CENTRAL ASIAN JOURNAL OF WATER RESEARCH (2022) 8(2): 46-69

https://doi.org/10.29258/CAJWR/2022-R1.v8-2/46-69.eng

Central Asian Journal of Water Research

Identifying suitable sites for rainwater harvesting using GIS & Multi - Criteria Decision Making techniques in Badghis Province of Afghanistan

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ABSTRACT

In Afghanistan, about 1/3 (12.5 mln) of the total population have no access to stable water supplies such as groundwater extraction, stream flow diversion, and reservoir storage. In areas with limited water sources, rainwater harvesting (RWH) can improve the availability of potable water. Due to RWH flexibility and applying different criteria, it can be used in various settings, making RWH a viable option for local communities. Within this study, suitable RWH sites were identified based on modern technological approaches (GIS and Multi-Criteria Decision Making (MCDM)) considering different biophysical criteria selected according to the requirements of the target area environment. The Analytical Hierarchy Process (AHP), Weighted Linear Combination (WLC) Model and hydrology tools were used as MCDM and GIS-based decisions, respectively. The proposed methodology was implemented in the target area of 11,772 km2. The obtained land suitability map was divided into five (5) RWH zones: highly suitable (7.84% of the total area), suitable (21.85%), moderately suitable (31.15%), marginally suitable (27.85%), and not suitable (11.31%). The research results show that highly suitable and suitable sites (3,495.47 km2) are located in mountainous zones with good elevation potential, proper valley shapes, and large catchment areas. RWH practices in these areas can be considered as renewable and sustainable alternatives to water demand saturation. In addition to being a solution in terms of providing water to water-scarce areas, RWH installations represent a good climate change response and water resource management means.

ARTICLE HISTORY

Received: November 16, 2021

Accepted: August 17, 2022

Published: October 14, 2022

KEYWORDS

rainwater harvesting, suitable site, GIS, MCDM, Afghanistan.

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Published by Kazakh German University, Almaty/Kazakhstan

1. Introduction

Afghanistan possesses sufficient potential water resources but lacks the infrastructure to utilize them. This is characterized as economic water scarcity due to the lack of economic capacity to fill gaps for efficient use of available resources (Seckler & Barker, 2010). Due to the internal conflicts over the past 40 years, the country has not been able to sufficiently develop its water resources (Related & In, 2014). According to the 2019 UNICEF Report, 12.5 mln people (33% of domestic population) have no access to improved drinking water in Afghanistan (Results, 2021), and 1.6 mln people still rely on surface water for drinking (National Rural WASH Policy 2016-2020, 2020). Groundwater extraction does provide a portion as drinking source (Mack et al., 2013), but water supply has diminished because of declining water levels (Electrical et al., 2015). In Afghanistan, about 85% of groundwater wells, 50% of springs, and 60-70% of traditional subterranean canals have become dry in rural areas (Qureshi, 2002), hosting 80% of the total population (Mahmoodi, 2008). Meanwhile, the development of existing traditional storage facilities for collecting snow and rainwater are not encouraged by related organizations (Qureshi, 2002). In the light of these factors, Afghanistan's Badghis Province represents one of the world's most water-stressed regions (Holden & Doshi, 2019).

Rainwater harvesting can reduce potable water shortage in areas where no other water resources are available (Mohanty et al., 2020). This practice is defined as harvesting and storing rainwater during rainy season(s) (Biswas & Mandal, 2015). A major advantage of RWH is the high quality of rainfall not requiring treatment in rural areas. Currently, RWH has become a sustainable alternative of curtailing the water crisis (Mohanty et al., 2020) widely utilized for this purpose worldwide. An investigation in 2007 showed that over 10 mln RWH reservoirs were constructed in China to supply domestic water for 22 mln people (Gould et al., 2014). In Chennai, India, 50,000 RWH installations were built in 2014 to provide potable water. For Australia, it has become a principal method of suppling household water (Mohanty et al., 2020). Moreover, similar studies were conducted in arid (Adham et al., 2018) and semiarid regions (Adham et al., 2017). RWH systems offer flexible solutions which can effectively meet existing small and largescale demands (Abdulla & Al-Shareef, 2009). The selection of suitable sites - particularly large ones - for creating RWH installations represents a challenge for water resource managers and planners (Shadmehri et al., 2020), because the implementation of RWH technology is dependent on the physiographic, environmental, technical, and socio-economic features of a specific region of interest, and the model suitable for one area does not necessarily work for another (Jasrotia et al., 2009). Another RWH advantage lies in its flexibility and easy use with different performance criteria, i.e. it can be used in a variety of settings. Other advantages of the method include low time and cost of evaluations, making it a viable option for local RWH managers and communities as a significant practice to reduce potable water shortage in areas lacking other water resources.

Multi-Criteria Decision-Making (MCDM) and Geographic Information Systems (GIS) can be used for identifying RWH suitable sites (Shadmehri et al., 2020), followed by the application of Analytical Hierarchy Process (AHP) and Pairwise Comparison (PWC) method as the base for MCDM analysis structured technique (Adham et al., 2018; Pérez et al., 2005). The data for the analysis can be obtained through a structured online questionnaire collected to ensure rating and weighing every criterion by experts. Also, the Weighted Linear Combination (WLC) and hydrology tools will used by GIS that have decision rule as an analytical method that can be used when dealing with MCDM for the final scoring of the map's combination (J. Malczewski, 2000). Generally, using GIS for site selection is based more on the application of deterministic rules guiding the integration of a set of parameter maps, so that alternative locations get arranged according to several settings on evaluation criteria (Malczewski, 2004).

Multiple studies (Adham et al., 2017, Adham et al., 2018, Shadmehri Toosi et al., 2020) identified RWH sites with the help of GIS & MCDM approaches by using quantitative and qualitative factors such as terrain, resource availability, soil strength, land use, etc. (Dugan et al., 2013). In the 1990s, most studies primarily focused on biophysical criteria; yet the studies conducted after 2000 started to include socioeconomic parameters (Shadmehri et al., 2020). The task can be obtained by locating the sites on topographic maps and on-the-ground examinations. Current studies utilize remote sensing to improve the understanding of hydrological and morphological variables (Saleh Alatawi, 2015). Hydrological, numerical, and decision-making models are also available for developing RWH (Franz et al., 2008).

Objectives of this study followed by structured contents that introduction part is consist; Afghanistan water resources situation, RWH concept and practices, proposed appropriate methodology and information about interested area for this study. Second section discussed about data, methodology, criteria selection and reclassification of criteria. In third section this study focused on results and discussion that weak and strength points evaluated and results showed by table and figures. In the last section, outputs of study proposed as conclusion and consideration for next steps of development in such interested area.

Study area

The study area (11,772 km2) within this research is located in the western region of Afghanistan (Badghis Province, Jawand District) between 35°26’49” to 34°31’18” north latitude and 63°39’44” to 65°5’12” east longitude (Fig. 1.).

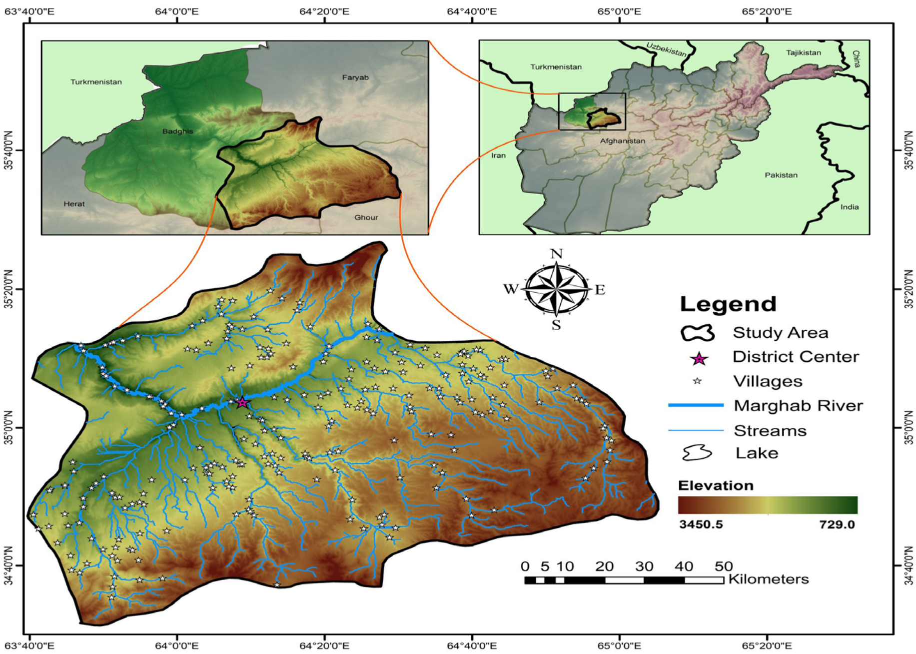

Figure 1. Study area

The target area borders on Faryab Province (to the north), Ghour and Herat Provinces (to the south), Ghour Province (to the east), and Qadis District of Badghis Province (to the west), and includes approx. 270 rural communities (villages) with over 250,000 population. The area is partly mountainous and consists of large earthen hills. The climatic conditions are arid and semiarid with cold winters and hot summers (Tamim, 2020), with the highest temperature reaching +45°C in summer and the lowest (-10°C) in winter. The estimated average annual rainfall amounts to around 250 mm (Mahmoodi, n.d.). The Murghab River flows in the northern section of the study area eventually reaching the Qaraqum Desert in Turkmenistan.

2. Data and methods

2.1. Data

To identify and evaluate RWH suitable sites by using GIS and MCDM techniques, the authors considered the instructions and listed parameters of the UN Food and

Agriculture Organization (FAO) – climate, hydrology, topography, agronomy, soils, and socio-economics (Kahinda et al., 2008), and six (6) biophysical criteria selected under this study, as shown in Table 1. The monthly rainfall data were obtained from Afghanistan Metrological Department (AMD), and five (5) other datasets of different resolution for the aforementioned parameters were downloaded from different sources (Table 1.). Slope and stream data – generated from DEM in GIS environment – were also considered.

Table I. List of data used within the study.

#	Title	Type	FAO Parameter	Resolution	Source	Period
1	Rainfall	Data	Climate	Monthly	AMD	2005-
2	DEM	Raster	Topogphy and hydrology	30*30m	USGS.NASA_ SRTMGL3	2017
3	Soil texture	Vector	Soil	Shape file	FAO.org (DSMW)	2017
4	Land cover	Vector	Agronomy	Shape file	FAO Afghanistan	2015
5	Soil drainage	Raster	Soil	250*250m	FAO Geonetwork	2016
6	Soil pH	Raster	Soil	250*250m	International Soil Reference and Information Centre (ISRIC) World Soil Information	2015

2.2. *Methods*

2.2.1. Process

The paper describes a methodology for determining suitable sites for rainwater harvesting by using the AHP as MCDM and GIS. Fig. 2. below outlines the general concepts and decisions applied within the framework of this methodology. The process begins with six (6) biophysical criteria evaluated qualitatively via MCDM-analysis, and quantitatively via GIS-analysis. The qualitative analysis uses the Saaty AHP Model (Saaty, 1977) to derive a structured questionnaire to query local experts on the criteria. Under this study, 20 experts local to Badghis Province filled out the questionnaire. Based on the survey results, a set of scores was applied to the AHP pairwise comparison model to generate the final qualitative weights. The quantitative GIS-analysis allowed classifying the six (6) aforementioned criteria into subcriteria considering RWH reservoir requirements in the ArcGIS environment. The Digital Elevation Model (DEM) and the majority of the target area's data corresponded to the GCS_WGS_1984 Projection, a geographical coordinate system using degree as angular unit. To make the datasets consistent, they were reprojected to the WGS 1984 UTM coordinate system (uses meter as linear unit) with planar coordinates. All datasets were reshaped from the global and/or national scale to the study area, as well as adjusted into a uniform resolution of the original DEM. In addition, the vector data were converted to raster for further analysis. The final GIS results were reclassified and resampled for utilizing in the WLC model, a common GIS-based decision algorithm for dealing with Multi-Attribute Decision-Making (MADM). Using the WLC model, the drainage network and associated drainage points were generated from the DEM for locating suitable reservoir locations.

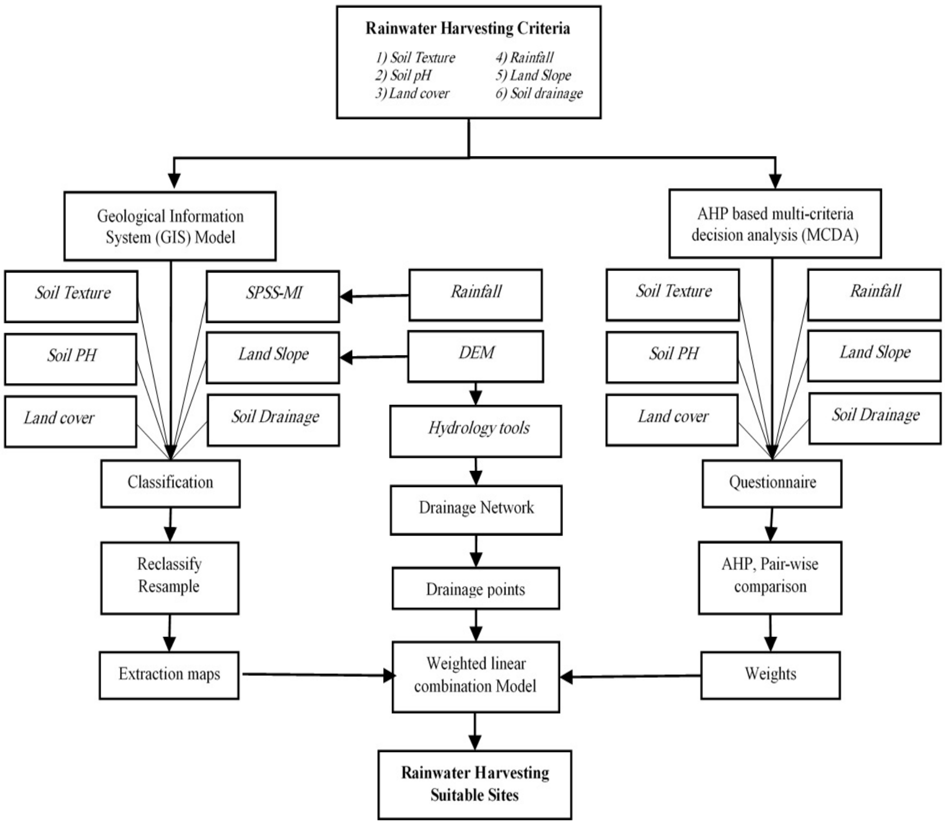

Figure 2. Methodology diagram.

By combining the results from the qualitative (MCDM) and quantitative (GIS) analysis, a set of RWH sites can be determined and presented as a "suitability map". To obtain the final suitability map for rainwater harvesting, the generated land suitability map was analyzed considering suitability degree and topographical analysis in Arc scene with the help of Triangulated Irregular Network (TIN).

2.2.2. Criteria selection

Choosing a water reservoir location suitable for RWH is challenging due to the complex criteria related to hydrological, geological, and economic parameters of a region of interest (Shahabi et al., 2016). The FAO lists six (6) key parameters for evaluating soil water conservation sites necessary for RHS (Kahinda et al., 2008). These include a region's climate, hydrology, topography, agronomy, soils, and socioeconomics. The first five (5) parameters were used to identify potential sites for small dams based on literature review, local expert opinions, and available data. In this study, the authors used a set of criteria (Table 1.) to represent the FAO parameters: rainfall for climate; nearby stream-flow measurements for hydrology; land slope for topography; land cover for agronomy; and soil texture, pH, and soil drainage for soils.

2.2.3. Multi-criteria decision making/Analytical hierarchy process

AHP represents a multi-criteria decision-making method providing a structured technique for organizing and analyzing elements in complex decision-making processes based on mathematics and specialized knowledge (Adham et al., 2018). The method was originally developed by Thomas Saaty in the 1970s (Saaty, 1977). Since then, it has been extensively applied in various disciplines (Shadmehri Toosi et al., 2020). AHP's important feature lies in the hierarchical representation (Fig. 3.) of a problem's components, revealing the relationships between the levels of information. The highest level in the hierarchy is the main goal (objective), with the lower levels made up of criteria and sub-criteria (indicators) feeding into that main goal (Saaty & Saaty, 2015). The required AHP results are the selected criteria weights calculated based on the pairwise comparison method (Pérez et al., 2005).

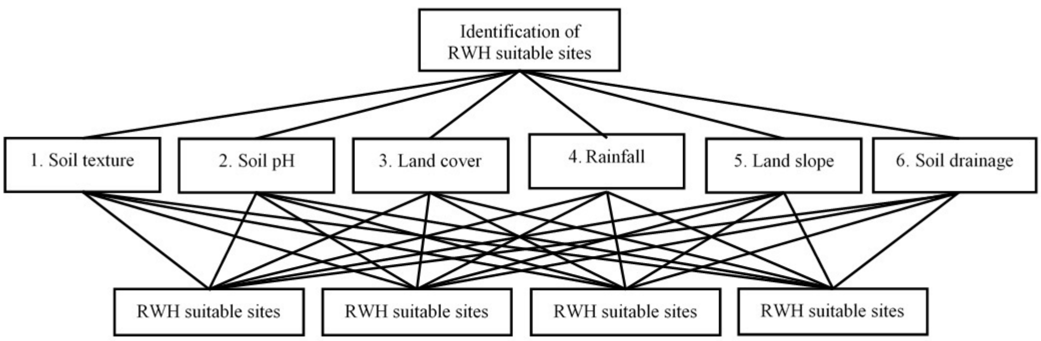

Figure 3. Hierarchy representation (Adham et al., 2018).

2.2.4. Reclassification of criteria

Decisions on including or excluding features in an analysis require measurable field knowledge and modeling experience (Forkuo, 2011). The values have to be prioritized even in a single layer, because some of them might be more desirable than others (Gorsevski et al., 2013). The classified results were produced using the ArcGIS Spatial Analyst Tools. The priority for each suitability class was given based on its implication as to site suitability for reservoir site selection. Each dataset had different ranges of values and numbering systems, hence the necessity for a common classification before using them for analysis. For this purpose, the FAO land suitability classification was implemented.

The criteria classification analysis is presented in Table 2. Because of the different scales of criteria measurement, the multi-layer process requires that the values contained in the criterion map are converted into similar units. Therefore, the criteria maps were re-classed into five (5) comparable units (Mahmoud & Alazba, 2014) corresponding to suitability classes, namely: “5” (highly suitable), “4” (suitable), “3” (moderately suitable), “2” (marginally suitable), and “1” (not suitable), with each criterion map comprising these classes. Generally, all the considered criteria were separated from each other by getting different locations of the aforementioned suitability classes. The rationale for applying each of the criteria is presented in the following sections.

2.2.4.1. Soil texture

Soil texture affects both infiltration and surface runoff rates. The soil textural class is determined by the percentages of sand, silt, and clay. Fine and medium textured soils are generally more desirable for RWH because of higher moisture retaining capacity. Soils with high water-holding capacities are more suitable for RWH (Adham et al., 2016). Sites with clay soils are the best for water storage due to clay’s low permeability and its ability to hold the harvested water (Mbilinyi, 2007). Soil texture, therefore, likely manifests a critical criterion for selecting RWH sites especially if the purpose is to preserve the water for human, livestock, and agricultural purposes (Al-adamat, 2008). Fig. 4. demonstrates the variety of soil textures based on clay content. The soil dataset describing the texture types within the target area was obtained from FAO.org/Geonetwork, and classified according to the soil textural triangle where clay, clay loam, and loam were positioned in the highest, while loam was positioned in the lowest suitability classes, respectively (Al-adamat, 2008).

2.2.4.2. Soil pH (power of hydrogen)

pH plays a key role in the suitability of land for rainwater harvesting purposes (Patangray et al., 2019). The study area’s soil pH ranged between 6.5 to 8.2, as shown in Table 2. and Fig. 5. The classified pH dataset for the study area did not demonstrate any unsuitable areas, with the majority of land characterized as moderately suitable and suitable, and a small percentage of highly suitable. The pH soil classification was previously executed under multiple studies considering different RWH objectives, including for potable water supply. The soil pH effects on the stored water quality were guided by water quality norms (Patangray et al., 2019).

2.2.4.3. Land cover

Land cover can restrict or improve the conditions for reservoir construction. In addition to current land use, its correlation with population growth and the need for it in the future should be likewise considered (Ajin et al., 2013). Under this study, land cover data were obtained from satellite imagery (Landsat 8, FAO Afghanistan 2017). A maximum-likelihood algorithm was used to classify land cover using the means, variances, and covariance from the signature. Nine (9) types of land cover were identified within the target area – water body, irrigated farmland, rainfed farmland, forests and shrubs, rangeland, residential area, fruit orchard, and barrenland – that were subsequently classified as per the requirements into five (5) suitability classes, as shown in Table 2. and Fig. 6.

2.2.4.4. Rainfall

In every water resource management study, besides the different temporal and spatial accuracy of data, consideration of reliable precipitation parameters poses another important task (Hong et al., 2004). According to a study requirements, understanding the usage of different types of these data is essential and has crucial impacts on the research outputs. Rainfall amount directly affects the selection of a site for RWH. A geologically potential site with abundant rainfall is economically and technically feasible, as it can help addressing largescale water scarcity issues. In general, the performance of a RWH installation is estimated based on the historical rainfall data without the possible climate impacts. However, a rainfall pattern is likely to change in the future as a consequence of climate change, which may affect the overall performance of a rainwater harvesting system (Haque et al., 2016). The historical observed data for the target area were retrieved from Afghanistan Meteorological Department, and subsequently classified into five (5) categories in terms of RWH suitability in arid and semiarid regions (Adham et al., 2017), as shown in Table 2. and Fig. 7.

2.2.4.5. Land slope

Digital elevation model is crucial for topographic analysis, as it represents the attributes of terrain such as elevation at any point, slope, aspect, and hydrological boundaries (Prof, 2015). Since slope affects reservoir safety – steep slopes pose a higher landslide risk, and gentle slopes are more efficient in this respect, as well as play an important role as to runoff production, sediment rate, erosion rate, and water flow rate (Adham et al., 2017). RWH is not recommended for sites with more than 5% of slope, because steep slope will cause erosion of reservoir embankments, and sediment will reduce dam life, thus making the entire project economically ineffective (Al-adamat et al., 2010). Within the framework of this research, the 30-meter resolution DEM was used to generate the slope map (Fig. 8.) and classifying slope into five (5) suitability classes (Table 2.) (Adham et al., 2018).

2.2.4.6. Soil drainage

Geological conditions determine the suitability degree for building reservoirs at specific sites (Emiroglu, 2014). Rocky foundations have relatively high resistance to erosion, pressure, and filtration (Dai, 2016). Natural soil drainage is the frequency and duration of periods when soil is unsaturated. State and county soil surveys which report this soil characteristic refer to it qualitatively as a drainage class with categories ranging among seven (7) classes from “very-poorly drained” to “excessively-well drained” (Cialella et al., 1997). Soil drainage has an important role with different characteristics for different objectives that rainwater harvesting reservoirs requirements have classified and shown in Fig. 9.

Table II. Criteria classification for AHP and methodology for assessing RWH sites in the study area (arid and semiarid regions).

#	Criteria	Classes (description)	Values	Suitability	
1	Soil texture (clay content %)	Clay	>20%	Highly suitable	5
		Clay loam	15-20%	Suitable	4
		Loam	11-15%	Moderately suitable	3
2	Soil pH (power of hydrogen)	Soil type	6.5-6.8	Moderately suitable	3
		Soil type	6.8-6.9	Suitable	4
		Soil type	6.9-7.1	Highly suitable	5
		Soil type	7.1-7.6	Suitable	4
		Soil type	7.6-8.2	Moderately suitable	3
3	Land cover	Rangeland	-	Highly suitable	5
		Rainfed farmland, barrenland	-	Suitable	4
		Irrigated farmland	-	Moderately suitable	3
		Fruit orchard, forests and shrubs	-	Marginally suitable	2
		Water, build-up	-	Not suitable	1

4	Rainfall (mm/ year)	Very high	>325	Highly suitable	5
		High	250-325	Suitable	4
		Medium	175-250	Moderately suitable	3
		Low	150-175	Marginally suitable	2
		Very low	<150	Not suitable	1
5	Land slope	Flat	<1.5%	Highly suitable	5
		Undulating	1.5-2.5%	Suitable	4
		Rolling	2.5-4.5%	Moderately suitable	3
		Hilly	4.5-7.5%	Marginally suitable	2
		Mountainous	>7.5%	Not suitable	1
6	Soil drainage	Imperfectly drained, poorly drained, very poorly drained	Clay	Highly suitable	5
		Moderately well drained	Clay loam	Suitable	4
		Well drained	Loam	Moderately suitable	3
		Somewhat excessively drained	Sandy loam	Marginally suitable	2
		Excessively drained	Sand	Not suitable	1

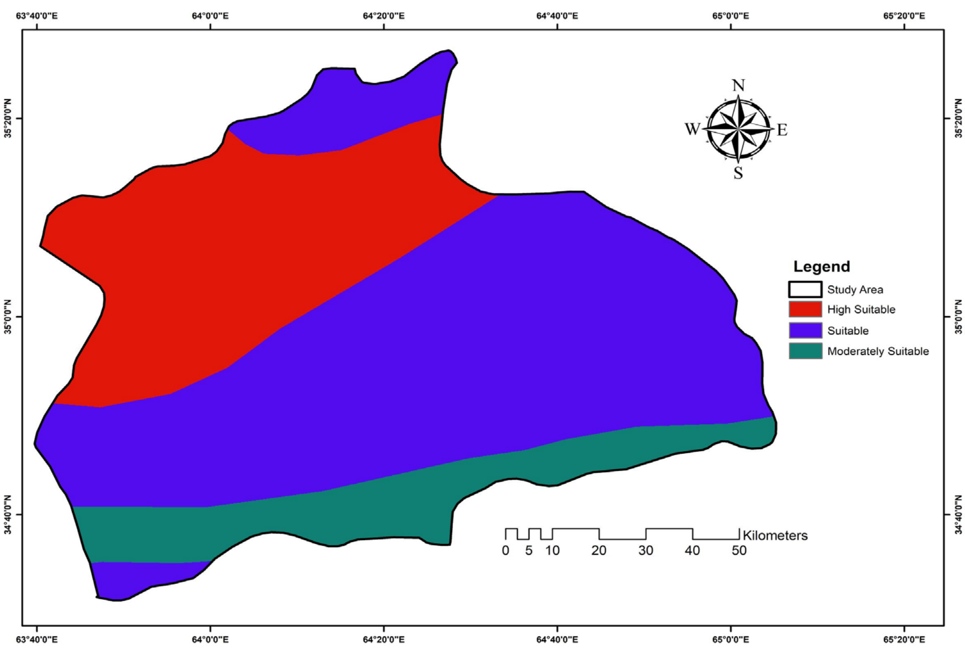

Figure 4. Soil texture classification.

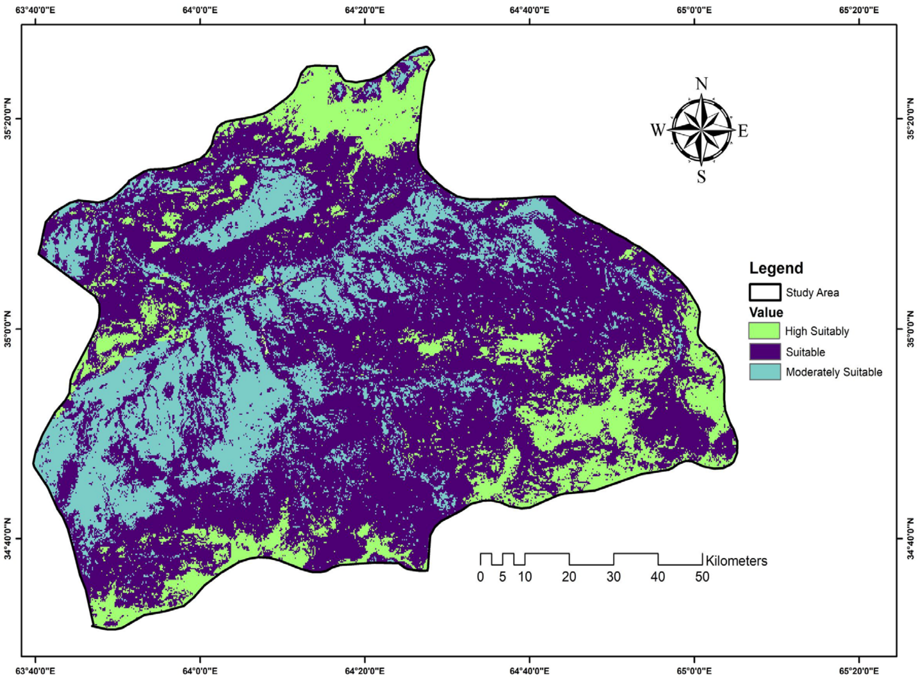

Figure 5. Soil pH classification.

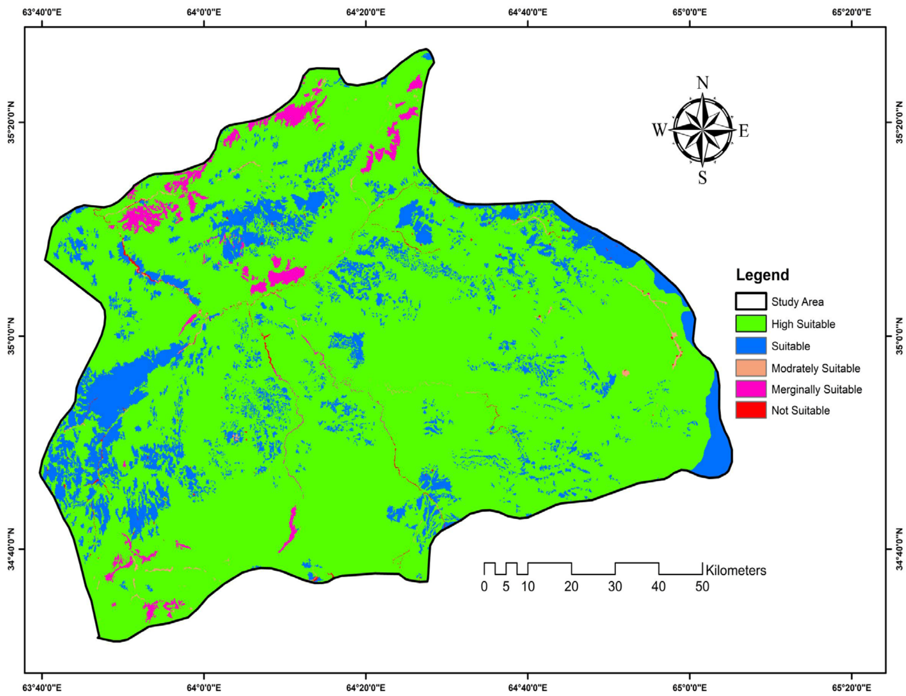

Figure 6. Land cover classification.

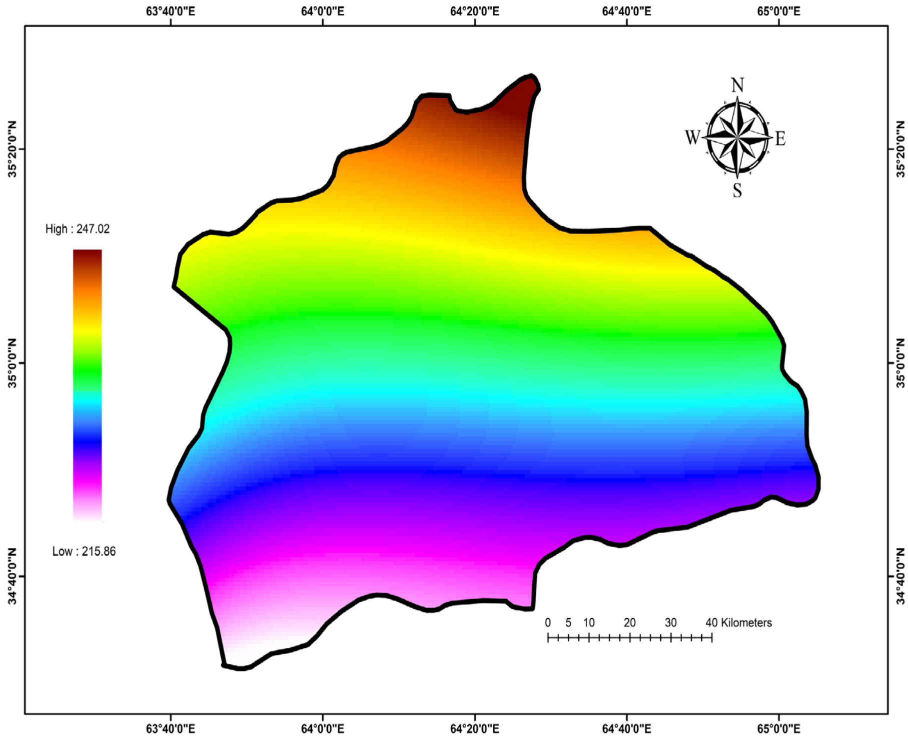

Figure 7. Rainfall map.

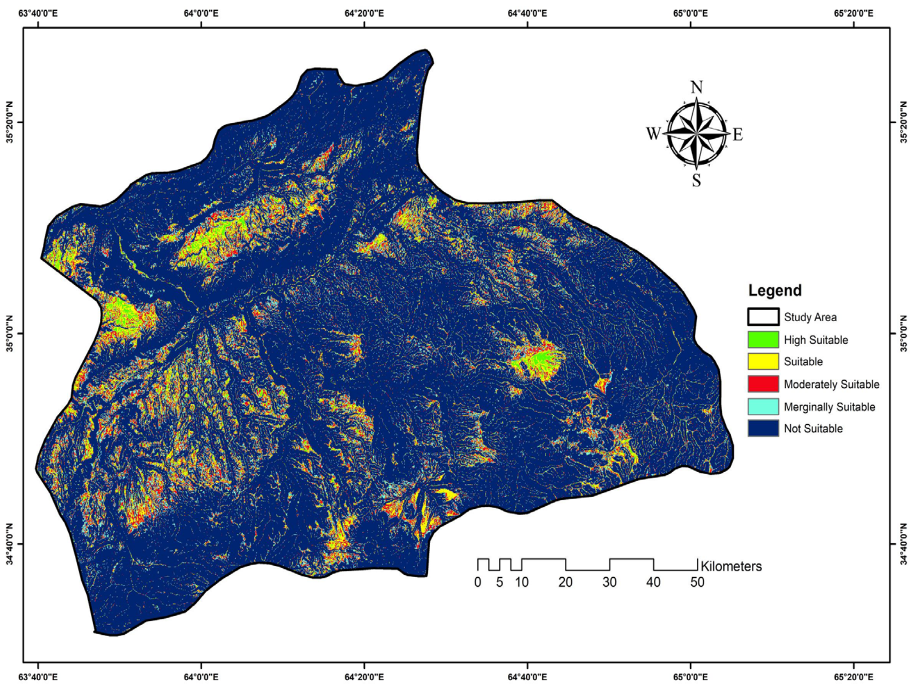

Figure 8. Slope classification.

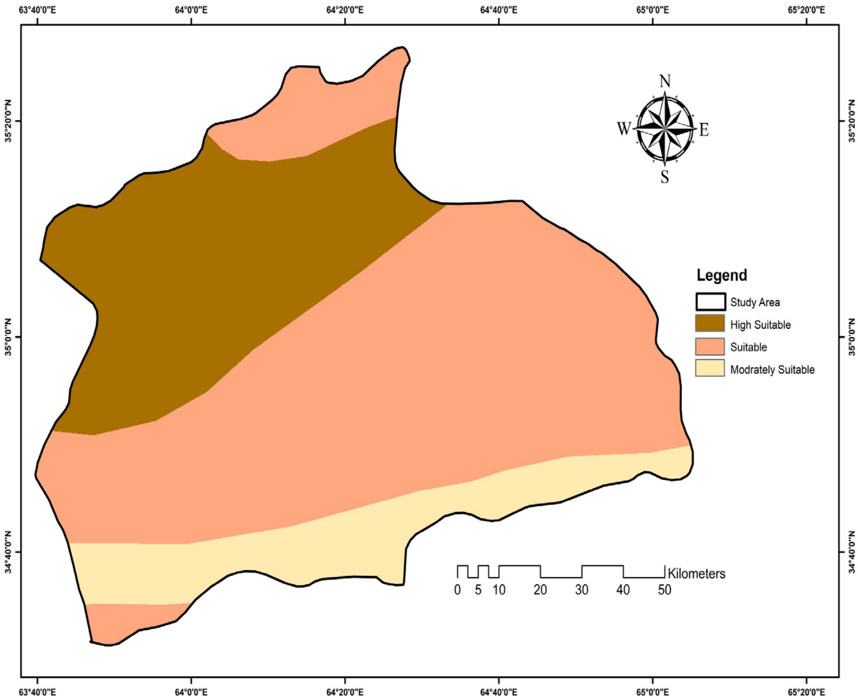

Figure 9. Soil drainage classification.

Drainage network/point extraction

For obtaining optimum objects, beside creating the land suitability map using the WLC model, extraction and demonstration of drainage points are necessary to select the sites suitable for RWH, because the map cannot indicate elevations and appropriate RWH sites. Thus, according to the research methodology (Fig. 2.) to extract drainage points, the drainage network was de-lineated based on the DEM using the Flow Accumulation tool (GIS environment hydrology tools). Flow accumulation in its simplest form is the number of upslope cells that flow into each cell. By applying a threshold value to the results of the Flow Accumulation tool, a stream network can be delineated. The case of all the water going out of a catchment from a drainage point represents the ideal RWH facility location. The ArcHydro and Spatial Analyst tools were used to produce streams and drainage points from DEM. Fig. 10. shows the study area water flow accumulation drainage network, with the 1st orders representing the 1st water receptors from water catchments, where the rain begins its earthly journey. Subsequently, the captured water from the 1st order goes into the 2nd order; and the water accumulated in the 2nd order goes into the next order, respectively.

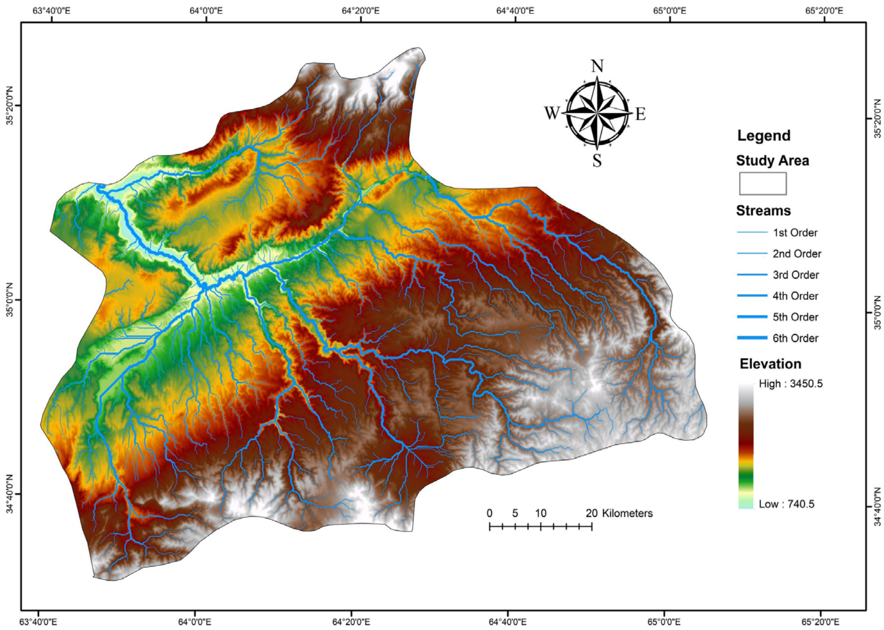

Figure 10. Stream orders.

The flow of water continues to the last order. Also, Fig. 11. demonstrates the water catchment drainage points where two drainages intersect. Drainage points are usually located at narrow geological sites extremely appropriate for RWH reservoirs. RWH suitable sites were generated based on the land suitability map considering drainage network and drainage point locations.

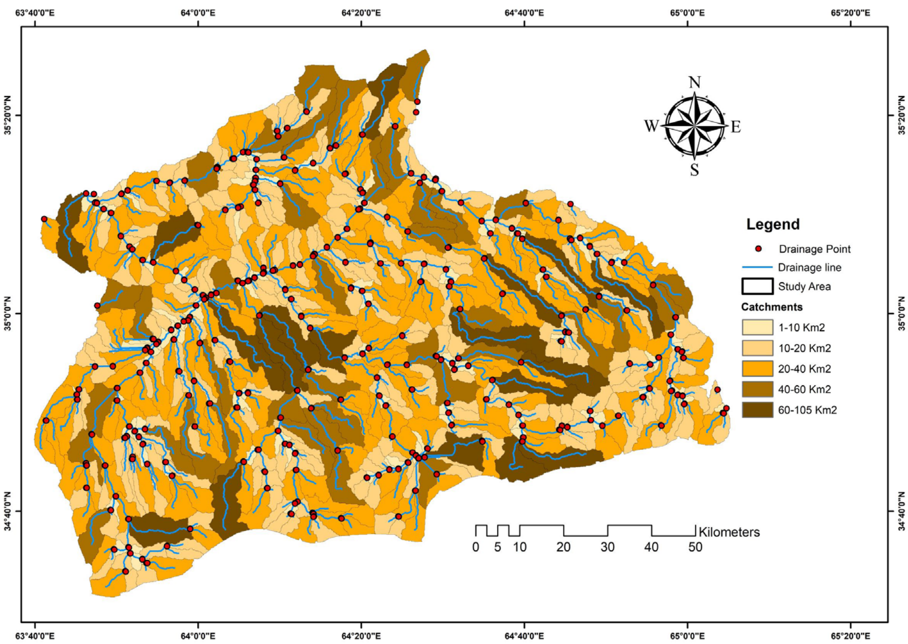

Figure 11. Drainage points and catchments.

3. Results and discussion

Suitable rainwater harvesting and geological response sites detected based on the recent technology (GIS and MCDM) were investigated considering different biophysical criteria (soil texture, soil pH, land cover, rainfall, land slope, soil drainage and stream orders) selected depending on the target area requirements. This research was performed to obtain and identify suitable sites for RWH. The obtained RWH land suitability map (Fig. 12.) indicates a mixture of suitability degrees within the study area. Criteria weights were generated based on the judgment of twenty (20) professionals collected through a structured questionnaire after the MCDM (AHP, pairwise comparison) analysis.

The structured questionnaire comprised six (6) questions related to six (6) selected criteria, and every criterion was attributed nine (9) degrees of importance to rate every importance degree of a criterion based on expert opinion. The surveyed experts were professionals possessing adequate experience and knowledge in related fields. They responded on the importance of every criterion by grading them from one (1) to nine (9), with “1” denoting the minimum and “9” the maximum importance of each criterion selected for this study. The survey was conducted online; the questionnaire was distributed among the target professionals to collect their responses and obtain the final weights. The survey results were subsequently analyzed using the AHP-pairwise comparison method, i.e. the responded importance of every criterion was compared against all criteria importance degrees, as shown in Table 3.

Table III. AHP weighing results.

#	Criterion	Weight
1	Soil texture	0.220
2	Soil pH	0.125
3	Land cover	0.060
4	Rainfall	0.199
5	Land slope	0.223
6	Soil drainage	0.173

The table above indicates that the land slope criterion (the highest weight of 0.223) became the most important in selecting RWH-suitable sites in this study; consequently, soil texture, rainfall, soil drainage, soil pH and land cover have importance roll respectively in suitable site selection. After classifying the selected criteria as per the study area requirements (Table 2.), related maps (Figures 4., 5., 6., 7., 8., and 9.) were created using GIS environment. Later on, the WLC model was applied to combine six (6) generated criteria maps considering their weights (Table 3.). In the WLC model, every criterion map – adjusted by cell size and geographical coordinates in GIS environment – has multiplied in related weight firstly and then has summed with remaining criteria by same method respectively. Finally, the output of the WLC model was the land suitability map (Fig. 12.) allowing to select sites suitable for RWH, similar to multiple other studies (Adham et al., 2017, Adham et al., 2018, Shadmehri Toosi et al., 2020) that were based on partially similar approaches, as well as similar factors (terrain, resource availability, soil strength, land use, etc. (Dugan et al., 2013).

The suitability ranking in the land suitability map (Fig. 12.) below generally starts from the southern section of the study area and gradually decreases towards the north. Based on the research results, most suitability areas are mountainous and consist of large earthen hills with good elevation potential and differing slopes. The sites with significant slope are not suited for building reservoirs (Mahmoud & Alazba, 2014). The sites in the northwestern section of the target area also demonstrated high suitability due to their gentle slope, but are not recommended as reservoir sites because of their proximity to the Murghab River (the latter can affect the RWH option).

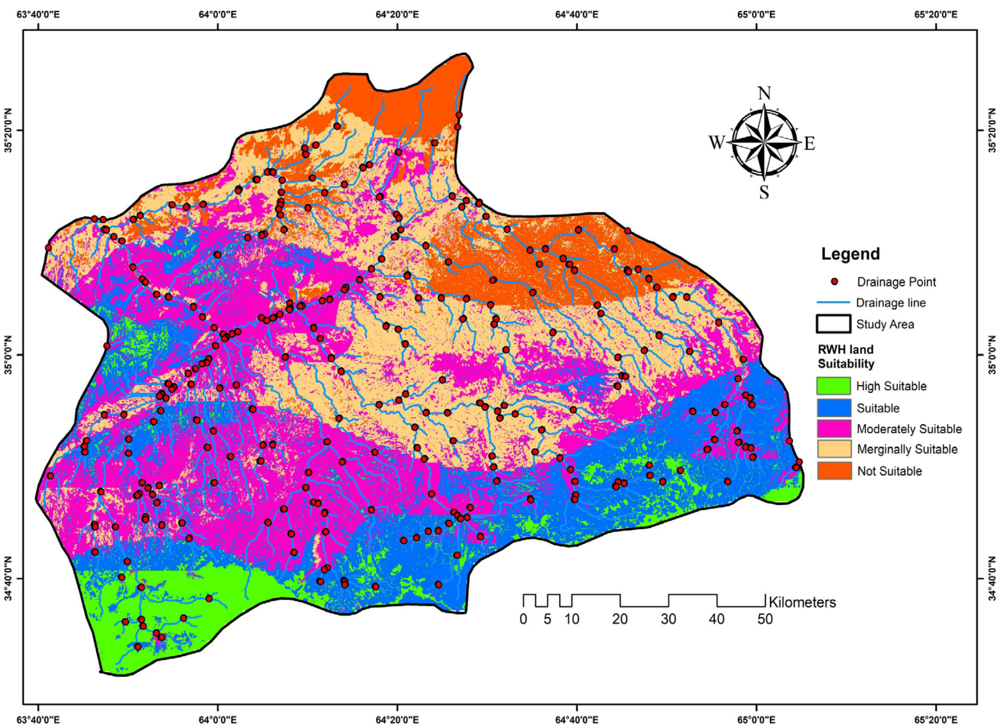

Figure 12. RWH land suitability map.

Other options included the valleys located in the southern section of the study area, specifically the ones with the shape suitable for reservoir construction (Yasser et al., 2013). Also, there is a high possibility that the valley bottom is flat defined as suitable for building reservoirs. The valley walls have a steeper slope, which can be defined as unsuitable. To deal with the challenge of detecting suitable sites, the RWH map underwent analysis based on the Triangulated Irregular Network method allowing to detect steep slopes as not responsive, as well as identify the potential areas for building RWH reservoirs. After this analysis and considering the elevation potential of different sites and land suitability ranks, five (5) suitable sites (Fig. 13. and Table 3.) were identified and proposed for construction at the first stage of the study. Although all the detected drainage points located in suitable and highly suitable areas as per the land suitability map (Fig. 12.) are applicable for RWH, each of them requires further surveying. Fig. 13. indicates five (5) proposed sites as RWH-suitable in accordance with the land suitability map.

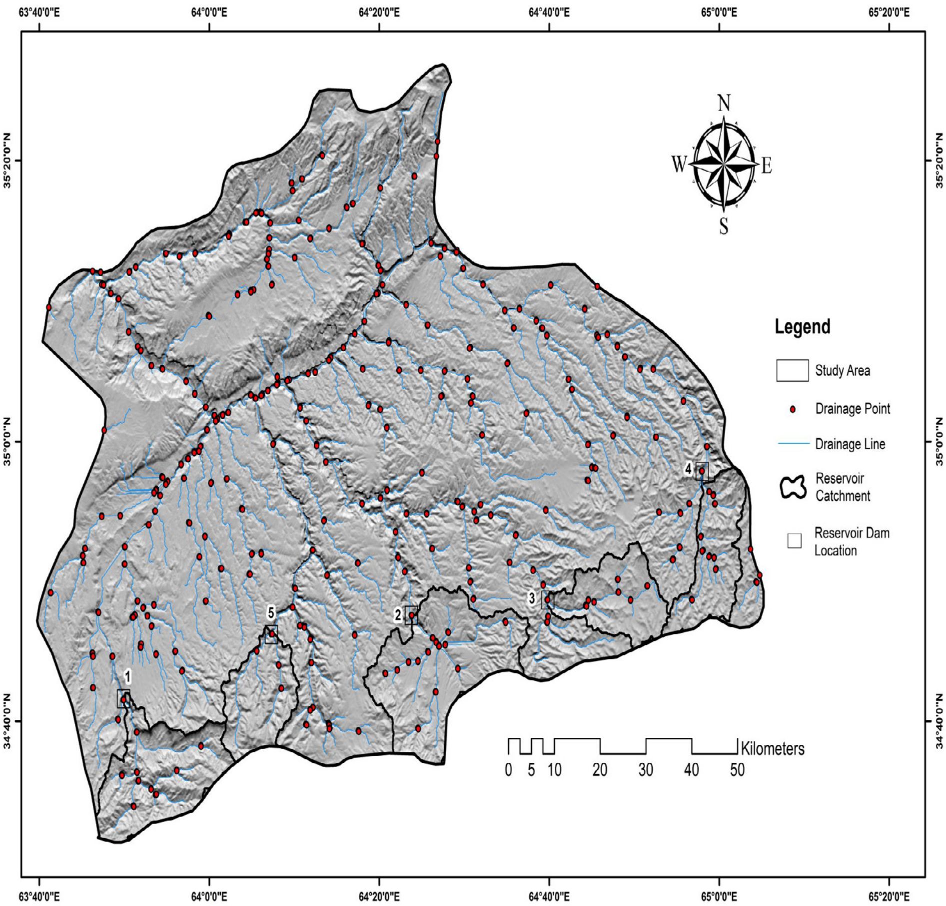

Figure 13. RWH reservoir location and catchment area map.

Table IV. Geological reservoir site selection priority ranking and RWH land suitability classes.

#	Priority rank	Land suitability class	Catchment area (km2)	Demand priority	GPS (WGS, 1984, Decimal Degrees)	
					Latitude	Longitude
1	1	Highly suitable	388.6	1	63.848	34.665
2	2	Suitable	529.03	1	64.421	34.773
3	4	Suitable	245.1	1	64.679	34.803
4	5	Suitable	247.5	1	64.967	34.950
5	6	Moderately suitable	231.25	1	64.122	34.773

To verify the land suitability map shown in Fig.12, it was compared with the GIS base map and Google maps, as well as field data. The obtained land suitability map (Fig. 12.) makes it possible to select suitable sites for RWH directly from this map, yet onsite visits are recommended to ensure higher quality investigation. Particularly, five (5) RWH sites were proposed as the result of this study (Table 4.) based on the integrated dataset and drainage points identified with the help of the RWH land suitability map (Fig. 12.) and TIN model. The proposed sites are all located in mountainous zones and characterized as highly suitable due to proper valley shapes and large catchment areas. The reservoir profiles were generated based on the their drainage point locations as GIS-based decision with 30 m resolution of DEM raster. That resulted in many options, hence for the application of reservoir sites. Fig. 14. below shows the selected reservoirs' cross-sections obtained from the DEM with the help of the 3D Analyst Toolbar in ArcGIS environment. As is obvious from Fig. 14, these locations have the appropriate width to construct suitable dams with desired height according to design requirements, given a good elevation potential.

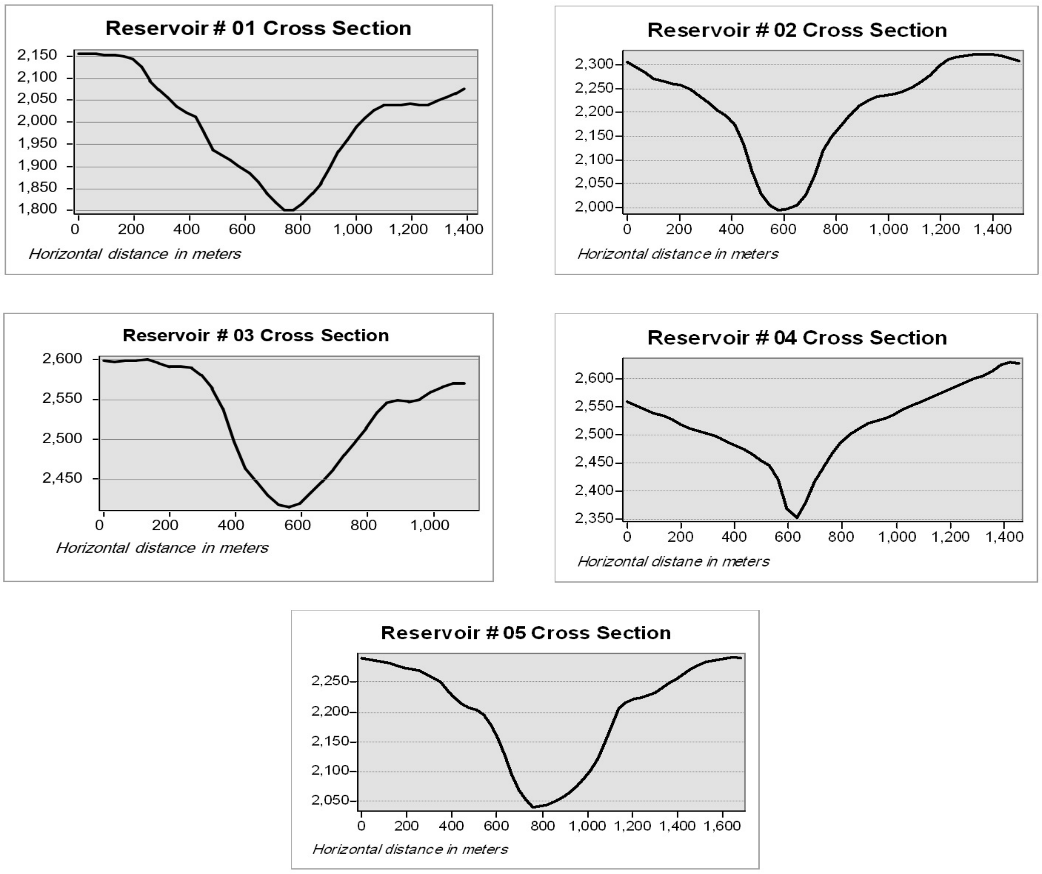

Figure 14. RWH reservoir cross sections.

Within the framework of this study, the lack of access to local data was one of the major factors affecting output accuracy, because local data are usually small-scale but have higher resolution compared to global datasets. This is the case in most developing countries. Under this research, several datasets were harvested from external sources and research organizations. The recent decades of war and conflicts have left Afghanistan with destroyed infrastructures and institutions, in their turn leading to underdevelopment. At present, any research of metrological and hydrological phenomena and relative parameters inside the country faces over two decades of gaps in historical data records (Akhundzadah et al., 2020). The resolutions of the used datasets were likewise different – from 30 m (ex.: DEM) up to 250 m (ex.: soil type and soil pH). The value of a cell represents the area covered by this particular cell, yet it does not necessarily mean that in reality the area covered by the cell has a uniform value across its entirety.

4. Conclusion

As a response to recent climate changes and as a means for managing water resources in Afghanistan, the construction of RWH reservoirs should be considered as a viable solution for regions deprived of other potable water supply options or lacking sufficient water to meet public and private needs. This study aimed to assess the target area – Badghis Province of Afghanistan – geologically as a structured method for identifying suitable RWH sites. The same method is applicable in similar areas (arid and semiarid) with due consideration of their unique criteria. Besides identifying RWH-suitable sites, the study also aimed to design a framework for rainwater harvesting reservoir site selection. As mentioned above, this approach can be applied more widely to evaluate potential sites for new RWH projects, thus increasing the likelihood of satis-factory long-term performance. In addition, due to the tool's flexibility and ease of use with different criteria and RWH performance indicators, it can be utilized in different settings. The tool's advantages likewise include low time and cost required for such evaluations, making the method a viable option and significant practice for local RWH managers and local communities in their effort to reduce potable water shortage in areas where no other water resources are available.

According to the land suitability map generated under this study, most suitable areas (highly suitable and suitable) are mountainous and consist of large earthen hills with good elevation potential. The valleys in the investigated sites have different slopes, thus making some of them (with steep slopes) not suitable for reservoir construction. The northwestern section of the target area showed higher suitability degrees due to gentle slope, yet they are recommended as reservoir sites because of their proximity to the Murghab River, which can negatively affect the RWH option. Further onsite surveying is necessary for the final selection of reservoir sites due to data and information system limitations. To expand the scope of such studies, enhancing the resolution of all datasets is recommended to increase the accuracy of the land suitability map. In addition, more precise and accurate meteorological data collected via a more dense meteorological station network are required for better analysis. Consideration of socio-economic factors can likewise improve the output quality of future studies.

References

Abdulla, F.A. & Al-Shareef, A.W. (2009). Roof rainwater harvesting systems for household water suply in Jordan. *Desalination*, 243(1-3), 195-207 (https://doi.org/10.1016/j.desal. 2008.05.013)

Adham, A., Riksen, M., Ouessar, M. & Abed, R. (2017). *Development of Methodology for Existing Rainwater Harvesting Assessment in (semi-) Arid Regions. Chapter 16*, April. (https://doi.org/10.1007/978-3-319-54021-4);

Adham, A., Sayl, K.N., Abed, R., Abdeladhim, M.A., Wesseling, J.G., Riksen, M., Fleskens, L., Karim, U., Ritsema, C.J., Abdeladhim, A., Wesseling, J.G., Riksen, M. & Fleskens, L. (2018). Author's Accepted Manuscript. *International Soil and Water Conservation Research* (https://doi.org/10.1016/j.iswcr.2018.07.003)

Adham, A., Wesseling, J.G., Riksen, M., Ouessar, M. & Ritsema, C.J. (2016). A water harvesting model for optimizing rainwater harvesting in the Wadi Oum Zessar Watershed, Tunisia. *Agricultural Water Management*, 176, 191-202 (https://doi.org/10.1016/j.agwat. 2016.06.003)

Ajin, R.S., Krishnamurthy, R.R., Jayaprakash, M. & Vinod, P.G. (2013). *Flood hazard assessment of Vamanapuram River Basin, Kerala, India: An approach using Remote Sensing & GIS techniques*. 4(3), 263-274

Akhundzadah, N.A., Soltani, S. & Aich, V. (2020). *The Kunduz River Basin, Afghanistan.*

Al-Adamat, R. (2008). *GIS AS A DECISION SUPPORT SYSTEM FOR SITING WATER HARVESTING PONDS IN THE BASALT AQUIFER/NE JORDAN*. 10(2), 189-206

Al-Adamat, R., Diabat, A. & Shatnawi, G. (2010). Combining GIS with multi-criteria decision making for siting water harvesting ponds in Northern Jordan. *Journal of Arid Environments*, 74(11), 1471-1477 (https://doi.org/10.1016/j.jaridenv.2010.07.001)

Biswas, B.K. & Mandal, B.H. (2015). *Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna, Bangladesh*, 2014

Cialella, A.T., Dubayah, R., Lawrence, W. & Levine, E. (1997). *Predicting Soil Drainage Class Using Remotely Sensed and Digital Elevation Data*. 63(2), 171-178

Dai, X. (2016). *Dam site selection using an integrated method of AHP and GIS for decision making support in Bortala, Northwest China By.* 14

Dugan, R.G., Cannon, E.C. & Garrigus, A.P. (2013). Geotechnical characterizations for the proposed Watana Dam site on the Susitna River, Alaska. ISCORD 2013: *Planning for Sustainable Cold Regions, Proceedings of the 10th International Symposium on Cold Regions Development*, 667-677 (https://doi.org/10.1061/9780784412978.064)

Electrical, V., For, S., Study, G., Sari, I.N., Qala, S., Districts, G., Sari, O.F. & Province, P. U.L. (2015). *Edited by Leendert Vijselaar*, June 2007 (https://doi.org/10.13140/RG. 2.1.4465.7128)

Emiroglu, M.E. (2014). *Influences on Selection of the Type of Dam*. August

Forkuo, E.K. (2011). *Flood Hazard Mapping using Aster Image data with GIS*. 1(4), 932-950

Franz, K.J., Hogue, T.S. & Sorooshian, S. (2008). Operational snow modeling: Addressing the challenges of an energy balance model for National Weather Service forecasts. *Journal of Hydrology*, 360(1-4), 48-66 (https://doi.org/10.1016/j.jhydrol.2008.07.013)

Gorsevski, P.V., Cathcart, S.C., Mirzaei, G., Jamali, M.M., Ye, X. & Gomezdelcampo, E. (2013). A group-based spatial decision support system for wind farm site selection in Northwest Ohio. *Energy Policy*, 55, 374-385 (https://doi.org/10.1016/j.enpol.2012.12.013)

Gould, J., Qiang, Z.H.U. & Yuanhong, L.I. (2014). *Using every last drop: rainwater harvesting and utilization in Gansu Province, China*. 33(2)

Haque, M.M., Rahman, A. & Samali, B. (2016). Evaluation of climate change impacts on rainwater harvesting. *Journal of Cleaner Production*, 137, 60-69 (https://doi.org/10.1016/j.jclepro.2016.07.038)

Holden, E. & Doshi, V. (2019). *Extreme water stress affects a quarter of the world's population, say experts*

Hong, Y., Hsu, K.L., Sorooshian, S. & Gao, X. (2004). Precipitation estimation from remotely sensed imagery using an artificial neural network cloud classification system. *Journal of Applied Meteorology*, 43(12), 1834-1852 (https://doi.org/10.1175/JAM2173.1)

Jasrotia, A.S., Majhi, A. & Singh, S. (2009). Water balance approach for rainwater harvesting using remote sensing and GIS techniques, Jammu Himalaya, India. *Water Resources Management,* 23(14), 3035-3055 (https://doi.org/10.1007/s11269-009-9422-5)

Kahinda, J.M., Lillie, E.S.B., Taigbenu, A.E., Taute, M. & Boroto, R.J. (2008). *Developing suitability maps for rainwater harvesting in South Africa.* 33, 788-799 (https://doi.org /10.1016/j.pce.2008.06.047)

Mack, T.J., Chornack, M.P. & Taher, M.R. (2013). Groundwater-level trends and implications for sustainable water use in the Kabul Basin, Afghanistan. *Environment Systems and Decisions*, 33(3), 457-467 (https://doi.org/10.1007/s10669-013-9455-4)

Mahmoodi, S.M. (n.d.). *Integrated Water Resources Management for Rural Development and Environmental Protection in Afghanistan*. 3

Mahmoud, S.H. & Alazba, A.A. (2014). *The potential of in situ rainwater harvesting in arid regions: developing a methodology to identify suitable areas using GIS-based decision support system* (https://doi.org/10.1007/s12517-014-1535-3)

Malczewski, J. (2000). On the use of weighted linear combination method in GIS: Common and best practice approaches. *Transactions in GIS*, 4(1), 5-22 (https://doi.org/10.1111/1467-9671.00035)

Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. *Progress in Planning,* 62(1), 3-65 (https://doi.org/10.1016/j.progress.2003.09.002)

Mbilinyi, B.P. (2007). *GIS-based decision support system for identifying potential sites for rainwater harvesting*. 32, 1074-1081 (https://doi.org/10.1016/j.pce.2007.07.014)

Mohanty, S., Bardhan, T. & Dey, A. (2020). *Rain Water Harvesting: A Viable Way to Combat Water Crisis*. July, 44-48

National Rural WASH Policy 2016-2020 (2020). Page 1

Patangray, A.J., Patil, N.G., Singh, S.K., Tiwari, P., Mishra, V.N., Pagdhune, A.R. & Patil, B.A. (2019). Soil Suitability Evaluation of Major Crops for Sustainable Land Use Planning in Kupti Watershed, Yavatmal District, Maharashtra. *Agropedology*, 26(2), 117-131 (https://doi.org/10.47114/j.agroped.2016.dec2)

Pérez, O.M., Telfer, T.C. & Ross, L.G. (2005). Geographical information systems-based models for offshore floating marine fish cage aquaculture site selection in Tenerife, Canary Islands. *Aquaculture Research*, 36(10), 946-961 (https://doi.org/10.1111/j.1365-2109.2005.01282.x)

Prof, A. (2015). GEO-SPATIAL DATA FOUNDATION FOR. 6(7), 61-68

Qureshi, A. (2002). *Water resources management in Afghanistan: The issues and options*. 14 (http://www.afghaneic.net/library/hydrological surveys/wor49.pdf)

Related, W. & In, P. (2014). *International Journal of Educational Studies*. 01(03), 137-144

Results, A. (2021). *Achieving results*

Saaty, T.L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3), 234-281 (https://doi.org/10.1016/0022-2496(77)90033-5)

Saaty, T.L. & Saaty, T.L. (2015). *Decision making with the analytic hierarchy process*. June (https://doi.org/10.1504/IJSSCI.2008.017590)

Saleh Alatawi, E.A. (2015). Dam Site Selection Using Remote Sensing Techniques and Geographical Information System to Control Flood Events in Tabuk City. *Journal of Waste Water Treatment & Analysis*, 06(01), 1-13 (https://doi.org/10.4172/2157-7587.1000189)

Seckler, D. & Barker, R. (2010). *of Water Resources Development Water Scarcity in the Twenty- first Century.* April 2013, 37-41

Shadmehri, A., Ghasemi, E., Ali, S. & Cheshomi, A. (2020). *A multi-criteria decision analysis approach towards efficient rainwater harvesting*. 582 (December 2019)

Shadmehri Toosi, A., Ghasemi Tousi, E., Ghassemi, S.A., Cheshomi, A. & Alaghmand, S. (2020). A multi-criteria decision analysis approach towards efficient rainwater harvesting. *Journal of Hydrology*, 582 (August 2019) (https://doi.org/10.1016/j.jhydrol.2019.124501)

Shahabi, H., Ahmad, B.A., Ahmad, B. Bin, Taheri Amiri, M.J., Keihanfard, S. & Ebrahimi, S. (2016). Assessment of WLC and fuzzy logic methods for site selection of water reservoirs in Malaysia. *Polish Journal of Environmental Studies*, 25(3), 1223-1231 (https://doi.org/10.15244/pjoes/61529)

Tamim, M.A. (2020). *Assessment of climate change impacts on environmental sustainability in Afghanistan*. November, 0-6 (https://doi.org/10.1051/e3sconf/ 202020801001)

Yasser, M., Jahangir, K. & Mohmmad, A. (2013). Earth dam site selection using the analytic hierarchy process (AHP): A case study in the west of Iran. *Arabian Journal of Geosciences*, 6(9), 3417-3426 (https://doi.org/10.1007/s12517-012-0602-x).