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Site Selections for Hill Dams in Oued Cherrat Watershed, NW Morocco: Weighted Overlay Approach

Abstract: The identifications of suitable locations for hill dam construction are confronted with various challenges, including environmental, technical, social, economic, and regulatory factors; these necessitate meticulous planning and management. This study employed geographic information systems (GIS) to identify and forecast potential sites within the Oued Cherrat watershed in northwest Morocco. A suitability map was developed by integrating multiple data sets, such as digital elevation models (DEMs), lithology, drainage density, and lineament density. By utilizing a weighted overlay analysis, the study area was categorized into segments with varying suitability levels for hill dam installation (ranging from unsuitable to very high potential). Covering an area of 39 km², the results indicated that 8% of the total area possessed very high potential. The findings were validated through field surveys that were conducted both prior to and following the study; these confirmed the high-potential areas that were identified by the model, thereby enhancing the reliability of the suitability map for future hill dam planning and flood-risk-mitigation strategies.

Keywords: site selection, hill dam, weighted overlay approach, Oued Cherrat

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1. Introduction

The selection of hill dam sites is a critical aspect of water-resource management – particularly in those regions that face water scarcity and environmental challenges. Hill dams, which are constructed on elevated terrains, play a vital role in capturing and storing runoff, thereby enhancing water availability for agricultural, domestic, and industrial use.

The identifications of suitable water harvesting sites is crucial for effective water-resource management – particularly in data-scarce regions and those hilly terrains where water availability poses significant challenges [1]. In these areas, the designs and implementation of water structures such as hill dams play pivotal roles in enhancing water conservation and ensuring sustainable agricultural practices. The unique topographical and geological features of hilly regions necessitate the careful consideration of site selections, as improper placements can lead to environmental degradation and ineffective water storage [2].

In the context of severe water crises (especially in those semi-arid regions that face issues such as fluoride contamination), the selections of potential dam sites become essential for sustainable management [3]. The implications of inadequate water-resource management are profound – often exacerbating existing socio-economic challenges and impacting food security. Therefore, effective strategies for identifying and developing water-storage solutions are more critical than ever.

The implementation of recharged dams and reservoirs in arid and semi-arid environments is vital for addressing water scarcity and enhancing resource availability [4]. These structures not only help capture water during rainy seasons but also contribute to groundwater recharge, thereby supporting ecosystems and agricultural productivity. The successful integration of these systems hinges on a thorough understanding of local hydrological conditions and environmental factors.

Various methodologies have been employed to systematically evaluate potential dam sites (including the analytic hierarchy process [AHP] and geographic information systems (GIS). These tools allow for multi-criteria decision analysis that effectively incorporate environmental, social, and economic factors into the site-selection process [5, 6]. Recent advancements in technology have further enhanced these methodologies, enabled more-precise assessments, and facilitated stakeholder engagement throughout the planning process.

Moreover, recent studies have highlighted the use of advanced visualization techniques such as 3D modeling to optimize dam-site selection and identify irrigation areas [7]. These innovative approaches not only improve the accuracy of site assessments but also enhance communication with local communities, thus ensuring that their needs and perspectives are considered in the decision-making processes.

Ultimately, this integrated approach to water-harvesting-site selection is essential for developing resilient water-management strategies in vulnerable ecosystems. By combining traditional knowledge with modern analytical techniques, it is possible to create sustainable solutions that address both immediate water needs and long-term environmental sustainability. Such strategies are crucial for enhancing the resilience of those communities that face water scarcity and ensuring the sustainable use of natural resources for future generations.

The main goal of this study is to identify potential hill dam sites within the Oued Cherrat watershed in northwest Morocco. To accomplish this, we will employ an integrated approach that utilizes GIS and overlay analysis and incorporates hydrological, geological, and satellite-derived data.

2. Materials and Methods

2.1. Study Area's Morphology and Geological Setting

The Oued Cherrat watershed lies in the Moroccan coastal plain near the Atlantic Ocean; it is situated in northwestern Morocco (Fig. 1) within the Rabat-Salé-Kénitra region and extends between the latitudes of 33°40′ N and 33°55′ N and the longitudes of 7°55′ W and 7°30′ W. It is bordered by the Bouregreg basin to the north and the Nfifikh basin to the south, with its outlet discharging into the Atlantic Ocean near the town of Bouznika. The main river originates in the Middle Atlas Mountains a prominent mountain range that extends across central Morocco. It flows in a generally south-to-northwesterly direction, traversing approximately 90 km before discharging into the Atlantic Ocean.

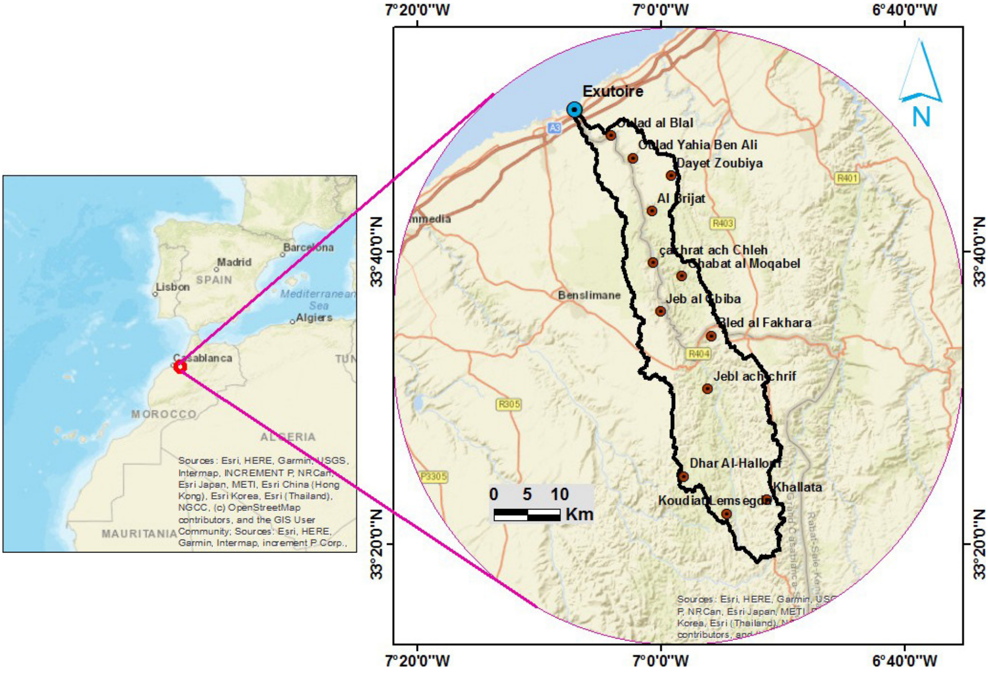

Fig. 1. Geographic situation of Oued Cherrat watershed

The Oued Cherrat watershed covers an area of around 510 km^2 and encompasses a diverse range of topographic features and land-use patterns. The southern part of the basin is characterized by the rugged terrain of the western Meseta, with elevations reaching up to 570 m above sea level. Toward the north, the landscape transitions into a more gently undulating plain, with the river meandering through a predominantly agricultural landscape.

The Oued Cherrat watershed is oriented in a northwest-to-southeast direction, with a perimeter of 103 km. The basin is controlled by the "Skhirat, Oued Cherrat" gauging station. This catchment is located between the Ykem and Nfifikh basins (both adjacent and parallel to them). It has a high compactness coefficient of 1.29, which is consistent with its overall morphological aspect. The length of the equivalent rectangular basin is 74 km (Table 1), which is six-times greater than its width; this indicates the generally elongated shape of the Oued Cherrat basin [8].

Table 1. Morphological characteristics of Oued Cherrat watershed

Watershed shape	Elongated
Area	510 km^2
Perimeter	103 km
Length of main watercourse (Oued Cherrat)	74 km
Length of equivalent rectangle	L = 74 km
Width of equivalent rectangle	l = 13 km
Compactness index	1.29
Roche index	0.11

The Oued Cherrat catchment belongs to the vast geomorphological ensemble of the northern coastal plateau (Fig. 2); this is the lowest compartment of the western central plateau and consists of vast monotonous plateaus that gently slope toward the ocean [9]. The deeply incised valley of Oued Cherrat allows for observations of the succession of rocks that constitute the substratum of the region [10].

A stratigraphic study of the primary terrains of Oued Cherrat has revealed the presence of three main systems: the Silurian, Devonian, and Carboniferous. The valley of Oued Cherrat and its margins are quite forested and are covered by Quaternary deposits that mask most of the primary terrains which are only outliers on the slopes of the Oueds and at the bottom of the Chaabats [10].

The Paleozoic deposits are quite variable and are represented by limestones, sandstones, argillites, pelites, conglomerates, and flysches. On the other hand, the Quaternary is represented by carbonate formations, red loess, sands and fluvial terraces (Fig. 2).

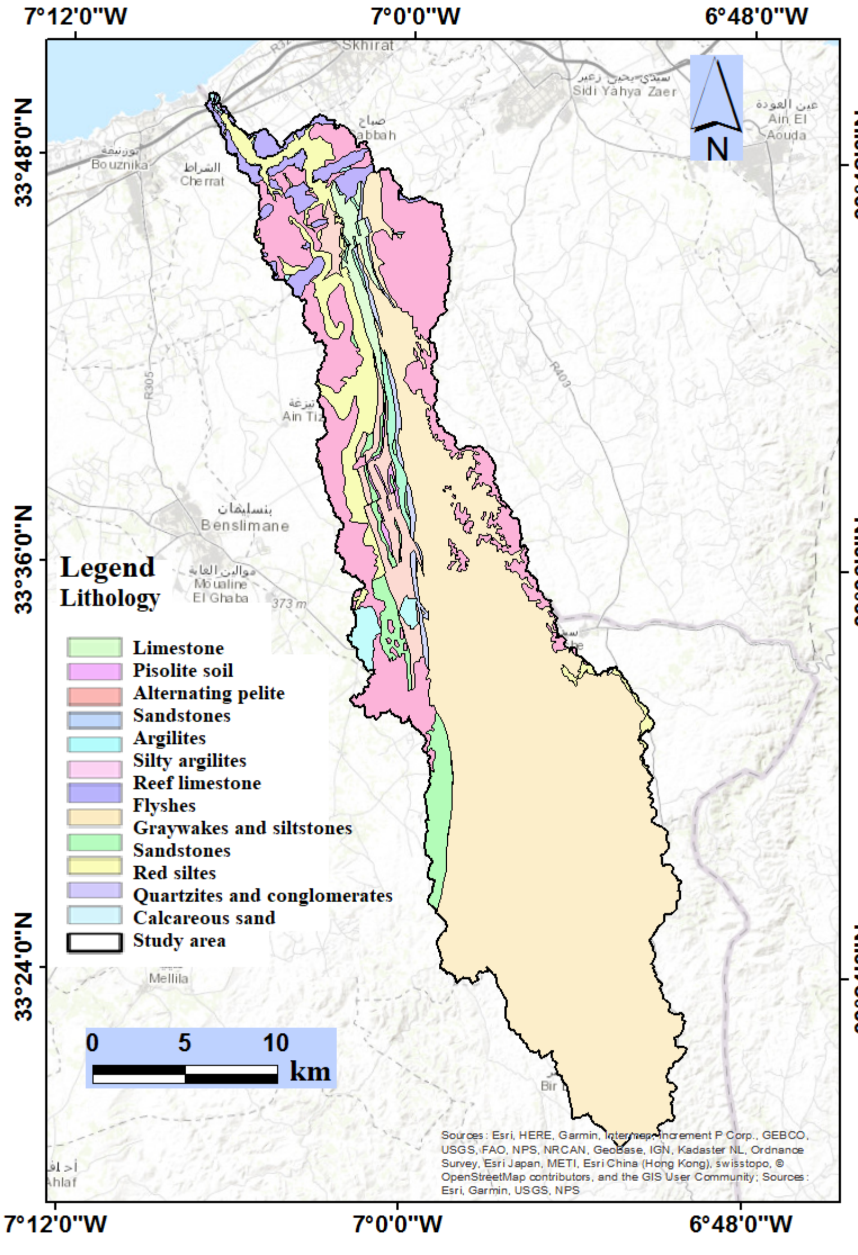

Fig. 2. Geological map of Oued Cherrat watershed

2.2. Methodology

The diagram below (Fig. 3) illustrates the workflow that was adopted during the development of this research paper. This workflow was designed to systematically guide our research process, thus ensuring that each phase was thoroughly executed and interconnected.

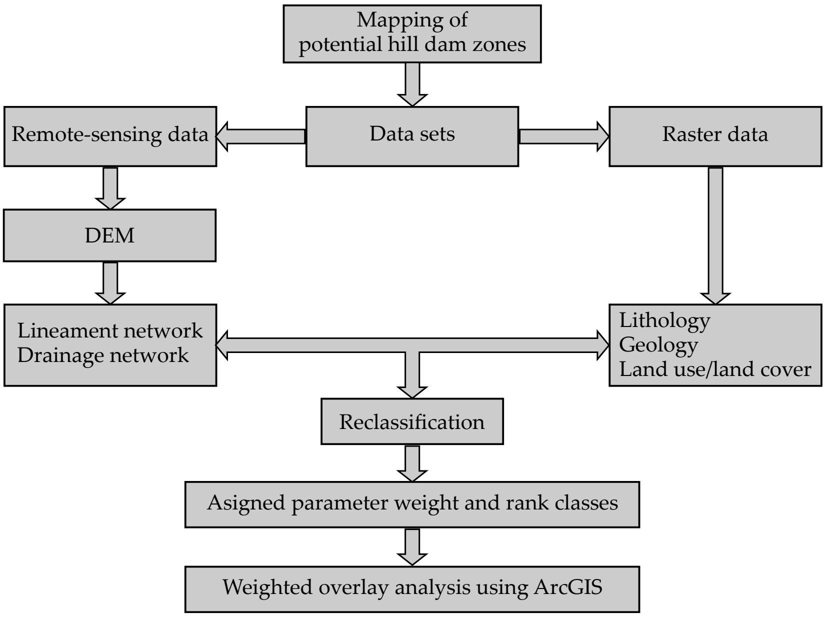

Fig. 3. Flow chart that illustrates step-by-step process of mapping potential areas for hill dam planning

Collecting Data

To conduct a thorough analysis of potential areas for hill dam planning, a methodological approach was employed that involved the collection and integration of various data sets; this included a 30-meter-resolution digital elevation model (DEM) that was sourced from NASA's Earth Science data, which was utilized to analyze the topography of the Oued Cherrat watershed. This provided critical information on the pertinent elevation and morphological characteristics. Geological data that was obtained from the Moroccan geological survey was integrated to evaluate the compositions of the underlying rocks (which are vital factors that affect water runoff and absorption). The lineament network that was derived from the DEM was examined in order to understand the structural features of Oued Cherrat. Furthermore, the study assessed the drainage network of Oued Cherrat (including any wadi systems) to elucidate the natural drainage patterns within the area; these were constructed based on the DEM data.

Weighted Overlay Analysis

All of the data sets underwent preprocessing, which included geo-referencing, resampling, and normalization to a standardized scale in order to ensure compatibility and accuracy. Subsequently, each data set was assigned a weight based on its relative significance in the identifications of hill dam sites – a determination that was informed by both fieldwork and a comprehensive literature review.

The weighted data sets were then integrated using ArcGIS (Version 10.5), resulting in a composite suitability map that delineated potential zones in Riyadh with low, medium, high, and very high suitabilities for hill dam construction. The accuracy of this suitability map was rigorously validated through field verification.

This methodology employed advanced geospatial techniques and a multi-criteria approach to thoroughly assess the suitability for hill dam construction in semi-arid environments. The findings of this study are anticipated to offer valuable insights for policymakers, water-management planners, and disaster-management authorities in Oued Cherrat and similar semi-arid regions worldwide.

The collection of a database of the adopted factors for hill-dam-site selection was one of the most important steps that affected the selection process. Based on previous studies and expert's opinion, uitable hill dam sites should be geo-environmental and economic concerns. Therefore, these sites must be designed to avoid unsuitable zones (besides, they should be).

A review of similar studies performed revealed that geological, environmental, and economic factors have strongly influenced the processes of selecting hill dam sites [1, 3, 5, 11–13] (Table 2).

Table 2. Previous published works using different approaches for selecting suitable hill dam sites

<table>
<tr><th>Method</th><th>Factors</th><th>Goals</th></tr>
<tr><td>AHP (Chandra et al., 2024) [5]</td><td rowspan="3">Hydro-geological, geomorphological, and geo-environmental</td><td>Site selections of dam constructions</td></tr>
<tr><td>PROMETHEE-II-AHP (Ashraf et al., 2024) [1]</td><td>Identifications and selections of prospective water conservation sites</td></tr>
<tr><td>FAHP and AHP (Ahmad et al., 2024) [13]</td><td>Determinations of potential rainwater-harvesting (RWH) zones</td></tr>
<tr><td>ML models (Ghosh and Bera, 2024) [3]</td><td>Hydro-geological, topographical, and environmental</td><td>Identifications of dam-site selections and groundwater-potential zones</td></tr>
<tr><td>Fuzzy logic and ANFIS (Mustafa et al., 2024) [12]</td><td rowspan="2">Hydro-geological, topographical, socio-economic, and environmental</td><td>Double assessments of dam sites for sustainable hydrological management</td></tr>
<tr><td>FAHP (Bastola et al., 2024) [11]</td><td>Identifications of suitable dam-construction sites</td></tr>
</table>

Validation

This research employed a comprehensive approach for verifying the accuracy of the hill-dam-suitability map that consisted of two distinct stages: an initial field survey (for assessing the necessity for hill dams), and a subsequent validation phase (which followed the study). The process involved comparing our predicted suitable areas with the locations of existing hill dams while considering the history and extents of past events in order to identify potential suitable zones.

On-site surveys were conducted in those areas that were identified as being suitable by the map – particularly near significant existing hill dams. These surveys aimed to observe the water accumulation and flow patterns by seeking physical evidence of flooding (such as watermarks, sediment deposits, and infrastructure damage). Additionally, insights from residents' experiences and observations were gathered in order to enrich the validation process. This thorough methodology ensured a robust verification of the hill-dam-suitability map, thereby enhancing its reliability as a tool for future hill dam planning and flood-mitigation strategies within the Oued Cherrat watershed.

A series of maps were generated to illustrate the areas within the watershed that were most suitable for hill dam construction. These maps incorporated several critical factors, including the digital elevation model, lineament network, lithology, and drainage density.

2.3. Digital Elevation Model

The digital elevation model (DEM) plays a crucial role in topographical studies due to its ability to capture and represent the accurate three-dimensional (3D) surface of the Earth. The key reason why DEM are important in topographical studies include its terrain analysis; DEMs provide detailed information about elevations, slopes, aspects, and other terrain characteristics [14], which are essential for understanding a landscape and its morphology. This information is crucial for applications such as hydrology, geomorphology, geology, and urban planning; moreover, DEMs enable extractions and analyses of drainage networks [15], including identifications of streams and rivers as well as their catchment areas. This knowledge is valuable for understanding surface-water-flow patterns, watershed management, and flood-risk assessment. Furthermore, DEMs are essential inputs for hydrological models, which are used to simulate and predict the movement and distribution of water in a landscape [16] (including estimation of surface runoffs, groundwater flows, and flood risks).

The elevations within the studied area (Fig. 4) varied from 15 m to 570 m, with the highest altitude being situated in the southern area upstream of Oued Cherrat and the lowest elevations being located in the northern region (downstream).

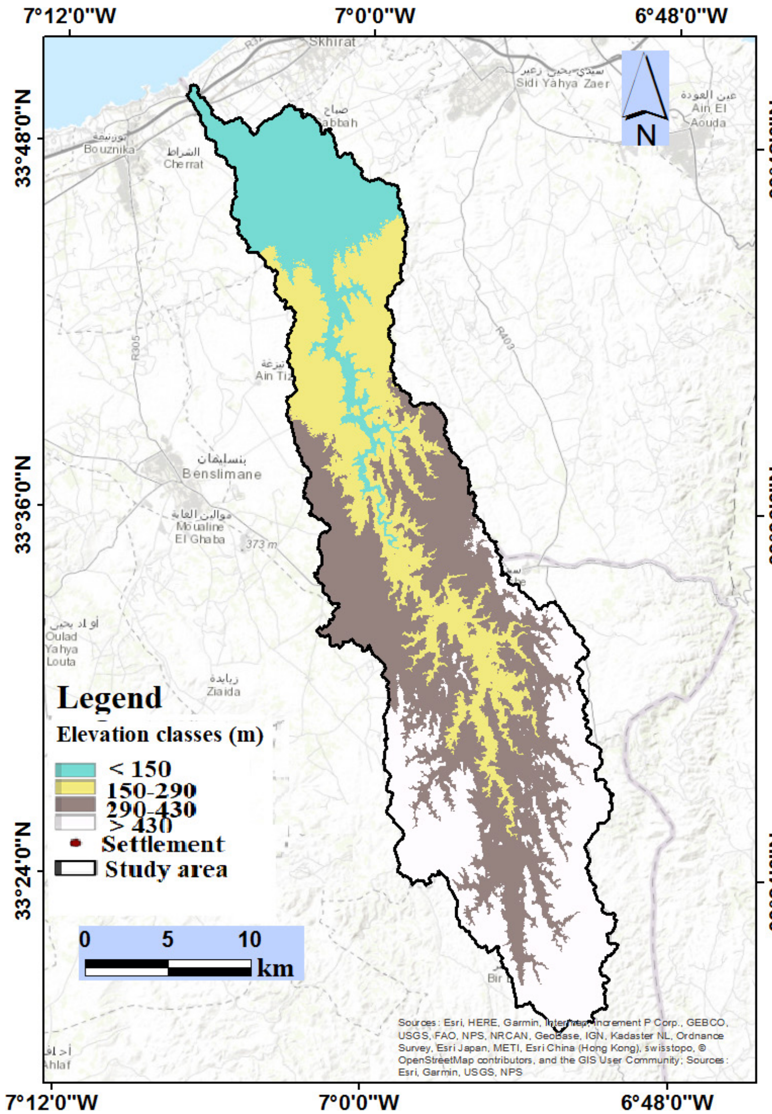

Fig. 4. Map showing elevation classes of study area

2.4. Drainage Network and Drainage Density

A drainage network refers to the system of interconnected streams, rivers, and tributaries that drain an area of land (also known as a watershed or drainage basin). The drainage network is shaped by the underlying topography, geology, and climatic conditions of the region. Characteristics of the drainage network such as stream order, stream density, and stream sinuosity provide valuable insights into the landscape and the hydrological processes within the watershed [17].

In this study, the Strahler classification [18] was employed; this is the most widely used and suitable method for the morphometric parameters of the Oued Cherrat watershed. The hierarchization of the hydrographic network of the Oued Cherrat watershed revealed stream orders that ranged from 1 to 6.

Oued Cherrat's drainage network is characterized by its extensive branching, which reflects the complexity of its watershed. The map below showcases the streams that were classified as orders 5 and 6 within this basin; these streams play a crucial role in the hydrology of the area, influencing water-flow patterns, sediment transport, and ecological dynamics (Fig. 5).

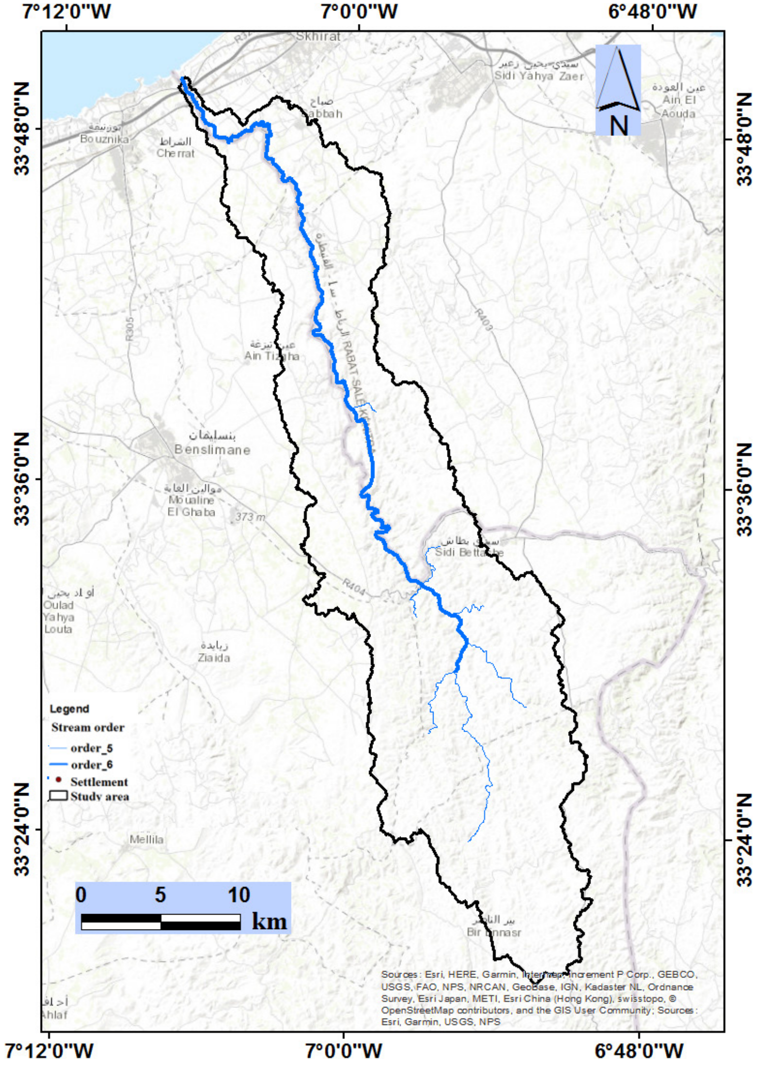

Fig. 5. Map showing fifth and sixth stream orders in study area

The drainage density is the total length of the streams of all orders divided by the area of the drainage basin; this indicates the closeness of the spacing of the channels [19]. The drainage-density map was generated by calculating the density of the stream network when accumulated at a particular location. The drainage-density map of the Oued Cherrat watershed was created using the Arc-GIS 10.5 Kernel density tool, which calculated the density of the stream network at specific locations. The tool utilized a raster surface and the input stream network in order to generate a map that showed the drainage density (in square kilometers) (Fig. 6).

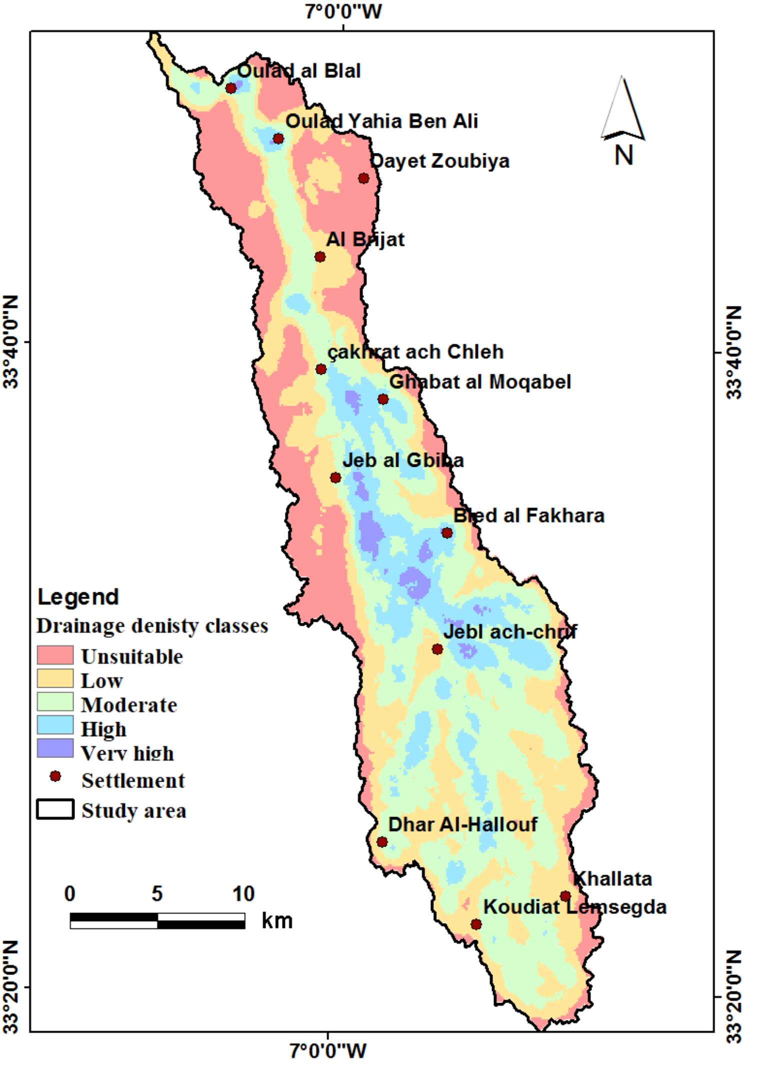

Fig. 6. Map that categorizes study area into five classes based on drainage densities

2.5. Land Use/Land Cover (LULC)

In the selections of hill dam sites, the land use and land cover (LULC) of the study area played a crucial role [20]; here is how LULC can be incorporated in such an analysis. The Oued Cherrat watershed is distinguished by the existence of a relatively diverse pedological structure due to climatic and lithological variations (Fig. 7). These factors significantly influence the development of soil in this region, affecting not only its composition and fertility but also the types of land use and land cover that can be sustainably supported.

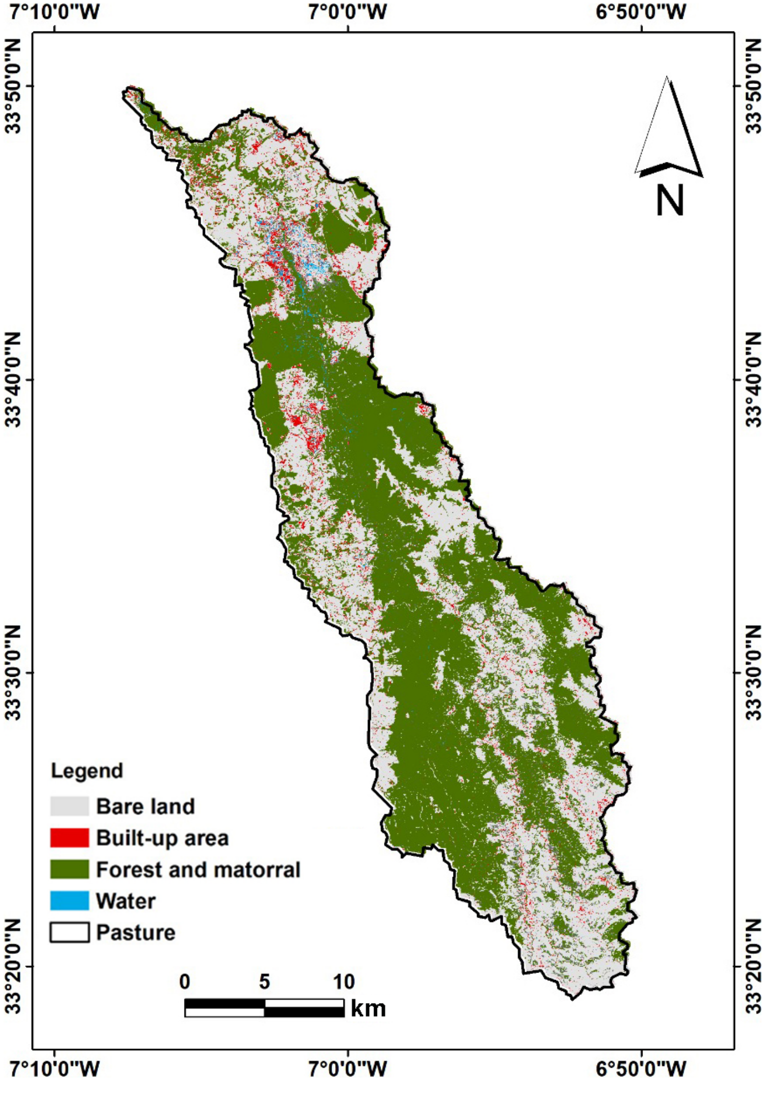

Fig. 7. Land use/land cover map of study area

2.6. Lineament Density

An analysis of the relationship among lineaments and a drainage network is an important aspect of geomorphological and hydrogeological studies, as this provides valuable insights into the structural controls on landscape evolution, the potential for groundwater resources, and the overall understanding of the complex interplay between the geological and hydrological processes within a given study area [21].

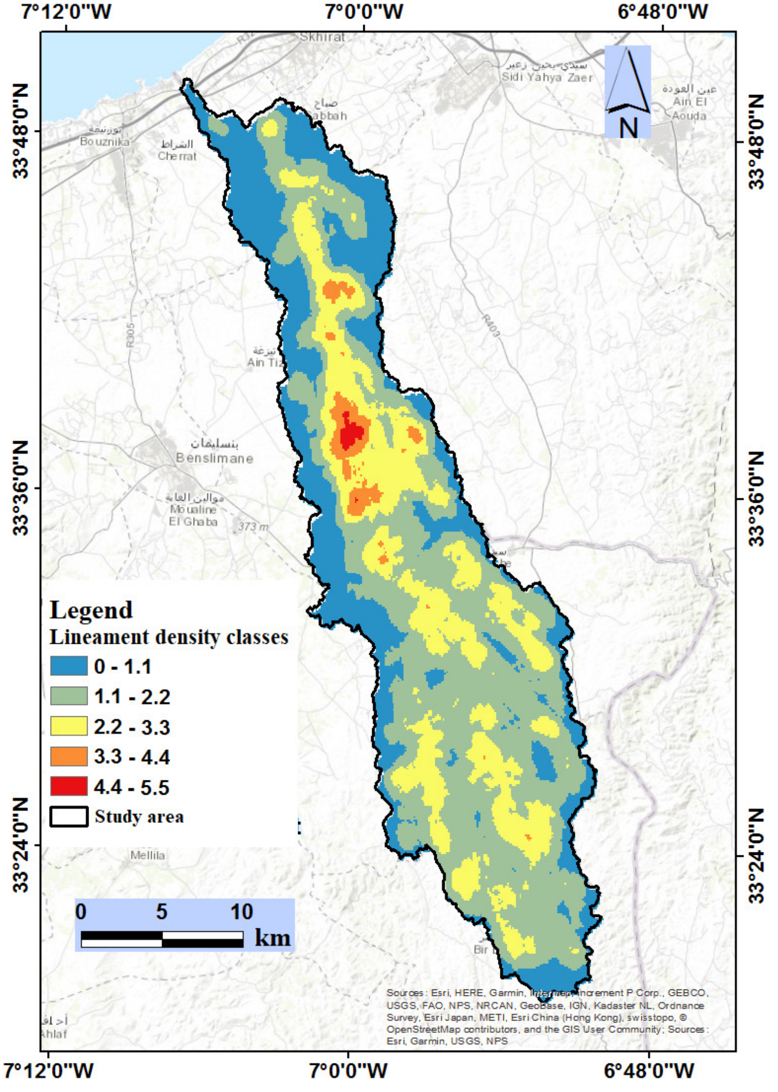

Fig. 8. Lineament-density map of study area

Lineaments, which are linear features on the Earth's surface that often indicate the presence of underlying geological structures such as faults, fractures, or dykes, can play a significant role in the development and organization of a drainage network. Streams and rivers tend to follow the orientations of lineaments – especially in those areas with high fracture densities or fault zones (as these structural features can influence the direction, flow, and density of surface-water drainage) [22].

Additionally, lineaments can act as barriers or conduits for groundwater flow, thus affecting the surface-water/groundwater interactions and the overall hydrological regime within a watershed. By analyzing the spatial relationship among the lineaments and the drainage network, researchers can gain insights into the potential for groundwater recharge, flow paths, and areas of high permeability (which are crucial for groundwater exploration and management).

Oued Cherrat's fractures are characterized by the high densities of its lineaments, which reflect the intricate geological features of the watershed. The map below illustrates the lineament density within this basin (Fig. 8).

2.7. Analysis of Drainage Network as Related to Lineaments and Faults

This step includes a comparison between the faults that are delineated on the geological map and the lineaments that were extracted from the DEM and Sentinel-2A imagery. In addition, it incorporates a directional rose diagram that represents the orientation of all of the identified fractures, thus facilitating a comprehensive analysis of the structural geology of the region (Fig. 9 on the interleaf).

The confrontation of the drainage network with the lineaments contributed to the definition of the genetic links among the orientations of the lineaments and the main directions of the surface water circulation (Fig. 10 on the interleaf). This statement highlights the key insights that can be gained by comparing the spatial patterns of the drainage network and the tectonic lineaments within the Oued Cherrat watershed.

3. Results and Discussion

Drawing from earlier studies, weights were systematically assigned to each criterion according to their respective importance in the assessment process; these weights reflected the critical role that each factor played in influencing the overall evaluation. Specifically, the assigned weights were as follows:

- elevation was weighted at 15%,
- lithology – 25%,
- lineament density – 15%,
- drainage density – 15%,
- land use/land cover – 10%.

This weighting scheme ensured a comprehensive and nuanced assessment by prioritizing the most influential factors in the analysis.

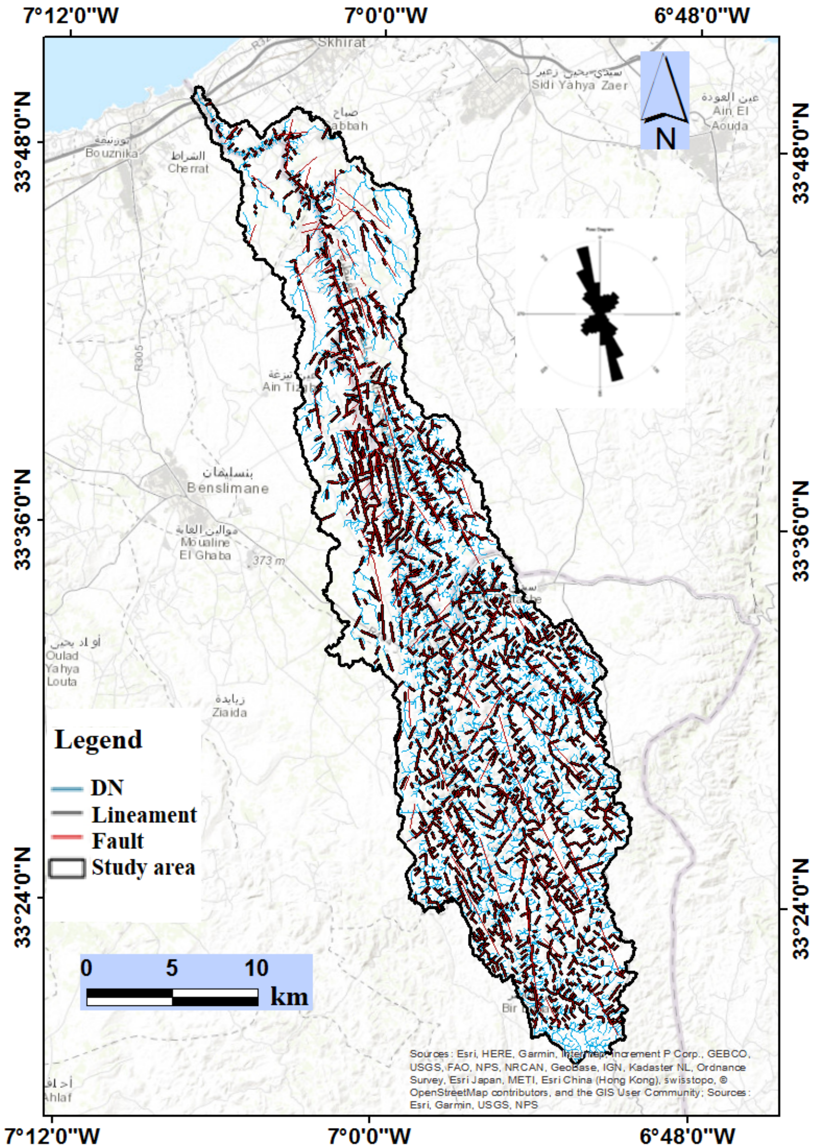

Fig. 9. Overlay map showing faults outlined on geological map along with lineaments that were derived from DEM and directional rose diagram

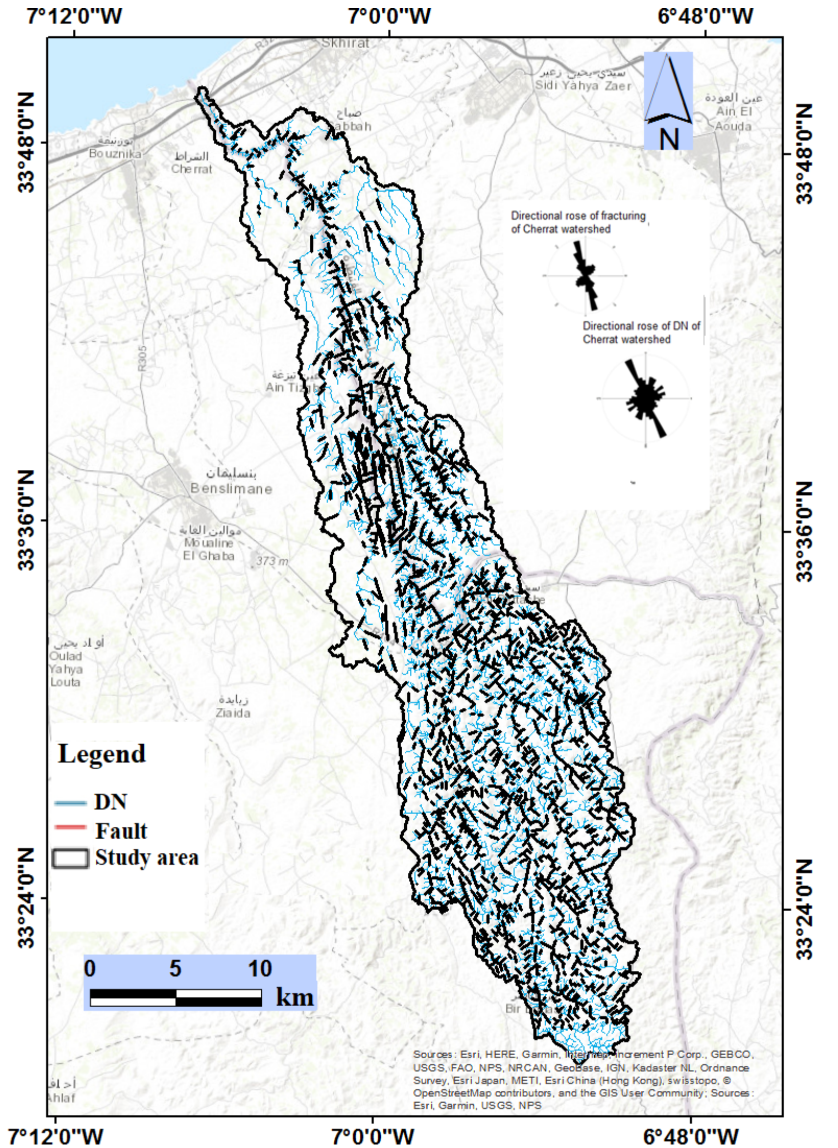

Fig. 10. Overlay map that illustrates interactions among drainage network and lineaments

The current study applied the same weights in the overlay analysis to assess potential hill dam sites within the Oued Cherrat watershed. The findings were presented through a data set that illustrated the varying levels of suitability across the different regions of the catchment area. The composite suitability map for the hill dam locations was generated by overlaying multiple data sets, including geo-environmental, hydrological, and geomorphological factors.

Before conducting the overlay analysis, each layer was categorized, assigned weights, and scored on a scale (Table 3). Among the factors that were considered, lithology received the highest weight, followed by elevation, drainage density, and lineament density; LULC was assigned the lowest weight.

Table 3. Five layers that were used in overlay analysis to find potential hill dam sites as well as their influences, classes, and scales

Parameter	Weight [%]	Classes	Rank
DEM	15	<150	4
		150–290	3
		290–430	2
		>430	1
Drainage density	15	1	1
		2	2
		3	3
		4	4
		5	5
		6	6
LULC	10	L1	1
		L2	2
		L3	3
		L4	4
		L5	5
Lineament density	15	C1	5
		C2	4
		C3	3
		C4	2
		C5	1
Lithology	25	Group 1 (sandstone)	1
		Group 2 (pelites)	2
		Group 3 (limestone)	3
		Group 4 (argillites)	4
		Group 5 (flysches)	5

In the Oued Cherrat watershed, analyses of a DEM and a Sentinel-2A optical satellite image showed the dominance of the NNW-to-SSE and NE-to-SW directions; these orientations corresponded to the major Hercynian structural trends [23, 24]. Their influence was evident on the entire drainage network.

According to Figure 11, the third-, fourth-, and fifth-order streams superimposed with the fractures over more-or-less long distances in several places; in other places, they intersected. All of the fracture directions influenced the watercourses; however, some hydrographic directions bypassed this control. The third-, fourth-, and fifth-order drains were correlated with the tectonic structures – particularly, with the fractures. Furthermore, the E-W lineaments were very infrequent; their influence was more perceptible on the small tributaries (first and second orders), but this decreased as the flow order increased.

Moreover, we also noticed that some drains in the drainage network (which escaped this control) followed the ENE-WSW direction. The differences in frequency that were observed between the directional rose of the hydrographic network and the fractures amounted to evidence of the presence of other factors that influenced the architecture of the Oued Cherrat watershed's drainage network; these included the geomorphology, the nature of the underlying rocks, the slope, and the anthropogenic activities.

The sixth stream order of the drainage network often marked the NNW-SSE orientation; this was due to the region's topography, with the presence of slopes that were usually directed toward the NNW and the presence of a faulty band of Oued Cherrat that favored this direction of the flow.

3.1. Suitability Classes of Hill-Dam-Site Selection

The suitability map for hill dam sites identified various potential zones within the Oued Cherrat watershed; these were classified into five categories: unsuitable, low, moderate, high, and very high (Fig. 11). The total study area measured 510 km², with 39 km² designated as having very high suitability for hill-dam-site selection.

Those areas with low suitabilities were primarily situated in the southern high-elevation regions. These locations exhibited unfavorable topographic conditions, efficient drainage systems, and relatively low urban density; this made them less conducive to hill-dam-site selection.

Moderately suitable zones typically encompass the central open spaces of Oued Cherrat; these areas were characterized by diverse topographical features. In contrast, high and very high suitability zones could mainly be found in the area with lower elevations. These regions have been particularly vulnerable to flooding, which has been exacerbated by rapid urbanization and inadequate drainage infrastructure. Consequently, there is an urgent need for effective flood-risk-mitigation strategies, including the strategic planning of future hill dams in these at-risk areas.

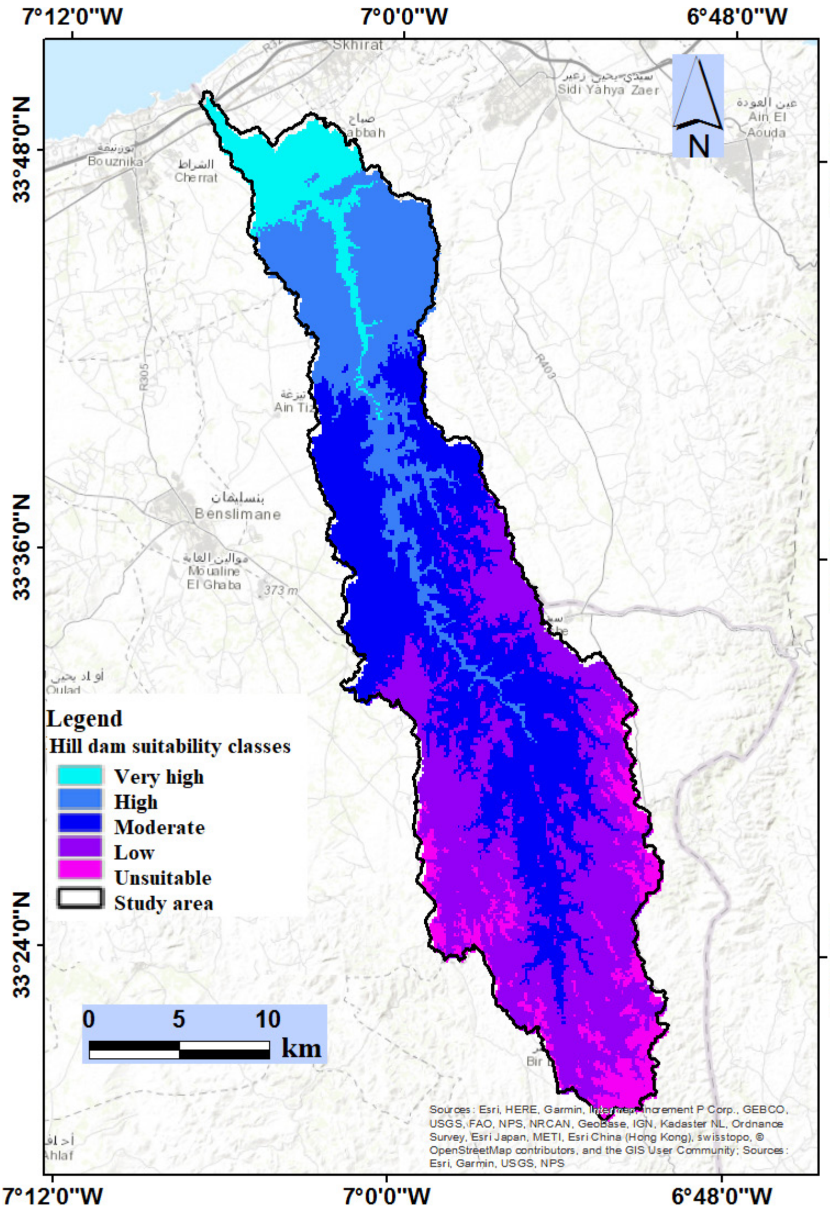

Fig. 11. Map of hill-dam-suitability classes of site selections

3.2. Study Limitations

While this study offers a thorough assessment of potential hill-dam-site selection in the Oued Cherrat watershed (located in northwestern Morocco), it is not without its limitations. Notably, the analysis relied on the drainage-density-network index without incorporating precipitation data and assumed that the existing land-use and urban-development patterns would remain stable. Given the rapid changes and developments that have occurred in the Oued Cherrat area, this assumption may not hold true. Additionally, the model did not account for climate change projections, which could significantly affect the accuracy of future hill-dam-site-selection predictions. Furthermore, alterations in land use and land cover (such as the establishments of new drainage systems or the implementations of green infrastructures) were not considered despite their potential impacts on the site-selection outcomes. These limitations highlight the necessity for regular updates to the suitability map for hill-dam-site selection and the ongoing refinement of the methodologies that are employed in such assessments.

4. Conclusion

The study effectively identified potential hill dam sites within the Oued Cherrat watershed through a weighted overlay analysis that integrated multiple data sets, including digital elevation models, lithology, land use/land cover, lineament density, and drainage density. The analysis classified the suitability of hill dam sites into five categories: unsuitable, low, medium, high, and very high potentials. The study area spanned 510 km^2; of this area, 8% was classified as having very high potentials for hill-dam-site selections, while the remainder fell into the categories of high, moderate, low, and unsuitable potentials. The findings were validated through preliminary field surveys that were aimed at calibrating the suitability map, followed by additional field surveys that confirmed the reliability of the final map. This comprehensive validation process ensured that water planners and disaster-management professionals have access to a reliable evidence-based resource for addressing water-management challenges in the Oued Cherrat watershed. Future research should explore the potential for hill-dam-site selection using newly developed methodologies in this area.

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CRediT Author Contribution

O. Z.: resources, methodology, software, writing.
A. L.: conceptualization, methodology, supervision.
M. M.: resources, methodology, software.
S. C.: conceptualization, validation, supervision.
M. S.: conceptualization, validation, supervision.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All of the data sources are publicly accessible.

The geological map was acquired from a catalog of geoscientific products from the Ministry of Energy, Mines, and Environment of Morocco (https://cartesgeoscientifiques.mem.gov.ma/catalogue/).

The topographical data was extracted from a digital elevation model (DEM) that was generated by the Shuttle Radar Topography Mission (SRTM) (https://earthexplorer.usgs.gov/).

The land use/land cover (LULC) map was developed based on a supervised classification using Lansat 8 imagery that was extracted from the following website: https://earthexplorer.usgs.gov/.

Use of Generative AI and AI-Assisted Technologies

The application of AI has been confined to enhancing the linguistic quality of the writing and ensuring the accurate translations of some specific passages.

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