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Rainwater Harvesting for Degraded Rangeland Rehabilitation in the Abu Fhihil Sub-basin, Riyadh, Saudi Arabia

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Abstract: In order to achieve the objectives set out in the Kingdom of Saudi Arabia's rangeland development strategy and its associated implementation plan, a series of programs, initiatives, and projects have been developed. One such project is the rehabilitation of degraded rangelands through the utilization of rainwater harvesting techniques. Indeed, in regions where water is scarce, rainwater harvesting represents an efficient solution for utilizing renewable water resources, thus contributing to the mitigation of the impacts of water scarcity in arid zones. Moreover, the deployment of rainwater harvesting techniques constitutes an important component in the restoration of degraded rangeland. The study was developed in accordance with a pre-established set of activities, as outlined in the research methodology. The proposed techniques for the collection of rainwater in the Abou Fhihil area are the construction of stone terraces on the hills and the construction of check dams in the main watercourse and gullies. Additionally, the construction of small crescent-shaped basins in the lower part of the area is recommended. The implementation of these hydraulic structures will result in the slowing down of runoff, the reduction of erosion and the recharging of groundwater. Furthermore, the construction of these hydraulic structures will facilitate the provision of water for trees, which will consequently exhibit accelerated growth.

Key words: Abu-Fhihil, degraded rangeland, rainwater harvesting, rehabilitation.

1. Introduction

Rainwater harvesting is regarded as an optimal method for utilizing renewable water resources. It facilitates the provision of supplementary water resources for diverse sectors. In the context of climate change, rainwater harvesting represents an effective adaptation measure with notable economic, social and environmental implications, particularly in arid and semi-arid regions [1]. The implementation of water harvesting techniques allows for the direct storage of surface runoff and rainwater in the ground. Additionally, the indirect method involves the collection, direction, and storage of surface runoff water in surface or groundwater storage facilities. The objective of water harvesting projects is to provide supplementary water sources for various applications, including human consumption, animal watering, and supplemental irrigation for crops, particularly during drought periods. Furthermore, these projects aim to increase groundwater levels and mitigate flooding. Water harvesting projects are also widely used in arid and semi-arid areas to develop vegetation cover, rehabilitate, and maintain degraded rangelands. The basic components of water harvesting systems are the watershed, storage techniques, and the target area [2, 3]. This work falls within the strategy of rangeland development in the Kingdom of Saudi Arabia, where the area of rangeland is estimated at about 146 million hectares, of which about 70% is degraded and requires work to restore and conserve it through protection, rehabilitation, rangeland management, and grazing organization. Many researchers have been interested in

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the issue of water harvesting and have studied the volume and coefficient of surface runoff using hydrological models and various other methods [4-7]. The initial stage of the investigation was dedicated to the evaluation of the current situation and climatic characteristics of the study area. The second axis was dedicated to the evaluation of surface inflow and the amounts of surface water runoff that could be harvested, in addition to the identification of the primary causes of rangeland degradation. The third axis focused on the solutions and procedures proposed for rainwater harvesting structures to rehabilitate degraded sites. The study revealed that the region experiences frequent, intense rainstorms, resulting in flash floods that cause soil erosion. Sediments transported by floods through gullies and wadis are deposited in depressions, contributing to the degradation and desertification of the watershed area.

2. Objective

The objective of this scientific paper is twofold: firstly, to present a synthesis of scientific knowledge and practical applications; secondly, to identify optimal methods and locations for implementing rainwater harvesting techniques in degraded rangelands within the Abu Fhihil sub-basin. The aim is to facilitate the rehabilitation of these rangelands, thereby reducing land degradation and soil erosion, and ensuring the sustainability of these ecosystems.

3. Methodology and Data

The methodology used and the data collected are described in the following sections. The study was based on the collection, analysis and processing of climate and water data, maps and satellite images, as well as field visits and measurements to further characterize and evaluate the situation at the study site. A DEM (Digital Elevation Model) was constructed using geographic information systems. The sub-basins, drainage network and morphometric characteristics of the watershed were extracted. A geomorphological and hydrological study of the site was also conducted. The characteristics of precipitation, its quantity, frequency and distribution were determined using the statistical software Hyfran [8]. In general, and in the same place, precipitation varies from day to day, month to month and year to year. Knowledge of these precipitation characteristics is essential for the study of surface runoff and for the development and management of watersheds .The present study comprises an analysis of precipitation on an annual and monthly basis. Furthermore, an analysis of the observed daily precipitation at the Thadiq climate station for the period 1984-2022 was conducted with the objective of calculating the anticipated water inflows to the Fhihil sub-basin. However, while the frequency of rainy days serves as an indicator of the overall wetness of the hydrological year, the actual runoff depends more on the specific type, intensity, and amount of precipitation, as will be demonstrated in the subsequent results. The methodology of this study was based on the following considerations:

(1) It is reasonable to consider precipitation falling on consecutive days as a single event.

(2) It is proposed that the SCS (Soil Conservation Service) method, which is described in detail in reference [9], be used. Surface runoff is calculated using the following equation:

$$Q = (P - I_a)^2 / (P - I_a + S) \quad (1)$$

Nevertheless, the SCS approach entailed the calculation of the CN (Curve Number) value. Furthermore, the surface runoff coefficient is determined on the basis of soil hydrological groups, land use, slopes and precipitation data. The USDA (United States Department of Agriculture) had previously classified four soil hydrological groups according to their composition and characteristics [10]. This method was selected for a number of reasons, the most significant of which were the absence of hydrological measurements (water levels and discharges) in the watershed and the lack and poor regularity of climatic measurements, particularly rainfall. Finally, peak flows and flood volumes have been identified. The implementation of appropriate rainwater harvesting structures at the selected sites is recommended, in accordance with the established criteria for determining the optimal locations and techniques for rainwater harvesting.

3.1 Peak Discharge

The maximum discharge is observed at the peak of the rainfall event. Following an exhaustive examination and assessment of the probability distribution of rainfall, the peak discharge for varying return periods was determined. This process requires determination of the concentration time (Tc), which plays a crucial role in the generation of surface runoff as a result of rainfall.

3.2 The Time of Concentration (T_c)

It refers to the time it takes for rainwater to reach the outlet of the catchment, starting from its most distant point. The concentration time is related to the morphometric characteristics of the basin. Many experimental equations have been adopted based on the characteristics of the basin, and therefore the Kirpich formula [11] is used to estimate the time of concentration, which is suitable for small basins according to:

$$T_c = 0.0195 \times L^{0.77} / S^{0.385} \quad (2)$$

where:

L: The longest watercourse (m);

S: mainstream slope (m/m);

T_c: concentration time (min).

The peak discharge time (T_p) is calculated as follows:

$$T_p = (T_c + 0.133 T_c) / 1.7 \quad (3)$$

where:

T_p: Peak time (hrs).

The peak discharge, Qp (m3/s), is calculated using the following equation, which takes into account both the concentration time and the peak time.

$$Q_p = 0.208\, A \times Q / T_p \quad (4)$$

A: area of the hydrological basin (km^2).

3.3 Estimation of the Volume of Surface Runoff Water

Although surface runoff plays an important role in the hydrological cycle for catchments, accurately predicting the coefficient and quantity of surface runoff remains a significant challenge, particularly in catchments without gauging stations (ungauged catchments). Prior to identifying potential sites for water harvesting, the SCS method was employed to estimate surface runoff water. This primarily requires rainfall data and the number (CN) as necessary inputs. The well-known SCS method [12, 13] was adopted for this purpose. As detailed in the UNESCO Technical Report [14], the runoff depth is calculated in accordance with the following equations:

$$Q = (P - I_a)^2 / (P - I_a + S) \quad (5)$$

The value of I_a is calculated as follows:

$$I_a = 0.2 \times S \quad (6)$$

The value of S, related to the value of curve number CN, is calculated as follows:

$$S = \frac{25400}{\mathrm{CN}} - 254 \quad (7)$$

If we replace the expression of "I_a" that is given in Eq. (6), we obtain the following equation.

$$Q = \frac{(\mathrm{P} - 0.2\ \mathrm{S})\ 2}{(\mathrm{P} + 0.8\ \mathrm{S})} \quad (8)$$

$$Q = 0, \text{ If } P < 0.2 \times S \quad (9)$$

This results in an equation with one variable, S, which can be obtained using the SCS method by considering the value of the curve number, CN.

where:

Q = runoff (mm);

P = rainfall (mm);

I_a = initial abstraction depth (mm);

S = the potential maximum retention, is indicated in millimeters.

The CN (Curve Number) parameter is employed for the calculation of the volume of surface runoff in a basin, taking into account the type of surface runoff, as well as the characteristics of soil and land cover in a specified area. The range extends from 100 for water bodies to approximately 30 for soil types with high porosity and rapid infiltration rates [10]. A high CN value indicates that most of the precipitation is lost as surface runoff, with only a minor proportion retained. Conversely, low values of the curve number indicate a high capacity of the soil to retain rainwater, resulting in minimal surface runoff.

4. Study Site

The study site is situated in the northern region of Riyadh, approximately 120 km from the city center (Fig. 1). Abu- Fhihil is located at latitude and longitude (Latitude: 25°18′9″ Longitude: 45°38′46″) in Al-Bir village, Thadiq governorate.

5. Sub-basin Characteristics

The area of the Abu Fhihil sub-basin is 18.53 km^2. Its perimeter is 35.9 km. By interpreting and analyzing satellite images and topographic maps, and by creating a DEM, purpose maps (elevations, slopes, sub-basins and drainage network) have been produced. Elevations range from 692 m above sea level to 892 m (Fig. 2). A variable slope from top to bottom characterizes the study area. In general, the area can be considered to possess a moderate but irregular slope, with variations in elevation across the study area. It is surrounded by some high hills from which most of the ravines, streams and tributaries originate. The average altitude is 792 m above sea level.

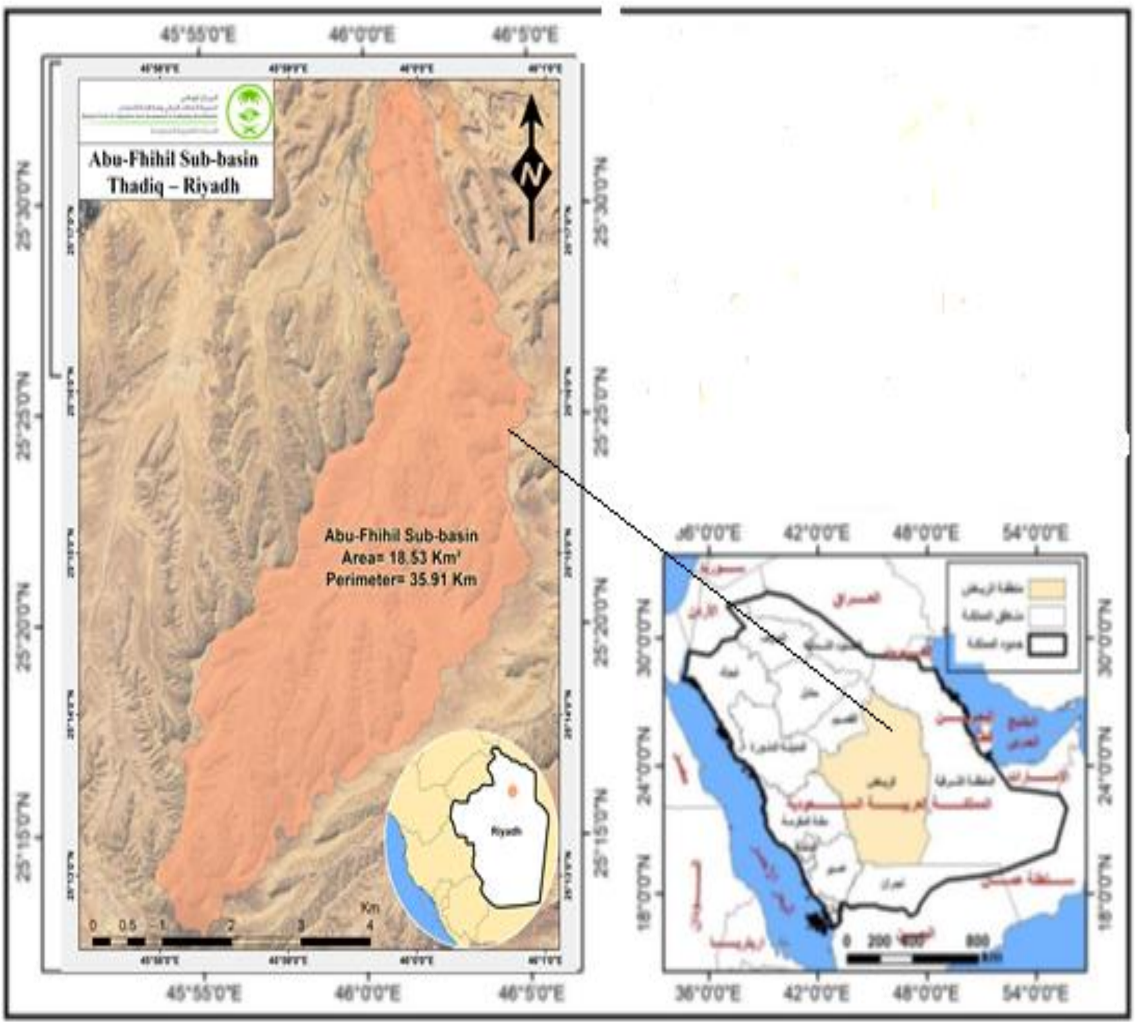

Fig. 1 Map of the study site of Abu Fhihil sub-basin, Thadiq, Riyadh.

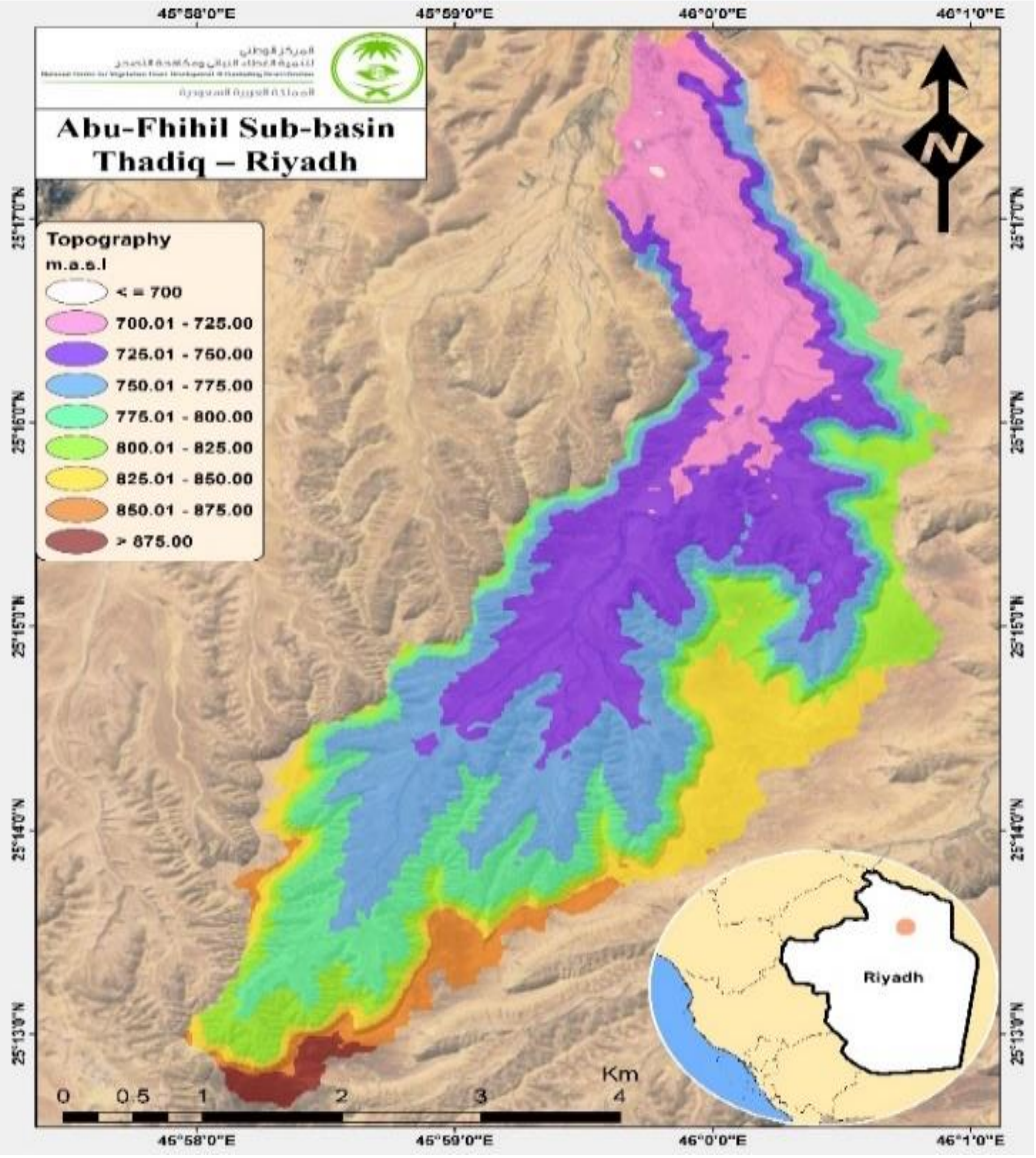

Fig. 2 Elevation map of Abu Fhihil sub-basin, Al-Bir, Riyadh.

In the study area, slopes range from 0 to 5%, Fig. 3. It can reach or exceed 30% in the plateau and hills.

The present study focused on the Abu Fhihil Sub-Basin area, which covers an area of 1,853 hectares. The area is elongated in shape and exhibits a compactness coefficient of 2.33. The Abu Fhihil Wadi traverses the area, which exhibits a slight slope of approximately 3%. The upstream area is characterized by the presence of sandy and clayey sedimentary soil, with a depth exceeding 1 m. The downstream area is distinguished by elevated topography and the occurrence of shallow calcareous gravel soil. This sub-basin is regarded as a degraded rangeland, particularly in the upper regions, for a number of reasons, including overgrazing, the quality and depth of the soil, the scarcity of precipitation, its poor consistency and distribution, and the frequency, duration and intensity of drought periods. During the field visits, a decline in the quality and diversity of the natural vegetation cover was observed. This was accompanied by the emergence of invasive and unpalatable plant species, the formation of a network of gullies and ridges (Fig. 4), and the development of surface soil erosion, particularly on the plateau and hills.

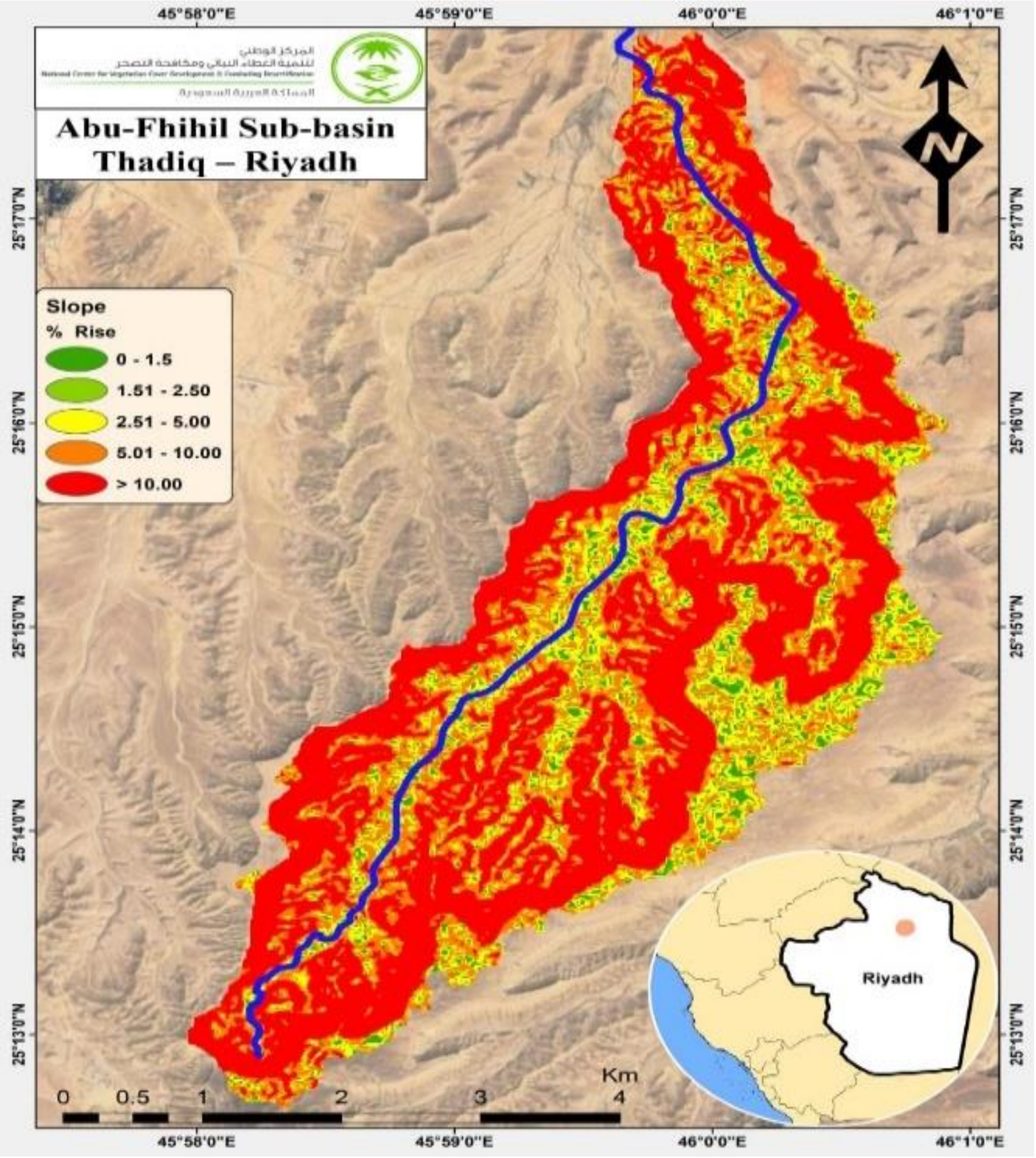

Fig. 3 Slope map of Abu Fhihill Sub-basin, Al-Bir, Riyadh.

As illustrated on the map, the Abu Hail sub-basin is characterized by streams and brooks of class 3 rank, with the formation of gullies (class 1) observed in the high areas. The main stream (Class 3) then develops gradually, as illustrated in Fig. 4.

6. Results and Discussions

6.1 Rainfall Data Analysis

The Thadiq station was utilized, bearing the designation 00473 R116. Its geographical coordinates are as follows:

Longitude: 45°37′00; latitude: 25°20′00; Elevation: 670.00. The data set comprised daily and monthly rainfall records from the Thadiq meteorological station, which is situated in close proximity to the study site. The data were sourced from the MEWA (Ministry of Environment, Water and Agriculture) and encompass the period between 1984 and 2022. The recorded data series was characterized by numerous gaps, largely attributable to a dearth of data in certain years, as well as the presence of some anomalous measurements. The data set was completed by downloading data published

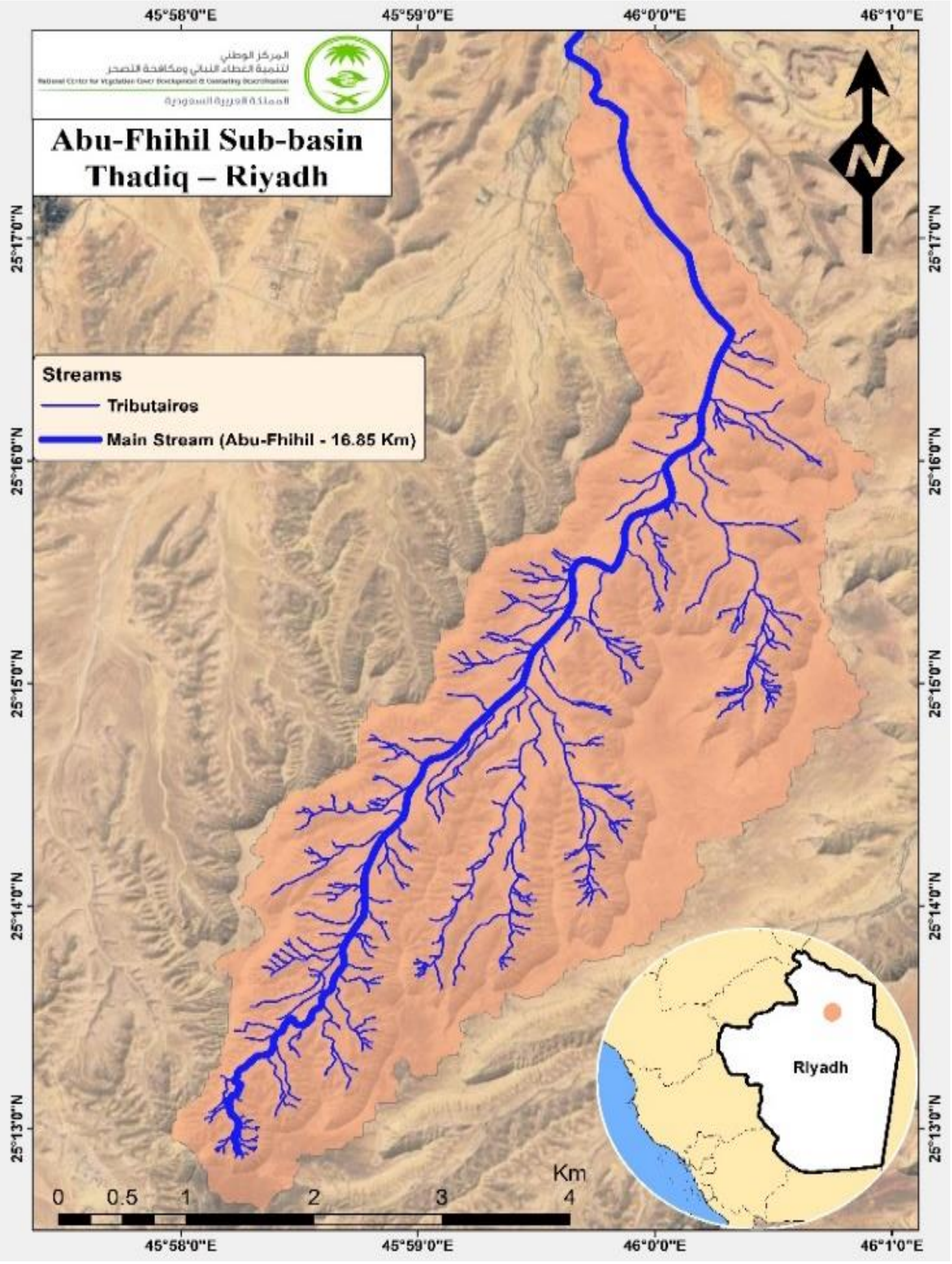

Fig. 4 Abu Fhihil drainage network map.

on certain websites (in Thadiq, Saudi Arabia Historical Data), checking, and correcting any outliers.

6.2 Data Analysis and Processing

The mean temperature in August is 36.4 degrees Celsius, while in January it is 9.8 degrees Celsius. The maximum temperature in the summer months is 45 degrees Celsius, with the potential for higher temperatures, while the minimum temperature in the winter months is 5 degrees Celsius. The region is typically characterized by elevated summer temperatures, a dry climate and relatively low winter temperatures. The average reference evapotranspiration is approximately 6.6 mm per day, reaching 10.7 mm per day in July and 2.7 mm per day in January. The humidity levels range from 15% to 48%.

6.2.1 Annual Rainfall

The mean annual precipitation is 103.7 mm. There is considerable variation from one year to the next. Fig. 5 illustrates the annual rainfall distribution at the Thadiq station.

In years with low precipitation, the annual rainfall is 62 mm, occurring once every three years on average (Table 1). In contrast, during years with high precipitation, the annual rainfall can reach 120 mm. The probability of annual rainfall reaching 120 mm is 66% (equivalent to two out of three years). The objective of water harvesting techniques is to provide supplementary water sources for plants and crops over a two-year period, with the intention of sustaining them for a three-year cycle.

The following table gives a summary of the annual precipitation depths (XT) for dry and wet periods for different return periods.

Considering that the rainy season in the study area begins in November (the hydrological year), it is clear that water collection and harvesting facilities play a key role in the use of water mobilized during the dry months (May to October) to support the seeds sown and the rangeland trees and shrubs planted, especially in the early years.

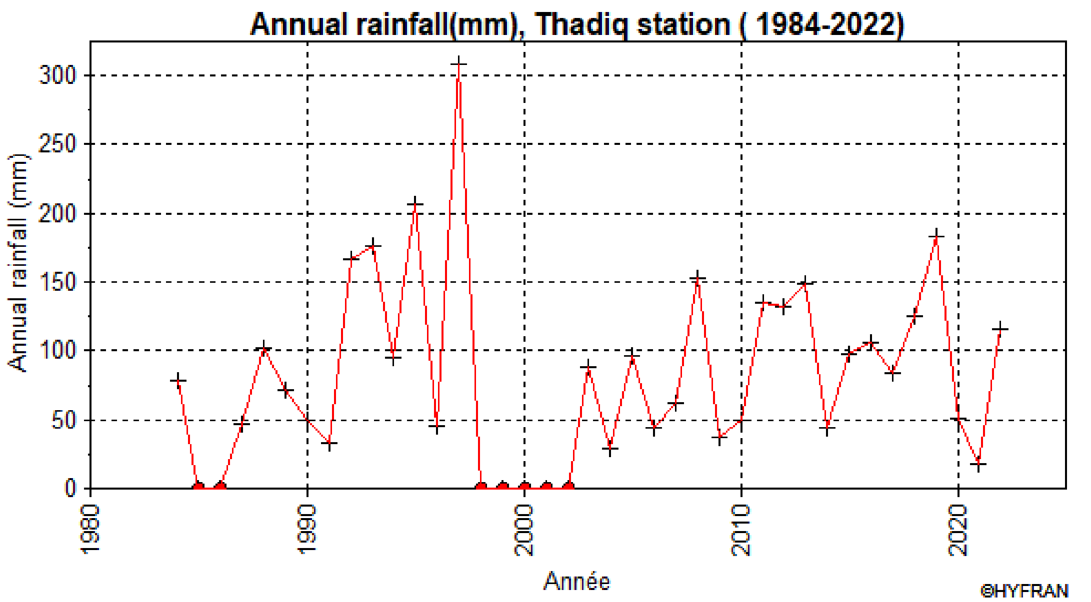

Fig. 5 Distribution of annual precipitation in Tahdiq (1984-2022).

Table 1 Annual precipitation depth at different return periods.

	Wet period				Dry period		
Return Period (years)	10	5	3	2	3	5	10
XT (mm)	180	140	120	89	62	48	30

6.2.2 Monthly Rainfall

With regard to the distribution of monthly rainfall, as illustrated in Table 2, it can be posited that the rainy season in the study area extends from November to May. The remaining months are characterized by a lack of precipitation. In the context of rainwater harvesting projects, it is essential to consider the seasonal distribution of rainfall in order to optimize the harvesting of available water resources and to determine the optimal timing for seed sowing and the planting of trees and shrubs.

Table 2 Statistical parameters, monthly rainfall, Thadiq station (1984-2022).

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Mean(mm)	10.41	6.66	21.17	22.15	5.76	0.02	2.14	0.17	0.00	1.29	21.51	12.44	103.70
Max.(mm)	59.63	44.33	90.00	115.50	32.19	0.50	57.80	3.15	0.00	28.90	192.80	106.00	307.80
Min.(mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.2
Standard deviation (σ)	17.12	10.51	25.78	28.31	9.57	0.10	11.12	0.63	*	5.69	46.45	23.23	68.01
CV	1.64	1.58	1.22	1.28	1.66	5.10	5.20	3.71	*	4.42	2.16	1.87	0.66

The mean monthly precipitation at the Thadiq meteorological station is as follows (Fig. 6).

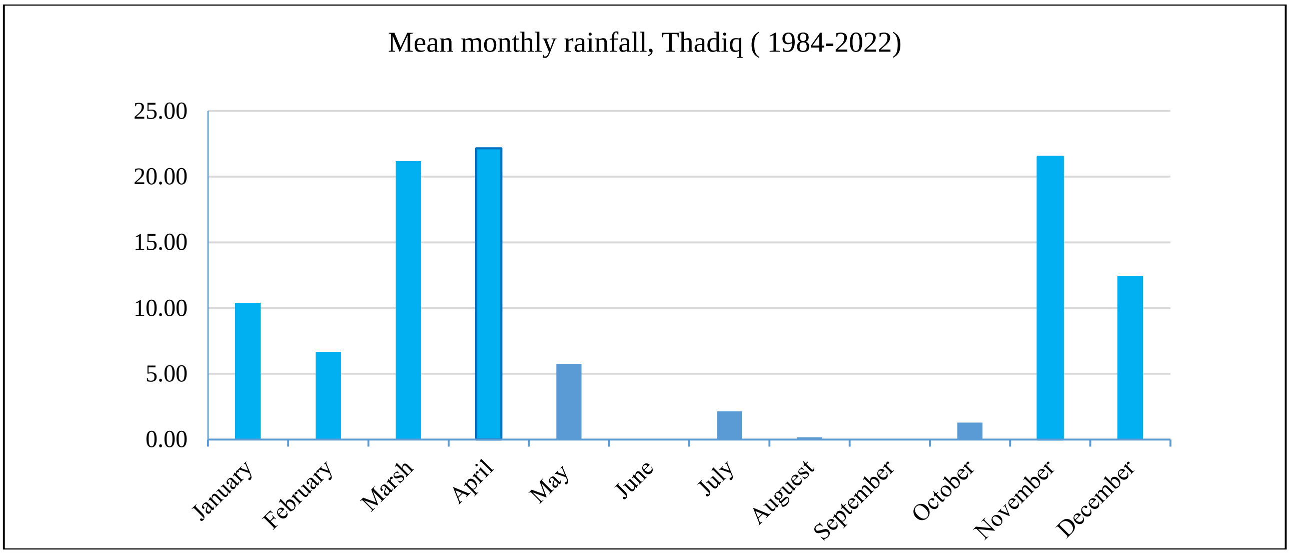

Fig. 6 Average monthly rainfall at Thadiq weather station.

The CV varies from 12.2% to 52%. A higher CV means greater dispersion around the mean. It is notable that March and April are the months with the highest precipitation levels, with the rainy season in the Thadiq area commencing in November and concluding in April. This indicates that the optimal period for planting trees and shrubs is during October and November, prior to the onset of the rainy season. Despite the limited and sporadic nature of the rainfall in the study area, it can potentially result in flash floods.

6.2.3 Daily Rainfall

Following an analysis of the annual, monthly and daily rainfall data, it was determined that the number of days with precipitation at the study site is, on average, six days per year, with instances of up to 30 days of rainfall occurring in some years. The mean number of days with precipitation exceeding 8 mm per day is 2 days, with an average of two storms per year. In extreme cases, there are 9 days per year with precipitation exceeding 8 mm per day. The frequency of rainfall events per year is indicative of the limited, scarce and variable nature of rainfall in the study area. The maximum daily rainfall records were analyzed in order to determine the maximum daily rainfall values for different return periods. The most appropriate statistical method for this purpose was found to be the Gumbel function distribution (Fig. 7). The following Table 3 presents the principal statistical indicators of maximum daily rainfall at the Thadiq station.

The study of extreme daily rainfall is typically conducted using extreme value probability distribution functions, such as Gumbel's law. An inappropriate selection of distribution law may result in inaccuracies in the estimation of rainfall values associated with varying return periods [15]. This study demonstrates that Gumbel's law is an appropriate and applicable probability distribution function for the data set, as the rainfall records are fully consistent with this law (Fig. 7). The empirical probability of non-exceedance, FN(xi), is given by the following equation, which is dependent on the plotting position of the Weibull function:

Table 3 Statistical indicators of maximum daily rainfall Thadiq station.

Station name	Years (1984-2022)	Mean rainfall (mm)	Max. recorded rainfall (mm)	Min recorder rainfall (mm)	Standard Deviation (σ) (mm)	Year recorded max daily rainfall	Coefficient of variation (C_v)
Thadiq	40	23.74	57.8	6	12.99	2022/07/31	0.55

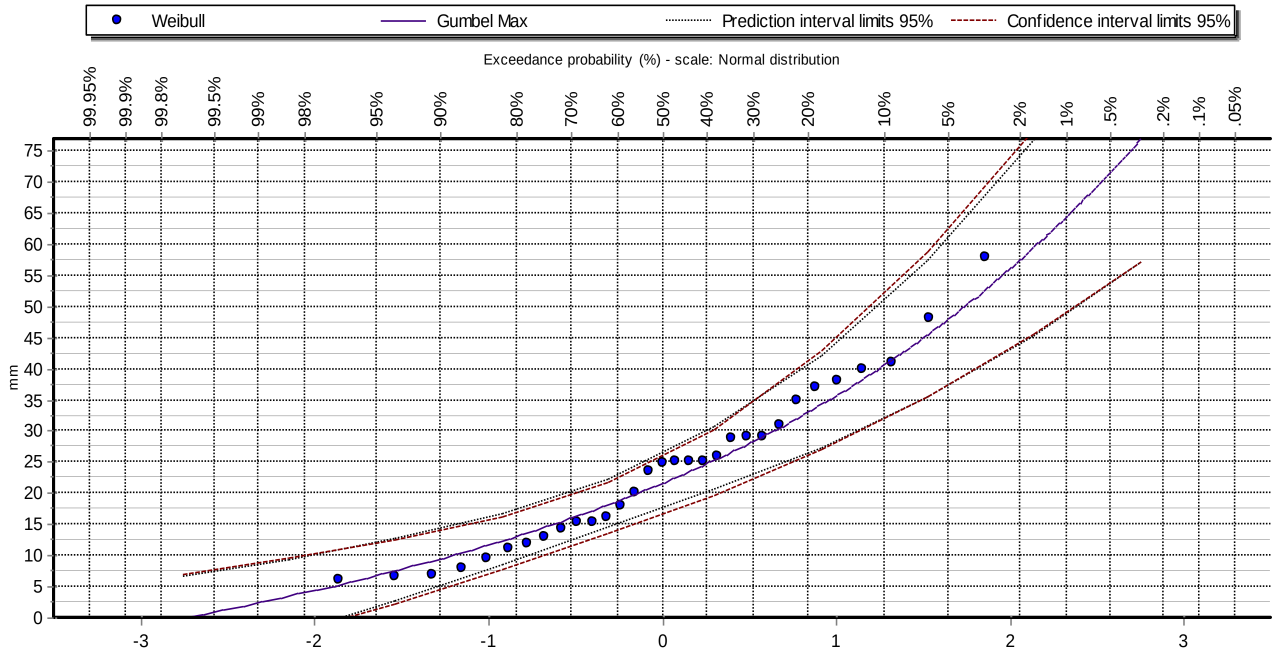

Fig. 7 Distribution function of maximum daily rainfall in Thadiq.

Table 4 Maximum daily rainfall values for different return periods according to the Gumbel distribution and the Log-Normal Distribution.

Return period, T (year)	2	3	5	10	20	50	
XT (mm)	21.6	27.03	33.08	40.7	47.98	57.43	Gumbel
	20.82	25.96	32.04	40.12	48.33	59.9	Log$N$

$$FN(x_i) = r(x_i)/(N + 1) \tag{10}$$

where N is the length of the sample (equal to the number of recording years) and $r(x_i)$ is the rank of the rainfall value x_i, sorted in ascending order, with i = 1, …, N.

The maximum rainfall values for different return periods have been derived and are presented in Table 4.

6.3 Discharge and Volumes

The estimation of peak flow (Qp) is calculated by applying equation 4, as outlined in the preceding paragraph 3. The time of concentration (Tc) of the catchment area is of significant importance in the calculation of peak flow. Direct surface runoff (excess precipitation) is estimated using the CN model (equation 8), which depends on land use and land cover, and the hydrological group of the soil. The runoff volume is the product of (Q) and the catchment area A. Using Equation 2 and applying it to the Abu Fhihil sub-basin, the estimated concentration time is approximately Tc = 36 minutes. Table 5 presents the peak discharge and volume of surface runoff values for different return periods (T) corresponding to maximum daily rainfall..

Table 5 Discharge and volume for different return periods.

T (years)	2	3	5	10	20	50
P (mm)	20.82	25.96	32.04	40.12	48.33	59.9
Q (mm)	3.98	6.75	10.55	16.24	22.54	32.03
Cr (%)	19.10	26.00	32.94	40.49	46.64	53.47
Q_p (m^3/s)	6.64	11.28	17.64	27.14	37.67	53.53
Volume (m^3)	73.682	125.055	195.570	300.976	417.725	593.514

About the study site of the Abu Fhihil sub-basin, the findings of the study conducted by Fouli et al. [16] indicate that the curve number CN is 88. A CN value of 88 seems realistic since the land is rangeland and the soil infiltration rate is low. The potential maximum retention value, defined as *S*, is 36.64 mm, while the initial abstraction value is 6.93 mm. Consequently, the relationship between rainfall (*P*) and surface runoff (*Q*) for the study area can be expressed as follows:

$$Q = \frac{(\mathrm{P} - 6.93)2}{(\mathrm{P} + 27.7\ )} \tag{11}$$

It is evident that precipitation levels below 7 mm in depth do not result in the generation of surface runoff. The mean number of rainstorms that result in surface runoff is three per year. The mean annual depth of surface runoff is 5.2 mm. The mean annual runoff coefficient is 16%. If we take the annual median, the resulting values for depth and runoff coefficient are 2 mm and 12%, respectively. The probability of 66% indicates that the probable annual precipitation in the wet period is approximately 120 mm. Conversely, the estimated annual rainfall for the dry period is 62 mm. Consequently, the corresponding volumes of surface runoff are 266.8 thousand cubic meters per year in the wet period and 137.8 thousand cubic meters per year in the dry period.

6.4 Rangeland Degradation in the Abu Fhihil Area

The causes of rangeland degradation can be either natural or anthropogenic in origin. The most significant natural causes are decreasing rainfall and increasing temperatures, climate change, and increasing drought [17]. Among the anthropogenic causes, poor rangeland management and irrational grazing systems are considered to be the most [18]. It is widely acknowledged that natural factors represent a primary contributor to the degradation of the Abu Fhihil rangelands, with varying degrees of impact across the sub-basin. Furthermore, the region has been subjected to extended periods of drought, accompanied by a notable decline in precipitation and over grazing. The degradation of rangeland has a considerable adverse impact on the economic and social aspects of local communities, as well as on ecosystems. In order to restore ecological balance in these degraded areas, it is necessary to implement a program of rangeland and ecosystem rehabilitation.

6.5 Identifying Suitable Sites for the Implementation of Water Harvesting Techniques

The identification of suitable sites for the implementation of water harvesting techniques represents a fundamental aspect of the process. A substantial body of research has been conducted by various scholars with the aim of identifying optimal locations and techniques for rainwater and floodwater harvesting [19]. Nevertheless, identifying the optimal methodologies and locations remains a challenging endeavor. In the study conducted by Ammar et al. [20], the primary methodologies employed for the selection of sites for water harvesting were classified and evaluated. The study identified three principal categories of criteria and characteristics that are most prevalent and employed in arid and semi-arid regions. The initial group of standards pertained to physical criteria, while the subsequent group incorporated social and economic considerations to supplement the former. In a study conducted by Oweis et al. [21], the researchers set minimum limits on the depth of the soil in order to ensure the viability of water harvesting methods. The study concluded that the depth of soil is contingent upon the planned activity in the rangeland area, which may include sowing seeds, planting shrubs and/or trees. For the planting of shrubs (contour shrubs), the recommended depth is 50 cm. Regarding the implementation of techniques for planting trees and seedlings (crescent, trapezoidal basins), the recommended depth is 90 cm. Similarly, for the implementation of earth contour terraces, the recommended depth is 100 cm. The most appropriate method of application in a given situation depends largely on the main objectives and needs of the project and the quality, availability and reliability of data. The Abu Fhihil basin can be subdivided into three distinct hydrological systems. Hills and plateaus act as the source of surface runoff. The soil is characterized by a shallow, gravelly composition, and the topography is characterized by moderate to steep slopes. The second hydrological system pertains to the ravines and the principal watercourse. The final area to be considered is the low-lying region located downstream.

6.6 The Following Techniques Proposed

Following the identification of the optimal locations for water harvesting, the most suitable techniques were proposed, Fig. 8. Despite the existence of a plethora of techniques [22], four techniques were proposed for implementation following an assessment of the current situation of the study area in the Abu Fhihil basin. The techniques proposed included the construction of dry stone terraces following the contour lines in the hills and plateau, the implementation of dry stone barriers in the head of the streams and gullies, the construction of check dams in the main watercourses, and the establishment of semi-circular bunds in the lowland area of the hydrological basin.

6.6.1 Dry Stone Barriers

A plethora of techniques exists for harvesting runoff water on hill slopes, including the use of stone terraces and contour lines, among others. It would be advantageous for rehabilitation efforts to concentrate on the implementation of techniques for the harvesting of rainwater and floodwater on the slopes of hills and plateaus, which represent the source area of surface runoff in the Abu Fhihil Basin. The construction of dry-stone barriers serves to reduce the volume of runoff on the plateau and hillsides, thereby facilitating water retention and enhancing the availability of water to plants. This, in turn, has been shown to improve plant growth, enhance soil quality, and mitigate the impact of water erosion. The planting of trees or pasture shrubs in these areas, upstream of the barriers, has the potential to accelerate the restoration of the ecosystem. This technique has demonstrated success and feasibility in developing vegetation cover and reducing erosion [23]. The stone barriers (contour terraces) proposed for the hills and plateau of the Abu Fhihil basin are widely used for the purposes of collecting water run-off and controlling soil erosion. In the hillsides and plateau area of the Abu Fhihil sub-basin, the management of the hills by dry stone terraces following the contour lines and the treatment of the gullies by stone bunds were recommended to stabilize the head of the streams and gullies, reduce run-off and conserve soil.

6.6.2 Check Dams

The principal techniques for the harvesting of water in gullies and valleys include the utilization of permeable dams reinforced with cement (concrete check dams) and porous or semi-permeable rock dams (stone terraces). Such structures act as barriers that intercept the flow direction of torrents and are often constructed from rock. They are built in valleys and tributaries, as well as in specific locations, with due consideration given to the height and slope of the site and the quality of the soil (rock dams built on degraded slopes). In the context of medium and high floods, the deployment of concrete check dams has the potential to serve as an effective means of reducing flood velocity and enhancing groundwater recharge. To prevent the flooding of watercourses, it may be necessary to construct check dams, which form part of the management of degraded rangelands. Such non-porous dams are commonly employed in pastoral settings. These dams assist in regulating and calming the flow of torrents, thereby

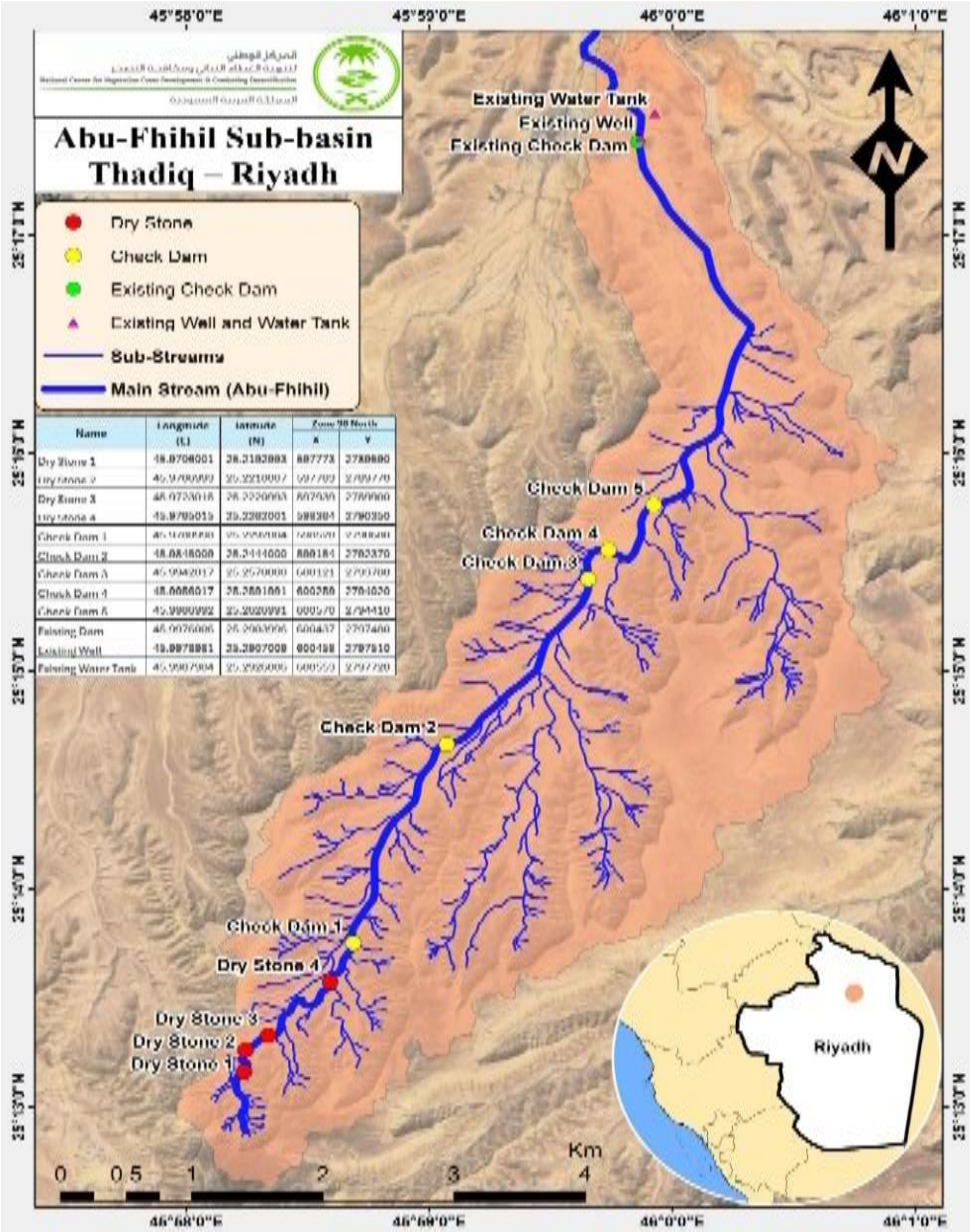

Fig. 8 Proposed techniques for rehabilitating the Abu Fhihl sub-basin.

stabilizing the bed of the watercourse and its banks [24, 25]. Furthermore, these dams facilitate the retention of water on site, either for agricultural purposes [26] or for groundwater recharge [27, 28]. In light of the characteristics of Abu Fhihil sub-basin, the construction of these dams will assist in the safeguarding of the pastoral trees that are dispersed along the waterway from potential damage. Furthermore, the construction of these dams will result in an increase in the volume of groundwater and the water level in the existing wells at the end of the basin. This will facilitate irrigation and support the establishment of the planned pastoral seedlings. These dams may become subject to infilling and deterioration. It is therefore essential that they are regularly monitored and aintained to ensure that they continue to perform their intended function. This work on the Abu Fhihil branch involved the construction of 11 check dams based on field studies and the topographical, geological and hydrological characteristics of the site. The dams were designed using the following methods:

(1) A survey of the watercourse was carried out and the locations of the dams were determined according to the criteria of slope, altitude and geological aspect, avoiding sinuous places, convergences of tributaries and branches and places with difficult access.

(2) The relationship between the water level and the surface area of each check dam site was also studied and the height was determined taking into account the preservation of the environmental aspect and the correct distribution of the flood water along the valley from upstream to downstream.

(3) Geotechnical tests were carried out to determine the depth of the foundations on which the dam would be built at each site. The dams were constructed at different depths, ranging from one to two meters below ground level, depending on the geology of the site and the results of the two-dimensional geoelectric survey at the dam sites.

(4) A height of 0.5 m above ground level was chosen to retain the water, which is the appropriate height for most check dams depending on the topography and slope of the valley. At this height, the flood continues its course through this spillway.

The body of the check dam was fixed by means of wings, which were built at both ends at a height of 40 cm to 50 cm above the level of the spillway.

6.6.3 Semi-circular Bunds

One potential technique for rainwater harvesting is the use of semi-circular or trapezoidal bunds, which can be employed to facilitate the planting of trees on the site. The proposed semi-circular bunds have the following dimensions: the diameter of the arch is 6 m, and the height of the barrier is 30 cm. The distance between the rows is 10 m (100 crescent arcs/ha) in a portion of the site area suitable for planting trees. The dimensions were selected to ensure an adequate runoff collection area and to consider the characteristics of the tree species. In the area where the slope is between 2% and 5%, the semicircular bunds can be implemented. The planting following the rows will be done alternately to achieve a closer approximation to the natural landscape.

7. Conclusion

This paper proposed some rainwater harvesting techniques for the rehabilitation of degraded rangelands in the Abu Fulfill sub-basin. The study produced significant findings pertaining to the assessment of peak discharge and surface runoff volume, as well as the identification of optimal locations for water harvesting within the study area. These findings will be utilized in the design of the water harvesting structures. Furthermore, the most effective water harvesting techniques to be deployed were identified within the study area. Notwithstanding the paucity of precipitation and the low surface inflow in the study area, the potential for rainwater harvesting and the maximization of rainwater utilization remain among the most significant measures in the Abu Fhihil sub-basin. This is particularly the case if the rainwater harvesting techniques are properly designed, as it is anticipated that over time, rehabilitation works will facilitate the development of vegetation cover and enhance rangeland productivity and sustainability. The implementation of techniques for the harvesting of floodwater and rainwater enables the collection and storage of water, thereby facilitating the spread of floodwater. The design and construction of check dams must be the subject of specialist studies before they are built, and under no circumstances should they be built without supervision. However, in order to ensure the security and longevity of the current water management strategies, it is imperative that grazing and access to the site be prohibited for a minimum of two years. It can be proposed that plans to rehabilitate degraded rangelands should consider the entire hydrographic basin, including the plateau, hills, waterways and downstream area, in order to develop and maintain the rangeland.

The main recommendations that emerged from the implementation of this study area are as follows:

(1) The volume of surface runoff at the study site is limited and occurs during exceptional rainfall events. It is therefore important to assess the intensity of precipitation events rather than annual precipitation rates when designing water-harvesting facilities.

(2) Rainwater harvesting (RWH) techniques represent a viable solution for augmenting water resources, thereby contributing to the rehabilitation and development of rangeland. Nevertheless, the implementation of these techniques requires the involvement of farmers, who require guidance and follow-up.

(3) It is important to complete the development of the Abu Fhihil sub-basin and propose it as a model demonstration site (field school) for rainwater harvesting, optimal use of natural resources and rangeland development, and to work on spreading this experience to other areas. The implementation of effective rangeland rehabilitation projects requires a multifaceted approach that integrates scientific and practical expertise. This encompasses the undertaking of field surveys to assess plant and soil conditions, the execution of technical and engineering studies, and the deployment of optimal techniques for water harvesting.

(4) It is recommended that a research study be developed to examine the impact of erosion control and water conservation structures on the magnitude and characteristics of floods and groundwater recharge in the Abu Fhihil watershed in Riyadh, Saudi Arabia.

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