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A Geomatics-based approach for controlling flash floods and augmenting water supply in arid and semi-arid regions

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Abstract

Flash floods in arid and semiarid regions usually occur suddenly with high intensity, damaging roads and communication networks, infrastructure, in addition to costs associated with loss of crops and livestock. Meanwhile, water scarcity is a significant challenge in arid and semi-arid regions due to their naturally minimal rainfall, which is sudden and irregular, and high evaporation rates. This necessitates the need to address water scarcity in arid and semi-arid regions through a variety of strategies such as sustainable water management practices, which entails exploring potential water resources and augmenting water supply. Among other potential water resources in arid and semi-arid regions is rainwater harvesting. At the level of catchment area, dams can be constructed to capture and store rainwater runoff during the sudden and irregular rainy seasons. This collected water can then be used for various purposes such as agriculture, domestic use, and recharging groundwater. Moreover, such water management structures can assist in flood control, augmenting water supply, and improving resilience to drought, which ultimately can contribute to sustainable development. This, consequently, requires proper design and site selection of such dams to ensure their sustainability and effectiveness.

This paper is intended to develop a Geomatics-based approach for multi-criteria suitability analysis for siting dams as water harvesting structures on a remote area with high potentials for development in eastern desert of Egypt. For this purpose, a methodology of four main steps was applied including collecting data, delineating drainage system, mapping suitability for siting dams, and finally evaluating the potential sites. The results showed that Wadi Um-Taghr has high surface runoff potential and susceptibility to flash floods. Suitability analysis for water harvesting structures revealed that most of the watershed, particularly the eastern and southern parts of the wadi, are suitable for rainwater harvesting. Among the three proposed potential dam sites, site “C” has the highest storage capacity and depth, making it the most favorable despite higher surface area and evaporation risk. The reservoirs of the suggested dams are estimated to have overall gross storage capacity of about 7.2 million m³ under full capacity scenario.

Keywords : Flash flood control, morphometric analysis, suitability analysis.

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منهج قائم على الجيوماتكس للتحكم في الفيضانات المفاجئة وزيادة إمدادات المياه في المناطق الجافة وشبه الجافة

الملخص

يرتبط بالفيضانات المفاجئة في المناطق الجافة وشبه الجافة حدوث أضرار بالغة بالطرق وشبكات الاتصالات والبنية التحتية، بالإضافة إلى فقدان مساحات من الأراضي الزراعية وما يرتبط بذلك من خسارة في المحاصيل والثروة الحيوانية. في الوقت نفسه، تُمثل ندرة المياه تحديًا كبيراً في المناطق الجافة وشبه الجافة نظراً لقلة تساقط الأمطار، وارتفاع معدلات التبخر. ويستلزم ذلك ضرورة معالجة ندرة المياه في تلك المناطق من خلال مجموعة متنوعة من الاستراتيجيات، مثل ممارسات الإدارة المستدامة للمياه، والتي تتضمن استكشاف موارد المياه المحتملة وزيادة إمداداتها. ومن بين موارد المياه المحتملة في المناطق الجافة وشبه الجافة حصاد مياه الأمطار، حيث يمكن بناء السدود لتجميع مياه الأمطار المتدفقة وتخزينها خلال موجات الأمطار المفاجئة وغير المنتظمة. ويمكن بعد ذلك استخدام هذه المياه المجمعة لأغراض مختلفة مثل الزراعة والاستخدام المنزلي وتغذية المياه الجوفية. وبالتالي يمكن أن تساعد هذه السدود في التحكم في الفيضانات، وزيادة إمدادات المياه، وتحسين القدرة على التكيف مع الجفاف، مما يدعم التنمية المستدامة لتلك المناطق. وبالتالي، ولتحقيق ذلك يجب أن يتم تصميم هذه السدود بشكل جيد واختيار مواقع مناسبة لها لضمان استدامتها وفعاليتها. يهدف هذا البحث إلى تطوير نهج قائم على الجيوماتكس لتحليل مدى ملاءمة متعدد المعايير لتحديد مواقع السدود لحصاد مياه الأمطار في منطقة نائية ذات إمكانات عالية للتنمية في الصحراء الشرقية بمصر. ولهذا الغرض، تم تطبيق منهجية من أربع خطوات رئيسية تشمل جمع البيانات، وتحديد نظام الصرف، ورسم خرائط لملاءمة مواقع السدود، وأخيراً تقييم المواقع المحتملة. أظهرت النتائج أن وادي أم تغر يتمتع بإمكانية جريان سطحي عالية وقابلية عالية للفيضانات المفاجئة. كما كشف تحليل الملاءمة أم الأجزاء الشرقية والجنوبية من الوادي، مناسبة لحصاد مياه الأمطار. من بين مواقع السدود الثلاثة المحتملة المقترحة، يتميز الموقع "ج" بأعلى سعة تخزينية وعمق، مما يجعله الأكثر ملاءمةً على الرغم من اتساع مساحة سطح خزان السد ووزيادة معدلات فقد المياه بالتبخر التبخر. وتُقدر سعة التخزين الإجمالية لخزانات السدود الثلاثة المقترحة بحوالي ٧.٢ مليون متر مكعب في ظل سيناريو السعة الكاملة.

الكلمات المفتاحية: التحكم في الفيضانات المفاجئة، التحليل المورفومتري، تحليل الملاءمة.

Introduction

Despite their generally dry conditions, arid regions receive rarely sudden heavy rainfall over a short period of time leading to flash floods with a wide range of catastrophic hazards (Mohamed and El-Raey, 2019) causing fatalities and economic loss (Zhang et al., 2021). Moreover, flash floods and subsequent deposition of large amounts of sediment in coastal water increase turbidity of water and threaten the natural ecosystems in coastal areas such coral reefs (Jones and Berkelmans, 2014). Meanwhile, Water scarcity is a significant challenge in arid and semi-arid regions due to their naturally minimal rainfall, which is sudden and irregular, and high evaporation rates. These areas typically receive limited rainfall, making it difficult to meet the increasing water demands of the growing population.

It is expected that climate change will exacerbate water scarcity by altering precipitation patterns, increasing the frequency and intensity of droughts and increasing water scarcity (Gosling and Arnell, 2013). These changes can further stress water resources in arid and semi-arid regions and may hinder attaining sustainable development. Also, the frequency of extreme weather events including flash floods, is expected to increase noticeably increase under different climate change scenarios (Zhang et al., 2021). Accordingly, the vulnerability to flash floods was repeatedly considered by the previous research work (Zhang et al., 2015; Shehata and Mizunaga, 2018; Mohamed and El-Raey, 2019; Hamdan and Khozyem, 2018; El-Magd et al., 2010; Elkhrachy, 2015). While other studies were concerned with assessing the impacts of flash floods on natural ecosystems in coastal areas (Jones and Berkelmans, 2014) and man-made infrastructure (Gabr and El Bastawesy, 2015).

This necessitates the need to address water scarcity in arid and semi-arid regions through a variety of strategies such as sustainable water management practices, which entails exploring potential water resources and augmenting water supply. Among other potential water resources in arid and semi-arid regions is rainwater harvesting (Helmreich and Horn, 2009). At the level of catchment area, varied water management structures can be constructed to capture and store rainwater runoff during the sudden and irregular rainy seasons. The collected water can then be used for various purposes such as agriculture, domestic use, and recharging groundwater. Moreover, such water management structures can assist in flood control, community water supply, and improved resilience to drought, which ultimately can contribute to sustainable development.

Water management structures harvesting in arid and semi-arid regions may include check dam, gabion, Gully plug, and stop dam. Generally, check dams are usually suggested for lower order streams in flat or gentle slope terrain. Also, check dams are suitable for soil type of less to medium permeable. Gabions are retaining walls made of stacked stone-filled gabions tied together with wire. Meanwhile, gully plugs are stones placed across gullies or valleys to slow down the speed of flowing water for a variety of purposes including, for example, preventing erosion, trapping sediments and pollutants, and retaining soil moisture due to infiltration. Finally, stop dam is an artificial wall that is constructed to stop totally the flowing water and consequently reservoir is created to fulfill the demand for water (Saha et al., 2018). However, establishment of dams may have significant impacts on ecosystems and downstream. This, consequently, requires proper design and site selection of such dams to ensure their sustainability and effectiveness. Therefore, a number of research work applied multi criteria suitability analysis for either assessing the locations of existing dams (Tata et al., 2024) or siting new dams (Pathan et al., 2022; Karakuş and Yıldız, 2022; Hagos et al., 2022).

The suitability analysis for siting dams should consider a number of criteria that ensure a set of appropriate conditions supporting maximum level of rainwater harvesting. The most common criteria employed for siting dams for rainwater harvesting in arid and semiarid regions typically including elevation, slope, soil type, land use/land cover distance to streams, distance to human settlements and distance to roads (Ammar et al., 2016). Generally, the suitability for dam construction has curve linear relationship with the elevation, where areas of moderate elevation are more suitable for dam construction compared to low and high elevations. Meanwhile, suitability for dam construction is inversely related to slope, where areas with smooth or gentle slope sites are more suitable for dam construction than steep slopes (Wang et al., 2021). It is worth mentioning that slope is a critical criterion in the case of small structure check dams as they require gentle slopes to reduce the velocity of runoff. However, in the case of conventional dams, which involve huge structures, slope criterion can be overlooked compared to other factors such as the catchment area, which should be large enough to ensure maximum water harvesting. In this respect, it was argued that the catchment area one of main is a prerequisite for determining the location of the dam (Wang et al., 2021). As high order streams in downstream parts have usually a relatively large catchment area, the downstream parts of a basin are more favorable for siting dams compared to upstream parts.

Also, the suitability for dam construction is directly related to the proximity to roads network and proximity to human settlements to reduce the costs of water transportation, (Karakuş and Yıldız, 2022). Moreover, due to the varied infiltration rates of different type of soil structure and thus their water holding capacity, areas with soil structure that has high infiltration rate such as sand is poorly suitable for constructing dam, while areas with clay soils are highly favorable (Dai, 2016).

Generally, the analysis criteria for siting dams in arid and semi-arid regions can be classified into here main categories: topographic, environmental, and socioeconomic aspects. The topographic criteria include elevation and slope, while environmental criteria comprise soil texture and land use/land cover pattern, and socioeconomic criteria include proximity to roads network and proximity to human settlements.

Despite different analysis models of multi-criteria suitability analysis, the previous research work applied Weighted Overlay Analysis, which represents the reality in a discrete space model, and require prior knowledge on the threshold limits for considered criteria and associated indicators identifying discrete levels of suitability accepts. Such a discrete space model may overlook subtle variations in the criteria considered and the results of the analysis may be misleading. Therefore, Fuzzy Overlay Analysis is more appropriate as it doesn't require prior knowledge on threshold limits of the considered criteria, and produce continuous suitability levels (Hassaan et al., 2021).

This paper is intended to develop a Geomatics-based approach for multi-criteria suitability analysis for siting dams as water harvesting structures on a remote area with high potentials for development in in eastern desert of Egypt.

Study area

The study area, Wadi Um Toghr, is in the northern part of the eastern desert (Figure 1), which is characterized by rugged terrain dominated by elevated mountains that are separated from the Red Sea coast to the east by a narrow coastal plain, where some small towns and tourist centers such as Safaga, El Qusseir, and Hargada are located. These mountains are essentially composed of that are formed mainly of igneous and metamorphic rocks, are sharply incised by deep, canyonlike wadies that discharge rainwater either toward the Red Sea or the Nile valley. The altitude of Um Toghr varies from 18 to 1417 meters above mean sea level. Despite the study area having arid climate conditions with limited rainfall, it sometimes receives irregular sudden and heavy rainfall events, which lead usually to flash flood representing a risk for the infrastructures and properties. For example, it was reported that the area has been exposed to seven events of flash floods during the period 1980-2000 (Saber et al., 2018). During the last two decades, the Red Sea coast region in general and Safaga area have been experiencing an increasing trend in the frequency and severity of flash food events. These flash foods pose significant threats to local communities, infrastructure, and the tourism industry in the Red Sea region (Abdelgawad et al., 2024). However, these flash flood events may represent a potential source of non-conventional freshwater resources that can support harvested (Baldi et al., 2020).

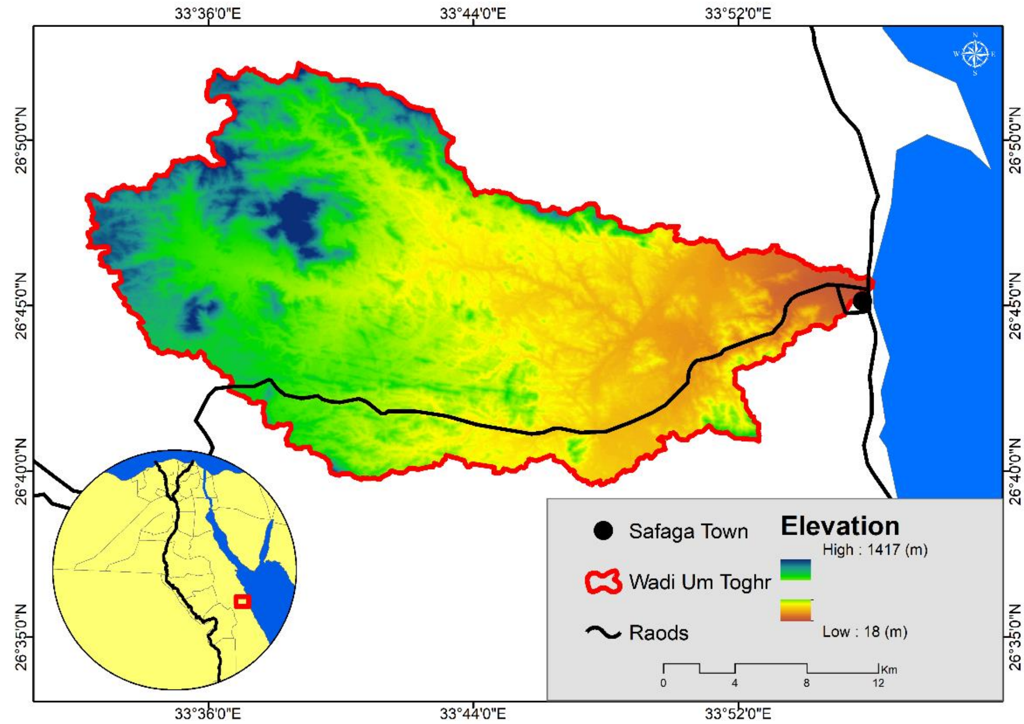

Figure (1): Study area situation

It should be noted that the analysis of rainfall data is essential for water harvesting as it may get insight into the flood discharges. For this purpose data on daily precipitation rate in Um-Taghr watershed during the period 1990-2025 was collected from The Climate Hazards group Infrared Precipitation with Stations (CHIRPS) dataset that provides a long period records on daily precipitation at a relatively high resolution (0.05°) (Funk et al., 2015). CHRISP data over the period 1990-2025, was downloaded through Google Earth Engine, which is an Internet-based platform that provides cloud-based computing algorithms (Gorelick et al., 2017).

Data and Methodology

To achieve the objective the paper in hand, a methodology of five main steps was suggested (Figure 2) as follows:

- Step I: Collecting data

This step involves identifying the analysis criteria based on different criteria discussed earlier in the introduction and the study area characteristics. It is worth noting that the analysis criteria should ensure a high level of comparability to differentiate between various parts of the study area. For this purpose, the potential analysis criteria were screened, and a short list of the most relevant criteria was developed. In this respect, four main criteria were selected to be considered in the suitability analysis including: elevation, catchment area, soil structure, and proximity to human settlements. Meanwhile, it was decided to ignore land use/land cover pattern due to the topography of the study area that is mostly hilly and mountainous, with a small town, Safaga, which is situated at the coastline of the Red Sea. Also, slope criterion was overlooked as the scope of the suitability analysis is for siting conventional dam rather than check dam. And finally, the proximity to roads was also disregarded as the study area has only one highway crossing the study area from the east to the west (Figure 1).

Upon identifying the most relevant criteria of analysis, necessary datasets on these criteria were collected, where a Shuttle Radar Topography Mission (SRTM) DEM was downloaded from Earth Explorer, which provides free worldwide coverage of satellite imagery-based DEM at a resolution of 1 arc-second (30 meters) (USGS, 2022). Tile no (n26_e033) of SRTM DEM covering the study area was downloaded. Also, The soil texture data was downloaded from World Soil Information, which provides downloadable global dataset of soil properties at a resolution of 250 meter (ISRIC, 2024). Meanwhile, the sites of different human settlements in the study area were digitized from topographic maps scale 1: 50,000.

- Step II: Delineating drainage system

This step involved employing Hydrology Analysis tool to extract drainage system, and catchment area of Wadi Um-Taghr through Hydrology Analysis tool (ArcGIS V. 10.8). in this respect, the acquired DEM was utilized to delineate flow direction, flow accumulation, extract drainage streams, and delineate the watershed of Wadi Um-Taghr.

- Step III: Mapping suitability for siting dams

This step is intended to perform multi-criteria suitability analysis to identify the potential sites of the dam with the maximum levels of water harvesting. For this purpose, soil map was classified, where various types of soil texture were assigned a preference value ranging from 1 to 5 based on their infiltration rates and thus their water holding capacity. Also, using GIS, Euclidean Distance tool, a raster surface representing proximity to human settlements was created. Moreover, the catchment areas of all high order streams (> 3) were delineated based on the drainage network systems of Wadi Um-Taghr produced in the 2nd

step. Thereafter, the delineated catchment areas were converted into raster surface.

Thereafter, the generated raster surfaces representing the four analysis criteria were employed to produce a preliminary suitability map through Fuzzy Overlay Analysis. According to Fuzzy Overlay Analysis, each considered criteria is transformed into a 0 to 1 scale, indicating the highest and least suitability levels, respectively. For this purpose, a variety of transformation algorithms can be applied to reflect the relationship between considered criteria and suitability. For example, "Gaussian" or "Near" algorithm can be applied to transform those criteria that have curve linear relationship with the suitability. Therefore, the midpoint of the input raster surface is transformed to the highest level of suitability and the suitability level decreases to 0 for values that deviate from the midpoint according to a normal curve. Meanwhile, "Small" algorithm is employed to transform those criteria that are inversely correlated with the suitability level, where small values of the input raster surface are transformed into highest level of suitability. In contrast, "Large" algorithm is directly correlated with the suitability level.

Upon transforming different raster surfaces depicting different criteria, they are integrated through Fuzzy Overlay analysis, to produce a continuous raster surface reflecting varied levels of suitability ranging between 0 and 1 for least and most suitability levels, respectively.

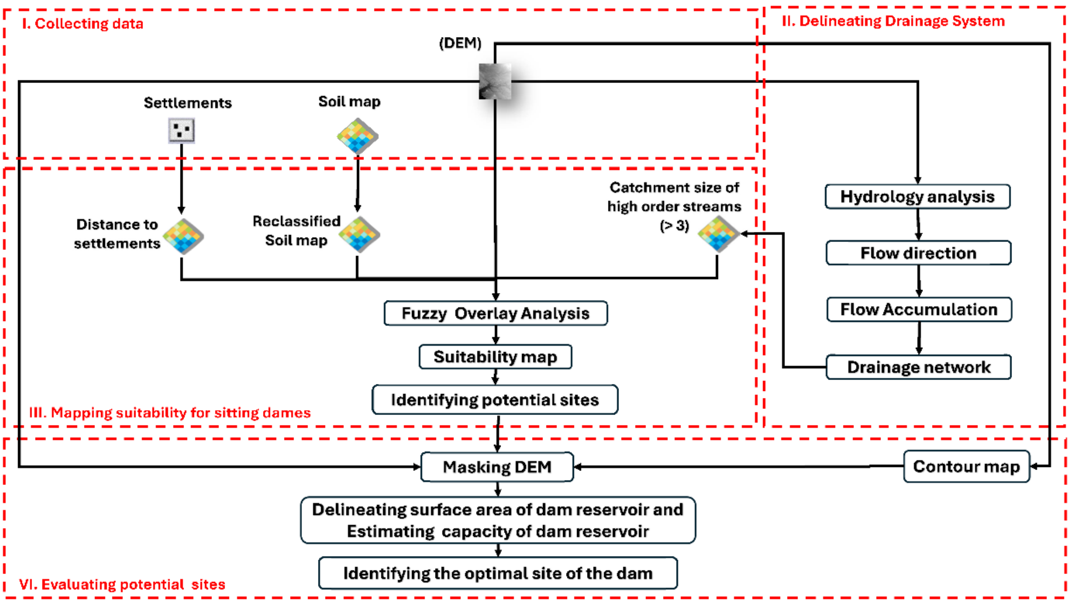

Figure (2): Methodology for identifying optimal site of dam for rainwater harvesting

- Step IV: Evaluating potential sites

Based on the preliminary suitability map and drainage system generated from the step II and step III, a number of suitable sites for water harvesting structures are identified. To evaluate each of these sites, a contour map was utilized to delineate the surface area of the reservoir of each dam under full capacity scenario through Spatial Analyst tools (ArcGIS V. 10.8). This is followed by masking the DEM by the extracted surface area of each dam reservoir under full capacity scenarios were. Thereafter, masked DEMs were employed in developing Area-Volume-Elevation (AVE) curve. Accordingly, the reservoir capacity of water harvesting structure in each site is evaluated using Spatial Analyst tools (ArcGIS V. 10.8).

Results and Discussion

The extracted drainage system of Wadi Um-Taghr watershed, which covers about 509 Km^2, has a dendric, tree like branching, pattern. Generally dendritic drainage pattern is characterized by irregular branching and spacing of the tributaries, where the tributaries join the upper stream order at acute angles (Zhang and Guilbert, 2012). Such a drainage pattern can be explained by the landscape of the area, which is characterized by the homogeneity of resistant bedrocks (Tripathi et al., 2017). It should be noted that the sixth-order outlet into the Red Sea suggests that Wadi Um-Taghr serves as a significant drainage catchment with a well-integrated fluvial system (Figure 3).

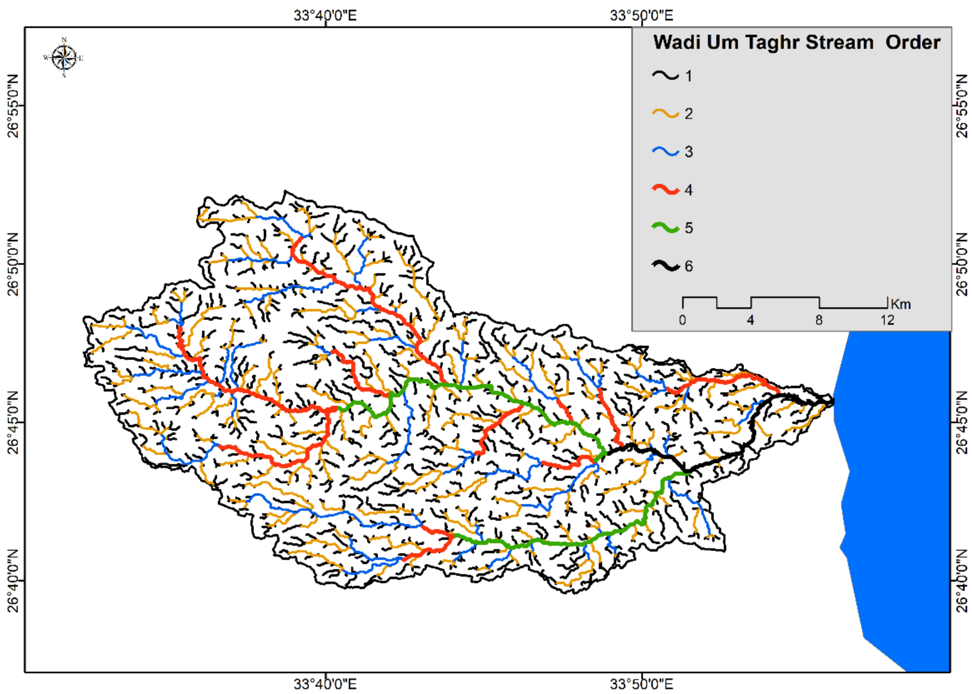

Figure (3): Drainage network of Wadi Um-Taghr

The drainage network of Um-Taghr Wadi consists of six stream orders, ranging from the smallest first-order streams to the main sixth-order trunk stream. (Figure 3). According to Strahler method, if two upper streams with equal order meet, then the downstream is assigned with the higher level in the two upper streams and in the case of meeting two upper streams with different order, the downstream is assigned with the higher level in the two upper streams (Dai, 2016). Generally, drainage system of Um-Taghr wadi was dominated by first-order streams, indicating a youthful drainage basin with high dissection and runoff potential. Also, it was noted that the number of streams decreases with increasing order, consistent with Horton's law of stream numbers. The large number of first-order streams, which accounted for 1057, indicates a youthful and highly dissected terrain with limited infiltration capacity, increasing surface runoff potential. The bifurcation ratio[1] of Wadi Um-Taghr tanged between 3 and 4.57 with an average of ~4.07, which suggests a moderately dissected basin. This can be attributed to underlying lithology or tectonic features. Also, **t**otal stream length also decreases with stream order, yet the average length increases, reflecting Horton's Law of Stream Lengths (Table 1).

Generally, it can be argued that the drainage network in Wadi Um-Taghr is in the early to mature stage of geomorphic development, where flash floods may occur due to limited infiltration and dense stream networks. Such consistent patterns in stream order and length ratios emphasize high susceptibility of Wadi Um-Taghr to flash floods, especially during intense and sudden rainfall events. This emphasizes the need for flood risk management in the wadi.

Table (1): Summary Statistics of drainage system of Wadi Um-Taghr

Stream order	No. of streams	Total length (km)	Average Length (km)
1	1057	498.9	0.47
2	265	299.3	1.13
3	58	127.2	2.19
4	13	71.3	5.48
5	3	37.6	12.54
6	1	16.8	16.81

[1] The bifurcation ratio is the ratio of the number of streams of a given order to those of the next higher order. It indicates structural control on the drainage pattern

The soil texture in Wadi Um-Taghr is predominantly composed of silt (53.75%) and sandy clay (45.13%). This means that over 98% of Wadi Um-Taghr is covered by low to moderately permeable soils while the other textures such as silty clay loam, sandy clay loam, and loamy sand cover less than 1% each. Both silt and sandy clay soil textures have moderate permeability, which means low infiltration capacity leading to moderate runoff potential and increase the risk of flash flooding,

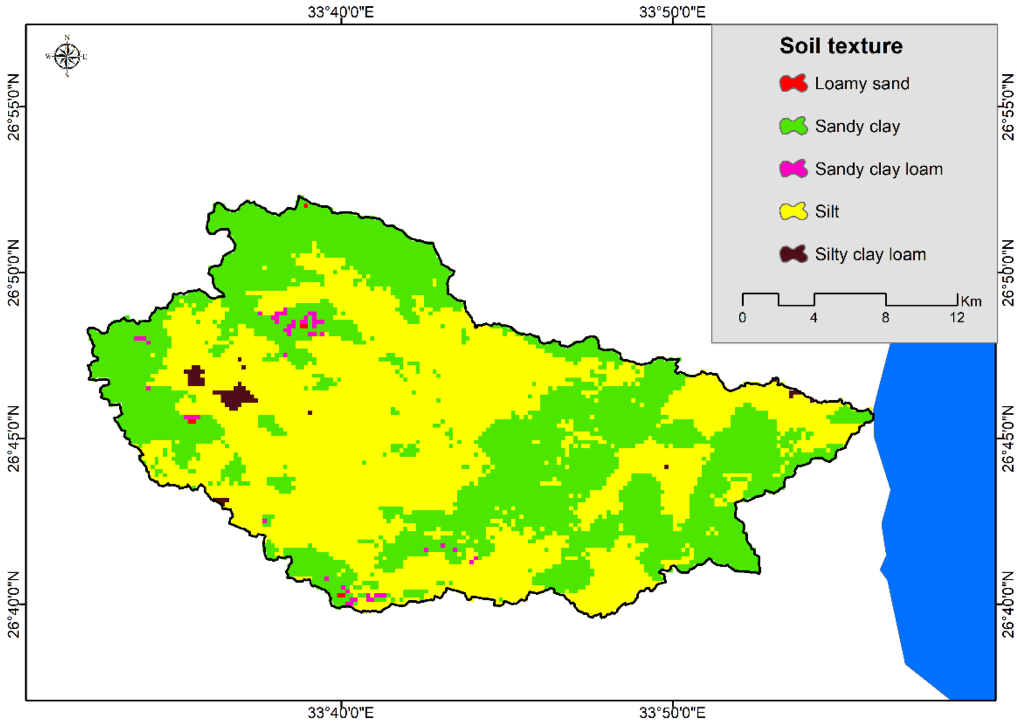

Figure (4): Soil texture in Wadi Um-Taghr

The transformed raster surfaces of four considered criteria revealed that different parts of Wadi Um-Taghr watershed have varied levels of suitability for siting water harvesting structures. Also, the same part within the watershed was found to have contradictory suitability levels according to different criteria. For example, while the middle parts of the watershed have high levels of relative suitability according to soil structure, they have a moderate level of suitability according to proximity to settlements. Similarly, north-eastern parts of the watershed have a high level of suitability according to proximity to settlements and catchment area, yet they have low level of suitability according to soil texture. Meanwhile, majority of the watershed have a low level of suitability according to elevation (Figure 5). This emphasized the importance of Fuzzy Overlay Analysis to evaluate the suitability for siting water harvesting structure in an integrated manner.

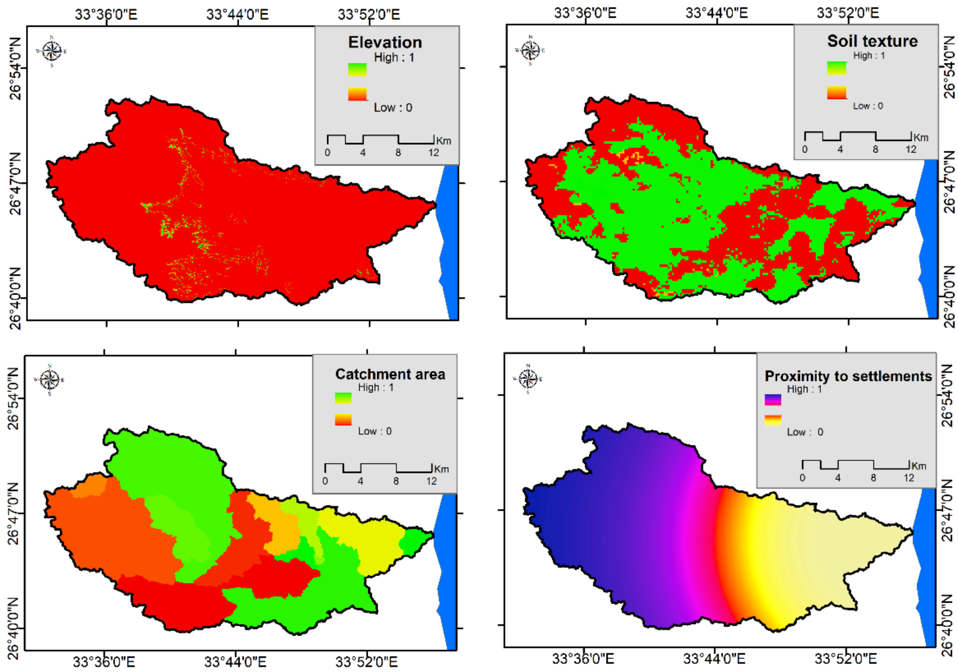

Figure (5): Fuzzy membership values of pixels for different criteria

The suitability map revealed that different parts of Wadi Um-Taghr have varied levels of suitability for siting dams, where the highly suitable areas are located mainly in the eastern and southern parts of the watershed (Figure 6). Therefore, these parts are more suitable for siting dams as they have the downstream of the wadi that ensure large catchment area and thus maximum water harvesting.

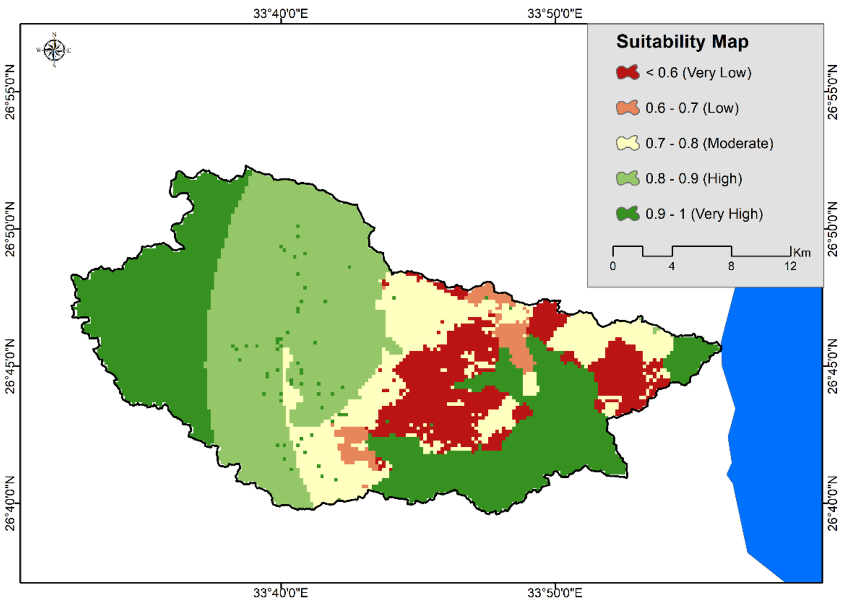

Figure (6): Suitability map

Major parts of the watershed area (422.08 km^2) have either a very high or high suitability level that represent together about 83.54% of Wadi Um-Taghr watershed (Figure 6). Meanwhile, 64.15 km^2 (12.7%) were found to have low or very low suitability levels (Figure 7). Also, minor parts of the watershed have moderate suitability levels (4%).

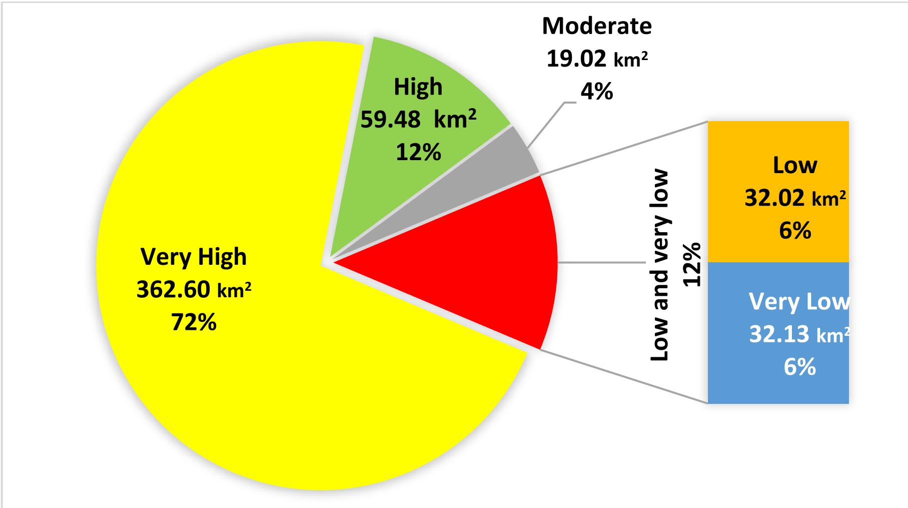

Figure (7): Relative distribution of Wadi Um-Taghr areas per different suitability levels

Based on the suitability map and drainage system, three potential dam sites can be proposed in very high suitable areas (Figure 8). Among these three proposed sites, the optimal site of the dam would generate a reservoir with the smallest surface area and the highest capacity. To delineate the surface area of the dam in each proposed site, the DEM was clipped by contour line that represents the level of water surface in each site.

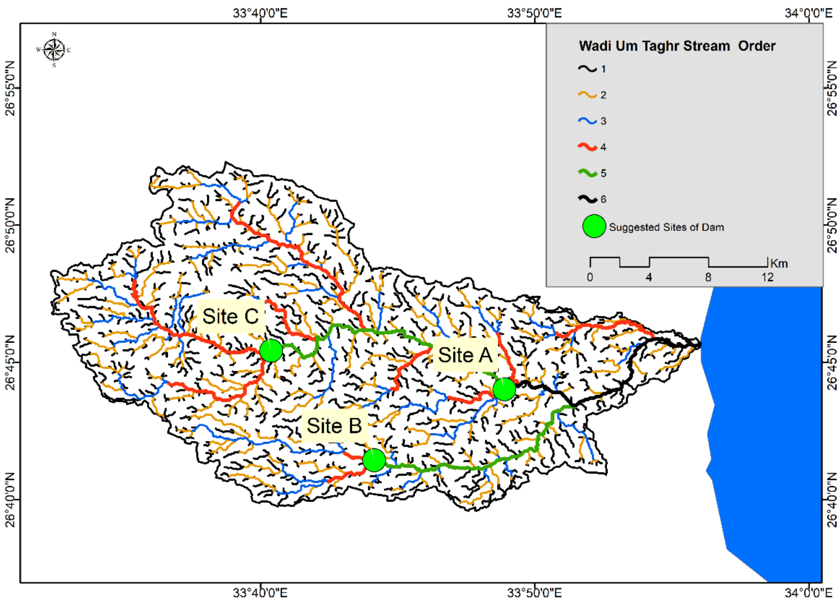

Figure (8): Proposed sites for dam

The elevation of bed levels at proposed dam sites were found to be 223, 360, and 440 m above mean sea level. The maximum crest height of the dams is estimated to be 231, 371, and 451 m above mean sea level at proposed sites “A”, “B”, and “C,” respectively. Meanwhile, the length of the dams’ walls, which were estimated to range between 180 and 350 meters in different proposed sites (Table 2).

To estimate surface area, storage capacity and depth of reservoir at different elevations were extracted using Surface Volume tool (ArcGIS 10.8). The extracted values were used to generate the area-volume-elevation (AVE) curve of the reservoir, which is usually employed to visualize the relationships between elevation, surface area and capacity of the reservoirs (Sayl et al., 2017). Based on area-volume-elevation (AVE) curve of reservoirs of proposed water harvesting structures in the study area (Figure 9).

The storage capacity of the Dams’ reservoirs was estimated to range between 611,000 and 3,697,000 m^3 (Table 2). Meanwhile, the surface area of the reservoirs is expected to cover a total area of 851,626 m^2 with a gross storage capacity of about 7.2 million m^3 under full capacity scenario.

Table (2): Attributes of dams and their reservoirs at the proposed sites

Site	Dam Attributes				Reservoir attributes		
	Minimum bed level at dam site (m)	Height (m)	Maximum crest height of dam (m)	Length (m)	Water surface elevation (m)	Surface area (m^2)	Volume (m^3)
A	222	9	231	345	230	176,384	840,600
B	343	28	371	180	370	133,648	611,100
C	437	14	451	350	450	541,594	5,697,000

Generally, it was found that the maximum depth of reservoirs of different dams at the three proposed sites under full capacity scenario were estimated to be 9, 28 and 14, meter at sites “A”, “B”, and “C”, respectively. Also, the depth of reservoirs is expected to be less than 10 meter in the case of site “A” and “B”, while only 39% pf the reservoir area is expected to have depth more than 10 meter in case of site “C”. It was found that reservoir in site “C” has the maximum surface area and storage capacity, which is followed by site “A”, while site ”B” is expected to have the minimum surface area and storage capacity.

It should be noted that the loss of water due to evaporation is inversely related to the depth and directly to the surface area of the reservoir. Based on this notion, it can be argued that the site “C” is expected to be more favorable for siting dam in the study area as it has the deepest reservoir, despite having maximum surface area and the longest width of dam.

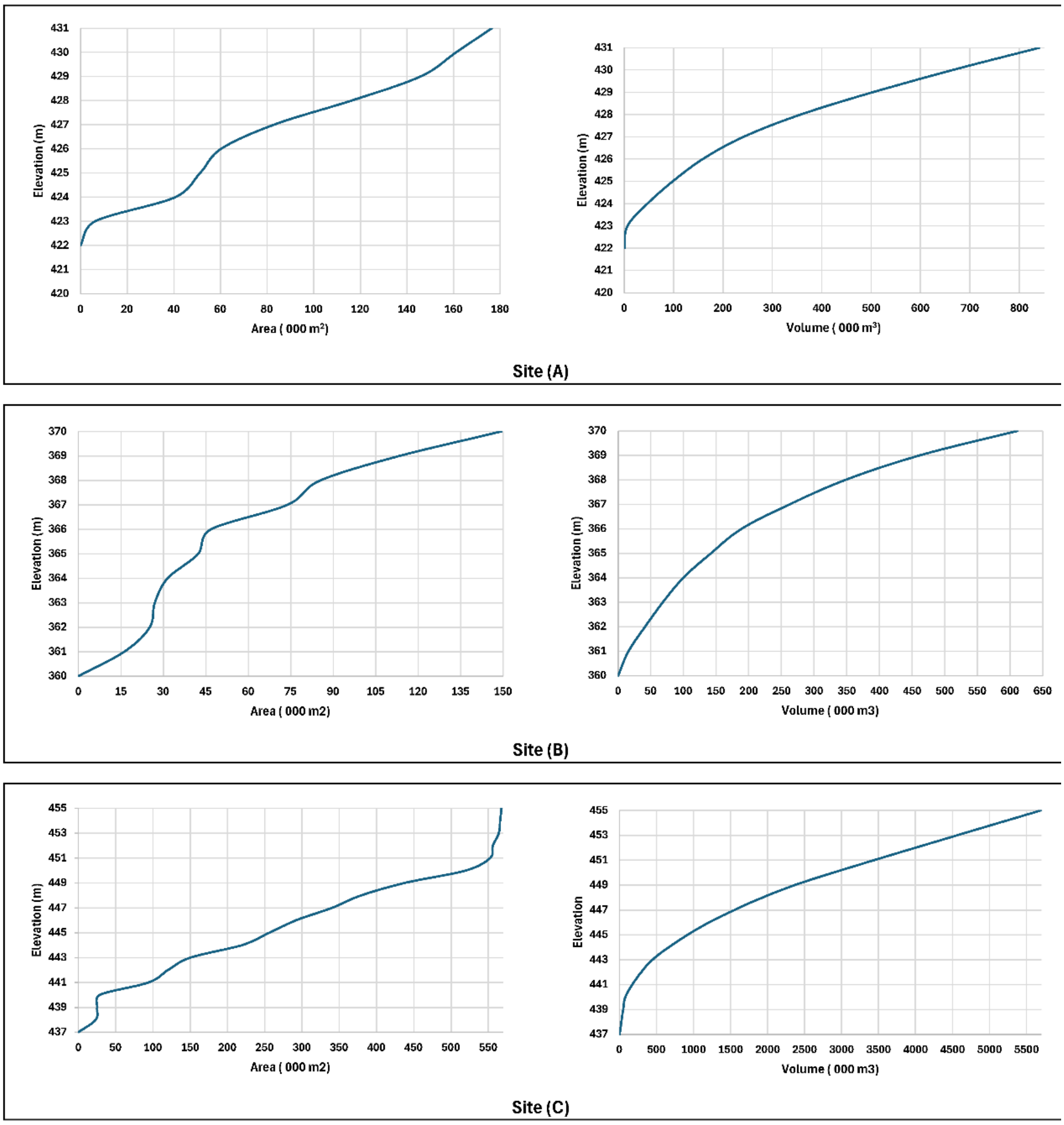

Figure (9): Reservoirs Area-Elevation and Volume-Elevation curve of dams in proposed sites under full capacity scenario

Conclusion

The study developed and applied a geomatics-based, multi-criteria suitability analysis using Fuzzy Overlay techniques to identify optimal sites for water harvesting structures in the Wadi Um-Taghr watershed. The watershed exhibits significant potential for rainwater harvesting due to its well-developed dendritic drainage network, limited soil permeability, and recurring intense rainfall events.

By integrating topographic, soil, hydrologic, and proximity-based criteria, the analysis revealed that over 83% of the watershed is highly or very highly suitable for dam construction, with the most favorable sites concentrated in the southern and eastern downstream areas. Among the three proposed sites, Site “C” was identified as the most optimal location due to its deep reservoir and highest storage capacity, which would minimize evaporative losses and maximize water retention. The results emphasize the importance of spatially informed, criteria-weighted approaches in water resource planning for arid and semi-arid regions, contributing to sustainable development, drought resilience, and flash flood mitigation.

It should be noted that the study focused on physical suitability and storage potential but did not evaluate potential ecological impacts of dam construction, downstream effects, or socioeconomic feasibility, including costs, community acceptance, or governance factors. Accordingly, future work should be conducted to assess the cost-effectiveness, and ecological trade-offs of the proposed dams to ensure environmentally and socially sustainable implementation.

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