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Identification of rainwater harvesting sites using the analytic hierarchy process and geographic information system in the Khemisset semi-arid region, Morocco

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ABSTRACT

The dynamics of water scarcity constitute a fundamental problem that is being aggravated by climate change, especially in arid areas. The application of rainwater harvesting (RWH) in combination with geographic information systems (GIS) facilitates the determination of areas where rainwater harvesting can be realistically adopted. This new approach enables the effective and precise delineation of zones most appropriate for the installation of rainwater harvesting systems. This research suggests an approach that involves an analytic hierarchy process with GIS and remote sensing (RS) methods for identifying potential sites for RWH according to various socio-economic criteria. The research was carried out in the Khemisset province in the western part of Morocco. A comprehensive potential RWH map was created considering 12 significant parameters like land use and land cover, soil texture, slope, elevation, drainage density, Geology, rainfall, stream order, distance to faults, distance to roads, and distance to residential areas. All these parameters were assigned some weights in ArcGIS 10.8 software. This process enabled the incorporation of all the thematic maps and resulted in a combined RWH map for the given study area. The research findings indicated that around 48% of the entire study area was found to be moderately suitable for RWH. The validation of the RWH map by checking it against existing dams confirmed that the used methodology had a high capability to identify appropriate locations for RWH.

Keywords: rainwater harvesting, arid regions, geographic information system, Khemisset, remote sensing.

INTRODUCTION

Water scarcity is a pressing problem in Morocco, and numerous studies have been carried out with a focus on diversified regions of the country. Ersoy et al. (2020) examined to what extent water supply affects solar thermal power plant and photovoltaic installation in southern Morocco's Drâa Valley. Authors considered regional water demand and supply under various scenarios and estimated realistic socio-economic development trajectories of their research. Jounaid et al. (2020) mapped northeast Morocco's potable water drinking water supply with drinking water scarcity analysis and multi-criteria analysis-based groundwater resource mapping. Hssaisoune et al. (2020) targeted Morocco's Souss-Massa basin groundwater resources with restoration methods to recover groundwater balance. Assaoui et al. (2021) created a two-dimensional numerical model to explore sedimentary conditions at Mechraa Hammadi Dam intake affecting drinking water supply. Salehi (2021) considered the world shortage crisis of water and water utility actions towards the crisis. Moumane et al. (2021) compared the spatiotemporal trend of groundwater level and salinity of Feija Basin and proved that the dramatic decline of groundwater level by the high production of watermelon. Hdidou et al. (2021) presented the feasibility of applying constructed wetland systems to treat and recycle wastewater in rural Morocco. Gagou et al. (2023) presented a research paper on mycorrhizal potentiality of date palm rhizosphere soil in Figuig oasis and presented differential mycorrhizal propagule rates at different sites. Ouharba et al. (2024) studied climatic change taking place in the Bouregreg Basin as per previous research with an increase trend being observed for temperature and reducing rainfall in northern Morocco. The general finding of such research is that water management strategies must be sustainable to enable the management of water scarcity in certain regions of Morocco.

Rainwater harvesting is one of the most effective water-saving technologies in Morocco, which has faced acute water scarcity conditions. Several research have been set up to identify the right areas to harvest rainwater using various techniques and methodologies. Merrouni et al. (2018), in their work, established that it is possible to apply the analytic hierarchy process (AHP) to identify large areas in Morocco's Eastern part. The research provides effective outcomes towards optimal utilization of AHP towards RWH planning in arid climatic areas. Likewise, Manaouch et al. (2021) used WaTEM/SEDEM model, GIS operations, and Fuzzy AHP method for the identification of potential ecological RWH locations in Morocco's Ziz Upper Watershed with some focus on harmonization of different sources of data for thematic layer development. El Ghazali et al. (2021) discuss two typical site selection procedures that are applicable to select a dam building site: GIS/RS and multicriteria analysis (MCA) assisted by GIS/RS. Ouali et al., in 2022 research, demonstrated that watersheds of water harvesting systems incorporated within agriculture and ecotourism occupy 87.72% of the area of the Toudgha watershed in the southeastern part of Morocco. Ammar et al. (2016) also conducted a systematic review with the objective of determining the appropriate locations for rainwater harvesting infrastructure in semi-arid and arid catchments. They established the foundation of integrated spatial analysis as the need to determine the viability of potential areas based on multiple criteria like hydrology, land use, and topography. AHP-GIS integration was evaluated as an absolute method of effective ranking and aggregation of the areas for rainwater harvesting and thereby gaining effective information for such an application in Morocco.

The determination of the most suitable spaces to be adopted for rainwater harvesting in the semi-arid region is most urgently dependent on land use and land cover (Adham et al., 2022). AHP technique has been found to be useful in quantifying the degree of prominence of such entities as Gavhane et al. (2023). Applying this method enabled us to determine the significance levels of all variables and hence give directions on the most suitable places where rainwater harvesting schemes are supposed to occur. Location selection for rainwater harvesting is regulated by such aspects as gradient, soil, runoff depth, drainage density, and mean annual rainfall (Gebremedhn et al., 2023). A recent study by Alrawi et al. (2023) elaborated on the use of the AHP as a multi-criteria decision analysis (MCDA) in the identification of the optimal location for rainwater harvesting. The research highlights that the identification of the locations must be carried out with extreme care so that maximum efficiency and effectiveness of the rainwater harvesting system are attained.

Although an enormous body of research is available concerning water scarcity and rainwater harvesting in Morocco, there are still considerable gaps. Most of these studies are limited to specific locations, technologies, or single case studies. The area encompassed by present research is comparatively less explored in literature. This is compounded further by various trends: growing demands for the creation of new industrial complexes, as well as intensifying pressures on infrastructure, will be poised to hugely boost urbanization over the coming several years. This growth will potentially add water resource demands, modify natural land processes, and enhance soil degradation and erosion. In accordance with this paradigm, the use of alternative and sustainable approaches, including rainwater harvesting systems, will address future water needs and act to increase the environmental sustainability of the region. Where empirical field data are unavailable or unobtainable, the approach presented in this research provides a suitable alternative for evaluating and establishing the viability of using RWH systems. This method is based only on free, credible, and worldwide available data, allowing for more strategic decision-making and, therefore, allowing the creation of more focused and effective field studies. This research proposes a practical methodology for the evaluation of the suitability of zones for RWH plants in arid and semi-arid regions through the application of GIS and the AHP. The aim of this study is to provide guidance for future planning activities and to maximize the use of water resources. The study also aims to mitigate water scarcity problems by separately assessing different environmental and geographical factors, which are then integrated into a composite map of potential rainwater harvesting locations. Lack of field data in semi-arid and arid regions is a serious problem in natural resource management, particularly for the implementation of RWH systems. The problem is due to the inaccessibility of the regions by way of extreme climatic conditions and rugged topography, lack of resources and funds for data collection over extensive areas, and lack of coordination and standardization in data collection. In addition, changes in climatic conditions quickly render this information obsolete. Nevertheless, there are feasible alternatives to these, such as RS and GIS, which are powerful tools for efficient management of surface water and contribute to the quest for sustainable solutions in the region. These techniques help in solving these problems by providing up-to-date and complete information about water resources and soil conditions, thus ensuring the sustainable management of resources in these sensitive regions.

The primary aim of this research is to generate a composite map that combines various environmental and geographical factors with a view to determining potential sites for the installation of RWH systems in the study areas. The principle behind this approach is the use of RS and GIS technologies, which provide effective tools for the integrated analysis and management of surface water resources. The final objective of this research is to come up with a systematic and replicable approach for identifying the most appropriate locations to install rainwater harvesting systems in arid and semi-arid areas, without the use of reliable field data. The aim of the current research is to produce a composite map by integrating various environmental and geographic parameters, like land use, slope, precipitation intensities, and erosion characteristics, to identify and rank regions of high prospect for RWH. The central hypothesis is that the application of multi-criteria integration, facilitated by GIS and the AHP, coupled with the sole utilization of publicly accessible data, will yield results that are transferable, valid, and applicable to a range of contexts with associated limitations.

METHODOLOGY

Study area

Khemisset province encompasses a total of 7537 km^2 in area. It is 86 km east from Rabat in the latitude position 33° 49′ north and the longitude position of 6° 04′ west, with an altitude at sea level being 409 m. The local climate is semi-arid and characterized by winter seasons that have mild, moderate, and rainy conditions and are humid and temperate with days of Chergui. The region's mixed relief creates appreciable local variations in climate, with obvious variability in minimum temperature ranging from 4 °C and maximum temperatures between 40 °C. Summer peak temperatures are generally between 16 °C and 26 °C but sometimes rise as high as 38 °C to 40 °C. The regional hydrographic system consists of many important rivers including the Bouregreg, Sebou, Beht, Ouergha, and Rdat rivers along with their affluents. There are several dams strategically located throughout the region, such as the Sidi Mohammed Ben Abdellah and El Kansera dams, that provide drinking, industrial, and agricultural water. There is also a significant groundwater reserve throughout the region, which contributes to its general water security. The Khémisset province is inhabited by a total population of 563,036 individuals, of which 307,932 reside in urban and 255,104 in rural areas (RGPH, 2024). This growing population places more pressure on the regional natural resources and infrastructure (Figure 1).

Data preparation

The most significant parameters used to define the RWH zone are hydrology, climate, topography, agronomy, and soil. In Table 1, the raw data were extracted from websites and subsequently processed appropriately in ArcGIS before use.

The most significant parameters used to define RWH are LULC, soil texture, slope, rainfall, distance to stream order, distance to faults, distance to roads, and distance to urban. These parameters have significantly contributed to estimating RWH

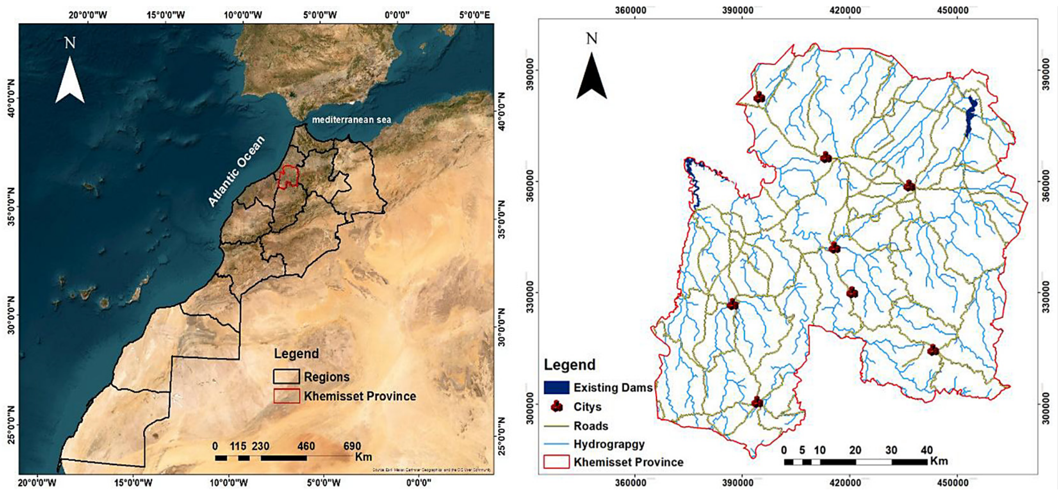

Figure 1. Geographical position of Khemisset province in western Morocco

potential in the study area. To simplify this analysis, the shuttle radar topographic mission (SRTM) digital elevation model (DEM) with 30-meter resolution was downloaded from the Earth Explorer website. This data was important in the ranking of streams and measuring the slope gradient of the research area. Rainfall data was also gathered to support the process of enhancement further, downloaded from the Earth data website. DEM, LULC map, and hydrological soil group were integrated in ArcGIS 10.8 to offer a comprehensive map of the study area. Residential area and road shapefile data were furnished by the General Organization of Remote Sensing of Morocco.

Values were assigned to each layer within this study in accordance with profound literature review and the opinions of experts through application of the AHP process. The layers with weights were then combined employing a MCDA process for generating the resulting layer (Table 2). The combined procedure allowed enhanced general perception of study area, presenting useful information in relation to following analysis and decision-making.

A methodological procedure flow diagram (Figure 2) was prepared to determine the most suitable locations for RWH. The procedure described by Saaty (1990) was applied in calculating the importance and weights of all the criteria according to the decision hierarchy structure. That involved preparation of a matrix of pairwise comparison, ranking of alternatives, and calculation of susceptibility class levels (Table 2). By permitting weighting of each criterion based on relative importance, the approach permitted a rational basis for prioritizing alternatives and choosing the best areas for use of RWH. Susceptibility ranking facilitated the determination of areas with a high likelihood for water scarcity or flooding and pinpointing interventions for where they will have greatest influence. This combined strategy not only ensured that the resources were adequately allocated but also helped to maximize the effectiveness of RWH interventions in addressing water management challenges in the area.

AHP and GIS modeling are used here to find RWH locations in the Khemisset province. Allocation of relative weights among various factors and identification of RWH factors with a notable impact are accomplished here.

Processing and creation of the thematic layers

AHP variables utilized in identifying potential locations for RWH are slope, LULC, soil type, precipitation parameters, drainage density, and runoff capacity, which all play a significant role in water accumulation, infiltration rates, and overall storage capacity. All parameters were extracted from freely available spatial data sets: the 30-meter resolution SRTM DEM was used in the generation of slope, elevation, and drainage layers; land cover and land use classification were accomplished with Landsat imagery; precipitation data were procured from NASA global climate data bases; and soil data were procured from the FAO soil database. These layers were rasterized into equal spatial resolution suitability maps and all parameters binned into suitability levels according to specific criteria (e.g., slopes 0–5% = very suitable, > 20% = unsuitable). Pairwise comparisons via AHP determined each

Table 1. Methods used to set parameter values for the AHP modeling

Data	Description	Source
SRTM[1]	Downloaded (DEM resolution 30 m)	https://earthexplorer.usgs.gov
Drainage density	Derived from DEM 30 m	
Landsat 8 OLI[2]	Downloaded (2021)	
Slope	Derived from DEM 30 m	
Elevation (m)		
Rainfall	Downloaded	http://power.larc.nasa.gov/data
Land use	Derived from Landsat 8 Oli image and field observation	https://earthexplorer.usgs.gov
Roads	Extracted	Google Earth: https://earth.google.com/web/
Rivers	Extracted DEM[3] 30 m	https://earthexplorer.usgs.gov
Faults	Extracted FAO geological map	https://data.apps.fao.org/
Geology	Downloaded	
Citys	Extracted	https://earth.google.com/web/
RWH	Evidence within the study area	Field data

Note: [1] The Shuttle Radar Topography Mission, [2] Operational Land Imager, [3] Digital Elevation Model.

parameter's weight according to expert opinion and literature citations concerning their relative importance in RWH site suitability. The weighted layers were subsequently overlaid using GIS's weighted overlay technique to derive a composite suitability map, thereby offering a reproducible and structured site selection process.

Twelve parameters were considered in this research while selecting the area suitability for RWH: flood susceptibility weight, slope, geology, LULC, rivers, rainfall intensity, runoff, elevation, roads, faults, Citys, and soil texture. Parameters were selected judiciously to enhance the accuracy of the areas identification of water harvesting suitability according to the study objective. Identification of suitable socio-economic indicators is needed in achieving desired outcomes as it considers indirect economic impacts to enable Rainwater Harvesting (RWH) site selection, e.g., distances to rivers, roads, and towns, have been widely applied in previous studies (Toosi et al., 2020). It is important to choose a location far enough from roads to avoid

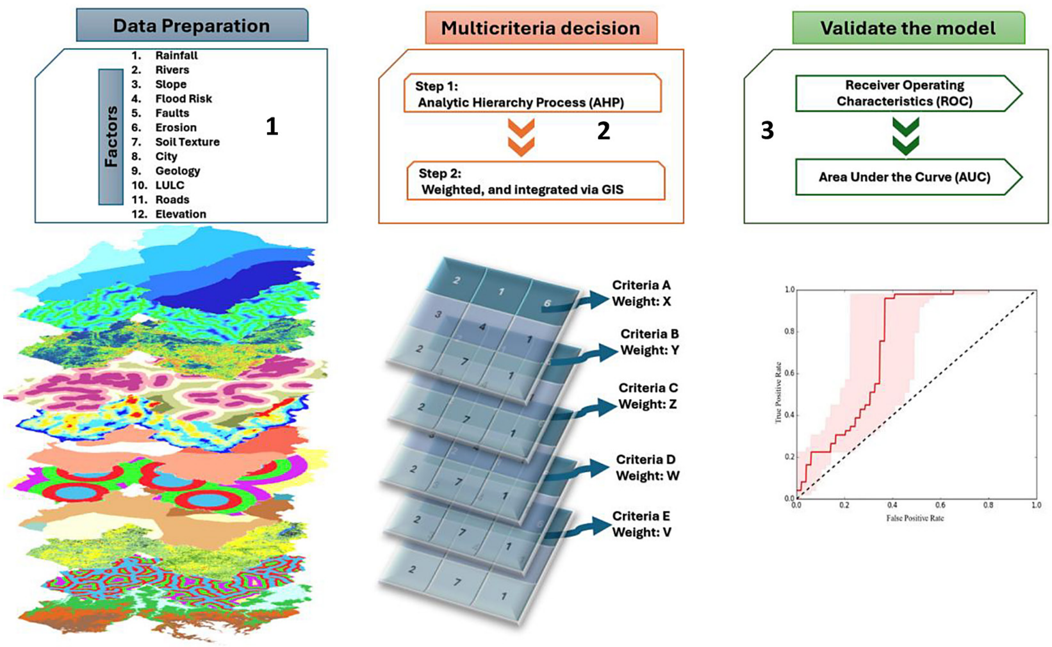

Figure 2. Flowchart of the procedures applied in the current study

any future controversy related to road development and urbanization (Al-Adamat, 2008).

Rainfall

The amount of rainfall is very important to facilitate the choice of the site location for RWH. The study site shows average annual rainfall which is given in Table 1. In the khemisset region, rainfall intensity ranges between 662 and 822 mm/year. This data represented the mean annual rainfall in the study area. It was used to create a map showing how rainfall is spatially distributed in different areas. The precipitation layer was then reclassified into suitability classes (i.e., areas of high rainfall = highly suitable, areas of low rainfall = less suitable). No formulaic multiplication or direct multiplication against rainfall values was performed in the final step; its influence was accounted for by including the AHP weight assigned and categorical reclassification to make its proportional contribution to the composite suitability map.

Slope

The degree of slope is a crucial consideration when selecting a RWH site. In the study area, slopes range from 5% to 70%. The slope degree was integrated into the AHP-GIS model by initially creating a slope map using a DEM and GIS software. The slope values (degrees or percent slope) were then reclassified into a series of suitability classes according to standard rainwater harvesting practice guidelines, for instance, gentle slopes (0–5%) very suitable because of water retention, moderate slopes (5–15%) moderately suitable, and steep slopes (>15%) unsuitable because of high runoff and erosion. These reclassified classes were scored according to their suitability. During the AHP process, slope was given a high significance for its overriding impact on runoff velocity and water holding. The weighted slope layer was then combined with the remaining thematic layers in the GIS-based weighted overlay to produce the ultimate site suitability map for rainwater harvesting site identification.

Flood susceptibility

This part of the study utilizes the AHP method in conjunction with GIS modeling to identify areas prone to flood hazards. Factors such as slope, rainfall intensity, distance from rivers, soil type, distance from roads, drainage density, TWI, elevation, and LULC were carefully considered and reclassified to map out different levels of flood hazards in the region. Each factor was assigned a weight and rank through pairwise comparisons to determine the severity of potential flooding. This allowed for the categorization of flood hazard areas into five risk levels: very high, high, moderate, low, and very low. A standardized scale ranging from 1 to 9, as per the system outlined in (Table 2), was used to assess the degree of impact, with a higher value indicating a greater risk level.

Soil texture

The composition of the soil plays a pivotal part in determining the ideal position for a RWH point. Soil type were classified according to their infiltration rate and water retaining capacity, rainfall harvesting suitability parameters. For example, clay soils with high water retaining capacity were found to be more suitable, while sandy soils with high percolation rates were found to be less suitable. A suitability score was accordingly assigned to each type of soil. The scores were then used to recast the soil layer in the GIS environment. In AHP, a weight indicating the factor's relative importance in relation to other factors was assigned to the soil factor. The weighted soil layer was then combined with the other environmental layers through conducting a GIS-based weighted overlay analysis to contribute to the final suitability map. The capability of the soil to absorb and retain water is essential for the success of RWH systems. The size, shape, arrangement, and distribution of soil pores are told by the soil texture, which eventually impacts the water harvesting eventuality of the area. Thus, understanding the soil composition is crucial to maximizing the effectiveness of RWH systems.

Table 2. Saaty's scale of preference (Saaty, 2008)

Intensity importance	Definition
1	Equal importance
2	Moderate importance
3	Importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Verry, very Importance
9	Extreme importance

Geology

The methodology for the procurement of the geological map of Morocco adheres to the use of open-source geospatial data by the FAO via its GeoNetwork portal. After opening this database, a thorough search was conducted. The data collected was then analyzed and synthesized with the help of the GIS software (ArcGIS), to overlay and compare different geological layers and create an integrative geological map of the nation. Data integrity was given top priority, and due checks and verifications were conducted to ascertain their accuracy and reliability. This approach facilitates the creation of an extensive and functional geological map to be utilized in subsequent geospatial analysis. The geological structure of the region plays a pivotal part in assessing the eventuality of RWH sites. Factors similar as gemstone texture, face hardness, pitch stability, and landslide threat are all told by the geological structure of the area. Understanding these aspects is essential in determining the felicity of a point for RWH. The face hardness of the gemstone, as well as the stability of the pitches, are pointers of the point's readiness for a water harvesting system. The presence of faults in the gemstone layers can also impact the effectiveness of the RWH system and water retention capabilities.

LULC

LULC plays a pivotal part in determining runoff patterns and the feasibility of water storage. The analysis involved close examination of satellite-derived LULC maps and reclassification of the land cover classes according to their suitability in rainwater harvesting. Specifically, the impervious surfaces, which are embodied by urban areas, were given low suitability values because of poor infiltration, whereas agricultural land and barren lands were provided with higher values since they could collect and retain runoff. Forested lands were ranked as moderately suitable since thick vegetation has the potential to minimize surface runoff. These suitability classes were reclassified in GIS on a standard scale (e.g., 1 to 5), with higher values indicating more suitable conditions for RWH. This reclassed LULC layer was then integrated into the AHP model, where it was assigned, a relative weight based on expert opinion and literature review and combined in the final suitability map using weighted overlay analysis.

Elevation

High- resolution DEMs are constantly employed in modeling RWH systems due to their significant impact on downfall patterns. Runoff, pitch, LULC, and other factors are nearly linked to elevation. In the study area, elevation varied from 44 measures below mean ocean position to 1314 measures above MSL.

Rivers

Rivers play a pivotal part in easing water runoff through dens, eventually leading to the collection and accumulation of water. This process directly impacts the eventuality for RWH. Basically, gutters mandate the volume of water that can be gathered and stored towards the main channel, impacting the feasibility of RWH practices.

Lineaments

To enhance water storehouse capacity by enforcing RWH systems, it's pivotal to consider fault lines. Determining a safe distance from fault lines is essential to help water loss through cracks.

City

When making spatial opinions regarding the selection of optimal spots for enforcing RWH systems, it's judicious to avoid agreement centers and civic areas.

Roads

When determining the optimal locales for enforcing RWH systems, roads are generally neglected from the spatial decision-making process due to profitable considerations, analogous to Settlement Centers.

Erosion susceptibility

This factor study employs the AHP system in confluence with GIS modeling to pinpoint areas susceptible to erosion hazards. Factors including Factors such as slope, rainfall intensity, soil, elevation, NDVI, and LULC were strictly anatomized and reclassified to delineate different situations of erosion risks hazards within the study area. Each factor passed a weighting and ranking process through pairwise comparisons to ascertain the implicit inflexibility of erosion (Kaddar et al,2024).

For every factors used in identifying RWH locations, we ranked and weighed through pairwise comparison using the AHP. This entails considering how significant a particular factor is relative to others on a scale of 1 (same importance) to 9 (very significant), based on expert judgment and literature review. For example, rainfall was ranked the highest because it influences the quality of the water in direct proportion, and LULC and slope were ranked very high because they allow for infiltration as well as runoff. Water drainage and soil were ranked medium because they determine how the water is stored and conveyed. The CR of the matrix was calculated in such a manner that the resulting comparisons were appropriate (it was determined that CR < 0.1 was necessary). The largest eigenvector of the input matrix was used to calculate the final weights for the GIS-based weighted overlay. The final RWH suitability map was derived by multiplying the reclassified raster layer of every factor by its assigned weight and adding them together. These weights and ranks were reasoned based on how they pertained to water flow and backed by research papers.

Analyzing AHP Processing mapping

The AHP is innovated on three abecedarian principles, factors determination, corruption, relative analysis, and prioritization. The AHP is a well- established procedure known for its rational and comprehensive approach, abetting decision-makers in resolving complex, multi-criteria issues. corruption proposition, is a crucial aspect of the AHP, involves breaking down a problem from its loftiest position into lower factors, making their resolution more manageable. This system allows to attack intricate problems effectively and efficiently (Saaty, 1983). The weights and ranks assigned to each criterion in Table 2 were derived from the synthesis of literature and expert opinion, using the AHP comparative scale ranging from 1 (equally important) to 9 (much more important). For example, precipitation ranked first because it is the greatest source of available rainwater; slope ranked relatively high because of its effect on runoff and potential percolation; LULC and soil type were weighted relatively moderately owing to their input into percolation and surface runoff. Drainage density and runoff were weighed too, although relatively less under this scenario. All pair-wise comparisons were made in terms of the contribution of one factor to effective RWH site selection in arid and semi-arid climates. After determining the weights for the pair-wise matrix, consistency was ensured using the CR, which ensured that judgments were logically consistent (CR < 0.1). The final weights were derived from the normalized eigenvector of the matrix and applied in the GIS weighted overlay analysis.

In the AHP, the thickness of pairwise comparisons in a judgment matrix is supposed to be respectable if the corresponding thickness rate (CR) is below (Equation 1). To begin with, the thickness indicator (CI) must be determined. This involves casting the columns in the judgment matrix and multiplying the performing vector by the vector of precedence's. This process provides an estimate of the maximum Eigenvalue, denoted as γ_{max}. latterly, the CI value is reckoned using the following formula:

$$CR = CI/RI \tag{1}$$

The CI is obtained using the following equation (Equation 2). Meanwhile, the random index (RI) is determined based on the Random Index (Table 3), which is dependent on the number of criteria (n) (Echogdali et al. 2018).

$$CI = (\gamma_{max} - n)/(n-1) \tag{2}$$

The maximum eigenvalue (λmax) is getting by this equation (Equation 3), ws represents the eigenvector (priorities) of the criteria or alternatives, wc represents the normalized weights (priorities) of the criteria or alternatives.

$$\gamma max = Average\ (w_s/w_c) \tag{3}$$

RESULTS AND DISCUSSIONS

Consistency analysis

The process of importing in MCDM is pivotal and requires careful consideration by experimenters. There are colorful styles available to determine weights, but it's essential that these weights are believable. In our study, all factors

Table 3. RI used to compute CR (Saaty,1980; Yap et al.,2018)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

contributing to RWH were distributed into five groups grounded on their implicit impact on the feasibility of RWH within each factor. We employed a standard scale of 1–9 (Table .1), to assess the degree of impact, with a score of 9 indicating an advanced position of significance. These assessments were made grounded on expert knowledge in the field and the significance of each factor in relation to RWH. To calculate the weights of each factor, we converted the values in the comparison matrix into probabilities of the total sum per column. The weight of each factor was also determined as the normal of each row in the standardized matrix. The performing weights, chance breakdowns, recommended RWH situations, and factor groups are presented in Table 4. This methodical approach ensures that the factors impacting RWH are directly weighted and considered in decision- making processes (Table 4).

In this study, RI represents the mean of an indicator of thickness, while the matrix Order and CI denote the indicator of thickness as expressed. An aimlessly generated pairwise comparison matrix is employed to calculate the arbitrary thickness indicator, RI. The RI value determined in this study is 1.48, as defined by Saaty. still, the thickness rate (CR) is calculated as the rate of the arbitrary indicator to the matrix thickness indicator, A CR value between 0 and 1 is considered respectable. Upon applying these approximations to the ormer judgment matrix, the deduced factors are as follows λav = 12.16, CI = 0.015, and CR = 0.010 After weighting the different factors (Table 5). The superposition of the 12 input factors will be conducted using ArcGIS software 10.8.

Applicable classes were assigned to the 12 named factors, followed by the construction of the AHP pairwise comparison matrix grounded on the preferences of each factor relative to the others. This matrix takes pairwise comparisons of the factors as input and produces their relative weights as affair. The contributing factors to RWH were distributed into five groups representing the degree of felicity of each order for RWH, to produce a weighting chart for the 12 factors. (Table 6).

For this research, RWH viability drivers were categorized into five based on the degree of influence they have on RWH viability, from lowest to highest. The drivers were categorized against the extent to which each of the drivers contributes to RWH viability using a combination of expert opinion and GIS-based analysis. Low-impact factors, i.e., land use and soil characteristics, with secondary control over RWH. Drainage density controlling water flow but to a lesser controlling extent. Factors of medium to high impact, i.e., slope and rainfall, having significant controls on the water runoff and availability. The most influential factors such as soil permeability, which affect directly and substantially water retention capacity. The most influential factors such as topography and rainfall intensity, which impact directly water harvesting efficiency. The ranking and weighting for all the factors were

Table 4. AHP matrix and factors weight

Parameters	Rainfall	Dist to rivers	Erosion risks	Slope	Lineaments	Flood risks	Soil type	Dist to City	Geology	LULC	Dist to roads	DEM	Weight %
Rainfall	1	1	1	2	3	4	5	6	6	7	7	8	25.31
Dist to Rivers	1	1	1	1	2	3	4	5	5	6	6	7	19.35
Erosion risks	1	1	1	1	2	3	4	5	5	6	6	7	19.35
Slope	1/2	1	1	1	1	2	3	4	4	5	5	6	13.80
Lineaments	1/3	1/2	1/2	1	1	1	2	3	3	4	4	5	8.75
Flood risk	1/4	1/3	1/3	1/2	1	1	1	2	2	3	3	4	5.55
Soil type	1/5	1/4	1/4	1/3	1/2	1	1	1	1	2	2	3	3.41
Dist to City	1/6	1/5	1/5	1/4	1/3	1/2	1	1	1	1	1	2	2.24
Geology	1/6	1/5	1/5	1/4	1/3	1/2	1	1	1	1	1	2	2.24
LULC	1/7	1/6	1/6	1/5	1/4	1/3	1/2	1	1	1	1	1	1.63
Dist to roads	1/7	1/6	1/6	1/5	1/4	1/3	1/2	1	1	1	1	1	1.63
DEM	1/8	1/7	1/7	1/6	1/5	1/4	1/3	1/2	1/2	1	1	1	1.18
SUM	5.0	6.0	6.0	7.9	11.9	16.9	23.3	30.5	30.5	38.0	38.0	47.0	100

Table 5. Normalization of RWH site selection matrix

Parameters	Rain	D_RI	Erosion	Slope	LINE	Flood	ST	D_CI	GEO	LULC	D_RO	DEM	Average	λ	CI	RI	CR	λ max
Rainfall	0.20	0.17	0.17	0.25	0.25	0.24	0.21	0.20	0.20	0.18	0.18	0.17	0.202	12.25	0.015	1.48	0.010	12.16
Dist to rivers	0.20	0.17	0.17	0.13	0.17	0.18	0.17	0.16	0.16	0.16	0.16	0.15	0.164	12.20				
Erosion risks	0.20	0.17	0.17	0.13	0.17	0.18	0.17	0.16	0.16	0.16	0.16	0.15	0.164	12.20				
Slope	0.10	0.17	0.17	0.13	0.08	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.129	12.13				
Lineaments	0.07	0.08	0.08	0.13	0.08	0.06	0.09	0.10	0.10	0.11	0.11	0.11	0.092	12.13				
Flood risk	0.05	0.06	0.06	0.06	0.08	0.06	0.04	0.07	0.07	0.08	0.08	0.09	0.065	12.17				
Soil type	0.04	0.04	0.04	0.04	0.04	0.06	0.04	0.03	0.03	0.05	0.05	0.06	0.045	12.19				
Dist to City	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.033	12.17				
Geology	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.033	12.17				
LULC	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.026	12.13				
Dist to roads	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.026	12.13				
DEM	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.03	0.02	0.021	12.11				
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		12.16				

Table 6. Classification and weighting of factors

Factor	Class	Class ranges
Rainfall (mm)	797–822	Very high
	771–796	High
	744–770	Moderate
	712–743	Low
	662–711	Very low
Rivers (m)	0–731	Very high
	732–1.540	High
	1.550–2.330	Moderate
	2.340–3.250	Low
	3.260–6.900	Very low
Erosion susceptibility (Level)	5	Very high
	4	High
	3	Moderate
	2	Low
	1	Very low
Slope (Degree)	0–4.94	Very high
	4.95–10.4	High
	10.5–16.7	Moderate
	16.8–24.4	Low
	24.5–69.9	Very low
Faults (m)	11.900–22.000	Very high
	7.700–11.800	High
	4.680–7.690	Moderate
	2.080–4.670	Low
	0–2.070	Very low
Flood susceptibility (Level)	5	Very high
	4	High
	3	Moderate
	2	Low
	1	Very low

Table 6 cont.

Soil texture	Clay	Very high
	Clay loam	High
	Silty Clay	Moderate
	Sandy clay loam	Low
	Sandy clay	Very low
City (m)	24.600–36.700	Very high
	18.400–24.500	High
	13.100–18.300	Moderate
	7.790–13.000	Low
	0–7.780	Very low
Geology	Granites	Very high
	Marls. sandstone. limestone. silts	High
	Shales. quartzites. limestones	Moderate
	Sandstone. shales. limestones	Moderate
	Limestones. molasses	Low
	Sandstone. and red clays	Very low
LULC	Bare lands	Very high
	Agricultural lands/grassland	High
	Forest/ sparse vegetation	Moderate
	Built up areas	Low
	Open water	Very low
Roads (m)	6.520–14.100	Very high
	4.310–6.510	High
	2.660–4.300	Moderate
	1.220–2.650	Low
	0–1.210	Very low
Elevation (m)	44–298	Very high
	298.1–484	High
	484.1–674	Moderate
	674.1–910	Low
	910.1–1.314	Very low

established from relative importance, following a standardized pairwise comparison method to balance and check for consistency. This classification allowed multiple criteria to be incorporated into the multicriteria analysis and offered an integrative methodology to assess the potential of areas for RWH systems.

RWH potential maps

Applicable classes were assigned to the 12 factors, followed by the construction of the AHP pairwise comparison matrix based on the preferences of each factor in relation to the others. This matrix takes pairwise comparisons of the factors as input and produces their relative weights. All factors contributing to RWH were distributed into five groups representing the importance of that factor for RWH, to produce a weighting chart for the 12 factors. also, suitable RWH sites were classified into five level grounded on the suitability of RWH.

Study area RWH suitability map was developed by overlaying various thematic layers using the weight of evidence (WOE) method. The map was categorized into five classes: very low suitable, low suitable, moderate suitable, high, and very high suitable (Figure 4). Upon analysis, it was estimated that the largest proportion of study area, which included 48% and occupied an area of 3615 km^2, was under the category of being moderate for RWH. Secondly, categories that were referred to as low and very low suitable covered 40% (3026 km^2) and 3% (188 km^2) of study area, respectively. Thus, 9% (706 km²) of the study area was determined to be under the category high suitable for candidate RWH locations (Table 7). This information presents valuable data to decision-makers and stakeholders who are involved in water resource management and sustainable development initiatives in the study region.

As can be seen from the rainfall map in Figure 3, rainfall in the study area varies between 642 and 822 mm/year. Rainfall distribution is well-defined spatially in the majority of the study area. Slopes of between 0 and 5% dominate the study area, with 8% of the area having slopes between 17 and 24%. Only 2% of the research area contains slopes of over 25%. Mountain ranges with elevated steep slopes enclose the southern boundary of the basin, while the north and eastern parts are gently sloping and are appropriate for RWH operations. Figure 3 is a soil map that provides excellent information on the land makeup

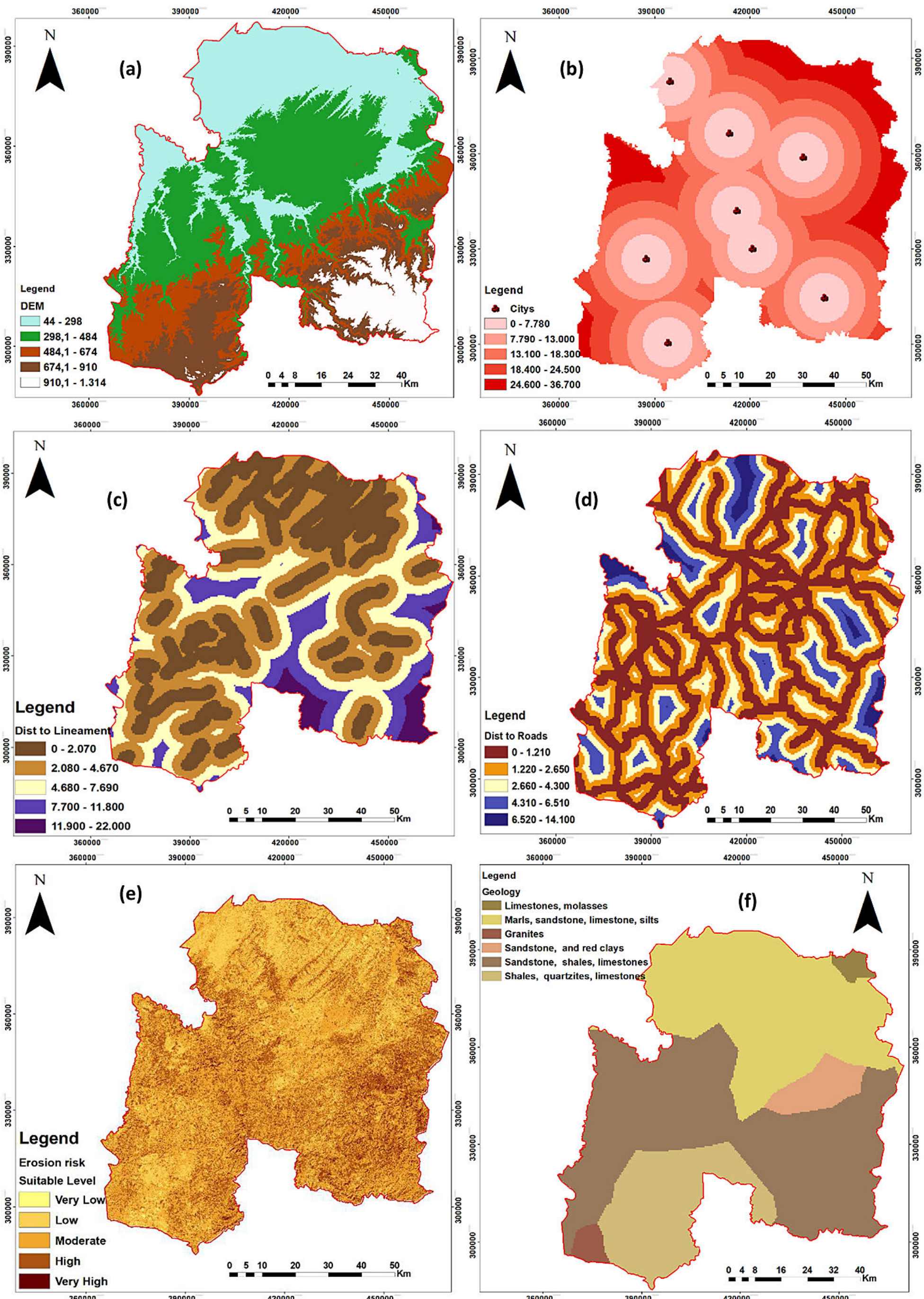

Figure 3. Input data for RWH sites maps showing: DEM (a), distance from city's (b), distance from lineament (c), distance from roads (d), erosion risks (e), geology (f)

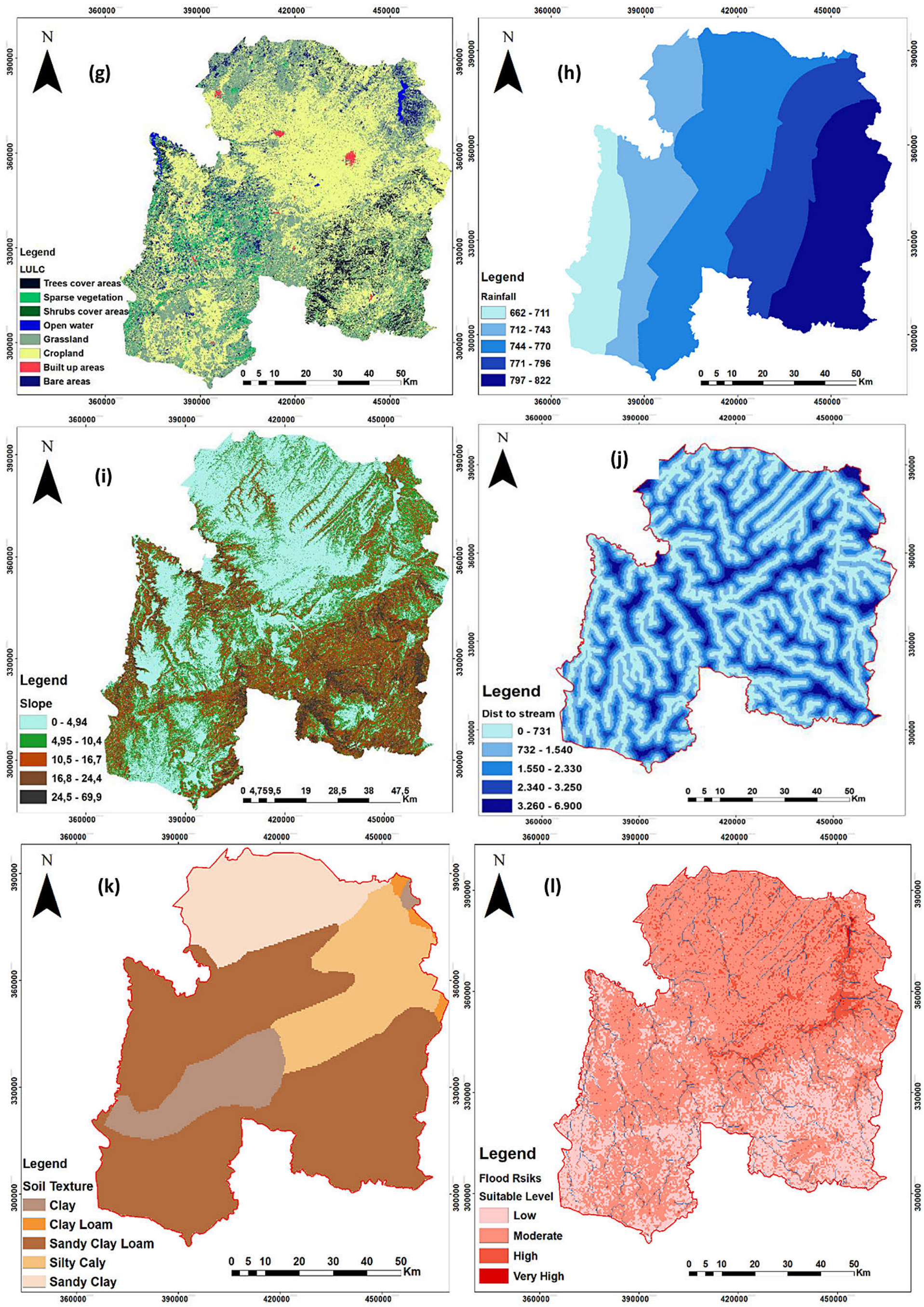

Figure 3 cont. Input data for RWH sites maps showing: LULC (g), rainfall (h), slope (i), distance from rivers (j), soil type (k), flood risks (l)

of the research area. Approximately 75% of the study area is composed of sandy clay soil, and low infiltration rate sandy clay loam when saturated and a normally fine structure. silty clay soil occupies 9% of the area, indicating a moderate infiltration rate. clay Loam and clay soil occupies 16% of the soil, which are regions of high runoff potential, low infiltration rates. The land use map provides a general indication of the land cover type around interest. From the observation, one can see that crops land occupies 40% of the area, trees, shrubs and vegetation occupy 24%, grassland occupies 20%, built up and bare surfaces occupy approximately 10% of the land, and open water occupies 6%. The rainwater harvesting potential map shown in Figure 4, show that the 'high' rainwater harvesting potential areas are distributed across the eastern regions of the plain and cover a total area of 706 km^2 (9%). In addition, the 'moderate' rainwater harvesting potential areas are mainly northeastern, center, and southeastern of the study area with an area

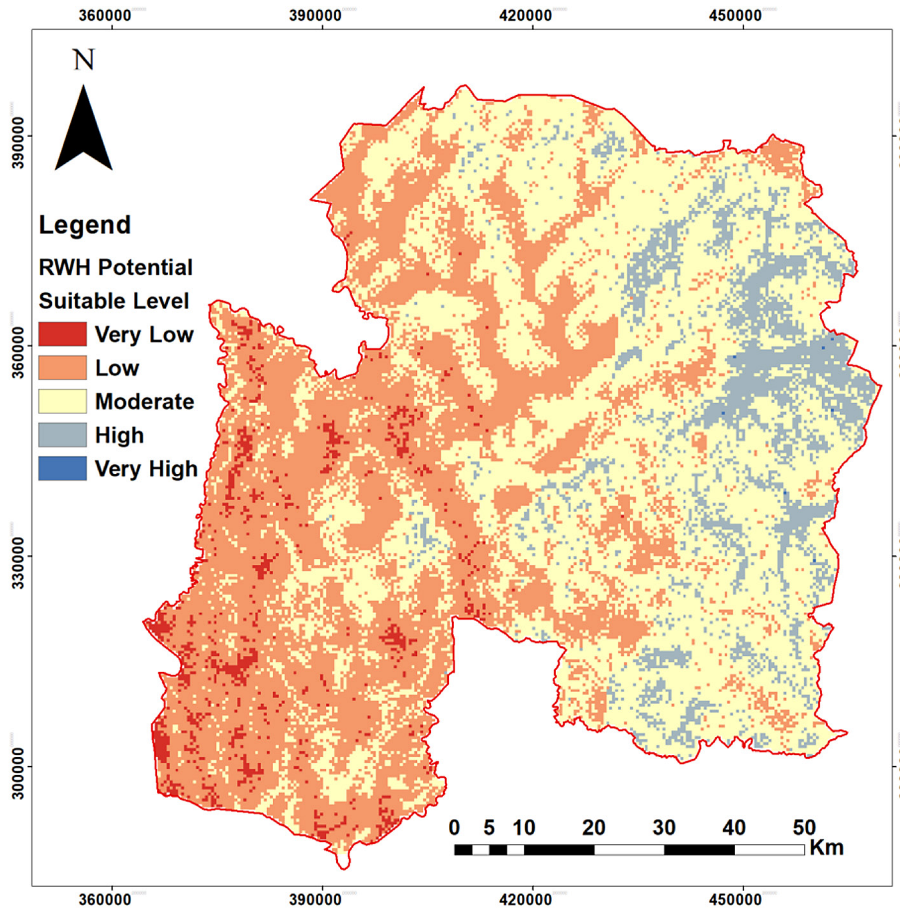

Figure 4. classified potential RWH suitability map

Table 7. Potential RWH class area

Potential zone	Area (ha)	Area (km^2)	Area (%)
Very low	18897.38	188.97	2.51
Low	302624.57	3026.25	40.15
Moderate	361501.29	3615.01	47.96
High	70616.54	706.17	9.37
Very high	124.32	1.24	0.02
Total	753764.11	7537.64	100.00

of 3615 km^2 (48%), the 'low' and 'very low' rainwater harvesting potential zone mainly situated close to the center and western of the study area with an area of 3212 km^2 (43% of the study area).

Validation and comparison

Model validation becomes especially critical within RWH site selection validation. It is an obligatory process involving critical comparison between model output and actual measurements aimed at determining the prediction validity and accuracy. Scientists can offer the guarantee that constructs of the actual world by a model are reasonably representative of the actual conditions using model validation. This enhances the reliability to achieve more accurate risk assessments in the future. In establishing the suitability of RWH locations, models should be tested by comparing their outcomes with observed data or information if available. Field measurements were first employed to test the outcomes of AHP models prior to comparison (Figure 5).

To cross-verify the AHP maps produced by the RWH models, field validation and ROC curves were performed. This rigorous validation

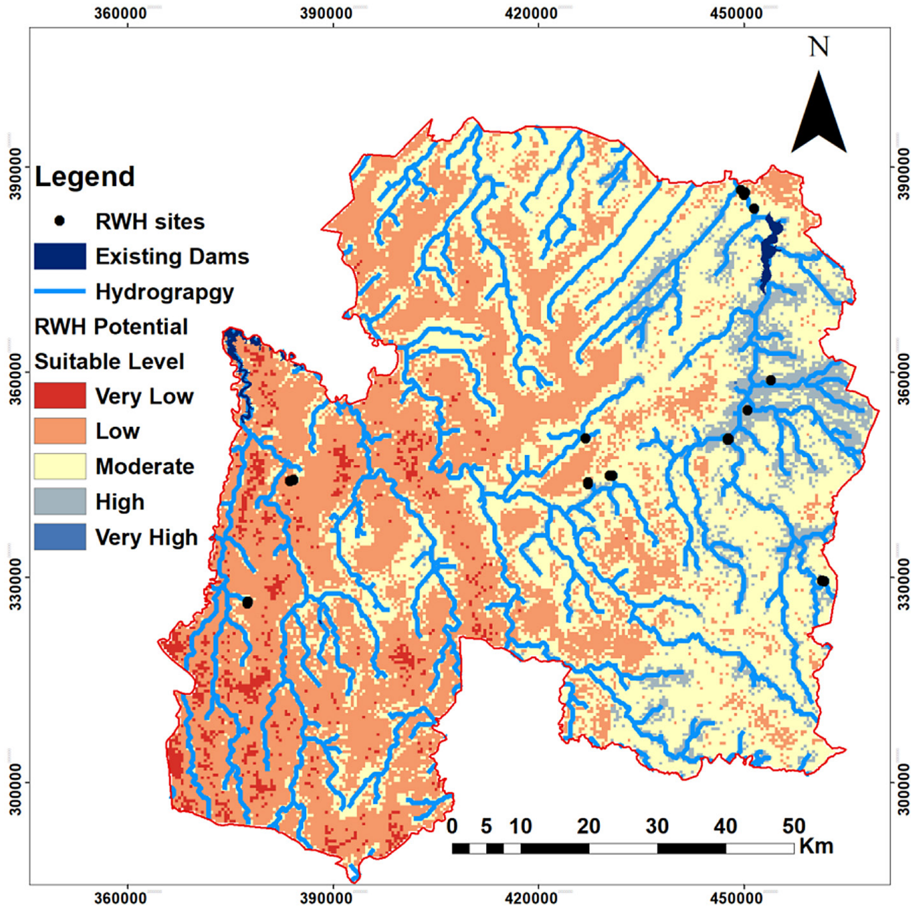

Figure 5. RWH suitable map with current sites

process is what led to high prediction precision and certainty levels and provided more scope for suitability analysis to the tool.

A good-fitting model has a range of 0.5 to 1 AUC values. ROC plots in Figure 6 indicate excellent and good accuracy for RWH, with an AUC, 0.83, corresponding to 83% accuracy of predictions. For illustration purposes. Field measurements provided us with substantial real-world data to compare our model predictions with. The ROC curves offered the means through which the performance of the models, as sensitivity and specificity, could be assessed. In general, the validation exercise confirmed the validity of the AHP models in risk area prediction and mapping.

Assignment of rational and believable weights to the influence factors is a crucial step in the process of making the outcome of spatial modeling believable and trustworthy within the MCDM paradigm. In this study, we applied the widely accepted decision-making tool, the AHP, to identify locations appropriate for RWH. Twelve environmental and physical key parameters were ranked and grouped into five thematic clusters regarding RWH feasibility. These were slopes, rainfall patterns, land use/land cover, drainage density, soil type, and others. With the help of a standard Saaty scale (1–9), expert opinion was utilized to form a pairwise comparison matrix, whose weights were determined by normalization of the columns of the matrix and averaging the rows. The consistency of the matrix was checked using consistency measures: the consistency index (CI = 0.015) and the consistency ratio (CR = 0.010), and they ensured that the judgments were acceptable and consistent (CR < 0.1). The factor weights were then integrated into a GIS environment (ArcGIS 10.8) to generate a composite RWH suitability map by overlaying the standardized thematic layers. Suitable classes were assigned to each factor, and the final suitability map was rated into five classes: very low, low, moderate, and very high. The result indicated that a large portion of the study area (48%, 3615 km^2) is categorized under moderate suitability, which indicates areas having the potential for RWH implementation under

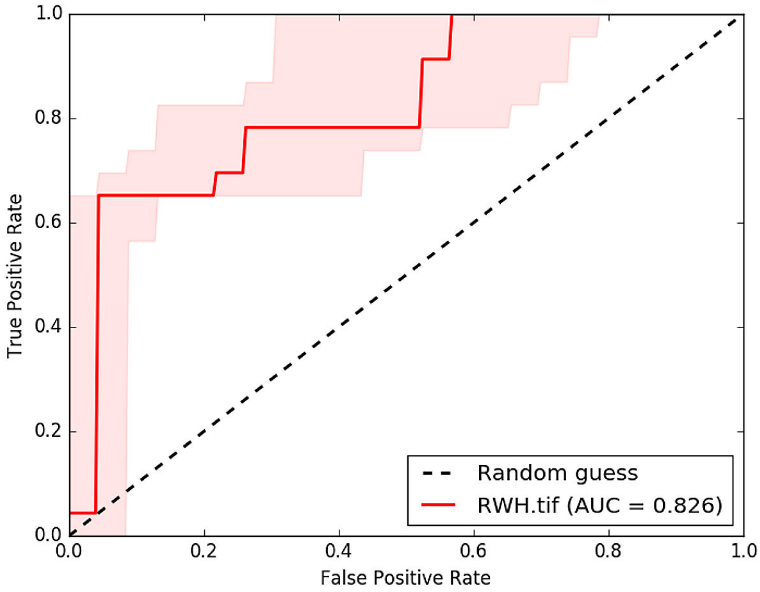

Figure 6. Prediction curve for the potential RWH suitability map

certain conditions. Low and very low suitability locations occupied 40% (3026 km²) and 3% (188 km²) of the region, respectively. Notably, 9% (706 km²) of the region was highly suitable, which occupies primarily the east and northeast sections of the region, where all favorable slope, soil, and rainfall conditions are met. Topographic analysis revealed that most of the area has gentle slopes (0–5%), with only 2% exceeding 25%, making it generally suitable for surface runoff collection.

Precipitation in the area ranges from 642 to 822 mm/year, with a spatial distribution pattern supporting collection in the central and eastern parts of the basin. From soil examination, it was found that about 75% of the area was composed of sandy clay loam and sandy clay soil, which are typically described by low infiltration rate as a desirable factor for surface water collection. Other soils such as silty clay (9%) and clay loam (16%) also contain varying levels of potential runoff. Agricultural land has been identified as the dominant landscape (40%), followed by shrubs and vegetation (24%), grassland (20%), urban and bare land (10%), and open water bodies (6%) with land use information. The map of RWH potential (Figure 4) is displayed in a visually pleasing manner that illustrates the spatial heterogeneity of suitability within the study area.

The areas of high potential occur primarily in the eastern region, then scattered areas of moderate potential in the northeastern, central, and southeastern regions. Low and very low suitability regions are generally distributed in the central and western regions, mainly equivalent to highly permeable zones or steep slope areas. Validation of the model was done through field observation and comparison with known hydrological conditions, confirming the AHP-GIS integration process in determining the real suitability for RWH. This stringent and systematic methodology presents a useful decision-support tool for planners, environmental managers, and policymakers, particularly for semi-arid and water-scarce regions. By integrating expert judgment, systematic weighting, and spatial analysis, the study demonstrates the potential of AHP-GIS modeling in supporting sustainable water resource management, site selection optimization for RWH systems, and long-term climate resilience and development planning.

CONCLUSIONS

The study confirmed that the use of AHP combined with GIS offers a scientific and efficient approach to evaluating environmental and socio-economic factors influencing RWH potential, one not regularly applied in the case of semi-arid regions like Khemisset. This approach made ranking of vital parameters possible with both expert views and quantitative predictions, thereby establishing data-based, open criteria for optimum RWH site selection. The main deficiency met in the current research work is applying an inexpensive, inexpensive method to seek out prospective locations of RWH where field observations are scarce. The current work also demonstrated its possibility of employing the same procedure in other sites having the identical climatic as well as infrastructural limitations. Through determination of the importance of field validation integration in modeling techniques, the research implies that constant real-world validation is necessary to maintain the pragmatic application and accuracy of results at level. This strategy allows for new opportunities in improving water resource management in arid and semi-arid regions and can be applied to other water-short regions.

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