eight factors including surface slope, drainage network, settlement, road and land cover, soil, geology, and runoff volume were used in the model to identify the potential sites. Soil data, landcover, and temporal-based (1981–2002) rainfall data were used as input variables in SCS method. SPOT 2.5 m resolution data were used to extract the landcover information. Furthermore, based on the soil infiltration rates (from the Soil Survey of Pakistan), four HSG groups were determined within the study area. Using the HEC-geoHMS tool, the data of landcover and HSG were integrated and unified in order to compute the curve number, which was in turn used as the input in the SCS method to compute the runoff of the study area. Figure 2 demonstrates schematically the methodology for the identification of the runoff potential in the study area.

2.5.1. Surface Slope

The slope of an area has significant influences on runoff, on the movement of surface water, and on recharge; therefore, it is one of the critical factors for site selection. In areas with gentle slopes, the process of surface runoff is slow, which allows more time for rainwater to percolate. However, high slope areas generally facilitate high runoff, allowing less storage time for rainwater, which results in relatively less infiltration. The slope of the area was calculated using DEM (30 m resolution) acquired from the ASTER GDEM site (www.gdem.aster.ersdac.or.jp/search.jsp accessed on 15 January 2011). The minimum scale range of the DEM is 1:250,000, while the maximum scale range is 1:1000. The resulting elevation of the study area ranges from 283 m to 1316 m (mean sea level) (Figure 6).

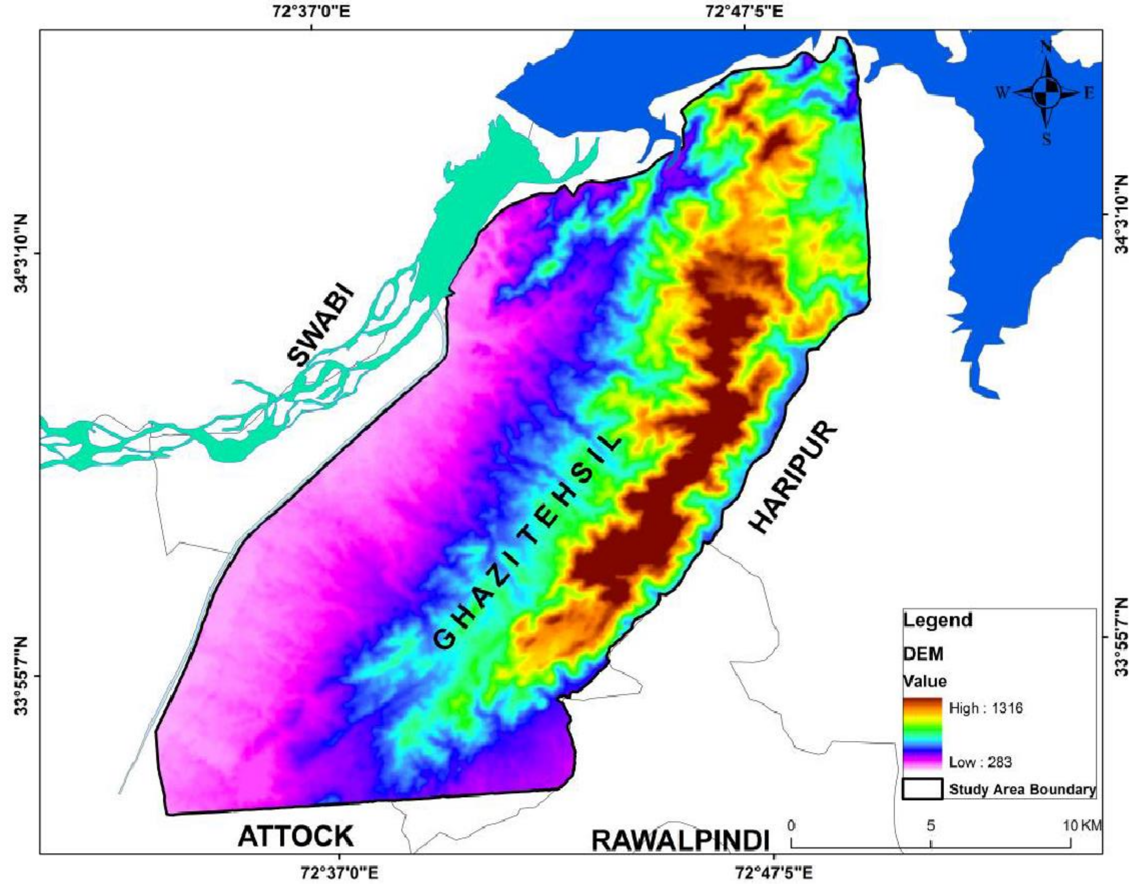

Figure 6. DEM (30 m) of Ghazi tehsil. The maximum elevation of the area is 1316 m and the minimum is 283 m (above sea level) (data source: ASTER GDEM website).

2.5.2. Drainage Network

Drainage is also an important input factor to be considered for the identification of potential sites for RWH. The DEM (30 m) was used as the input in Arc Hydro tools for the terrain pre-processing (consisting of a series of steps) menu to extract the drainage network of the study area. The drainage system of the area (found as dendritic) and RWH should be kept close to the drainage network. Hence, the variable proximity to drainage was introduced, and appropriate values were assigned to different sites, where the lowest ranking number was given to the sites farthest from the drainage network. The steps performed included computing the fill sinks, flow direction, flow accumulation, stream segmentation, stream definition, and watershed delineation.

2.5.3. Soil Data

The soil for RWH should be fertile and should not be saline or sodic. In addition, sandy soil usually makes water harvesting infeasible as it renders high infiltration, and thus runoff does not occur. Ultimately, even with a large quantity of rainwater pouring in, the water cannot be conserved in the sandy soil. The soil map used here was collected from the Soil Survey of Pakistan (Peshawar). This map was classified and assigned with four major classes based on infiltration values given by the USDA Natural Resource Conservation Service (NRCS).

2.5.4. Geological Data

The geology of an area is a significant factor in the formation of soil and in shaping the physical characteristics of a watershed. The geological characteristics, in effect, control both the movement of groundwater from surface stream to subsurface aquifers and the contrary movement. Geological maps of the area covered by topographic sheets numbers 43 B/12 and 43 C/9, at a scale of 1:50,000, were acquired from the Geological Survey of Pakistan (Peshawar) for the extraction of the required information on lithologies in the study area (Figure 7a,b).

Within this study, lithologies are described by four types of deposits: silt and sand-rich (Terraced Formation), gravel-rich (Stream channel Formation), clay, and quartz-rich (Piedmont Formation, Manki Formation and Tanawal Formation). The gravel and sand rich deposits are the least suitable for RWH because they cannot retain rainwater for a long period. The clay-rich deposits are the most suitable because of their low permeability and water infiltration into subsurface aquifers.

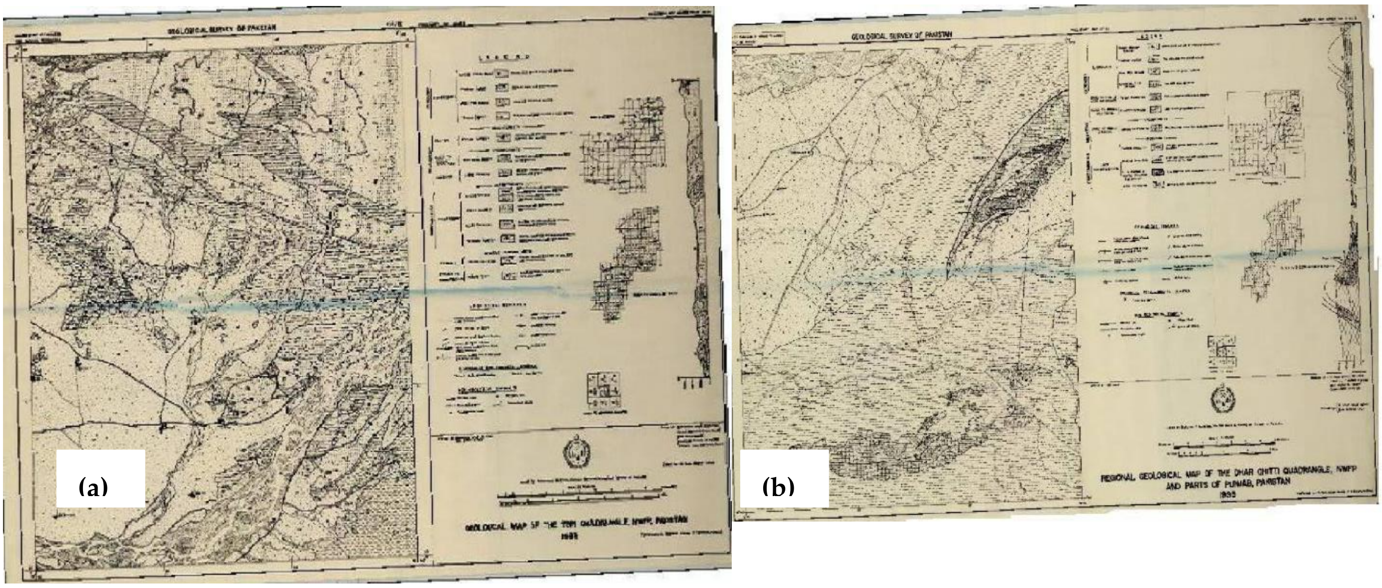

Figure 7. (**a**) Geological maps (sheet no. 43C/9) of Ghazi tehsil at a scale of 1:50,000 were used to extract the lithology information (Data Source: Geological Survey of Pakistan, Peshawar Office). (**b**) Geological maps (Sheet No. 43B/12) of Ghazi tehsil at a scale of 1:50,000 were used to extract the lithology of the study area (Data Source: Geological Survey of Pakistan, Peshawar Office).

2.5.5. Landcover and Land Use Data

Landcover is a key factor in runoff estimation and RWH studies. Runoff yield increases gradually with corresponding environments, from forest cover, grassland, farmland, and barren land to built-up area [51]. Satellite images of SPOT 5 (December, 2007), with a spatial resolution of 2.5 m, were used to extract the basic landcover information of the study area. Different parts of the area were classified into the following landcover types: thin vegetation, thick vegetation, barren land, built-up area, and water bodies. In this area, barren land and water bodies (nullah and streams) are considered suitable for RWH, thin vegetation with low interception and retention values is considered less suitable, and thick vegetation with high interception values is considered not suitable. The land use classes of built-up areas, roads, and settlements were also marked as not suitable. Impervious surfaces such as roads and settlements have low infiltration potentials, and hence such surfaces are also classified as non-suitable.

Additionally, the RWH structures need to be constructed at a reasonable distance from the built-up areas to allow future growth of infrastructure and urban development. In this research, the settlement areas and a zone of 500 m around them were considered not suitable for the RWH structures. Similarly, the roads and a zone of 180 m around them were classified as less suitable for RWH structures. The areas between 200 m and 500 m away from settlements may be considered suitable if the purpose is to utilize harvested water for municipal use. In the present case, the proposed application is for agricultural needs, and therefore, it was suggested that the sites should be located away from the settlements and close to the agricultural lands.

2.6. Rainwater Harvesting Techniques (Structures)

Rainwater harvesting by runoff conservation structures (Gully Plug, rock fill dams, check dam, and bench trenching) is basically intended to slow or stop running water. In drought-prone areas, RWH can be adopted to address the serious problems of drought and water scarcity (contour trenching and subsurface dams) [52]. After the identification of the potential sites for RWH, the prospective locations for RWH structures were subsequently determined. Although there are various different RWH structures, by analyzing the conditions of the study area, only four structures were recognized as worth being considered, including farm ponds, check dams, Gully Plugs, and Nigarims. The results of potential sites for RWH were also used as input parameters along with other factors, i.e., surface slope, drainage network, settlement, roads, and runoff volume. The methodology for selecting the potential sites for structures was the same, but the criteria and ranking for these structures were different. For example, drainage networks received more weighting in check dams than other structures. Similarly, the slope for Nigarims was given more weighting as per the guidelines of IMSD, INCOH, and FAO [53–55].

a. Farm Ponds

Farm ponds are small earthen barriers built in agricultural lands with slopes ranging from 1% to 6%. Farm ponds are constructed with the objective to convert a long slope into several shorter and less steep slopes to minimize flow velocity and thereby reduce the erosion by runoff water. Sites for farm ponds were identified following the guidelines of IMSD, INCOH, and FAO, as well as considering the topographic and climatic conditions of the study area. These include areas with streams and a proximity of 30 m, with surface areas with slopes of less than 10 degree. In addition, this structure should be constructed more than 250 m away from settlements. The methodology adopted to identify the potential sites for farm ponds (Figure 2) was designed using the mentioned parameters, their suitability tags, and rank rationality set (listed in Table 1).

Table 1. Parameters, their suitability, and ranks for selecting suitable sites for farm ponds. Surface slope, drainage network, settlement, roads, runoff volume, and rainwater harvesting result parameters were classified and weighted, and ranks were assigned in order to perform overlay analysis. The suitability and ranks were set based on IMSD (1995), INCOH (1995), and FAO (2003) guidelines (source: Bhaumic and Rao 2003, Rao et al., 2008) [55,56].

Parameters	Suitability	Rank
Surface Slope	Data	
Slope <10 degrees	Suitable	3
Slope 1–20 degrees	Less suitable	2
Slope >15 degrees	Not suitable	1
Drainage network		
Streams and an area of 30 m around them	Suitable	3

Table 1. *Cont.*

Parameters	Suitability	Rank
Area between 30 m and 60 m away from stream	Less suitable	2
Area >60 m away from stream	Not suitable	1
Settlement		
Area >250 m away from settlement	Suitable	3
Zone between 200 m and 250 m away from settlement	Less suitable	2
Settlement and a zone of 200 m width around it	Not suitable	1
Roads		
Area >250 m away from road	Suitable	3
Area between 100 m and 250 m far away from road	Less suitable	2
Road and an area of 100 m width around it	Not suitable	1
Runoff volume		
Moderate runoff	Suitable	3
Low runoff	Less suitable	2
High runoff	Not suitable	1
Rainwater harvesting sites		
RWH suitable sites	Suitable	3
RWH less suitable	Less suitable	2
RWH not suitable	Not suitable	1

b. Check dams

Check dams are of greater importance than other structures due to their role in controlling soil erosion. When constructing a series of check dams along a stream course, the spacing between two check dams should be beyond their water spread. Parameters used to identify potential sites for check dams are the surface slope, drainage network, settlement, roads, runoff, and results of potential sites for rainwater harvesting. By integrating all these thematic layers and weighting values (according to IMSD, INCOH, and FAO guidelines), suitable sites for check dams were then identified. These include areas with streams and their proximity of 30 m, with surface areas with slopes of more than 20 degrees. In addition, this structure should be constructed at a distance of more than 250 m away from settlements and roads. The related criteria are shown in Table 2.

Table 2. Categorization and ranking for selecting suitable sites for check dams; parameters of surface slope, drainage network, settlements, roads, runoff volume, and rainwater sites results are shown with their suitability and ranks rationally set based on IMSD (1995), INCOH (1995), and FAO (2003) guidelines (source: Bhaumic and Rao 2003, Rao et al., 2008) [55,56].

Parameters	Suitability	Rank
Surface Slope		
Slope <10 degrees	Suitable	3
Slope 1–20 degrees	Lesssuitable	2
Slope >15 degrees	Not suitable	1
Drainage network		
Streams and an area of 30 m around them	Suitable	3
Area between 30 m and 60 m away from stream	Less suitable	2

Table 2. *Cont.*

Parameters	Suitability	Rank
Area >60 m away from stream	Not suitable	1
Settlement		
Area >250 m away from settlement	Suitable	3
Zone between 200 m and 250 m away from settlement	Less suitable	2
Settlement and a zone of 200 m width around it	Not suitable	1
Roads		
Area >250 m away from road	Suitable	3
Area between 100 m and 250 m far away from road	Less suitable	2
Road and an area of 100 m width around it	Not suitable	1
Runoff volume		
Moderate runoff	Suitable	3
Low runoff	Less suitable	2
High runoff	Not suitable	1
Rainwater harvesting sites		
RWH suitable sites	Suitable	3
RWH less suitable	Less suitable	2
RWH not suitable	Not suitable	1

c. Nigarims

These catchments are used for growing trees and bushes. The size of the catchment area required for a cultivation area is found by equating the amount of water available from the catchment area to the amount of water needed by the cultivated area. These include areas with streams and their proximity of 30 m, with surface areas with slopes of more than 20 degrees. In addition, this structure should be constructed at a distance of more than 100 m away from settlements, as well as more than 70 m away from roads. The methodology adopted (Figure 2) to identify the potential sites for Nigarims with analytically set criteria are given in Table 3.

Table 3. Categorization and ranking for selecting suitable sites for Nigarims. Surface slope, drainage network, settlement, roads, runoff volume, and rainwater results are classified into three categories—suitable, less-suitable and not-suitable classes—based on criteria rationally set by IMSD (1995), INCOH (1995), and FAO (2003) (source: Bhaumic and Rao 2003, Rao et al., 2008) [55,56].

Parameters	Suitability	Rank
Surface Slope		
Slope >20 degrees	Suitable	3
Slope 5–20 degrees	Less suitable	2
Slope <5 degrees	Not suitable	1
Drainage network		
Streams and an area of 30 m width around them	Suitable	3
Area between 30 m and 80 m away from stream	Less suitable	2
Area >80 m away from stream	Not suitable	1
Settlement		
Area >100 m away from settlement	Suitable	3
Area between 50 m and 100 m away from settlement	Less suitable	2

Table 3. *Cont.*

Parameters	Suitability	Rank
Settlement and an area of 50 m around it	Not suitable	1
Roads		
Area >70 m from road	Suitable	3
Area between 20 m and 70 m away from road	Less suitable	2
Road and an area of 20 m around it	Not suitable	1
Runoff volume		
High runoff	Suitable	3
Moderate runoff	Less suitable	2
Low runoff	Not suitable	1
Rainwater harvesting sites		
RWH suitable sites	Suitable	3
RWH less suitable sites	Less suitable	2
RWH not suitable sites	Not suitable	1

d. Gully Plugs

Gullies are formed because of the erosion of topsoil by the flow of rainwater. Eventually, a gully assumes a substantial form, and the erosion increases. To prevent erosion, barriers or plugs of different types of material are then put across the gully at certain intervals. For the potential site determination of the gully structure, six parameters, including surface slope, drainage network, proximity to settlement, proximity to roads, runoff volume, and the resultant RWH map, were considered. Classifications and rankings with these factors were made, and criteria were set analytically (based on IMSD, INCOH, and FAO guidelines). These include areas with streams and their proximity of 30 m, with surface areas with slopes of more than 20 degrees. In addition, this structure should be constructed at a distance of more than 100 m away from roads. The criteria used for the identification of the potential sites for gully plugs are listed in Table 4.

Table 4. Categorization and ranking for selecting suitable sites for gully plugs. Surface slope, drainage network, settlement, roads, runoff volume, and rainwater harvesting results are classified into three categories—suitable, less-suitable and not-suitable categories—according to the guidelines of IMSD (1995), INCOH (1995), and FAO (2003) (source: Bhaumic and Rao 2003, Rao et al., 2008) [55,56].

Parameters	Suitability	Rank
Surface slope		
Slope >20 degrees	Suitable	3
Slope 10–15 degrees	Less suitable	2
Slope 15–20 degrees	Not suitable	1
Drainage network		
Streams order (3,4) and an area of 30 m around them	Suitable	3
Area between 30 m and 80 m away from stream	Less suitable	2
Area >80 m from stream	Not suitable	1
Settlement		
Area >230 m from settlement	Suitable	3
Area between 200 m and 230 m away from settlement	Less suitable	2
Settlement and an area of 200 m around it	Not suitable	1

Table 4. *Cont.*

Parameters	Suitability	Rank
Roads		
Area >100 m from road	Suitable	3
Area between 70 m and 100 m away from road	Less suitable	2
Road and an area of 70 m around it	Not suitable	1
Runoff volume		
High runoff	Suitable	3
Moderate runoff	Less suitable	2
Low runoff	Not suitable	1
Rainwater harvesting sites		
RWH suitable sites	Suitable	3
RWH less suitable	Less suitable	2
RWH not suitable	Not suitable	1

3. Results

The final results of the study were obtained with the consideration of several thematic layers in addition to the IMSD (Integrated Mission for Sustainable Development) guidelines. According to our approach in the present study, the spatial output includes the runoff estimation of the study area, identification of the potential sites for RWH, and finally, suggestions of related major structures for RWH, i.e., farm ponds, check dams, Nigarims, or gully plugs (Figure 6), on the basis of maps generated as discussed above (Figure 5). In addition, we aim further to compare the spatial results with the findings on this area from the government organization (Small Dams Organization) of the Irrigation Department Peshawar.

3.1. Runoff Estimation

Although runoff is a critical hydrological factor, for ungauged watersheds, the reliable prediction of the rate and quantity of runoff from land surfaces into stream and rivers is relatively challenging as well as time consuming. However, this hydrological information is necessary to deal with many issues in watershed management. Before the identification of the potential sites for RWH, the Soil Conservation Service Method (SCS) was used to estimate the runoff conditions. The SCS method requires rainfall and watershed coefficients (called curve number (CN) as inputs, which represent the runoff potential for landcover soil, in order to show runoff potential in the study area. The spatial results (Figure 8) of the runoff potential in the study area exhibit high runoff in the mountainous area because of high and irregular slopes, while low runoff was depicted in the plains as a result of the diversion of rainwater.

3.2. Potential Sites of Rainwater Harvesting

The demand for water in the area cannot be met with only groundwater sources. Hence, the potential sites for RWH storage are of critical value as prospective solutions for the additional storage of surface water [57]. For the present study area, different parameters were used to identify the potential sites for RWH. According to the survey (by Irrigation Department, in 2004) [58], in terms of annual rainfall patterns and physiographic and socioeconomic conditions, there are excellent opportunities for RWH in this area. Therefore, in this study, we have included the identification of RWH sites. The results reveal that most of the sites are within regions with a gentle to flat topography in the premises of agricultural and fertile plain (locally, *Kari* plain). Overall, the RWH potential was categorized into three classes, and the geographical area under each class was computed as given in Table 5. The spatial distribution of potential sites for RWH is shown in Figure 9. The classification of RWH potential shows that 28.73% of the total area is suitable for this practice and 51.72% is less-suitable, with 19.55% of the area classified as not suitable.

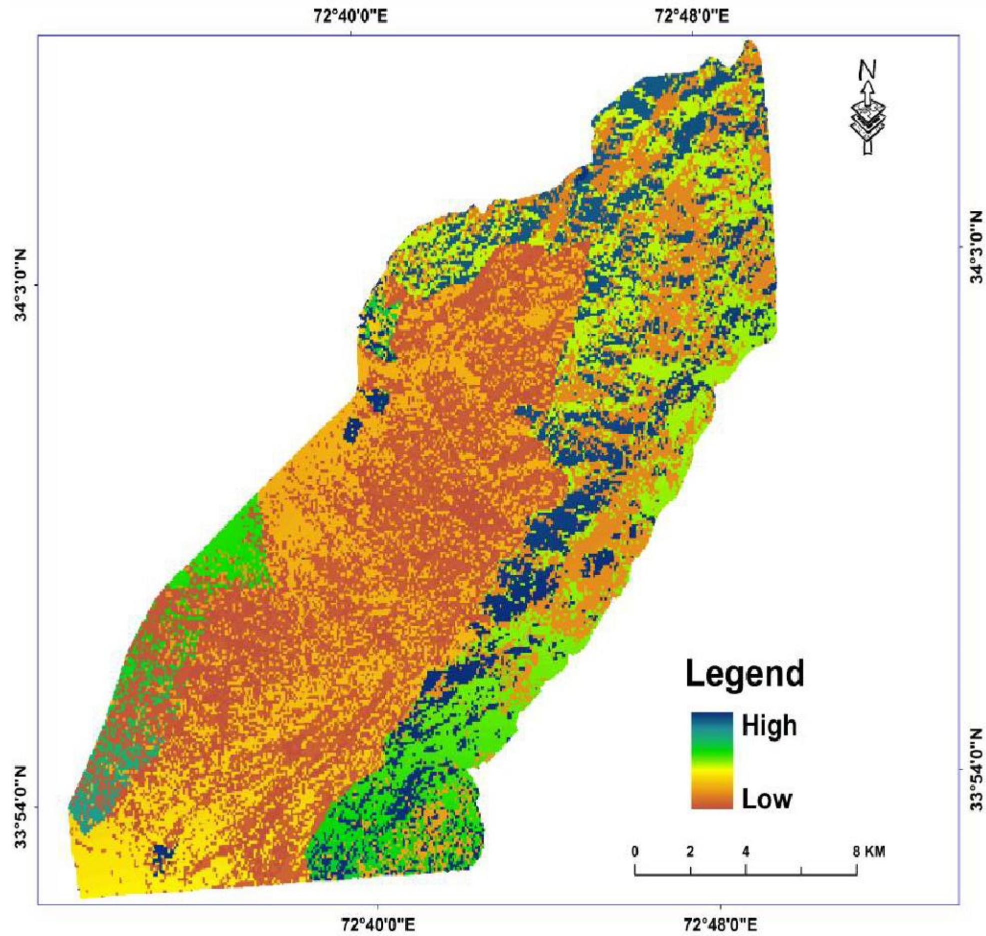

Figure 8. Runoff potential distribution in the study area.

3.3. Potential Structures for Rainwater Harvesting

Once the potentials for rainwater harvesting in the study area were investigated, another critical factor was to identify the potential RWH structures. For this purpose, surface slope, drainage network, settlement, road, runoff volume, and the results of RWH potential sites were incorporated in the GIS overlay analysis. Table 5 displays the distribution of the potential sites for RWH structures within the study area, including farm ponds, check dams, gully plugs, and Nigarims. In the region, 28.73% of the total area is suitable for RWH. Based on our categorical analysis of suitability for RWH, it was observed, in terms of geography, that most of the potential sites are in the low to moderate slopes (Figure 9). The spatial distribution was obtained by performing overlay analysis on different required parameters, i.e., surface slope, drainage, landcover, soil, geology, road, settlement, and the runoff volume. According to our results, we marked with blue and lime colors the suitable and less suitable areas, respectively, while the red color represents unsuitable areas for RWH.

The overall analysis for RWH and related structures reveals that, within the region, 28.73% of the total area is suitable for RWH, 10.63% for farm ponds, and 5.75% for check dams. Since these sites lie in the areas with gentle slopes, they are thus more feasible for irrigated agriculture. In addition, about 8.92% of the area is suitable for the construction of gully plugs, while about 13.79% is suitable for Nigarims.

Table 5. Distribution of potential sites for RWH and related structures in the study area.

Suitability	RWH		Farm-Ponds		Check-Dams		Gully-Plugs		Nigarims	
	Area (km^2)	% of total	Area (km^2)	% of total	Area (km^2)	% of total	Area (km^2)	% of total	Area (km^2)	% of total
Suitable	100	28.37	37	10.63	20	5.75	31	8.92	48	13.79
Less-suitable	180	51.72	145	41.67	154	44.25	152	43.67	125	35.92
Not-suitable	68	19.55	166	47.7	174	50.00	165	47.41	175	50.29

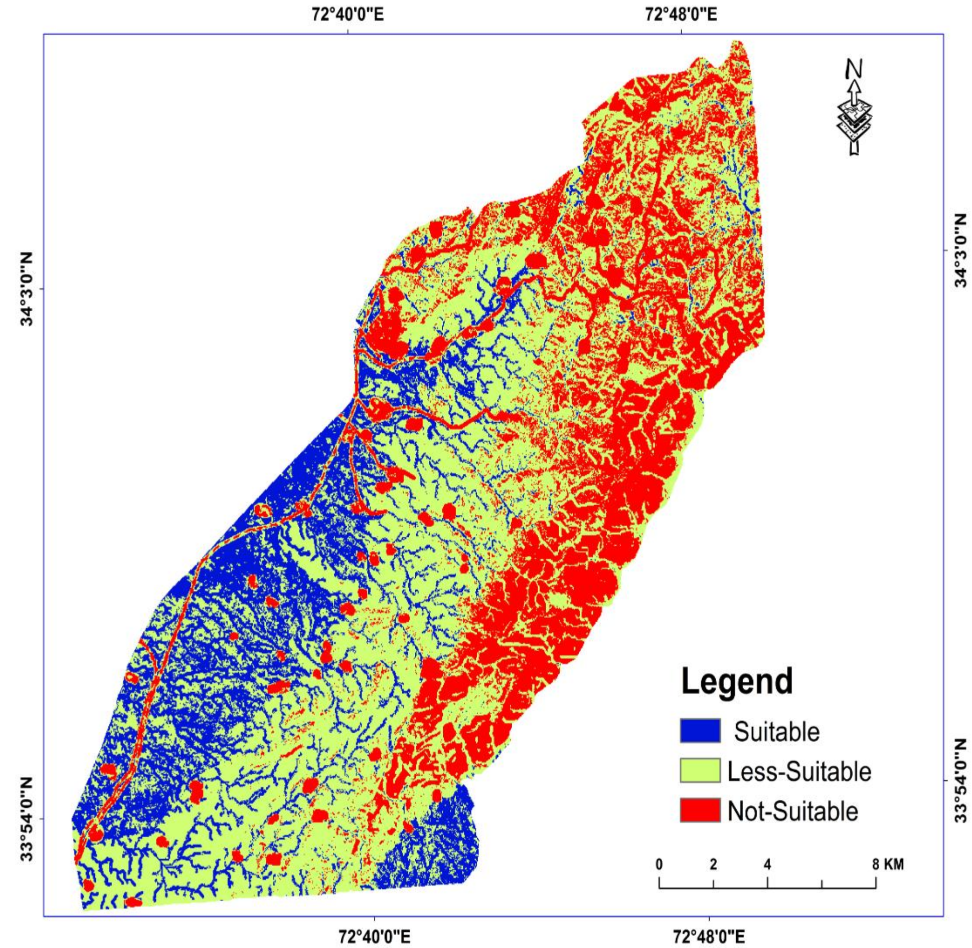

Figure 9. Area suitability for rainwater harvesting.

3.3.1. Farm-Ponds

On the map for farm ponds based on spatial computation, potential sites are classified into three categories, i.e., suitable, less suitable, and not suitable, with different color ramps (Figure 10) showing suitability-marked potential sites (identified within area of gentle slopes and agriculture). The analysis is based on the criteria and the ranking (set in Table 3) along with the overlay analysis of the surface slope, drainage network, proximity to settlement, proximity to road, runoff, and RWH results. The results are as follows: about 10.63% of the total area is suitable, 41.67% less suitable, and 47.7% is not suitable for farm ponds in the study area. The geographical area under each category was computed as shown in Table 5, which illustrates that out of the total area, 10.63% of the area is appropriate for siting farm ponds, 41.67% of the area is less suitable, and 47.7% of the area lacks suitability.

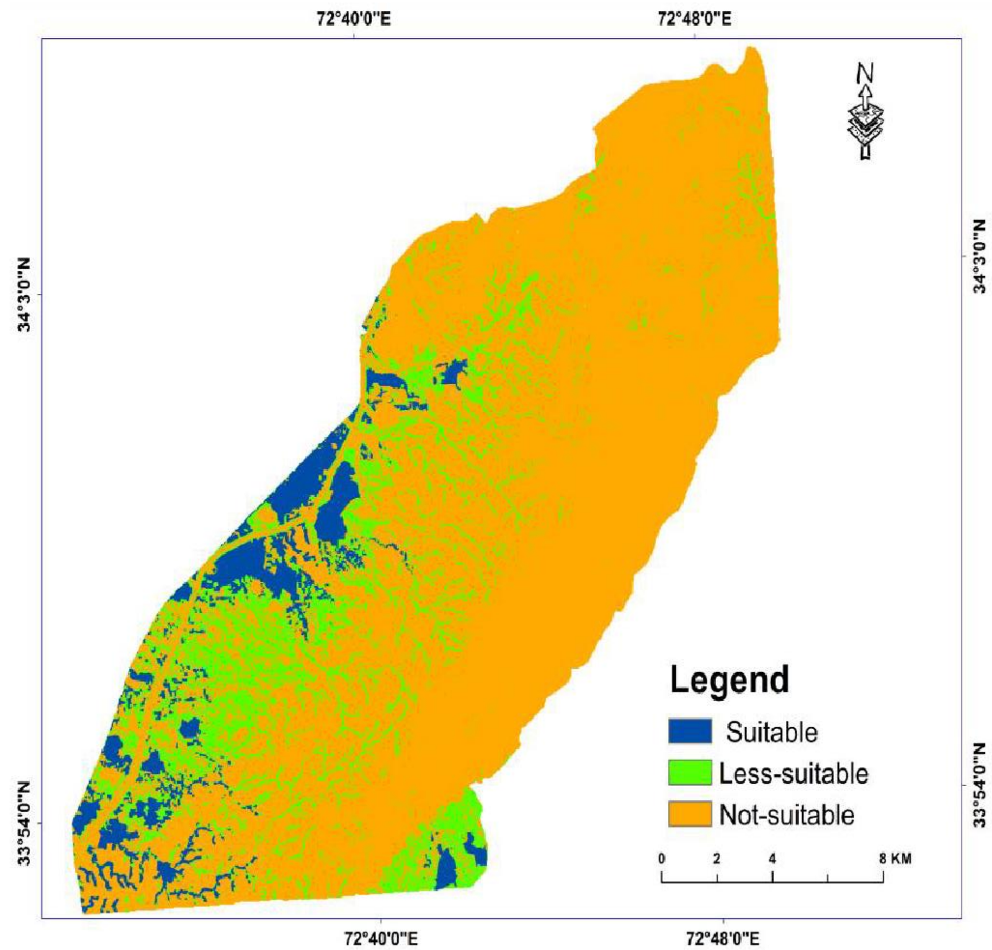

Figure 10. Categories of suitability for farm ponds.

3.3.2. Check Dams

For check dams, similarly, three categories of the resultant map were defined, i.e., suitable, less suitable, and not suitable (Figure 11). This analysis is also based on the set criteria and ranking (Table 2) as well as on an overlay analysis of the critical parameters including surface slope, drainage network, proximity to road, proximity to settlement, runoff, and RWH results of the study area. In addition, the spatial extent of each class was computed and is shown in Table 5. According to these results, most of the potential sites are identified on major streams at low slopes with 5.75% of the total area as suitable, 44.25% less suitable, and 50% not-suitable for check dams within the study area (Figure 11).

3.3.3. Nigarims

Nigarims are structures enclosed by earth bunds which are contoured in such a way that in the lowest corner, there is an infiltration pit in order to reduce soil erosion and to store rainwater. Runoff from the small catchment area is then collected and stored in the pit. These structures are deemed the best for orchards, particularly in higher slopes. For the identification of the potential sites for Nigarims in the area, a similar analysis-based approach was adopted, i.e., the criteria and ranking set (in Table 2) and overlay analysis of surface slope, drainage network, proximity to settlement, proximity to road, runoff, and RWH results. The geographical area for each class was computed and is displayed in Table 5. There are, again, three categories—suitable, less suitable, and not suitable—to which the different regions may be attributed (Figure 12). The spatial distribution-based map showing the categories of suitability for Nigarims is presented in Figure 12, where potential sites are identified in the area with moderate slopes. It was found that about

13.79% of the total area is suitable and 35.92% is less suitable, while 50.29% of the area is not suitable for Nigarims.

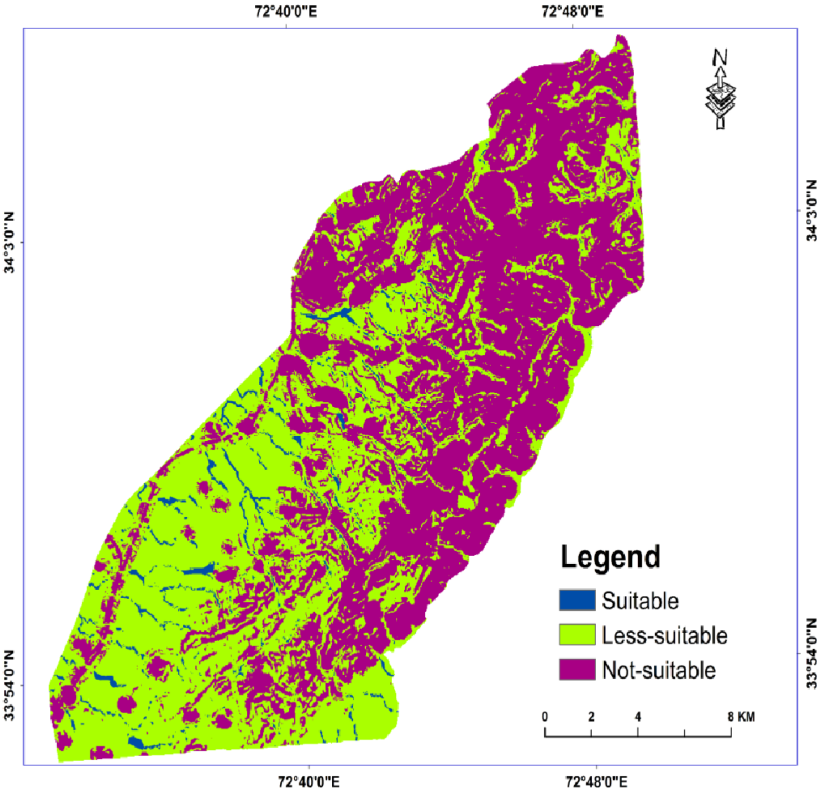

Figure 11. Potential sites for check dams.

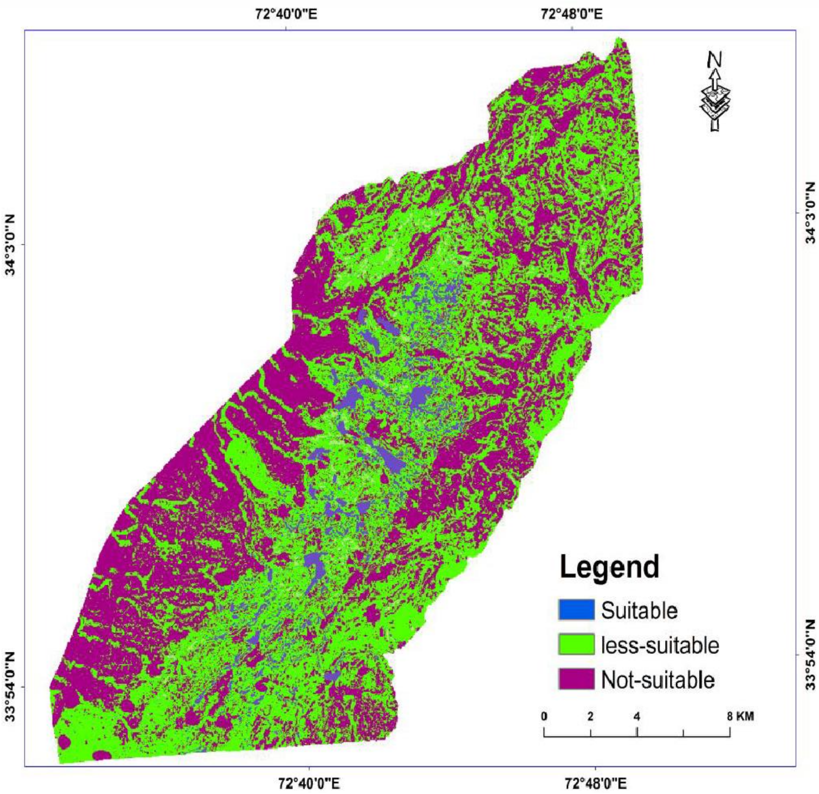

Figure 12. Categories of suitability for Nigarims.

3.3.4. Gully Plugs

Gully plugs are a good structure for water storage as well as nutrients and soil within valleys or along the major streams. The suitability-based sites in the study area were classified into three categories: suitable, less suitable, and not suitable (unsuitable). The spatial distribution-based potential sites for gully plugs were identified in the moderate slopes (Figure 13), while the geographical area for each class is mentioned in Table 5. The results show that 8.92% of the total area is suitable, 43.67% of area is less suitable, and 47.41% of the area is identified as not suitable for these structures.

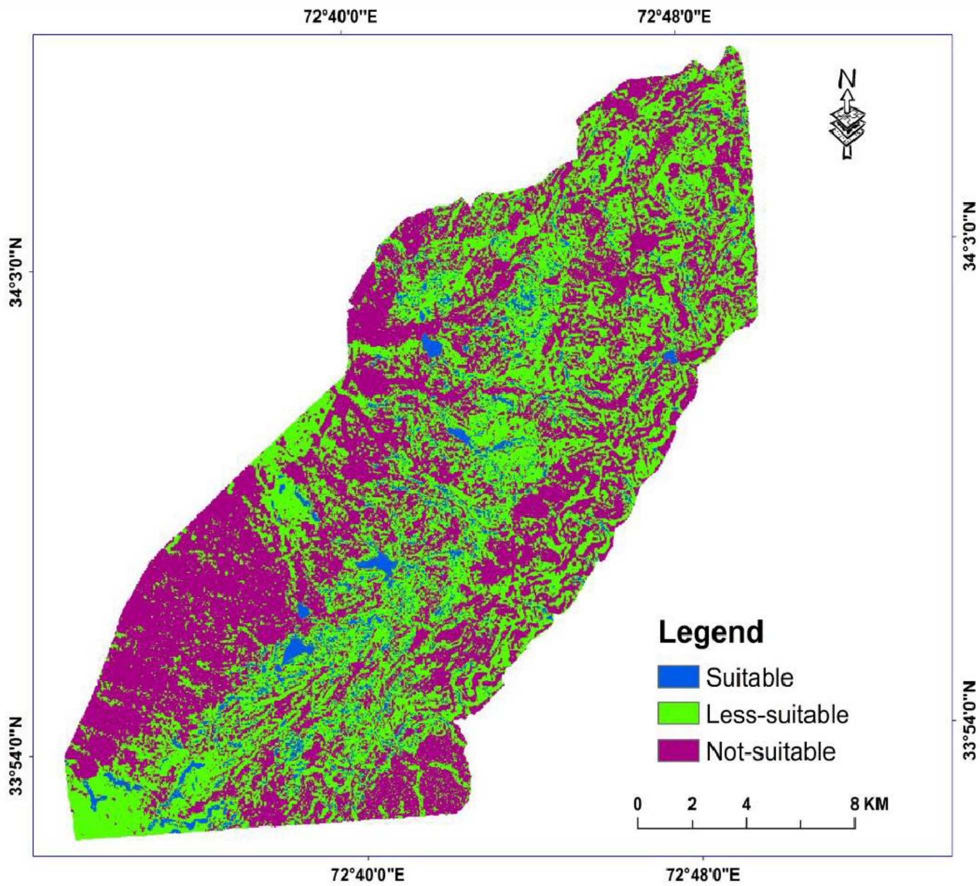

Figure 13. Potential sites for gully plugs.

3.4. Composite Overlay Analysis and GIS Results with Their Correlation to Field-Based Results

To determine the suitable sites for RWH structures, various factors such as surface slope, drainage network, roads, settlement, runoff potential, and rainwater harvesting results were considered. By integrating all thematic layers and weightage values, a composite map was generated in Arc GIS environment (using GIS function and Remote Sensing data). In the development of this composite map (Figure 14), site suitability analysis for farm ponds, check dams, gully plugs, and Nigarims was carried out, and the results are displayed here.

The composite overlay analysis map (Figure 14) depicts suitable sites for the construction of farm ponds, Nigarims, gully plugs, and check dams. The stream network was drawn from DEM (30 m resolution). In the investigated area, farm-ponds and check dams are located in the premises of agricultural and plain areas, while gully plugs and Nigarims are within the piedmont and relatively high slope areas. Overall, for RWH structures, we followed the guidelines suggested by the IMSD, INCOH, and FAO. Consequently, in the resultant composite analysis-based map (Figure 14), sites A and B are proposed for the dams.

Aiming at the identification of potential sites for small dams, the irrigation department of Peshawar (KP province) conducted a field-based survey (back in 2004) within the studied area. They identified two candidate sites for the small dams, namely site (A) (khairbara) and (B) (kotehra), as shown in Figure 15. Thus, to validate the accuracy of their assessment, we performed a spatial correlation analysis between the suitability results and potential sites derived from our approach proposed here and the field survey bases suitability map. It was readily observed that the site suitability results for check dams and gully plugs are highly consistent with the results of the present study (Figure 14). As clearly displayed in the following figure, these two sites, identified by the irrigation department for small dams, essentially coincide geographically and statistically (through spatial correlation analysis) with the GIS-based suitability results developed here for RWH structures, including farm ponds, Nigarims, check dams and gully plugs.

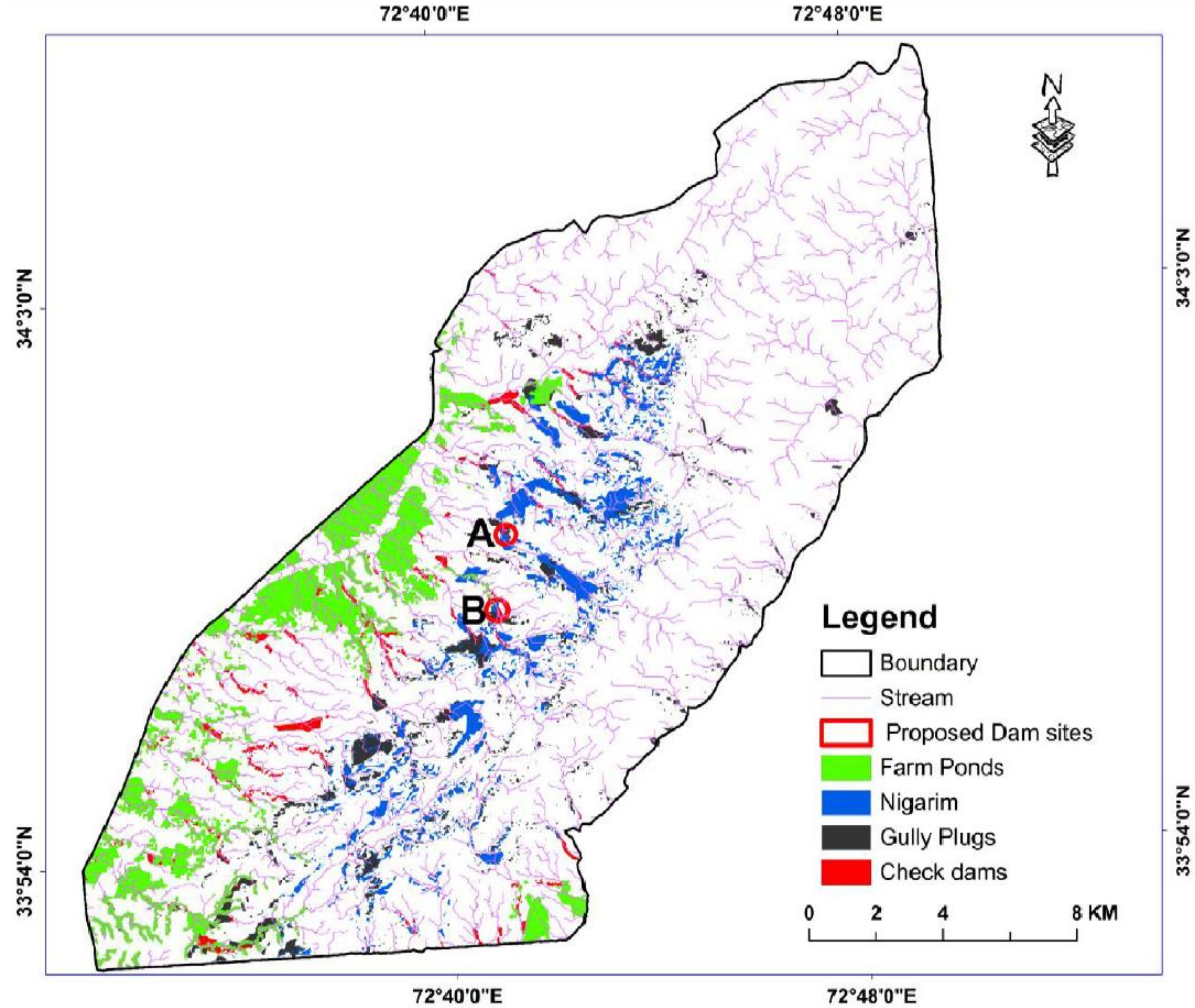

Figure 14. Composite map: suitable sites identified for construction of farm ponds, Nigarims, gully plugs, and check dams.

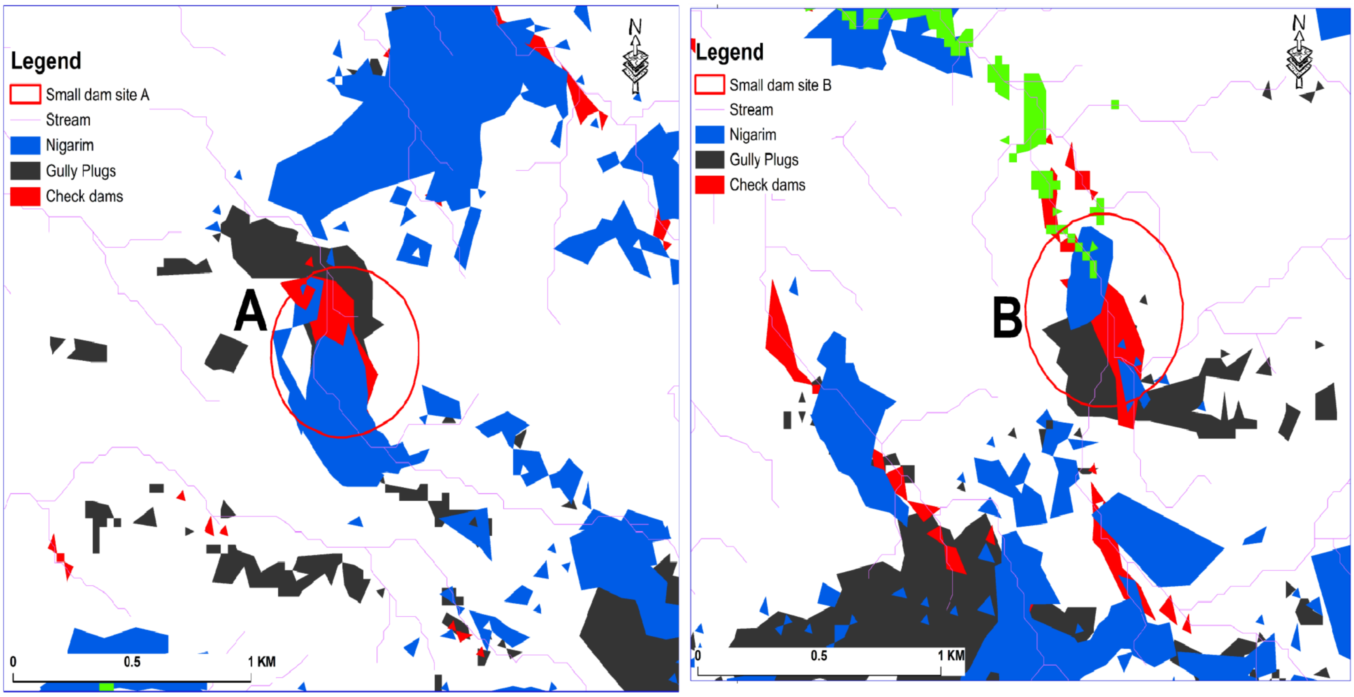

Figure 15. Close view of the identified locations of the small dams (**A**,**B**).

4. Discussion

Our analysis of the runoff estimation of the study area, the identification of the potential sites for RWH, and the final suggestion of related structures for RWH showed that the runoff potential is high in the mountainous area due to high and irregular slopes, while low runoff was depicted in the plains due to the diversion of rainwater (Figure 8). The classification of RWH potential shows that 28.73% of the total area is suitable for this practice and 51.72% is less suitable, followed by 19.55% of area being not suitable. The additional critical analysis of the potential RWH structures reveals that, out of the total area, 28.73% of the area is suitable for RWH, 10.63% for farm ponds, and 5.75% for check dams. Since these sites lie in the area with gentle slopes, these are more feasible for irrigated agriculture. In addition, about 13.79% of the area is suitable for Nigarims, while about 8.92% of the area is suitable for the construction of gully plugs, respectively. According to the spatial results of the overall suitability for RWH, the west to south areas are determined as most suitable. From the critical aspect of the settlements factor, sites in these parts of the area can be termed as most suitable for RWH structures.

The classification (different categories) based spatial results map of suitability for farm ponds structures shows that about 10.63% of the total area is suitable, 41.67% is less suitable, and 47.7% is not suitable. In addition, based on the analysis of geographical area (Table 5), 10.63% of the area is appropriate for siting farm ponds, 41.67% of the area is less suitable, and 47.7% of the area lacks suitability. From the spatial results of the overall suitability analysis, some of the west-ward areas are determined as most suitable for farm ponds. According to the spatial results for check dams within the area, most of the potential sites are identified on major streams at low slopes with 5.75% of the total area as suitable, 44.25% as less suitable, and 50% as not suitable. Additionally, on the basis of spatial results of the overall suitability, only some of the areas are determined as suitable for check dams, which lie in the west to south-ward parts of the study area.

The spatial distribution-based map (showing categories of suitability) for potential sites for Nigarims in the area shows that about 13.79% of the total area is suitable, 35.92% is less suitable, and 50.29% of the area is not suitable. The overall spatial-based suitability shows that some areas within the central parts of the study area are suitable for these structures. The spatial results for gully plugs show that 8.92% of the total area is suitable, 43.67% of area is less suitable, and 47.41% of the area is identified as not suitable for these structures. The spatial-based suitability shows that some areas within the central parts, as well as the north–south side of the study area, are suitable for these structures.

After the validation of the accuracy assessment, the spatial correlation analysis evidently established the accuracy of the suitability results for potential sites developed in this study, especially for check dams and gully plugs, via their consistency with the suitability map (irrigation department of Peshawar, KP) obtained from field surveys (Figure 14). These two sites were already identified (by the irrigation department) for small dams and spatially correlate with present suitability-based spatial results for RWH structures including farm ponds, Nigarims, check dams, and gully plugs.

The present approach of SCS-CN adopted for this study has proved to be a reliable technique for the overall determination and identification of suitable sites for RWH structures. The proposed RWH structures, particularly check dams and gully plugs, are also considered as cost effective, as these use locally available materials. Additionally, our work has also contributed to the assessment of the natural setup of this area for the better exploitation and management of rainwater resources. Prospectively, this approach can be implemented in all such regions with hilly terrain. As this study provides a pre-assessment of RWH potential with the consideration of major critical factors, integration with additional related local factors as well as real-time ground truthing can enhance future investigations.

5. Conclusions

Conventional rainfed farming in the Ghazi tehsil area (Khyber Pakhtunkhwa, Pakistan) is confronted by challenging water resource issues. Sustainable and viable solutions depend largely on the development of more effective water management practices. Keeping in view the rainfall intensity and physiography of the study area, the irrigation department of Khyber Pakhtunkhwa (KP) has completed a feasibility analysis of small dams using their own conventional methods, i.e., field-based survey techniques. Geospatial technologies (GIS) have been very effective at facilitating studies of water management by providing database management, the analysis of various critical thematic layers, and the derivation of suitability results. The present study aimed to estimate the runoff potential of the mentioned area in order to identify the potential sites for rainwater harvesting and to suggest related structures such as farm ponds, check dams, gully plugs, and Nigarims. Through experiments and actual applications, the method of curve number generation through HEC-GeoHMS in the GIS environment has proved to be an excellent tool to provide planners and decision-makers with a reliable approach for flood water analysis. Additionally, the runoff estimation showed that hilly terrain has high runoff values, which can be related to the high slopes that provide rainwater with potential downward speed, whereas in the plain area, the runoff is low because of the spread of water in different directions. The identification of potential sites for rainwater harvesting through weighted overlay analysis shows that 20% of the area was deemed suitable, 52% less suitable, and 29% was found not suitable. These results were further incorporated for the determination of potential sites for farm ponds, check dams, gully plugs, and Nigarims. Consequently, 10% of the area is recognized as suitable for farm ponds, 5.74% for check dams, 21.5% for Nigarims, and 8.9% was suitable for gully plugs. In conclusion, the present study will be helpful for developing sustainable rainwater management in the studied area, and, as the authors believe, it will prove insightful for decision-makers and planners to apply the analysis in related areas at both national and global levels.

Author Contributions: D.K.: writing—original draft and preparation, formal analysis, methodology; A.R.: writing—original draft and preparation, methodology, investigation, supervision, review of the manuscript and English correction; T.S.: writing—review and editing, resources; H.-W.V.Y. and Y.-A.L.: original draft—extensive editing and finalizing. All authors have read and agreed to the published version of the manuscript.

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