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**Purposeful scientific research as a pillar of sustainable development**

# choosing suitableasites for water harvesting process in al-rakash basin, west of karbala governorate by using remote sensing

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## ABSTRACT
The research area is roughly 420 square kilometers in size and is situated inside the Karbala Governorate from the southern region of Wadi Alubaidh to the northern extension of the Razzaza Lake District, has elevations ranging from 43 to 214 m above sea level. The predominant climate in this area is described as desert, with a tendency toward exceptionally dry weather. The region receives 108.2 mm of rainfall on average each year. The average yearly temperature is 31.8 ºC due to the climatic conditions. A noteworthy 18.46mm water surplus, or 17% of the total reported rainfall, is noted. Careful evaluations of the Rakash Basin's linear, aerial, and relief features were necessary to perform a comprehensive amorphometric study. The streams in the Rakash Basin can be categorized as seventh order streams, according to this analysis. An important hydrogeological feature of the area is the existence of aquifers, with the Al-Dammam Formation emerging as the main water-bearing layer. An estimated 13.87 mm of groundwater recharge (GR) accounts for roughly 15.09% of all recorded rainfall. The majority of groundwater flow patterns originate in the west and southwest and eventually converge in the east and northeast. An average value of 0.0033 reflects this hydraulic gradient. Based on the Analytic Hierarchy Process (AHP), Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) have been combined in a complete approach. Making appropriate maps for groundwater recharge (GWR) and water harvesting (WH) locations is the goal. This method evaluates the relative importance of the factors affecting site selection in addition to outlining possible sites for these activities.

**Keywords:** Rakash Basin, Water Harvesting, Multi-Criteria Decision Analysis, Ground Water Recharge,Gis.

## 1. Introduction
water is essential For human survival and success, The presence of water is one of the most significant factors contributing to the formation and development of states. water supplies are extremely limited (Al-Ansari, 2013).
In its broadest definition, water harvesting is the process of collecting runoff for productive use. It usually entails concentrating precipitation from a larger region for storage in a much smaller area to reduce water loss.

Precipitation in arid and semi-arid regions is primarily below potential evaporation and is not uniformly distributed, resulting in frequent dry spells during the agricultural season, surface runoff, and valley erosion. Water harvesting is therefore crucial to preventing flood water from evaporating and allowing it to be preserved for later use.

In many nations throughout the world, Harvesting rainfall (RWH) or water (WH) has been pushed as a solution to the excessive exploitation of groundwater resources in recent decades (Buraihi, 2016). According to Buriahi (2016), water harvesting is a technique for gathering water that has been applied in arid and semi-arid regions where there is not enough rainfall to sustain crops development in both home and agricultural settings. Catching rainfall where it falls and storing it for later use or releasing it into groundwater is known as rainwater harvesting. It is also known as the collecting and storage of rainwater in surface or subsurface aquifers.

By building appropriate structures or altering land management practices to promote infiltration and aid in water conservation, surface runoff can be decreased. By improving groundwater levels and increasing WH assists with the amount of water per unit of planted area to alleviate the challenges of water scarcity, particularly for home and agricultural needs (Cook, 2000), The study region lies in Iraq's western region between the longitudes (43° 28 '- 43 ° 36') East and latitudes (32 ° 17 '- 32 ° 22') North at Karbala Governoratea. It encompasses a region of 420 km² (Figure 1) and (Figure2).

In terms of geology, The Dammam, Euphrates, and Nfayil rivers are used to order the outcrop formations in the research area from oldest to youngest Formations (Figure 3). Additionally, there are Quaternary deposits (Pleistocene- and Holocene) that are located southwest and south of the Rakash Valley and are represented by gypcrete, polygenetic deposits, and valley fill sediments. (Goff and Jasim, 2006).

The study's objective is to use remote sensing and GIS tools to identify potential locations for harvesting structures that would store water underground. Additionally, morphometric analysis of the drainage basin will be performed in order to comprehend the Rakash Valley's hydrological and morphological features.Abbreviations should be defined at first mention and used consistently thereafter. Abbreviations should not be used only once unless it seems necessary for clarity.

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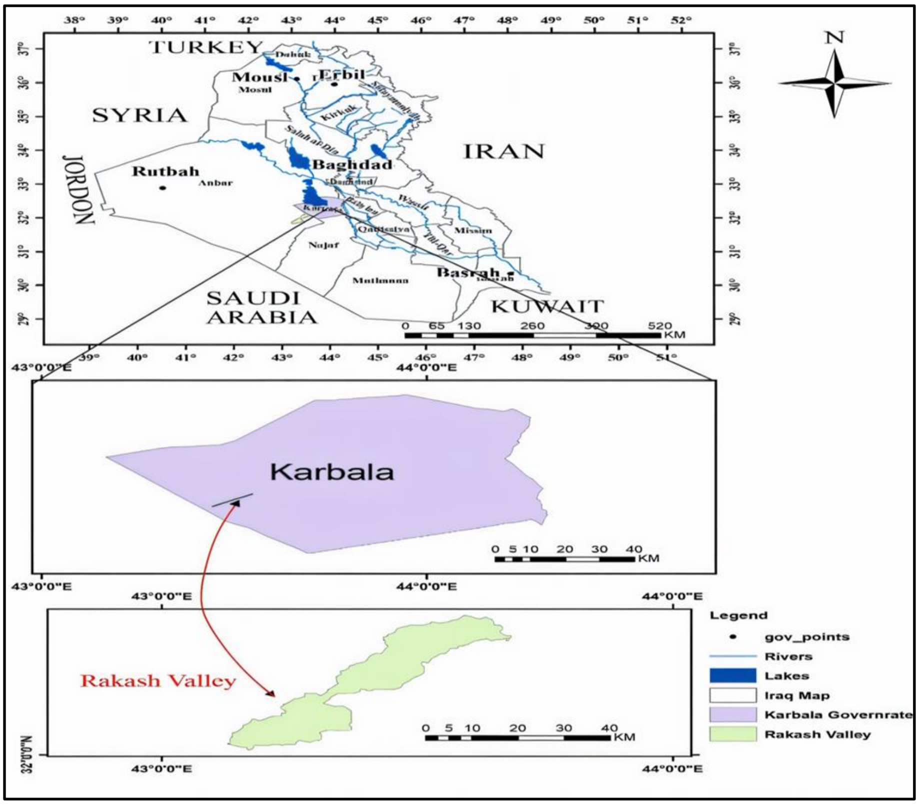


**Fig. 1.** Location map of the study area showing the Rakash Basin

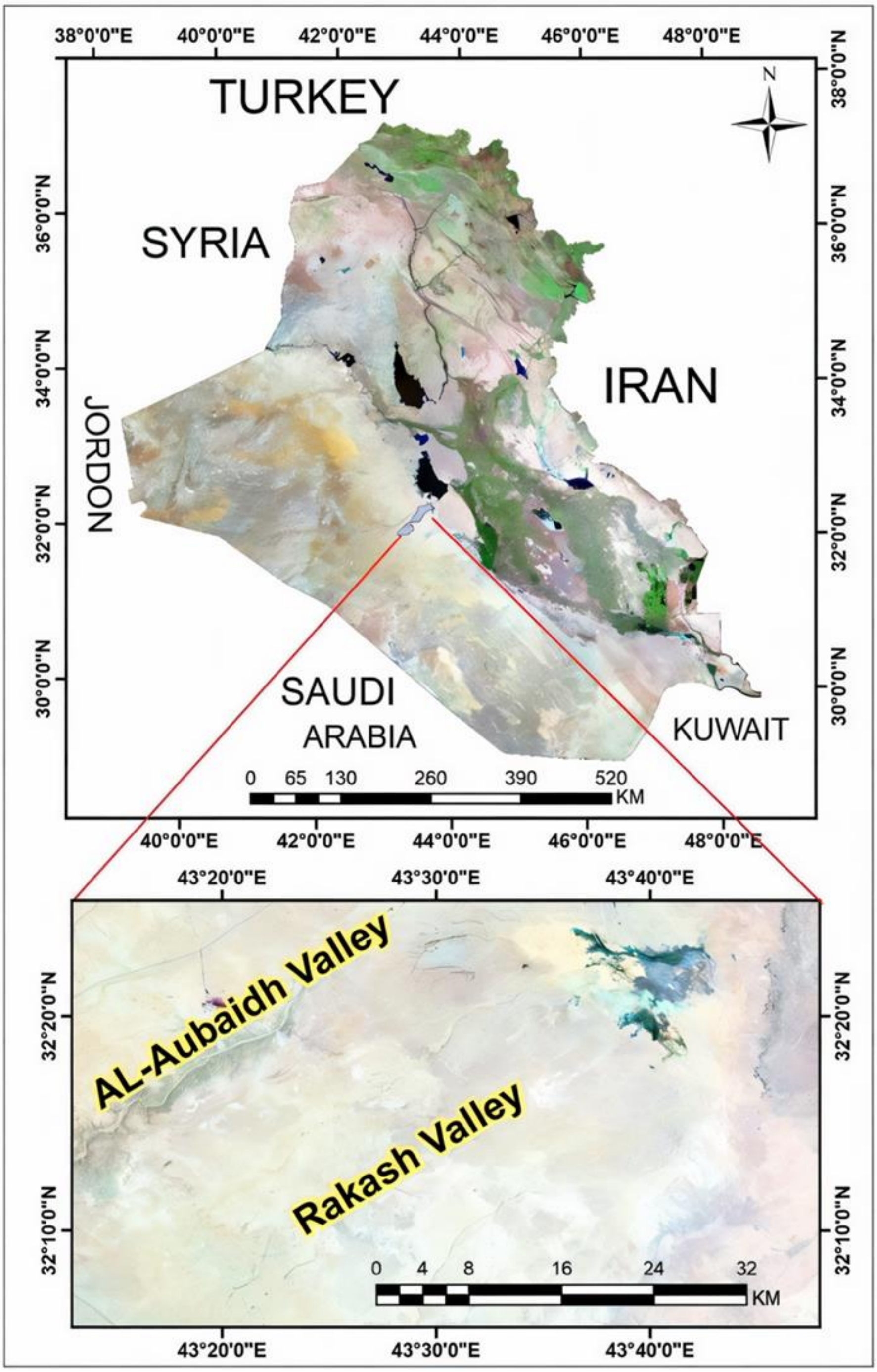


**Fig. 2.** Satellite image showing the valleys in the study area

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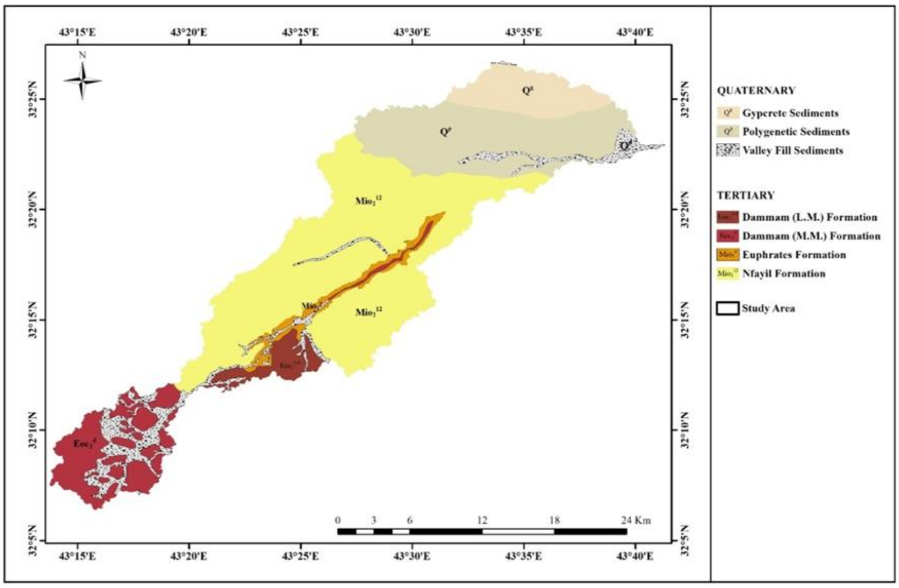


**Figure 3.** Geological map of study area.

## 2. Materials and methods

The data collection for sites selections of WH and GWR are listed below:

1. Several Iraqi government agencies provided RS and supplementary data about the research area. An picture from Landsat 8 (spatialaresolution of 30m) of the research region was obtained in 21/9/2022as shown in figure (4) and table (1).

Field work

The field work was started in December 2022, including trips:

- A reconnaissance field survey in the study area to get a broad understanding of the geological, geomorphologic, number and the allocation of drilling wells, tube wellsaand springs.
- five deep wells were determined and static water level was taken, All of these wells were working exclude one well, due totheir owners left their farms or factories, all wells were locating by using GPS (Global Positional System) type (GPS map 72, Garmin) to determine the accurate position (Longitude, latitude and Elevation m.a.s.l.)

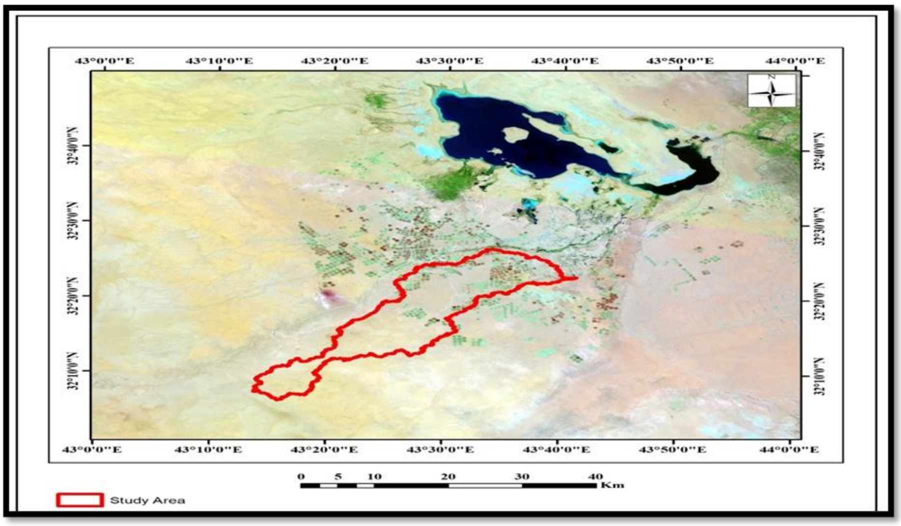


**Fig. 4.** Digital Data of Satellite Landsat-8 Sensor (Row: 35 and path: 169). (Sources: USGS, 2017).

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**Table 1.** LandSat-8 OLIand TIRS Bands (µm).

| **Landsat Operational land Imager(OLI)and Thermal Infrared Sensor(TIRS)** | | |
|---|---|---|
| Bands | Wavelength(micrometers) | Resolution (meters) |
| Band1-UltraBlue(coastal aerosol) | 0.435 – 0.451 | 30 |
| Band2-Blue | 0.452 – 0.512 | 30 |
| Band3-Green | 0.533 – 0.590 | 30 |
| Band4-Red | 0.636 – 0.673 | 30 |
| Band5-NearInfrared(NIR) | 0.851 – 0.879 | 30 |
| Band6-Shortwave Infrared(SWIR)1 | 1.566 – 1.651 | 30 |
| Band7 Shortwave Infrared(SWIR)2 | 2.107 – 2.294 | 30 |
| Band8-Panchromatic | 0.503 – 0.676 | 15 |
| Band9-cirrus | 1.363 – 1.384 | 30 |
| Band10-Thermal Infrared(TIRS)1 | 10.60 – 11.19 | 100 (30*) |
| Band11-Thermal Infrared(TIRS)2 | 11.50 – 12.51 | 100 (30*) |

2. The DEM digital elevationmodel (resolution, 30m × 30m) usedin this study. Shuttle Radar Topography Mission (SRTM) of the United States Geological Survey (http://www.usgs.gov). Figure (5) illustrates the DEM of the studyarea after filling the holes.

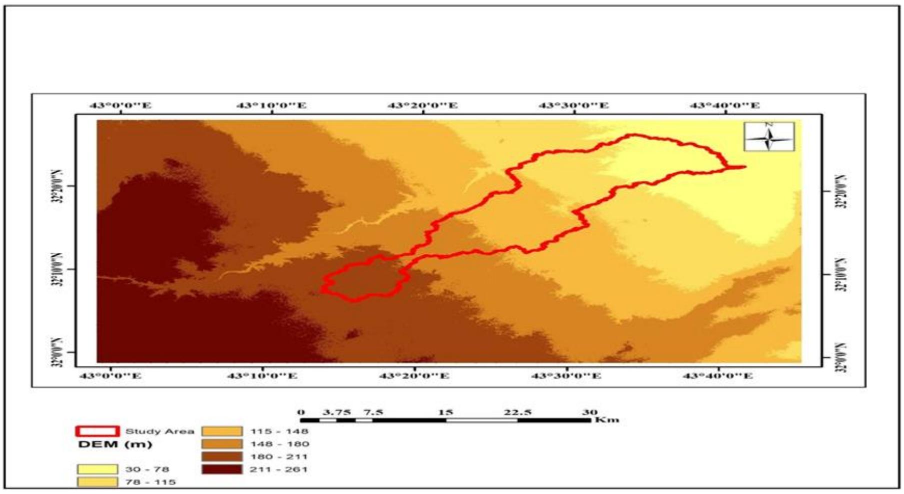


**Fig. 5.** DEM of the study area, (Sources: USGS, 2022).

3. Climatologicaldata covering 20-year period (2000–2020) for 1 station were gathered from the Iraqi MeteorologicalOrganization andSeismology. The rainfall data for the entire research area was interpolated using ArcMap 10.5. Figure (6) illustrated the spatial distribution of the total mean annual rainfall in the spatial distribution of meanannual rainfall in the study area.

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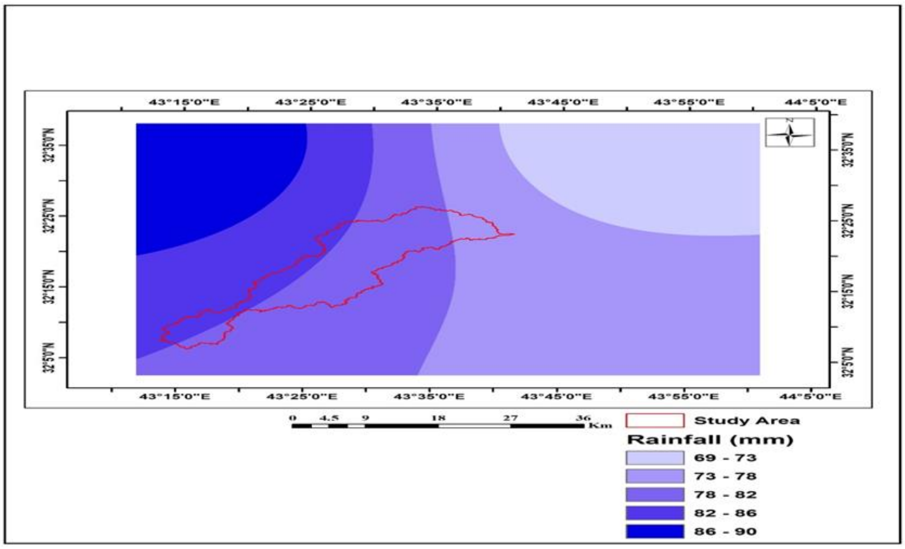


**Fig. 6.** Distribution of the overall mean yearly rainfall at five locations across time (2000 to 2020).

## 3. Results

### 3.1. Land Use/ Land Cover (LULC)

Land cover refers to the physical landtypes present in an area, such as forests, wetlands, impervious surfaces, agricultural lands, andother land uses. This valuable information is typically obtained through the analysis of satellite andaerial imagery, providing crucial insights for landscape managers. In the context of this study, land cover data was obtainedusing two distinct methods: analysis of remotely sensed imagery and field surveys. These complementary approaches ensured a comprehensive understanding of the current landscape. Using the gathered data, a LandUse/Land Cover (LULC) map was meticulously prepared using GIS 10.5 as depicted in figure (7) and table (2). This LULCmap served as a visual representation of the various land cover types present in the study area. To further enhance its utility, the LULC map was subjected to classification process, taking into account the suitability of different areas for Water Harvesting (WH) and Groundwater Recharge (GWR) structures.

By classifying the LULC map based on its relevance to specific water management techniques, the study aimed to identify regions with distinct potential for various WH and GWR structures. This approach allowed for a targeted and informed decision-making process, enabling the implementation of tailored water harvesting strategies based on the characteristics of different land cover types.Overall, the combination of remotelysensedimagery analysis, field surveys, and GIS-based LULC mapping proved to be an effective approach indeciphering the land cover patterns and their implications for water management initiatives. This integration of geospatial data and field-derived information contributes to a holistic understanding of the landscape and facilitates the adoption of sustainable water harvesting and groundwater recharge practices.

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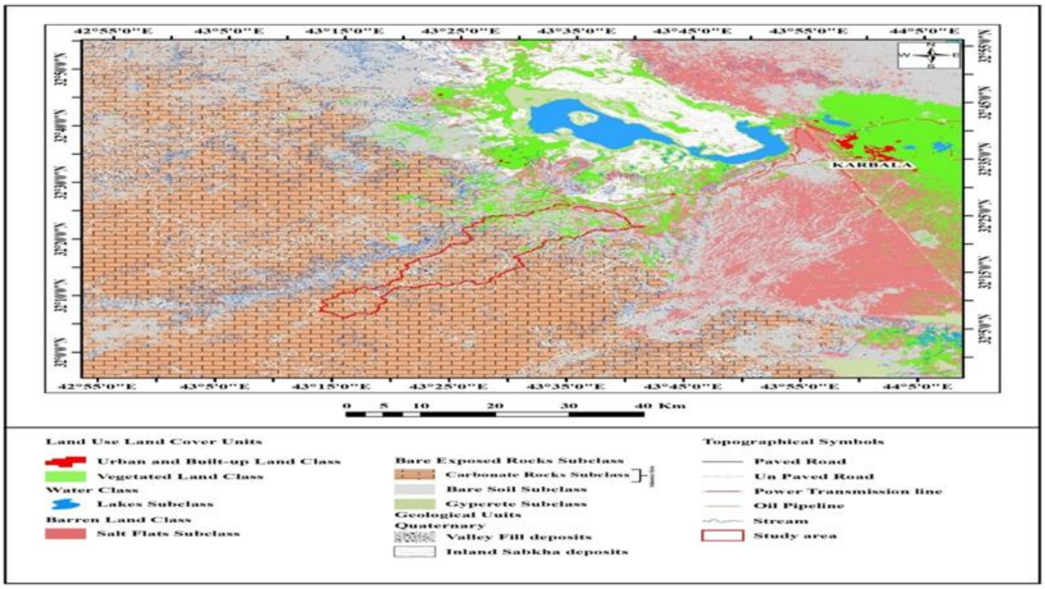


**Figure 7.** LULC map of studyaarea.

**Table 2.** The study area's land cover as determined by Landsat -8 (USGS, 2022).

| Land cover type | Area(km2) | Area% |
|---|---|---|
| WATER | 0.0882 | 0.5 |
| VEGETATION | 18.3168 | 4.7 |
| BARE SOIL | 75.4722 | 18 |
| SALT FLAT | 28.4733 | 6.8 |
| CARBONATE | 151.8789 | 35 |
| VALLEY FILL | 122.202 | 29 |
| INLAND SABKHA | 23.706 | 5.8 |
| GYPCRETE | 0.0081 | 0.2 |
| Total | 420.145 | |

### 3.2. Surface runoff

The Soil Conservation Service Curve Number (SCS-CN) method, now known as the Natural Resources Conservation Services Curve Number (NRCS-CN) method (USDA-SCS 1993) has emerged as a widely adopted approach for estimating surface runoff in ungauged watershed systems. This methodhas been validated to accurately and quickly forecast runoff in such regions (Dawood, 2017).

However, it is essential to recognize the limitations of the SCS curve number method as provided by the USDA-SCS (1993):-

(i) The method assumes uniform hydrologic characteristics within the soil group of the basin. This assumption may not hold true in areas with varying soil properties, potentially impacting the accuracy of the runoff estimates.

(ii) The SCS curve number method relies on the assumption of uniform and evenly distributed rainfall over the entire basin area. In reality, rainfall patterns can be spatially and temporally variable, which may influence runoff predictions.

(iii) Additionally, the accuracy of the method is contingent on the uniformity of all other characteristics of the watershed's hydrology.

Despite these limitations, the SCS-Curve Number method remains a valuable tool for estimating runoff in ungauged watersheds, especially in regions where dataconstraints and limited hydrologic information present challenges for water resources management and planning.

The United States Department of Agriculture (USDA) created this technique, which uses daily storm rainfall data and the rainfall-runoff equation to estimate the depth of direct runoff:-

$$Q = (P - Ia)2/ (P - Ia) + S \;\ldots\ldots\ldots\ldots\ldots\ldots\; (1). \text{ When } P > Ia$$

$Q = 0$ When $P \leq Ia$

Where: Q: Depth of direct runoff (mm),

P: rainfall (mm) for the period (2000-2020) at station.

Ia: Initial abstraction, S: The potential maximum retention storage.

The relation between (I& S) was estimated by analyzing rainfall – runoff data from many small watersheds (USDA-SCS, 1975). The empirical relationship is:

$$I = 0.2S \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (2).$$

$$Q = (P - 0.2S)2/ (P + 0.8S) \;\ldots\ldots\ldots\ldots\ldots\ldots\; (3). \text{ When } P > Ia$$

The potential maximum retention storage (S) is connected by equation to the curve number in (mm):

$$S = 25400 / CN - 254 \;\ldots\ldots\ldots\ldots\ldots\ldots\; (4).$$

The water response to the basin components of the examined area is expressed by the CN values, which range from( 1 to 100) between high and low permeability. The lower values are highly permeable to water and vice versa, These figures come from a classification of the basin according to the predominant soil type. Two soil types (C and D) were identified using the SCS-CN approach.

**3.3. Water Harvestingand Ground Water Recharge construction**

This study focuses on two primary water harvestingtechniques: Surface Runoff Water Harvesting and RainwaterHarvesting (RWH). However, it is important to address the challenge posed by steep slopes, which accelerate the downward flow of maximum runoff water. This rapid flow can lead to soil erosion, resulting in degraded land and preventingdirect storage of water in aquifers. To combat this issue, various structures like check barriers, farmponds, and percolation tanks can be constructed strategically to control the runoff water.

By implementing these structures and taking advantage of the presence of gravel and sand quarries in the vicinity, the study aims to enhance Water Harvesting (WH) and Groundwater Recharge (GWR) processes. Notably, these methods not only serve the purpose of augmenting water resources but also offer additional benefits. They can effectively contribute to flood mitigation, reducing soil erosion, and facilitating changes in land use patterns.

Overall, this integrated approach not only addresses water scarcity concerns but also addresses environmental challenges, such as erosion and flooding. Byleveraging various water harvesting techniques and appropriatestructures, the study seeks to achieve sustainable water management while promoting overall ecosystem health and resilience.

Based on the reviews of the literature, Here, two approaches are suggested at suitable locations within the watershed under study:

**3.3.1. In-channelamodifications**

This approachaexplores a cost-effective method for water harvesting (WH) and groundwater recharge (GWR). It involves the installation of check-barriers andapercolation tanks in a valley bed using locally available constructionamaterial sourced from the alluvium stream.

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**Check Barriers**

Check-barriers are modest constructions erected in small streams perpendicular to the water flow, specifically designed for water harvesting (Vashist, 2016). These barriers facilitate the storage of water within undergroundcaves and fractures that are part of the aquifer. This stored water can be effectively utilized for aquifer recharge. One of the significantadvantages of this approach is that the water stored underground is not as susceptible to contamination caused by various human activities prevalent in the research region, including farmland and quarries. Additionally, geologicalformations play a crucial role in supporting the effectiveness of this water harvesting and groundwater recharge technique. Check barriers serve the primary purposeof capturing water, primarily for irrigation during the wet season and subsequently for livestock anddomestic use during the dry season. They come in various sizes and can be constructed using different materials such as gravel, sand, clay, and silt (Vashist, 2016). The selection of an appropriate site for building check barriers follows specific criteria outlined by the guidelines of the Integrated Mission for Sustainable Development (IMSD) (Bamne, 2014).

a. The slope should be lessthan 15 per cent.

b. The land may be used as riverbed, shrub land, or bare ground.

c. The infiltration rate of the soil should be less.

d. The type of soil should be sandy clay loam.

**Percolationtanks (settling ponds)**

Percolationtanks are constructed by constructing earthen bunds across little creeks to effectively store water from runoff. (Limaye, 2011). The primary objectives of The tanks are twofold: first, to capture surface runoff from the catchment areas, and second, tofacilitate Water storage and its percolation into the soil substrata. This process helps in elevating the groundwater level within the zone of influence of the percolation tanks. Additionally, percolation tanks play a crucial role in reducing the silt flow that would otherwise enter multipurpose reservoirs, protecting their capacity to store living water.

When selecting suitable sites for percolation tanks, the IntegratedMission for Sustainable Development (IMSD) guidelines (Bamne, 2014) are followed. These guidelines incorporate a new approach to ensure sustainable water management and groundwater recharge while considering ecological, social, and economic factors.

a. The slope should be less than 10 per cent.

b. The infiltration rate of the soil should be moderately high.

c. Scrub land or arid land may be the land cover or use.

d. The type of soil should be silt loam.

**3.4. Wells and Boreholes**

This technique for collecting water is among the most widely used techniques, involving the extraction of water from the water table through a hole excavated on the surface. Traditionally, aquifers have been passive recipients of harvested water, acting as natural storage for the collected water. However, in response to the growing concern of depleting aquifers, there is a recentsurge in water harvesting techniques that focus on directly recharging these rapidly declining resources. These methods aim to replenish aquifers, raise the falling water table, and enhance overall water supply (Edugreen, 2007).

Among the techniques used, retention wells and boreholes play a significant role in diverting substantial volumes of surface flow from steep cliff faces. This diversion has been instrumental in revitalizing natural springs, which, as reported by local communities, had previously dried out (Rockstrom et al., 1999). The adoption of these innovative approachesdemonstrates a new theory of active aquifer management, emphasizingathe importance of replenishing and augmenting groundwater resources to ensure sustainablewater availability.

### 3.5. The optimallocations forWH (Water Harvesting) and GWR (Ground Water Recharge) sites utilizing the Boolean logic AND operator

Numerous techniques exist for Thematic layers are logically integrated, categorized, and rationalized. The use of the Boolean logic AND operator in this investigation emerged as the chosen approach for the reclassification of integrated maps into categories of suitability and unsuitability concerning WH and GWR. This entailed attributing a value of unity (1) to suitable layers and a value of zero (0) to unsuitable ones. The process, conducted within a Geographic Information System (GIS) context, resulted in the creation of binary logical maps. These maps, guided by Boolean logic, reorganized the thematic layers, as depicted in Table (3).

**Table 3.** The classification ofthematic layers used in Boolean logic for GWR optimum sites.

| Layers Potential GWR Sites | Classes | Boolean Binary Weight |
|---|---|---|
| Good | Suitable | 1 |
| Moderate | Unsuitable | 0 |
| Poor | Unsuitable | 0 |

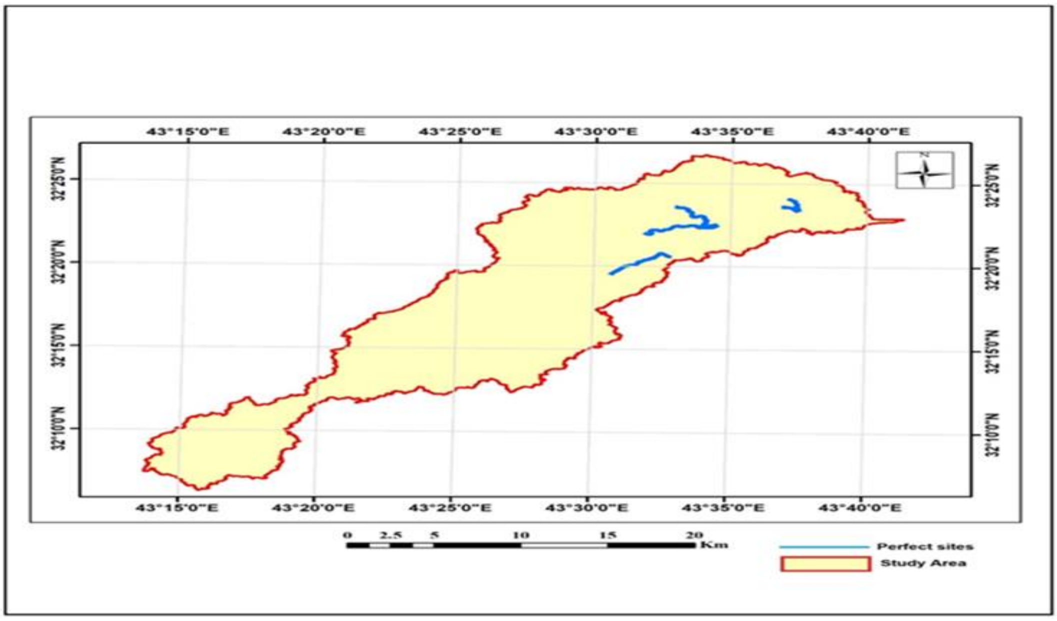


**Fig. 8.** Perfect sites for the study area.

These maps hinged on the foundational layers designated for Boolean operations, as demonstrated within the same table. By isolating the beneficial layers representing potential WH and GWR sites, this method facilitates the decision-making process for stakeholders. This selection aids decision-makers in efficiently identifying optimal sites while minimizing resource expenditure and operational complexity.

### 3.6. Optimum sites for check barriers

The identification of optimal check barrier sites is contingent upon their alignment with specific criteria outlined in the IMSD (Integrated Management forSustainable Development) guidelines, as expounded in Section 5.3.1. These standards include qualities like the site's positioning within fourth and fifth order drainage systems, congruence with stipulated land use patterns, soil composition, and slope

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characteristics.While a substantial number of sites within the study area watershed demonstrated appropriateness for the installation of the check barrier, discernment through empirical observation and experiential knowledge hasled to the recommendation of only three sites as truly optimal for check barrier construction, as illustrated in Figure (9). These sites have been judiciously selected based on their alignment with parameters such as land class (specifically agricultural land designation), slope gradients (below 15%), and soil type (sandy clay loam composition). Such meticulous site selection serves The overall goals of conserving water and soil, alongside the augmentation of groundwater resources,Remarkably, it is noteworthy to highlight that one of the proposed check barrier sites coincides with the existing location of the Rakash check barrier.

Appropriate autumn/spring crops might be grown, and the suggested check barriers could be very helpful as supplemental watering during the dry season.

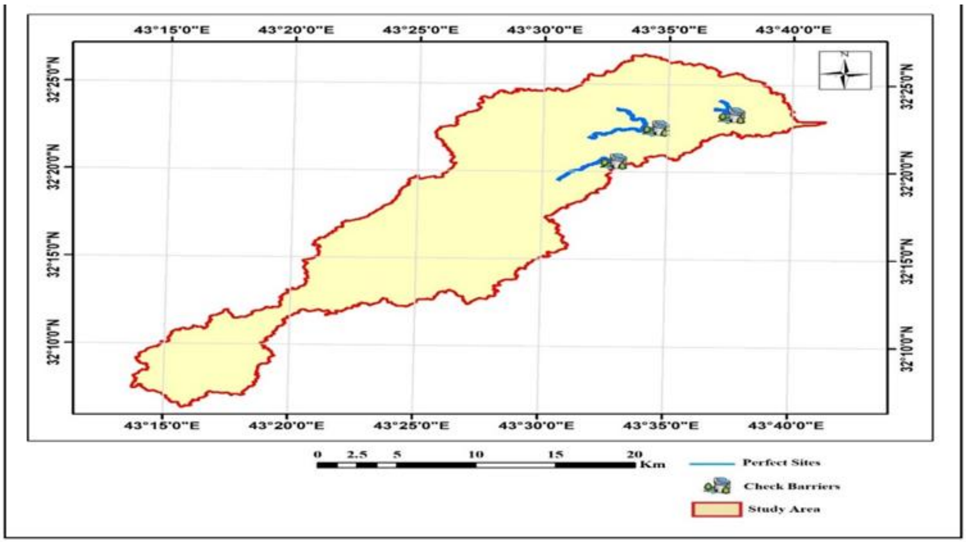


**Fig. 9.** Check Barriers for the study area.

### 3.7. Optimum sites for percolation tanks

Finding the best sites for percolation tanks is essential, hinging on factors such as soil composition with high infiltration rates and adherence to IMSD guidelines. A meticulously chosen set of five sites has been put five forthe construction of these tanks (Figure 10). Notably, these sites are situated within the geological outcrops of Al-Dammam Formation, characterized by fractures that serve as direct conduits for groundwaterrecharge. Furthermore, the selected sites are nestled within sandy silt lom soils, a perfect matc with mild incline below 10% for groundwater recharge (GWR). These sites, encompassing barren terrain with gentle slopes below10% are placed with consideration. They also fall within the domain of second and third order drainagesystems, effectively shielding the percolation tanks from potential harm brought about by excessivearunoff. This meticulous selection process ensures alignment with the IMSD guidelines, thereby improving these percolation tanks durability and viability.

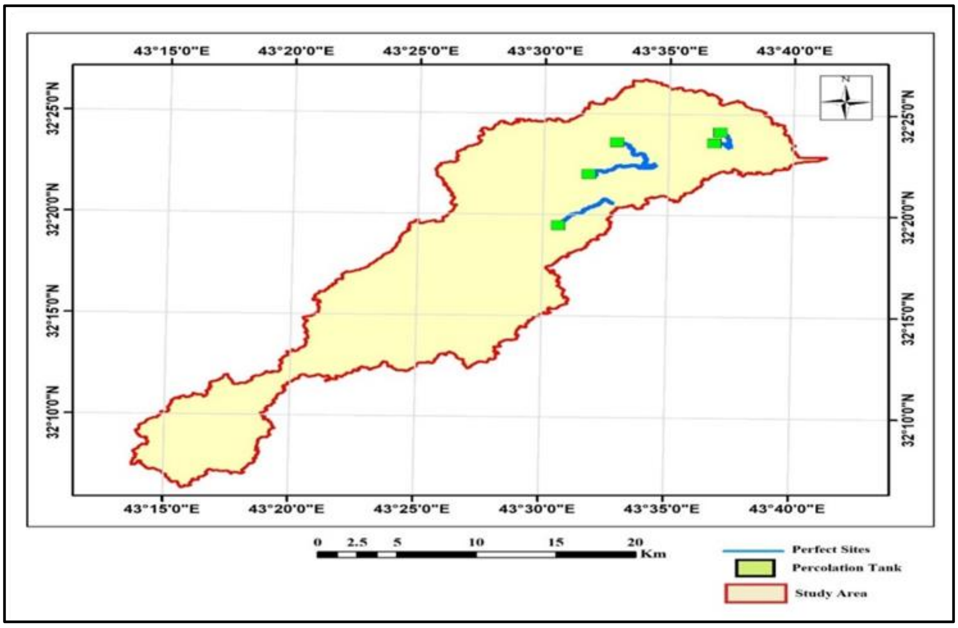


**Fig. 10.** Percolation tank for the study area.

### 3.8. Optimallocations for the recharging of wells and boreholes

The identification of appropriate locations for wells and boreholes focuses on regions characterized through higher runoff rates and slower penetration of precipitationWithin particular land use and land cover (LULC) in the research area zones, predominantly marked by mixed rangelands and soil texture categorized as Type C, exhibit properties that impede rapid water infiltration due to the presence of certain clay components. In these scenarios, drilling wells and boreholes emerges as the optimal strategy for facilitating the infiltration of runoffawater into the underlying aquifer system. This intervention not only serves to slow down runoff, but it also serves as a protective measure, curbing potential contamination.

Consequently, the selection process for suitablewell and borehole drilling sites prioritized areas where the geological outcrops of Al-Dammam Formation are prevalent. This Formation holds significance as the primary aquifer within the surveyed region (Figure 11), underscoring its pivotal role in sustaining groundwater resources.

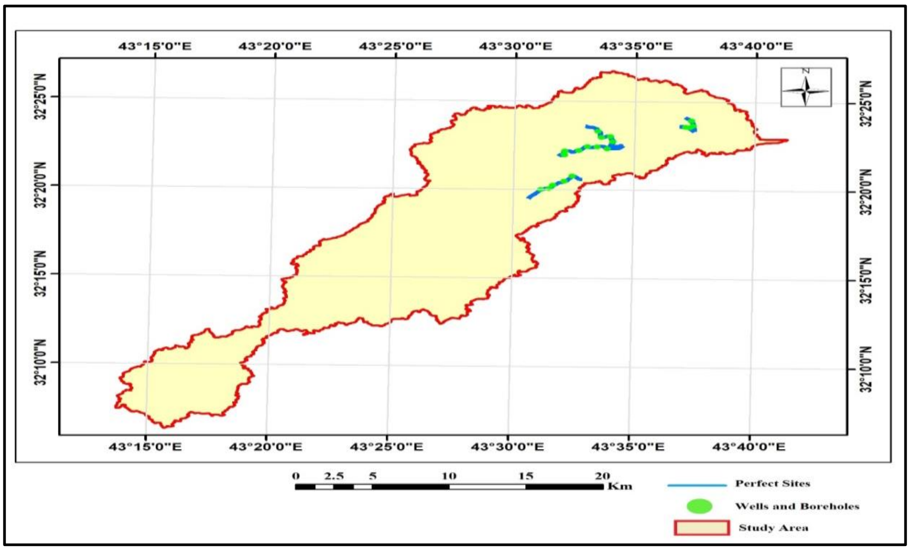


**Fig. 11.** Wells and Boreholes for the study area.

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## 4. Discussion

The current study highlights the effective fusion of a thorough literature review, extensive data gathering techniques, as well as an architecture for the Analytic Hierarchy Process (AHPThe way relative weights develop for the various site selection criteria was greatly aided by earlier research studies that were carefully explained in literature study. This combined strategy used Multi-Criteria Decision Analysis (MCDA), Geographic Information Systems (GIS), and Remote Sensing (RS) techniques to efficiently and accurately identify appropriate Groundwater Recharge (GWR) and Water Harvesting (WH) zones.

By combining seven thematic layers using the AHP approach, The study was improved by the MCDA methodology. Issues like drainage and runoff were particularly visible because of their large weights in the AHP framework. This procedure led to the identification of three distinct suitability categories for WH and GWR sites good suitability zone moderate suitability zone and "poor suitability zone Using Boolean techniques to synthesize MCDA data, WH and GWR suitability map was produced that indicated the optimal locations for WH and GWR interventions, such as check barriers and percolation tanks.The WH and GWR sites that were found to be inside the high suitability zone are very important.. Strong features include increased runoff depth, logical drainage order, geological makeup, groundwater (GW) depth, slope inclination, soil texture, and Land Use/Land Cover (LULC) characteristics are all present in this area. The viability of WH and GWR activities in the research area is supported by this body of information.

The use of RS and GIS is a useful tool in the process of narrowing down a wide range of potential locations to a select few ideal ones in an effort to save time and money. The application of the MCDA technique is essential for identifying potential WH and GWR sites. This procedure is based on combining criteria, including their weighted multiplication, and then rating and unifying them.

One of the most important factors in determining GWR site classification is geological characteristics. Interestingly, the rocks in the research region include natural cracks that provide significant interconnected water flow channels. Thus, the geological layers of which the Al-Dammama Formation is a noteworthy example are given more attention.

In GWR projects, groundwater depth becomes a crucial factor that has a big impact on project schedules and drilling costs. The ideal zones, shown by GW depths between 2 and 42 meters, represent a more advantageous environment for GWR implementations.

The selection of Water Harvesting (WH) and Groundwater Recharge (GWR) sites is significantly influenced by the gradient of the terrain, particularly slope. Gentle slopes are ideal for these activities, and the study region exhibits a preference for these types of settings. In particular, the majority of the best locations that have been found have slopes that fall between 0 and 0.70 percent, which emphasizes how important low gradients are when choosing a location.

Because it is incorporated into the Curve Number (CN) approach, which is a crucial component in determining runoff depth, soil texture is also a crucial criterion. The importance given to runoff depth highlights how closely it is related to crucial factors like soil texture. Because it controls the amount of rainfall that can seep into the aquifer, the relevance of this parameter is further magnified. Notably, Hydrologic Soil Group (HSG) categories C and D contain the bulk of ideal WH and GWR sites. Sand and sandy loam textures, which indicate an innate capacity for natural GWR from the seepage of surface rains, are characteristics of these classifications.

One significant factor affecting WH and GWR chances is Land Use/Land Covera (LULC), which has a significant effect on optimal site distributions. In particular, because there is a dearth of grassland in the research area, numerous ideal locations align with bare soil and valley sedimental landscapes. This restriction in the grassland category highlights a relevant restriction for the smooth implementation of GWR projects.

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## Conclotion

The use of artificial recharging techniques offers a workable way around this restriction. In order to provide a variety of artificial recharge structures, including check barriers, percolation ponds, recharge shafts, injection wells, and rooftop harvesting, these approaches include the strategic identification of sites appropriate for a variety of hydro-geological situations (Dhakatea et al., 2013). By using artificial recharge wells, water loss from evaporation is reduced and the flow of collected water to the groundwater table is accelerated.

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