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Identification of Suitable Structures for Rainwater Harvesting and Natural Aquifer Recharge in a Mountainous Basin using GIS-based Multi Criteria Analysis

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Abstract:
A healthy ecosystem that supports all living forms depends on water, which is the most magnificent natural resource. Considering the acute global water scarcity, it is critical to investigate rainwater gathering techniques that incorporate practical drought mitigation strategies. In addition to providing a selection of the best sites for natural aquifer recharge, the ultimate objective of this work is to determine where rainwater harvesting structures can be built for efficient and successful rainwater harvesting management in the research region. The current work also focuses on identifying possible locations for natural aquifer recharging utilizing RS and GIS methodologies because the water table is rapidly declining. Land use/land cover, slope, soil, runoff, drainage density, and road limitations were the five criteria used to identify RWH locations using GIS-based MCEs. Using the soil and water assessment tool approach, the observed runoff depth varied from 0-900 CMS, and the RWH unit's appropriateness ranged from highly suitable to least suitable. The Panjkora River Basin's total area of 1128.395 km^2 is the most suitable for building farm ponds, whereas 954.756 km^2 is the moderate suitable. The Suitable area for check dam building is 350.58 km^2, while the moderate area is 245.31 km^2. According to the results, 1572.518 km^2 are the most suitable areas to build gully plug structures in order to prevent soil erosion and store rainwater, while 3742.38 km^2 are of moderate appropriateness. In the current study seven local influencing factors e.g. land use and land cover (LULC), drainage density, slope, population density, water table, elevation, and soil types to accomplish the objective of natural aquifer recharge sites. More than 72% of the basin, have been classified as having Moderate to Very High potential for artificial recharge. The land area is categorized as Highly Suitable in 30.19% of cases and Very High Suitability in 1.01% of situations. In terms of hydrology, this spatial correlation is quite important. Highly or Very Highly suitable locations for recharge are found in many sections of the Moderate and Poor groundwater zones. Particularly in areas where traditional groundwater extraction is no longer technically or economically feasible, these interventions would encourage vertical infiltration, lessen runoff, and aid in the restoration of dwindling aquifers. Water managers can implement location-specific, data-driven methods to increase climate resilience and long-term water security in the Panjkora Basin by coordinating recharge planning with natural recharge potential and current groundwater stress.
Keywords: *Natural aquifer recharge, GIS, MCA, RS, Runoff*

1.1 INTRODUCTION:

water is one of the most important natural resources that sustains economic growth and human needs (Sinha Babu & Datta, 2015). Watersheds provide the basis for the planning and management of natural resources, such as land and water (Zerga, 2025). Watersheds are thought to be the best unit for planning and managing land and water resources (Kumar et al., 2021). Harvesting water simply means collecting surface runoff for use primarily in domestic and agricultural. Structures that collect water are crucial for protecting valuable natural resources like soil and water, which are reducing faster every day (Wassie, 2020). The basic objective of water harvesting is to reduce sedimentation in reservoirs, control runoff, maintain groundwater levels, grow vegetation, store extra water for later use, and reuse as needed. The exact spot of the water harvesting site is crucial for both design and location (Lancaster, 2019). In many countries, especially those that are developing, water scarcity is a serious issue (Ibrahim et al., 2023).

Climate change and growing water demand are straining water supplies as a result of agricultural and urban growth (Mitiku et al., 2024).

Finding appropriate locations and technologies is crucial to the success of Rain water harvesting (RWH) systems (Yegizaw et al., 2022). A field survey in a limited area is the most popular technique for locating possible RWH sites. For larger areas, remote sensing (RS) and geographic information systems (GIS) are utilized as alternatives (Ullah et al., 2024).

It is now more frequent to evaluate the biophysical environment and find appropriate RWH sites using GIS and RS data (Adham et al., 2018; Alene et al., 2022). It was recommended that RWH use GIS as a tool for problem-solving and decision-making during the decision-making process. When the identified factors are integrated, the GIS-MCE combination offers a clear, objective, and straightforward method for selecting appropriate locations for RWH technologies (Alene et al., 2022). Many variables, including physical characteristics or an amalgamation of socioeconomic and physical characteristics, affect the selection of the RWH location (Al-Qatawneh et al., 2025; Bojer et al., 2024).

The researchers identified the factors that might influence the possible RWH site using Integrated Mission for Sustained Development (IMSD) principles and FAO standards (Ammar et al., 2016). Adham et al. (2018) cite the FAO's list of criteria for identifying RWH potential areas, which includes soils, Land scenarios (land use/cover), climate (rainfall), hydrology (runoff and drainage density), topography (slope), and socioeconomic factors (distance to stream, main road, settlement, etc.).

As a result of groundwater discharge over time, shallow groundwater abstraction structures have dried up and water levels have risen (Shamsudduha et al., 2011). In addition to demand side control, rainwater collecting and artificial recharge are potential solutions to the problems (Hussain et al., 2019). The balance between the supply and demand of water resources can be maintained by recognizing the importance of recharge processes (Shen & Chen, 2010). It is important to recognize the potential of groundwater recharge zones (GRPZs), which are areas where the ground surface permits groundwater infiltration and percolation (Odoh & Nwokeabia, 2024). Water may therefore seep into the soil, move into the vadose zone, or flow unhindered (Dahan, 2020; Osman, 2012; Stephens, 2018). Naturally, regions excessive and continuous exploitation of groundwater resources makes restoring groundwater reservoirs a time-consuming and often inadequate operation (Zeidan, 2017). Restoring depleted groundwater supplies is frequently accomplished through artificial recharge (Gale et al., 2002; Kebede et al., 2024). For artificial groundwater recharge initiatives to make a substantial contribution to the restoration of groundwater resources, suitable locations must be found (Asano, 2016). This is especially crucial because the majority of the study area is supported by crystalline rocks with very limited primary porosity (Nicksiar & Martin, 2014). Alternative methods based on mathematical models, such as the analytical hierarchy process (Nguyen, 2014), analytical network process (Saaty & Vargas, 2013), SCS-CN method (Mishra & Singh, 2003), and multi-criteria analysis (Dodgson et al., 2009), have been proposed by certain individuals, while the majority of research on this subject has employed weighted index overlay techniques (Awawdeh, ElMughrabi, & Atallah, 2018). It is quite concerning that no prior studies have been carried out in this basin to determine the possible location of groundwater recharge zones, given the annual decline in the groundwater table. Consequently, locating the artificial groundwater recharge zone and replenishing it with rainwater will be advantageous. Finding the active groundwater recharge zones in the Panjkora River Basin is the primary objective of this study.

2.1 The study area

The research area is located in the eastern region of Pakistan's Khyber Pakhtunkhwa province, within the Hindu Kush Mountain range. it covers a geographic range between latitudes "34.33°–35.0° N and longitudes 71.0° E–72.0° E." (Figure 1). In this region, the Panjkora River flows from northeast to southwest, joining the Swat River close to Qalangi (village) after merging with several tributaries. The Hindu Raj Mountains, sometimes referred to as the Eastern Hindu Kush, are the source of the Panjkora River, which is the main tributary of the Kabul River. The name Panjkora, which means "five torrents" in Pashto, refers to the five main streams that flow into it on its 220-kilometer journey from its source to the village of Totakan. Among the major streams that feed the river are Jandol, Barawal, Gawaldai, Dir, and Kohistan. The Dir Upper, Dir Central, Bajaur and Dir Lower districts of Khyber Pakhtunkhwa province comprise the Panjkora basin. The research area's elevation ranges from roughly 5,773 meters in the north to 568 meters in the south. Near the southern portions, the elevation falls below 1,950 meters. 4,173 meters is the highest point along the eastern basin boundary. Summers here are hot, with temperatures ranging from 15.9 to 33.1 °C while winter are cold, with night time temperatures often dropping below freezing. Snowfall is frequent at higher altitude, occasionally blocking mountain passes due to snow and ice. A total of 82 glaciers, both large and small, contribute to the flow of the Panjkora river basin by accumulating glacier milk, or melted water (Shaw, 2014). The monsoon seasons (June–September) produce effectively about 800 mm of rain, with annual rainfall ranging from 823 to 2,149 mm (Mahmood & Rahman, 2019). Its soil composition varies from clayey to sandy loam, and it is prone to erosion on steep, vulnerable slopes.

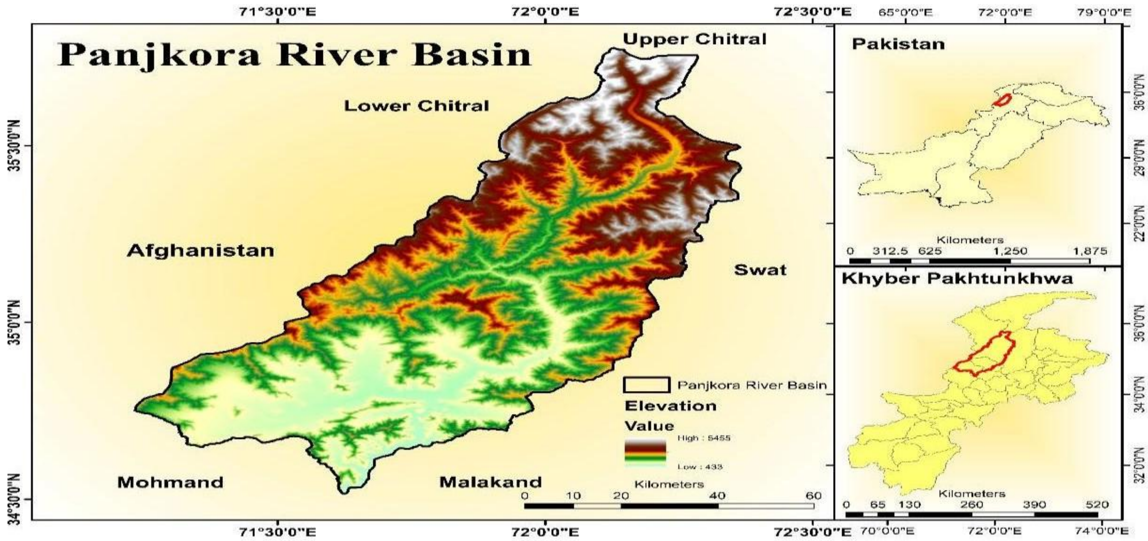

Figure 1: Showing the study area Map.

2.2 Methodology:

This study having two objectives one is to locate suitable site (Intervention) for rainwater harvesting and the second one is to locate ideal structure/intervention for ground water recharge.

The following steps was followed for suitable interventions in the Study area

- The Surface runoff of the study area was calculated using ArcSwat hydrological model, to check the intensity and frequency of the surface water, for the hydrological model Soil texture, Land cover land use, Digital elevation model and Daily rainfall and Temperature data was utilized.
- For the selection of the suitable intervention in the study area input parameters for the RWH were taking in to consideration i.e. RWH potential map, surface slope, drainage network, major settlement, and roadways. The weight and ranks were given in accordance with IMSD, INCOH, and FAO recommendations.
- A detail field survey was conducted to physically verify the model result and the suitable location for the RWH interventions.
- After the analysis and Filed survey the final location map of the Farm ponds, check dams, and gully plugs was derived.

2.3 Methodology for suitable site identification for NAR.

The study second objective is to identify the best location to instal the natural aquifer recharge facilities in the study area. The following steps were carried out to achieve the ultimate goal of the study.

- The NAR zone map that was already procced was verified in the detail field survey. Where 7 different parameters were considered.
- The detail ground water potential zone map was generated to analyse the current ground water condition in contrast with the already procced NAR map.
- For ground water potential zone 7 parameters were considered i.e. soil, geology, rainfall, lineament density, drainage density, Slope, elevation. The parameters was ranked on the basis of satty scale of importance on the basis of Multi influencing model.
- The NAR results and the GWPZ results was cross checked and accumulation with the filed observation the appropriate locations for Recharge wells and Roof top rain water harvesting was suggested.

3 RESULTS AND DISCUSSION

3.1 Suitable sites for RWH

The primary objective of rainwater conservation using runoff conservation structures, such as check dams, gully plugs, rock fill dams, and bench trenching, is to decrease or halt water flow. In drought-prone areas, RWH can be utilized in two efficient ways to address the serious problems of drought and water scarcity: contour trenching and subsurface dams (Mfitumukiza et al., 2022). After potential RWH Zones in the study area, the most ideal locations to build RWH structures were identified. Only three RWH possible structures were deemed worthy of consideration following an analysis of the conditions in the research area (gully plugs, check dams, and farm ponds). The results for potential RWH zones were also used to determine input parameters for the RWH structures, including surface slope, drainage network, settlement, and roads. Although the ranking and criteria for these constructions varied, the procedure for selecting possible sites for the structures remained the same. Drainage networks, for example, were given more weight than other structures in check dams. Similarly, the slope for gully plugs was given extra consideration in compliance with IMSD, INCOH, and FAO guidelines (Khan et al., 2022).

3.2 Hydrological Model:

The Panjkora River Basin's Arc SWAT model simulation (Figure 2) output offers vital information about the temporal distribution of important hydrological elements, which can direct the strategic planning of watershed interventions and rainwater harvesting projects (Ngigi, Savenije, & Gichuki, 2007). In order to determine priority times and sites for conservation structures, the data which show notable seasonal variations in rainfall, snow, surface water yield, sediment transport, and evapotranspiration provide a useful foundation. With significant precipitation in the late winter and early spring months, especially in February and March, and a secondary peak in the monsoon months of July and August, the rainfall pattern is clearly bimodal. February has a significant amount of snow accumulation (100.51 mm) and rainfall (182.12 mm) Table (1), suggesting that it is a critical month for replenishing soil moisture and starting surface drainage through snowmelt processes. The month of March has the highest water yield (230.01 mm), indicating that integrated runoff management techniques like retention basins, terracing, and hillside reservoirs would be especially useful in this time frame to absorb excess flow and lower peak discharge downstream. These peaks demonstrate the necessity of silt traps, check dams, and vegetative barriers as well as other reinforced soil and water conservation structures in highland regions to stabilize slopes and regulate sediment transport.

Month (2000-24)	Rainfall (mm)	Snow (mm)	Water Yield (mm)	Sed. Yield (mm)	ET (mm)
Jan	102.68	42.75	65.1	0.65	1.49
Feb	182.12	100.51	82.98	4.86	7.26
March	243.19	0.00	230.01	8.00	6.44
April	154.27	0.00	135.62	71.91	19.99
May	86.16	0.00	81.10	3.28	4.42
June	62.53	0.00	52.90	11.69	10.78
July	141.70	0.00	100.34	7.09	41.76
Aug	139.16	0.00	122.39	5.91	18.0
Sep	76.99	0.00	68.46	7.55	8.74
Oct	73.71	12.64	50.51	38.15	3.93
Nov	57.78	0.94	42.72	2.71	14.59
Dec	61.69	20.78	40.90	0.95	21.02

Table 1 Monthly Data Report of Panjkora River Basin (Based on Daily Data (PMD 1980-2024)

3.3 Discharge from the catchment (1981-2024)

Significant variability can be seen in the discharge trend of the Panjkora River Basin from 1981 to 2024. In the late 1980s and early 1990s, there were several high-flow occurrences above 700 CMS, which were probably caused by heavy rainfall and quick snowmelt. Peak discharges gradually decrease over time, particularly after 2000 (Figure 3), suggesting possible changes in upstream land use, climate patterns, or the results of watershed initiatives.

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Sharp peaks still appear occasionally in spite of this drop, indicating that the basin is still susceptible to unexpected runoff events. This pattern emphasizes the necessity of a dual approach to water management: localized rainwater collection and recharge structures to absorb moderate flows and improve groundwater during times of decreased runoff, and flood control infrastructure to manage extreme flows in high-risk years. The significance of flexible, climate-responsive planning for sustainable water resource management is highlighted by the shifting discharge dynamics.

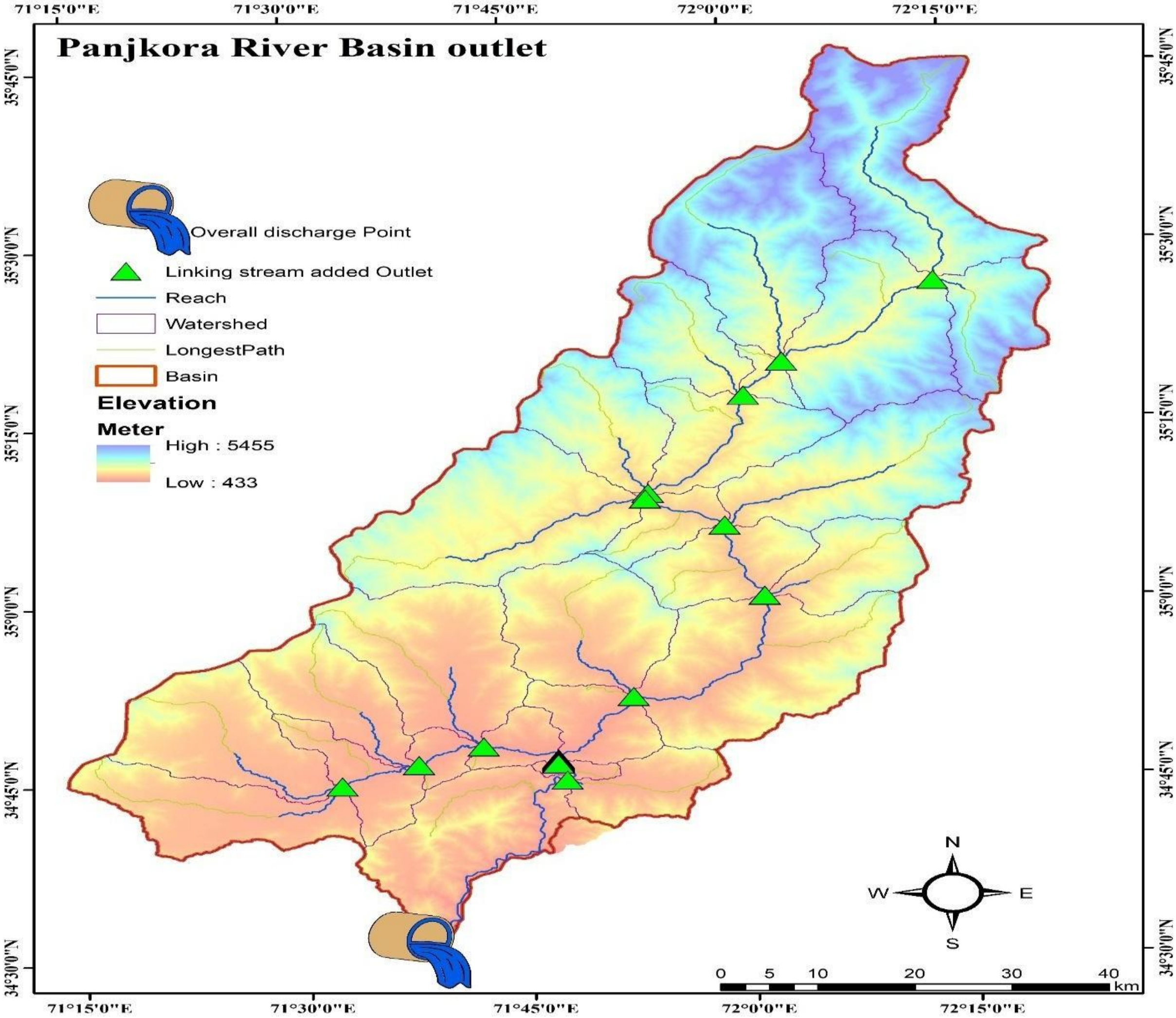

Figure 2 Map Showing Catchment area

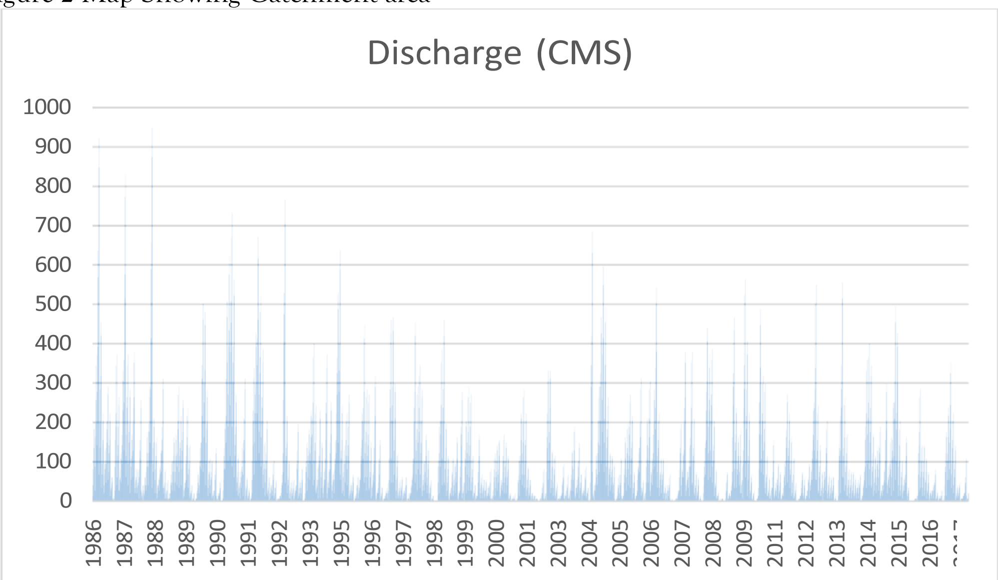

Figure 3 Showing Discharge (outflow) in CMS

3.4. Suitable rainwater Harvasting Sites

i. Farm Ponds: Farm ponds are Small earthen barriers with a slope ranging from 1% to 6%. The goal for constructing farm ponds is to divide a long slope into multiple shorter, less steep slopes in order to lessen flow velocity and the erosion caused by runoff water. The IMSD, INCOH, and FAO recommendations were followed in the process of identifying farm pond sites, with due consideration given to the research area's topography and climate. These include regions with surface areas that have slopes of less than 10 degrees, streams, and a 30-meter distance. Furthermore, this construction needs to be built more than 250 meters away from any populated areas (Table 2). Different layers like Distance from roads, Distance from streams, Distance from main urban areas, topography and RWH suitability maps were reclassified and weighted overlay tool were applied. The analysis based on table no revels that in overall Panjkora river basin 1128.395 km^2 area having highest suitability and 954.756 km^2 having the moderate suitability for construction of Farm Ponds. These areas having the capacity to store rain water for later use. (Figure 4a) Showing the locations and suitability map of Farm ponds in Panjkora river Basin.

Factor	Classes	Index	Rank
Slope	<10° 1°-20° >15°	Most Ideal Moderate Ideal Least Ideal	5 3 1
Streams Network	Around the Streams Location 30m and 60m away from streams Location >60 m	Most Ideal Moderate Ideal Least Ideal	5 3 1
Urban/ Major Settlements	>250 m away from settlements Location 200-250m away from settlements Location in 200 m zones width	Most Ideal Moderate Ideal Least Ideal	5 3 1
Major and Minor roads	Locations 250m away from roads Locations 100m to 250m far away from roads Road and an area of 10 m width	Most Ideal Moderate Ideal Least Ideal	5 3 1
RWH Map	Most suitable Moderate Suitable Least Suitable	Most ideal Moderate ideal Least ideal	5 3 1

Table 2: Criteria for Farm Ponds based on IMSD (1995), INCOH (1995), and FAO (2003) guidelines (source:(Khan et al., 2022).

ii. Check Dams: Check dams are more significant than other types of construction because of their ability to reduce soil erosion and store rainwater. The distance between two check dams while building a chain of them along a stream channel should be greater than their water spread. Surface slope, drainage network, settlement, roadways, and results for potential rainwater harvesting sites are parameters used to identify potential check dam locations. Suitable locations for check dams were then found by integrating all of these thematic layers and weighting values (in accordance with IMSD, INCOH, and FAO criteria. These consist of surfaces with slopes more than 20 degrees, as well as places with streams within a 30-meter radius. Furthermore, this construction needs to be placed more than 250 meters away from any roadways or populations. The related criteria are shown in (Table 3). Different layers like Distance from roads, Distance from streams, Distance from main urban areas, topography and RWH suitability maps were reclassified and weighted overlay tool were applied. The final analysis revels that in overall Panjkora river basin 350.58 km^2 area are most ideal and 245.31 km^2 area are moderate ideal for construction of Check dams. These areas having the capacity to store rain water and also recharge ground water. These structures can also prevent the floods in the areas (Figure 4b).

Factor	Classes	Index	Rank
Slope	<10° 1°-20° >15°	Most Ideal Moderate Ideal Least Ideal	5 3 1
Streams Network	Stream 30m surroundings Stram area from30m-60m >60 meter from stream	Most Ideal Moderate Ideal Least Ideal	5 3 1
Urban/ Major Settlements	>60 m away from settlements Location 200-250m away from settlements Location in 200 m zones width	Most Ideal Moderate Ideal Least Ideal	5 3 1
Major and Minor roads	Locations 250m away from roads Locations 100m to 250 m far away from roads Road and an area of 100 m width	Most Ideal Moderate Ideal Least Ideal	5 3 1
RWH Map	Most suitable Moderate Suitable Least Suitable	Most ideal Moderate ideal Least ideal	5 3 1

Table 3: Criteria for Check Dams based on IMSD (1995), INCOH (1995), and FAO (2003) guidelines (source:(Khan et al., 2022).

iii. Gully Plugs: Rainwater erosion of topsoil results in the formation of gullies. Gradually, the erosion increases and a gully takes on a more definite shape. Then, at specific intervals, barriers or plugs made of various materials are placed across the gully to stop erosion and store rainwater for later use. Five factors were taken into consideration for the probable site assessment of the gully structure: surface slope, drainage network, proximity to settlement, proximity to roadways and the resulting RWH map. Based on recommendations from the FAO, INCOH, and IMSD, classifications and rankings were created using these characteristics. Analytical criteria were also developed. These comprise surfaces with slopes greater than 20 degrees, as well as places with streams within a 30-meter radius. Furthermore, this construction needs to be built more than 100 meters away from any highways or small roads (Table 4). Different layers like Distance from roads, Distance from streams, Distance from main urban areas, topography and RWH suitability maps were reclassified and weighted overlay tool were applied. The analysis for gully Plugs structures releveled that 1572.518 km^2 area are the ideal places to construct gully structure to store rain water and stop soil erosion while 3742.38 area having the moderate ideal situation.

Figure 4c.

Factor	Classes	Index	Rank
Slope	<10° 10°-15° 20°-15°	Most Ideal Moderate Ideal Least Ideal	5 3 1
Streams Network	Stream Network order (3-4) 30m surroundings Stram area from30m-80m >80 meter from stream	Most Ideal Moderate Ideal Least Ideal	5 3 1
Urban/ Major Settlements	>230 m away from settlements Location 200-230m away from settlements Location in 200 m zones width	Most Ideal Moderate Ideal Least Ideal	5 3 1
Major and Minor roads	Locations 100m away from roads Locations 70m to 100 m far away from roads Road and an area of 70 m width	Most Ideal Moderate Ideal Least Ideal	5 3 1
RWH Map	Most suitable Moderate Suitable Least Suitable	Most ideal Moderate ideal Least ideal	5 3 1

Table 4: Criteria for Gully Plugs based on IMSD (1995), INCOH (1995), and FAO (2003) guidelines (source:(Khan et al., 2022).

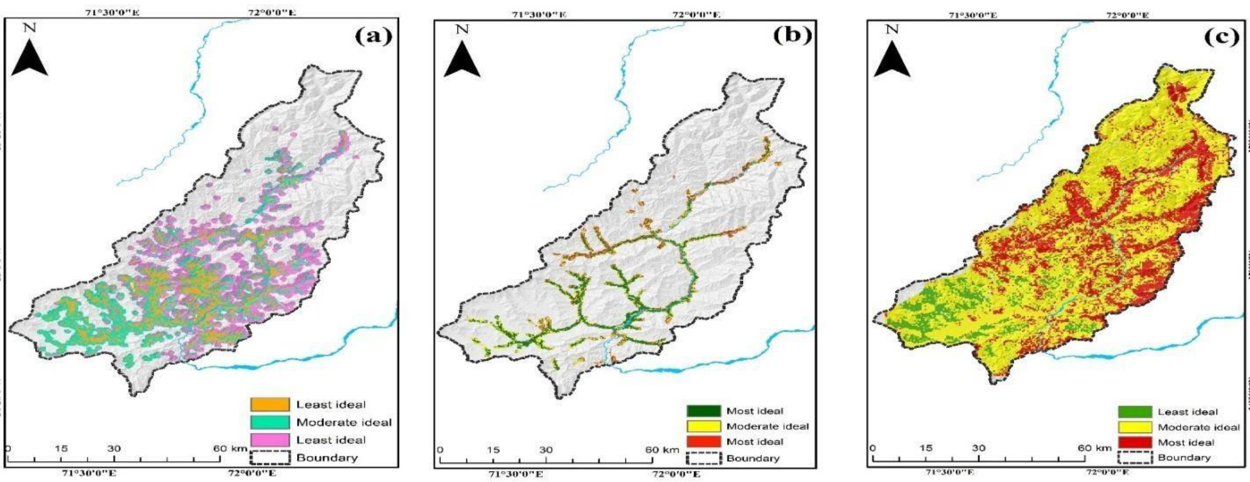

Figure 4. Suitable areas, (a) Fam Ponds, b) Check Dams, c) Gully Plugs.

3.5 Ground water Situation in the basin

Water availability is crucial to human survival and the sustainability of contemporary ecosystems, particularly for ensuring food security for the growing population (Munang, Thiaw, & Rivington, 2011). High population density, unequal water resource distribution, time and space constraints, economic growth, and climate change are all contributing factors to the scarcity of surface water resources (Arnell, 2004; O'Connell, 2017). As a result, there is more demand for groundwater, which supplies 30% of the freshwater on Earth. Furthermore, it would be impossible to maintain rapid urbanization and population growth without taking advantage of subterranean water supplies (Arnell, 2004; Sarwar et al., 2021). Nonetheless, there is a significant dearth of information and research-based data about possible locations with adequate subsurface water supplies. Accurate, economical, automated, near-real-time information can be obtained by using remote sensing data with different spatiotemporal, spectral, radiometric, and temporal resolutions (Belgiu & Stein, 2019). Field observation and a multi-influencing factor (MIF) technique were used to map the groundwater levels and zones for the present study. To determine groundwater potential zones and level, seven significant input elements were selected: drainage density (DD), geology (G), land cover, lineament density (LD), rainfall (R), soil type (ST), and topography (slope, TG). Each of these elements has an impact and interacts with other elements in various ways. The relationships between the various influencing factors were established (Figure 5) (Verde et al., 2018), and weights, rankings, and relative strength were assigned (Zhu et al., 2018). Multi-influencing factor (MIF) technique is used to maintain uniformity after these characteristics were entered into a GIS platform and processed to assign relative weightage and score (Swain, Paul, & Behera, 2024). Combining all of the contributing elements with their respective weights, weighted overlay analysis was utilized.

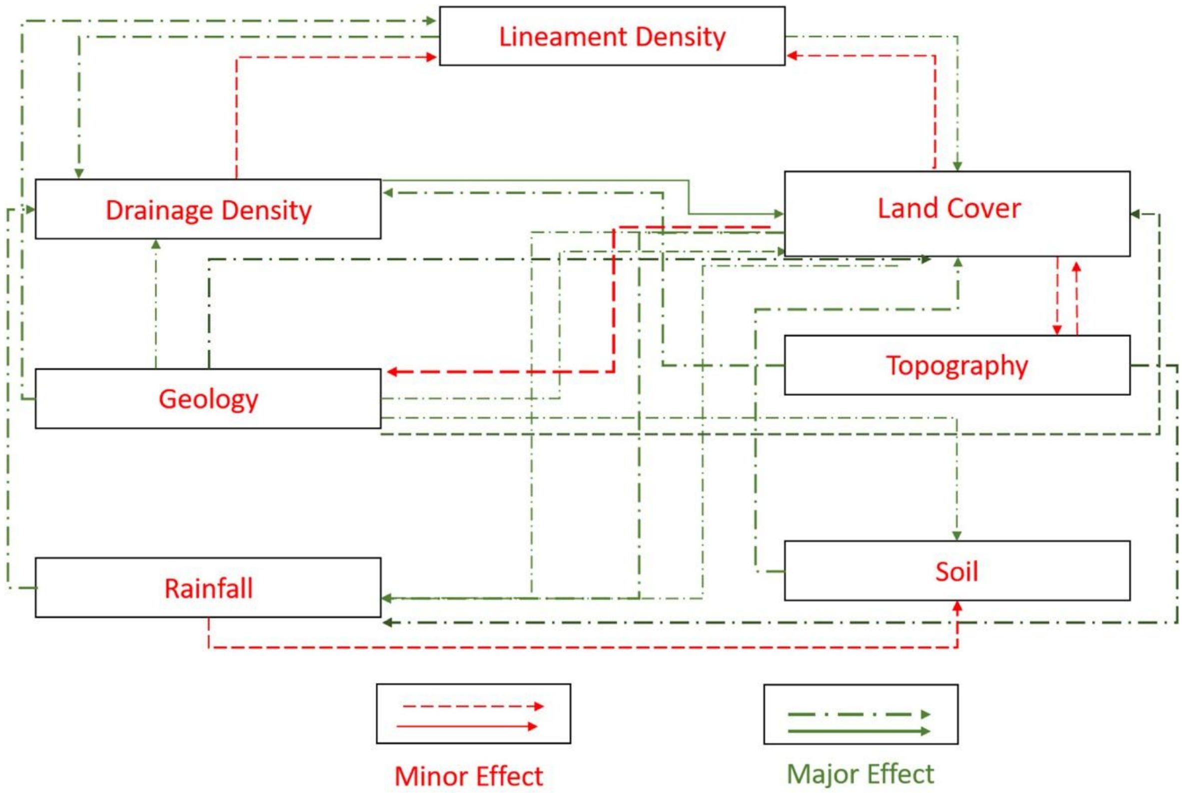

Figure 5 (Relationship between factors)

The depth to the water table and the related spatial extent have been used to classify the Panjkora River Basin's groundwater potential. Zones appropriate for groundwater extraction and recharge operations are identified with the use of this mapping. The 74.73 km^2 Very High Potential zone, which has a shallow depth of 0 to 50 feet (Figure 6 table 2), shows regions with readily accessible groundwater that are perfect for extraction and recharging. With moderate drilling efforts, the 1,375.31 km^2 High Potential Zone, which has depths ranging from 50 to 80 feet, provides favorable conditions for groundwater utilization. The poor zone (150–300 ft) comprises 872.90 km^2, whereas the moderate zone (80–150 ft) covers 3,548.56 km^2. (Figure 4). The water table is substantially lower in these places (Poor zone), extracting groundwater is more challenging, expensive, and energy-intensive. To increase water availability and sustainability, these areas need targeted groundwater recharge interventions such managed aquifer recharge methods, recharge wells, and check dams. In the Panjkora River Basin, this depth-based classification aids in directing the planning of water resources and establishing priorities for areas that require conservation and recharge. This classification facilitates efficient planning for the basin's groundwater development and management.

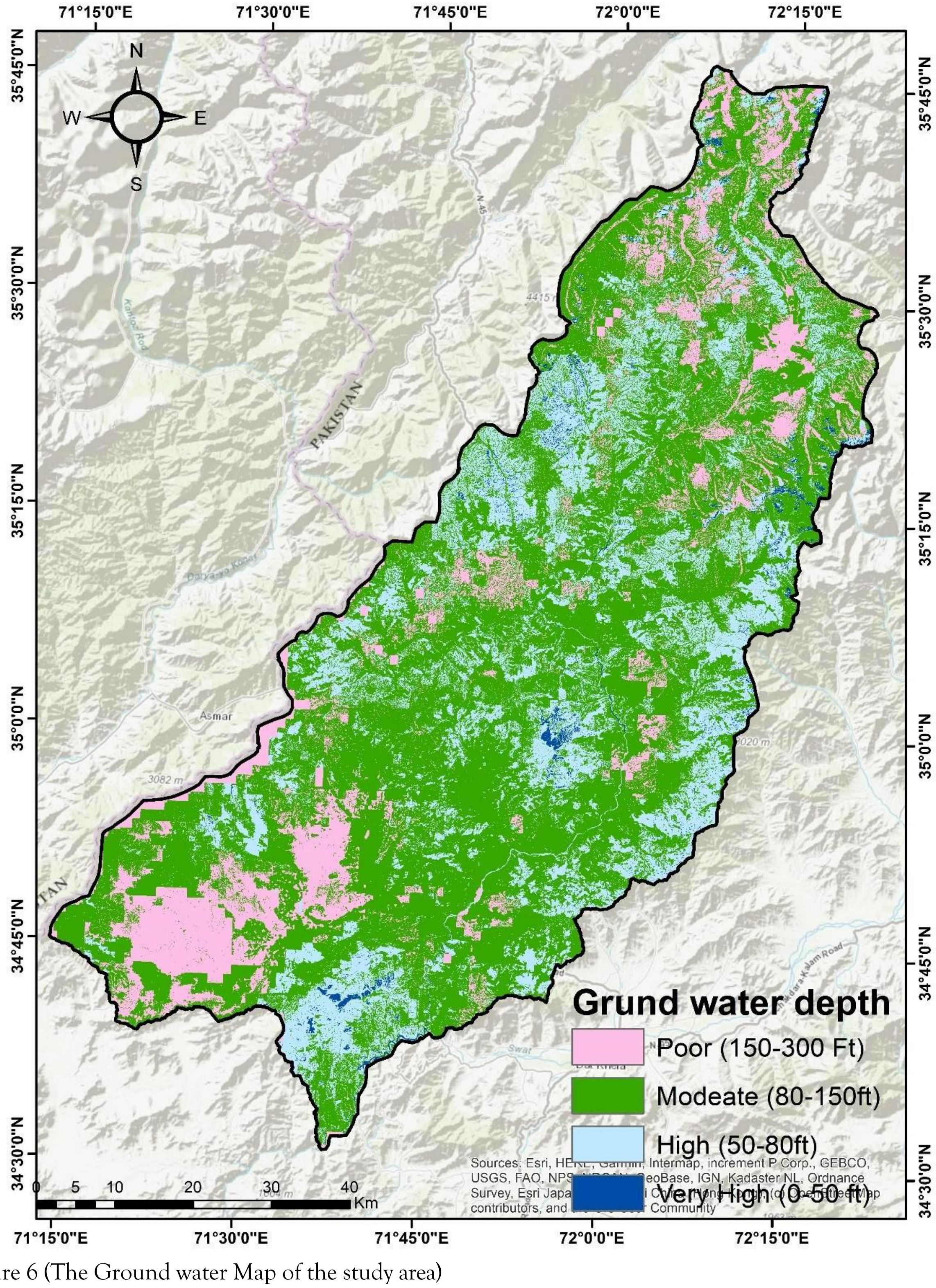

Figure 6 (The Ground water Map of the study area)

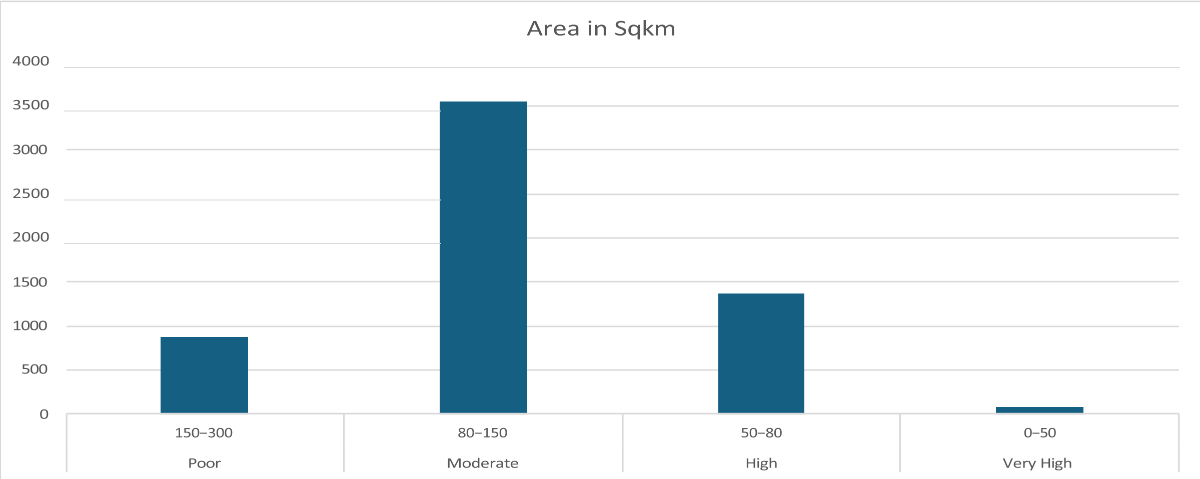

Figure 7 (Ground water zones)

Zone	Depth (ft)	Area in Sqkm
Poor	150-300	872.901591
Moderate	80-150	3548.562703
High	50-80	1375.313043
Very High	0-50	74.733627

4 Suitable sites map for NAR

The NAR Model, which divided the land into NAR indexes, was used to create a map of natural aquifer recharge. The index increases in value from 14 to 210. NAR index 14–22, 23–25, 26–36, 37–100, and 110–210 are the five classes into which the NAR index was further reclassified. The upper basin had the lowest NAR index, with a yearly rainfall of 69–76.9 mm and a rather shallow water table ranging from 45.2-146 meters. There are forests and snow covering most of the area. While metamorphic rocks are located in the top regions of the basin, where the index is low, the most populated and urbanized areas are found in the central and lower portions, where the index is larger than 100. People from the upper basin moved to the lower basin due to extreme weather and the need for life facilities, which directly affected the ground water by exerting pressure. The deep-water table and generally little rainfall are features of the range area in the east of the basin, where the index is high. Figure (8).

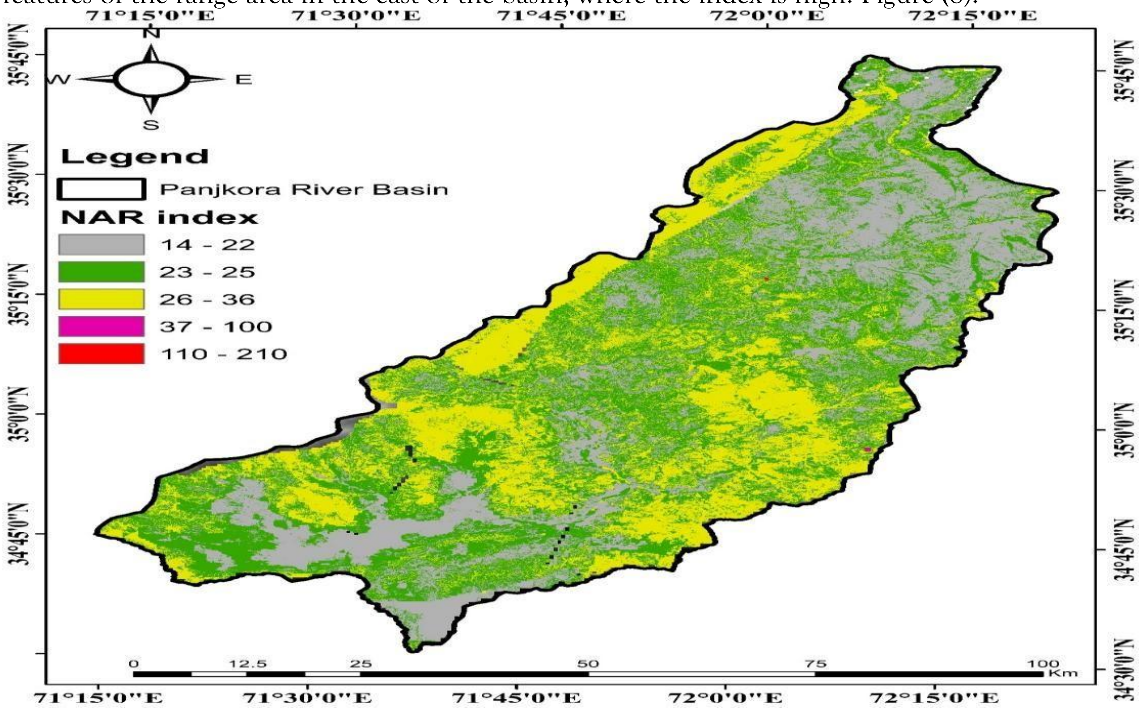

Figure 8 (NAR index Map)

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4.1 NAR map and Ground water Map comparison

The groundwater conditions in the Panjkora River Basin are varied, with large areas of the region falling into the Moderate (80–150 ft) and Poor (150–300 ft) groundwater zones. Together, these zones span over 4,400 km^2, indicating deeper water levels that are difficult, expensive, and energy-intensive to extract. Despite the growing groundwater stress in these regions, they are also important targets for measures aimed at sustainable management. A potential prospect is revealed by a parallel examination of aquifer recharge suitability derived from hydrological, geological, and topographic characteristics. There is a Moderate to Very High potential for artificial recharge in more than 413,000 hectares, or more than 72% of the basin. The land area is categorized as Highly Suitable in 30.19% of cases and Very High Suitability in 1.01% of cases. In terms of hydrology, this spatial correlation is quite important. Highly or Very Highly suitable locations for recharge are found in many areas of the Moderate and Poor groundwater zones. This overlap implies that regions with deeper water tables and diminishing groundwater levels also provide favorable subsurface geology, permeable soils, and moderate slopes—all of which are ideal natural conditions for boosting recharge. Significant increases in groundwater availability can result from the targeted installation of Managed Aquifer Recharge (MAR) structures in these overlapping zones, such as check dams, recharge wells, and percolation ponds. Particularly in areas where traditional groundwater extraction is no longer technically or economically feasible, these interventions would encourage vertical infiltration, lessen runoff, and aid in the restoration of dwindling aquifers. Water managers can implement location-specific, data-driven methods to increase climate resilience and long-term water security in the Panjkora Basin by coordinating recharge planning with natural recharge potential and current groundwater stress. By taking an integrated strategy, recharge activities are guaranteed to be sustainable and successful, supporting the hydrological balance of the basin.

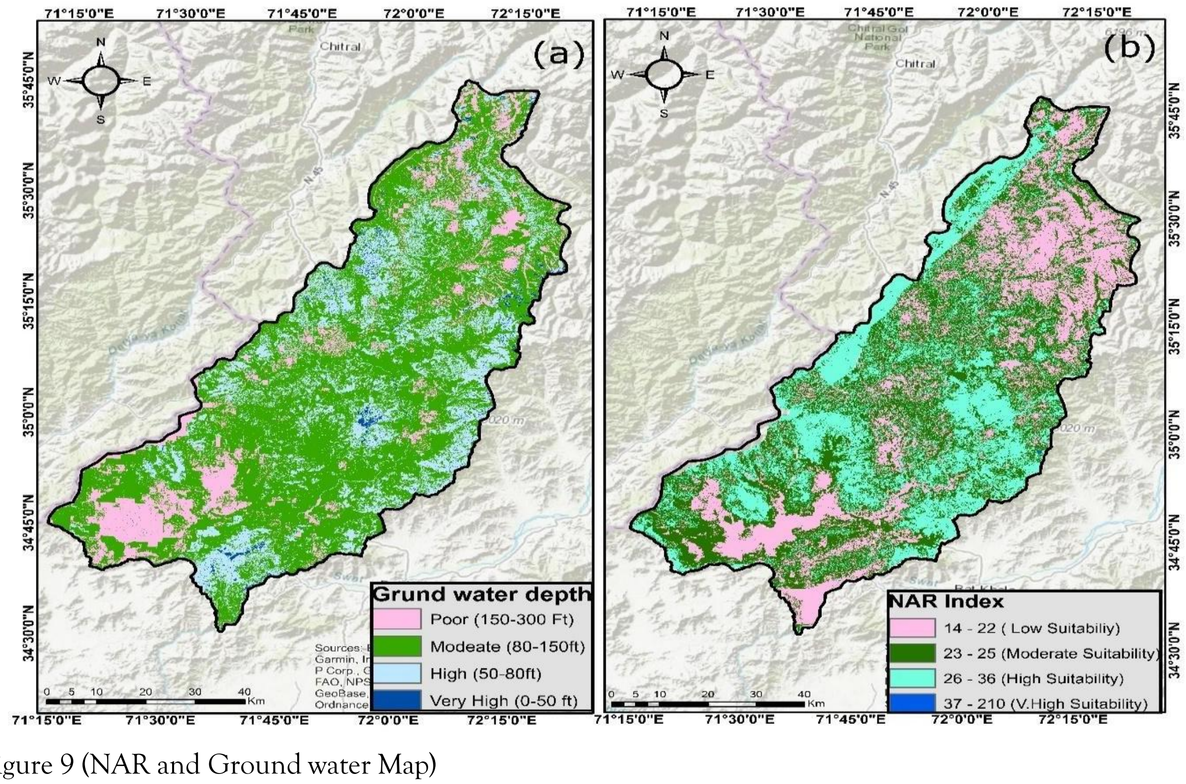

Figure 9 (NAR and Ground water Map)

4.2 Recharge wells and Roof top Harvesting

33 natural aquifer recharge (injection) wells were suggested in these areas following the study. It is projected that these wells will be essential to boosting groundwater supplies and guaranteeing sustainable management of water resources. The study also found five locations for rooftop rainwater gathering to support the aquifer recharge approach. These locations have been selected since they have the capacity to effectively collect and use rainfall, which will lessen surface runoff and aid in groundwater recharge. The availability of government land, structural soundness, and proximity to populous areas were important factors in the site selection process. To make implementation easier and eliminate land acquisition issues, public properties with sufficient rooftop space and structural soundness to support harvesting infrastructure were given priority. Rooftop harvesting systems and natural aquifer recharge wells are two

suggested interventions that offer a comprehensive strategy for managing water resources. The project intends to improve groundwater levels in key areas, lessen the effects of water scarcity on domestic supply, agriculture, and ecosystems, and minimize reliance on external water sources by optimizing local water resource utilization. It does this by utilizing the high and very high suitable zones for aquifer recharge. Likewise, it is expected that the rooftop harvesting locations will function as demonstration projects, highlighting the viability and advantages of rainwater harvesting in urban and semi-urban settings. By using the collected rainwater for non-potable uses like cleaning, irrigation, and groundwater replenishment, the strain on the current water supply can be reduced.

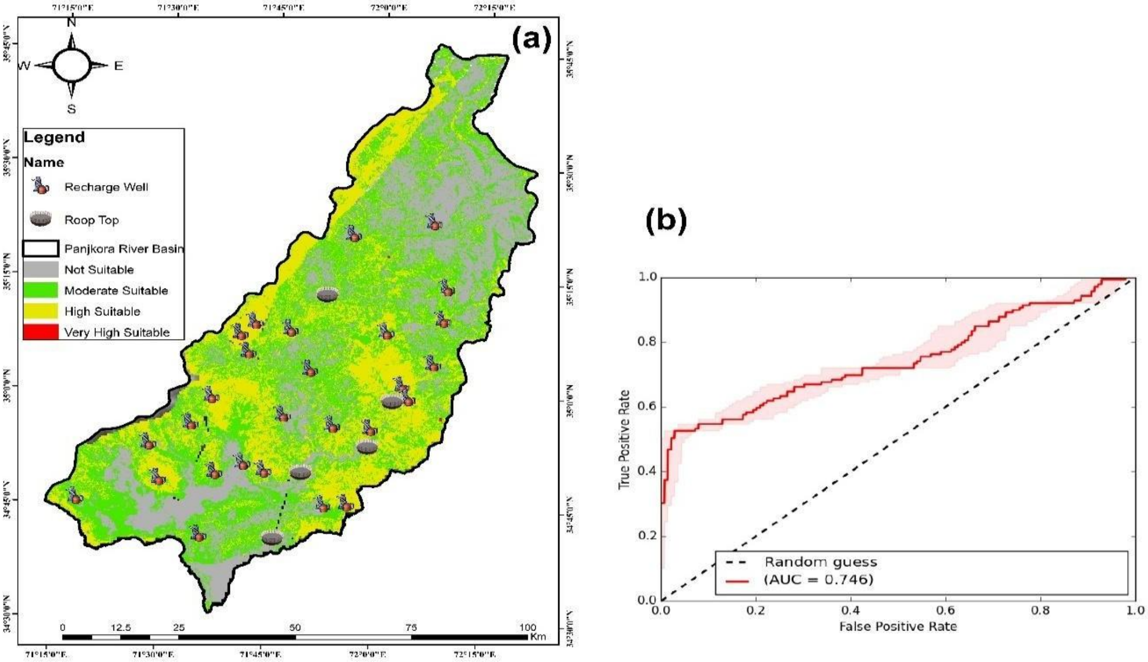

Figure 10

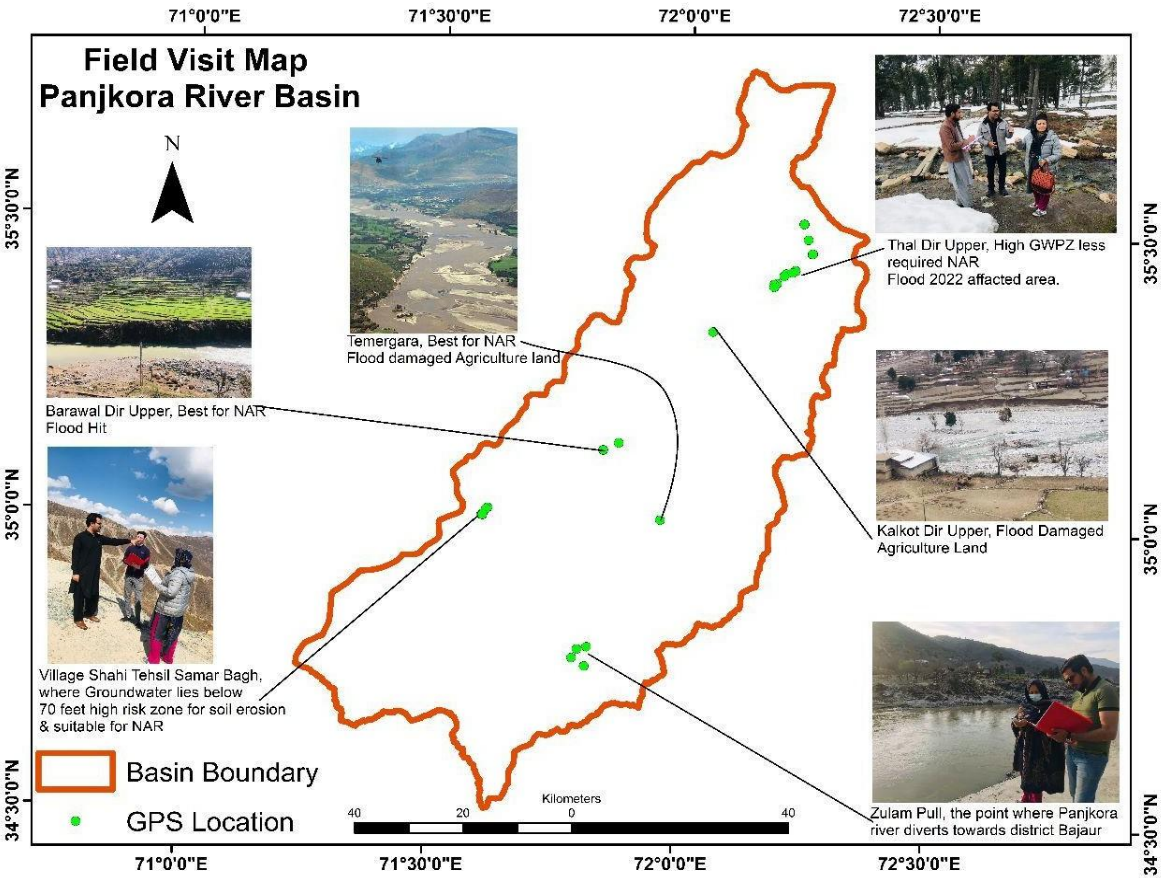

Figure 11 Field observation

5 CONCLUSION

The most magnificent natural resource is water, which is necessary for a healthy environment that supports all life. It is crucial to investigate rainwater collection techniques that incorporate sensible drought-reduction strategies due to the acute water constraints that exist globally. Finding potential sites for rainwater collecting structures to be built in order to manage rainwater harvesting in the study area effectively and efficiently is the aim of this study. To determine a potential suitable RWH location, a weighed overlay analysis was used, giving each factor a certain amount of weight. RWH locations were determined using GIS-based MCEs and five criteria: slope, soil, runoff, drainage density, land use/land cover, and road restrictions. The soil and water assessment tool approach revealed a runoff depth of 0-900 CMS, and the RWH unit's suitability varied from highly appropriate to not suitable.

For the development of farm ponds, the Panjkora River Basin's overall area of 1128.395 km^2 is the most suitable, whereas 954.756 km^2 is the moderate suitable. The most suitable area for check dam building is 350.58 km^2, while the moderate suitable area is 245.31 km^2. The study of gully plug structures revealed that 3742.38 km2 had the moderately perfect conditions, while 1572.518 km^2 were the best areas to build gully structures in order to prevent soil erosion and store rainwater. The research highlights regions that are favorable for growth, which is a huge advantage for the best possible development of rainwater harvesting sites. At the same time, it protects other land uses by controlling the future growth of rainwater harvesting sites. As a result, the community and the surrounding natural environment may experience a higher sustained quality of life. This allows us to make well-informed decisions on environmental circumstances. As a result, suitability analysis is an effective technique for locating and organizing rainwater gathering sites. Refinement is feasible when necessary because GIS application is a novel and adaptable technology for suitability analysis. Choosing the most suitable locations for natural aquifer recharge is one of the most crucial phases in the management of water resources. The current work focuses on identifying possible locations for natural aquifer recharging utilizing RS and GIS methodologies as the water table is rapidly declining. Seven local impacting factors land use and land cover (LULC), drainage density, slope, population density, water table, elevation, and soil types—have been included in the current strategy in order to accomplish the aforementioned goal. The potential for artificial recharge has been determined to be Moderate to Very High for more than 413,000 hectares, or more than 72% of the basin. Interestingly, 1.01% of the land area is in the Very High Suitability class, and 30.19% is in the Highly Suitable category. The hydrological implications of this spatial association is enormous. Many of the locations designated as Highly or Very Highly suited for recharging are found in the Moderate and Poor groundwater zones. According to the study's conclusions, sectorial areas where water resources are more vulnerable and water demand has surpassed expectations should receive extra attention. In the future, hand pump data and private tube wells might be combined to provide more precise water table depth forecasts at different points throughout the region. To further improve the accuracy of the results, it is also advised to use machine learning in conjunction with high-resolution imageries.

The current study will provide policymakers with valuable insights for better groundwater resource management in terms of aquifer distribution, exploration, and recharge based on appropriate sites. The suggested method might also be useful for determining appropriate locations for natural aquifer recharge in both developed and developing nations.

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