# Identification of Potential Check Dam Sites Using Multicriteria Decision Support System: A Case Study of Wana District, South Waziristan


**By**

**Shakeel Ahmed**

**(2020-NUST-MS-GIS-330479)**


**A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Remote Sensing and GIS.**


**Institute of Geographical Information Systems**

**School of Civil and Environmental Engineering**

**National University of Sciences & Technology**

**Islamabad, Pakistan**



**January, 2023**

# THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by **Shakeel Ahmed (Registration No. 330479) MSRSGIS of Session 2020 (Institute of Geographical Information systems)** has been vetted by undersigned, found complete in all respects as per NUST Statutes/Regulation, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ____________
Name of Supervisor: Dr Javed Iqbal
Date: 11-9-2023

Dr. Javed Iqbal
Professor & HOD IGIS, SCEE (NUST)
H-12, Islamabad

Signature (HOD): ____________
Date: 11-9-2023

Dr. Javed Iqbal
Professor & HOD IGIS, SCEE (NUST)
H-12, Islamabad

Signature (Associate Dean): ____________
Date: 11.9.2023.

Dr. Ejaz Hussain
Associate Dean IGIS, SCEE (NUST)
H-12, ISLAMABAD

Signature (Principal & Dean SCEE): ____________
Date: 12 SEP 2023

PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

## ACADEMIC THESIS: DECLARATION OF AUTHORSHIP

I, **Shakeel Ahmed**, declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

"Identification of Potential Check Dam Sites Using Multicriteria Decision Support System: A Case Study of Wana District, South Waziristan"

I confirm that:

1. This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text.
2. Wherever any part of this thesis has previously been submitted for a degree or any other qualification at this or any other institution, it has been clearly stated.
3. I have acknowledged all main sources of help.
4. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.
5. None of this work has been published before submission.
6. This work is not plagiarized under the HEC plagiarism policy.

Signed: ……………………………

Date: 9/15/2023

# *DEDICATION*

*"To my dear mother who give me confidence in all ups and down",*

*"To my dad who give me love and strength each second…&*

*"To my friends and teacher who helped me throughout research and beyond."*

*"To my sisters and brothers."*

# ACKNOWLEDGEMENTS

All praise is owed to Allah, who is the Almighty and Most Merciful. Who is the master of all knowledge and the knower of the unknown. All praise goes to Allah, who granted me the wisdom and direction necessary to do this. The most important thing is His unending mercy and blessings. My entire gratitude is due to Him alone. My thanks to my family who believed in me and prayed for my success especially my father who supported me in every aspect possible. My mother whose prayers took me where I am today. My very special gratitude to my supervisor Dr. Javed Iqbal who not only supervised me for the work but also be kind enough to extend his support in every problem that I came across. His farsightedness and visionary judgement made this day possible. May Allah reward him in return. My thanks to all my collages who helped me whenever I need them, their respect, courtesy and availability are highly acknowledged. May Allah shower his blessings upon them.

Shakeel Ahmed

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| Abbreviation | Explanation |
|---|---|
| AHP | Analytical Hierarchy Process |
| WLC | Weighted Linear Combination |
| IPCC | International Panel on Climate Change |
| LULC | Land Use and Land Cover |
| DEM | Digital Elevation Model |
| AI | Artificial Intelligence |
| KJs | Cretaceous and Jurassic Metamorphic Rocks |
| Pg | Paleogene Sedimentary Rock |
| TKim | Tertiary and cretaceous Igneous and Metamorphic rock |
| Jms | Metamorphic and Jurassic Sedimentary Rocks |
| Ks | Cretaceous sedimentary rocks |
| JTr | Triassic sedimentary and Jurassic rocks |
| N | Neogene sedimentary rock |
| CRU TS | Climatic Research Unit Time series |

# Abstract

Decreasing water resources is one of the main concerns throughout the world and specially in Pakistan. South Waziristan, district of Pakistan is facing severe water shortage from the past few decades. The best way to control scarcity of water resources is construction of water harvesting structure at a suitable location, which need very critical measure considering many criteria for the selection of sites for harvesting structure. Using GIS and remote sensing we can select optimal sites for check dam very efficiently and effectively. In this study we adopted GIS and Multicriteria decision analysis using Analytical Hierarchy Process and Weighted Linear Combination for locating appropriate locations for water harvesting check dam in WANA city of district South Waziristan Pakistan. Various confined layers i.e. Land Cover, Soil, Slope, Precipitation, Geology, Drainage density, fault line and road networks were created and then assigned weight to each layer according to their importance for check dam and apply Analytical Hierarchy Process and Weighted Linear Combination for finding a suitable zone for check dam first. The AHP method give us significant results than WLC, while validating with existing check dam sites of the study area. Analytical hierarchy process gives us result ranging from high potential to low potential zone which was classified into three zones i.e., low potential zone, moderate potential zone and high potential zones. Out of a total area of 3742 sq.km, high potential zones occupy 805 $km^2$ (21.24%), moderate potential zones occupy 1697 $km^2$ (45.35%), and poor potential zones occupy 1240 $km^2$ (33.13%). After selecting suitable zones, sites for check dam was marked by using stream order which was created from DEM using ArcMap. $2^{nd}$ and higher stream order was chosen for check dam. Out of the suitable zones a total 28 suitable sites for check dam were marked by physical visits to the study area and using google earth pro in high suitability and moderate suitability zones.

# CHAPTER 1

# INTRODUCTION

Water is an important natural resource which is necessary for maintaining of any kind of life on planet earth. WANA, South Waziristan is facing severe water scarcity from the past twenty year because of agricultural land development and increase in population nearly all karezes are dried up and ground water table decreases in very alarming rate from the past twenty years and nearly 70% Most of the people depend on agriculture for their living, while agriculture is totally dependent on ground water which cause severe drop of ground water table. In many regions of the world, groundwater irrigation is essential for improving rural communities' livelihoods and agricultural output. For instance, since 1950, the area in South Asia with irrigation facilities has increased thrice. The main groundwater users in South Asia are India, Pakistan, and Bangladesh, with combined annual extractions of around 321 billion m3 (India: 231 bm3; Pakistan: 60 bm3; Bangladesh: 30 bm3). Compared to the rest of the world, where the percentage is 40%, more than 85% is used for agricultural uses. These three nations use groundwater to irrigate 48 million ha (mha), or 42% of the world's groundwater-fed crops (Qureshi, 2020). For more than 2 billion people worldwide, groundwater is their main supply of water, and it provides around 50% of all the water needed for cultivation (Siebert et al., 2010). There are various groundwater-related issues, and groundwater contamination and overuse have drawn attention on a global scale (Gleeson, Wada, Bierkens, & Van Beek, 2012). With the increase in population agricultural land development is increasing which will further drop water table and people will not even find drinking water. To overcome this problem some precautionary measures are the need of the hour including less water consumption and constructing of networks of check dams while check dams require suitable sites for their construction.

Groundwater resources are in greater demand because of population expansion, urban sprawl, and agricultural expansion. The target locations for groundwater exploration and recharge is determined utilizing both remote sensing and GIS methods. When evaluating hydrogeological systems, the GIS mapping method has proven to be a beneficial tool. It offered a centralized location for mapping, visualizing, combining, analyzing, and making decisions (Ahmed & Shabana, 2020). Even though the groundwater is a significant as well as necessary resource of water, and it is not managed adequately; The aquifers throughout the planet are running dry. as a result of overuse, which is a severe worry, particularly in arid places where the situation is even more concerning (Ousrhire, Jarar, & Ghafiri, 2020).

The overuse of ground water will create water scarcity at alarming rate in near future if not tackle effectively and efficiently. With the approach of GIS, we can find suitable target points for construction of check dams which will accumulate and harvest water from different source maintaining a balance hydrological dynamic. To ensure that crucial elements are taken into account when managing resources, the water supply unit has to be delineated while adhering to the hydrogeological regime. In general, the types of underlying rocks, the width of weathered material, the composition and geomorphic setting, and the environmental conditions affect water recharge, flow, and evolution (Sener, Davraz, & Ozcelik, 2005)

With the development of satellite remote sensing, a platform has been created for the integration of useful data, including land use/land cover, drainage, lineaments, slope, soil, topographic wetness index, lithology, and geomorphology, This helps in identifying whether a major groundwater resource is likely to be located in a specific area. (Aluko & Igwe, 2017). Since groundwater is an important natural resource for human water use and supply is anticipated to become even more crucial under future climatic conditions, it is crucial to ascertain human sensitivity to groundwater effects caused by climate change. Future rainfall variability will rise while snow/ice storage falls, resulting in higher streamflow variability with lower low flows and, ultimately, less reliable surface water(Kundzewicz et al., 2007). Further we can assess the socio-impact of ground water by processing satellite data of different time and socio data like population.

A check dam is a small dam constructed across a drainage channel or a small stream to prevent or control erosion, to retain water, and to increase groundwater recharge. The purpose of a check dam is to slow down the flow of water, reduce soil erosion, and recharge groundwater. Check dams are commonly used in dryland areas to conserve water and prevent soil erosion.

This study focuses on the sustainable development of the WANA region, with a specific focus on South Waziristan. Its main objective is to identify potential zones and sites for constructing check dams using the Analytical Hierarchy Process. The method considers various criteria, such as hydrology, topography, land use, and socio-economic factors, to identify suitable locations for check dams. The study's outcomes can have significant positive impacts on the region's water resource management, soil conservation, and agricultural development. The construction of check dams in identified potential zones can help control soil erosion, recharge groundwater, and increase water availability for agricultural and domestic use.

## 1.1. Check Dam

Check dams are generally made of stones, boulders, or concrete, and are designed to withstand the force of the water. They are constructed in a series to slow down the water and reduce its velocity, allowing sediment to settle and soil to be retained. Check dams can also be used to create small ponds or wetlands, which can provide habitat for wildlife and improve the quality of water. Check dams are often used in areas where there is little or no vegetation, which can lead to soil erosion and water runoff. They are also used in areas where there is a need to recharge groundwater, which is important for agriculture and drinking water. Check dams can be constructed by local communities or government agencies and can be an effective tool for watershed management. In short, a check dam is a small dam that is constructed to slow down the flow of water, prevent erosion, and increase groundwater recharge. They are commonly used in dryland areas to conserve water and prevent soil erosion and can also provide habitat for wildlife and improve the quality of water.

### 1.2. Rationale

Water is an important natural resource. Scarcity of water is a dreadful problem that is present in Pakistan and many other nations. Pakistan is ranked fourteenth out of the world's seventeen "very high-water risk" countries, along with desert Saudi Arabia. Climate change is a global phenomenon that primarily manifests itself through global warming, causing negative consequences on natural resources, anthropogenic activities, and natural disasters, as reported by the International Panel on Climate Change (IPCC). El Nino and La Nina have had adverse impacts on hydrologic regimes and ecosystems. The average temperature has increased by 0.4°C from 1895 to 1995, leading to severe floods in several years and the worst-ever droughts in Pakistan from 1998 to 2004 (Hussain & Mumtaz, 2014). Pakistan is among the world's most water-stressed countries, with a surface water potential of 140-million-acre feet (MAF) and an underground water reserve of 56 MAF. The per capita annual availability of water has reduced from 5140 m3 in 1950 to 1000 m3 at present, and the country is rapidly approaching water scarcity(Ahmad & Hussain, 2018). To mitigate the adverse impacts of climate change on the water crisis in Pakistan, it is necessary to develop integrated national, provincial, and local-level master plans that consider technical, social, environmental, administrative, and financial aspects (Hussain & Mumtaz, 2014). In the country, more than eighty percent of the population experiences acute water shortage for at least one month out of the twelve months of the year. Aside from surface water, the last line of defense for water supply in Pakistan, the groundwater resources, are severely depleted, primarily due to the need for agriculture water. By 2025, the entire nation can experience a water shortage due to the current situation. Pakistan urgently needs water collection infrastructure that can be used for more than just irrigation (Basharat et al., 2014).

### 1.3. Significance

About 70% population of South Waziristan depends on agriculture for its livelihood and agriculture of WANA is mostly reliant on groundwater resources that are drawn from well, on account of that frequent use of ground water, the water table of WANA is going down day by day with alarming rate and the drop of water table disrupts many orchards of apple and other fruits in past 10 year. In order to protect the agriculture and ecosystem of WANA we need to store rainwater coming from mountains and pass through WANA plain within minutes for which check dams at different seasonal channels will be very useful for storing rainwater which will not only recharge ground water but will use for irrigation purpose. Through integration of GIS and Remote sensing using fuzzy logic using Slope data, Drainage channels, elevation, Geology, soil. Fault and Land Cover of WANA we can find the best site for check dam sites and will analyze the socio-economic impacts of check dam on study area.

Check dams are essential in preventing soil erosion in hilly and mountainous areas. They help to slow down the flow of water, thereby reducing the velocity of water, and the sediment load carried by water. As a result, the soil in the upstream of the check dam can be retained and used for agricultural purposes.

### 1.4. Objectives

The study aims were to contribute significantly to the sustainable development of the WANA region, specifically in the South Waziristan area, by identifying potential zones and sites for the construction of check dams. To achieve this objective, the study utilizes the Analytical Hierarchy Process, which is a powerful tool for multiple criteria decision analysis. The method considers several parameters, including hydrology, topography, land use, and socio-economic factors, among others, to identify potential sites for check dams. The study's findings can have significant impacts on regional water resource management, soil conservation, and agricultural development. The construction of check dams in identified potential zones will help to control soil erosion, recharge groundwater, and increase water availability for agriculture and domestic purposes. Moreover, the overall objective of this research is:

- The objective of the study was to Identify Potential zones & sites in WANA South Waziristan using Multicriteria decision analysis and its validation with existing check dams.

# CHAPTER 2

# LITERATURE REVIEW

Water is the second most important element for life, right after oxygen. You couldn't last more than a few days without it as water makes up more than half of your body weight. On the other side, you can go for weeks without eating. Because of the effects of expanded groundwater extraction and climatic change, water shortage is growing globally. Due to the world's rapid population expansion, there is an increasing need for drinkable water for human consumption, agricultural demands, and commercial usage. The result is, it is becoming more important to assess the potential of groundwater resources and aquifers' producing abilities (Arefin, 2020). The development of sustainable groundwater supplies requires better management techniques and artificial recharge (Arshad, Zhang, Zhang, & Dilawar, 2020). The most effective strategy now available to enhance the region's groundwater conditions is artificial recharge. Geographic Information System (GIS) modelling using the Analytical Hierarchy Process (AHP) context is used to define artificial recharge sites using the key elements that are crucial to groundwater occurrence. The weighting for individual factors been assigned depending on the significance of these factors in the location decisions for artificial recharging using datasets from various sources including Landsat-8 satellite pictures (Khan, Govil, Taloor, & Kumar, 2020).

Remote sensing techniques and GIS are used in conjunction for the creation and evaluation of ground water potential zones and sites, and efficient management of groundwater assets. To define ground water prospects zones, a variety of thematic spatial layers are employed, including soil maps, geology maps, land use land cover (LULC), elevation maps, topographic wetness index maps, stream distance maps, slope maps, stream volume maps, curvature maps, and rainfall maps (Alikhanov, Juliev, Alikhanova, &

Mondal, 2021). Groundwater zones show significant spatial and temporal variation. These variables include hydrological elements including water bodies, irrigation, soil types, geology, and geomorphology as well as land use and cover, soil kinds, precipitation, and evaporation.(Lee, Kim, & Oh, 2012). The Kilinochchi district's need for freshwater rises in 2021 due to the limited supplies for rainwater in the dry season. identifying possible ground water zones in Sri Lanka, Kilinochchi district the analytical hierarchy method was used in conjunction with integrated remote sensing (RS), and GIS to achieve the major goal as a identifying the best locations for water harvesting structure. The Kilinochchi district's ground water prospects zones were defined by superimposing confined layers of geomorphology, geology, land cover, drainage density, slope, soil texture, lineament, and rainfall. Groundwater zones were identified using a weighted overlay analysis after the confined layers were included into a GIS (Geographic Information System). Five potential zones were identified. The validation of the ground water potential map using the existing 79 wells showed a good forecast accuracy of 81.8%. This indicates that the outcomes of combining AHP and GIS-RS are compatible when utilizing with the already existing well water depth. The AHP based RS-GIS method was a practical and effective method for evaluating prospective groundwater zones (Pathmanandakumar, Thasarathan, & Ranagalage, 2021).

In 2019, GIS and Remote Sensing approaches were employed to try to discover ideal places for the construction of artificial recharge structures in southern India, Amaravati aquifer system, to improve the wells' sustainability and reverse the downward trends in groundwater levels. In a GIS overlay analysis, the eight layers i.e. slope, geomorphology, geology, soil, land use, weathering depth, post-monsoon water level, and waterbodies/drainage were integrated. Thematic maps were created using data from ASTER, Survey of India Topo sheet and Remote Sensing Satellite of India IC. Later, raster data was created from these maps. Data on the depth of the groundwater from the existing 248 deep wells and weathering thickness from the monitoring stations were combined. There identified four zones: very high, high, moderate, and extremely bad (Senthilkumar, Gnanasundar, & Arumugam, 2019). Groundwater supplies in a region will be sustainably replenished as a result of check dams' appropriate maintenance. According to most of the research, improving groundwater quality and head using check dams is generally regarded as one of the best strategies to improve communal well-being. According to a case study conducted near to Chennai, the check dam has increased the level of the groundwater by up to 1.5 meters. This makes managed aquifer recharge via check dam the ideal solution for the effective and long-term management of groundwater supplies (Renganayaki & Elango, 2013). Moreover, check dams can also enhance agricultural land development which will lift society economically (Lucas-Borja, Piton, Yu, Castillo, & Zema, 2021). Check dams have been utilized for a variety of reasons throughout the world, such as controlling torrents, improving water supplies, developing agricultural land, and restoring watersheds. Governments at the federal, state, and local levels have invested in and are still investing in basin-scale control erosion projects, which may involve maintaining and building of new check dams.

Groundwater accessibility is dependent on time and space of an area, to enhance the efficiency and efficacy of water delivery, use, and availability. There has been a rise in the building of water collecting structures across streams and watersheds in past few years. Several purposes, including flood control, irrigation, hydropower, industrial use, community and river canalization, have directed to the construction of water harvesting structure, because of the rise in water demand. In order to meet the study's goals, possible dam construction locations in Imo State, Nigeria, were discovered via a geographic information system, remote sensing methods, and fuzzy logic. Other climatic and geophysical factors that were taken into consideration include stream order, geology type, rainfall, runoff,  soil type, and land cover. According to their role in identifying potential dam sites, these characteristics were given fuzzy membership classifications. To create the appropriate dam site selection map, The fuzzy overlay approach was used to combine the fuzzy members for all the criteria. (Ajibade et al., 2020). Planning, execution, operation, and ongoing monitoring are essential components in developing and managing water resources sustainably. Due to India's growing population and diminishing water supplies, the government has a serious, intractable difficulty in providing clean water to all citizens, both in the rural and urban areas, to replace, supplement, and improve the earth's resources with methods that are both quick and inexpensive, remote sensing and GIS technologies must be employed efficiently in water resource research (Amalraj & Pius, 2018; Shenbagaraj). In arid regions, the recharge amount is lower than in semi-arid regions, which can have negative implications for the sustainability of groundwater resources. Pakistan's arid climate, coupled with increasing population, changing climate conditions, and the misuse of water resources, has led to a situation of water scarcity. The Hab watershed, located at the border of Sindh and Baluchistan in Pakistan, is a crucial source of water supply for the industrial area and mega city of Karachi, which is facing a water shortage of about 50 percent against its rapidly increasing demand. To address this issue, the Hab watershed was selected for a study using Remote Sensing and GIS tools, which are effective for assessing and exploring potential groundwater sites within a watershed(Sadaf, Mahar, Younes, & Geology, 2019). In today's world, the contamination of groundwater has become a significant concern for communities. The combination of rapid population growth in developing countries and climate change has led to an increased demand for water, making groundwater resources critical for avoiding water scarcity issues and social tensions (Berhanu & Hatiye, 2020).

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1. Study Area

Research area consists of three tehsil Wana, Birmal and Tiarza of South Waziristan District of Ex-FATA Pakistan (Figure.1). Wana is the summer headquarter of the district and classified as arid climate region with extreme aridity in summer. According to 2017 census of Pakistan population of the study area is 0.38 million which is 56.47% of the total population of South Waziristan. About 70% of people in Wana is rely on agriculture to support themselves. The fruits from the research area are well-known. The area grows a variety of fruits, including tomatoes, grapes, apricots, pears, apples, and grapefruits. The region has a strong dry fruit sector. The three most popular are walnut, cashew, and pine nuts. Average annual precipitation is from 225 to 333 mm per year. The study region is elevated between 274 and 3445 meters above sea level. The study area is sloppy where the highest elevation starts from North and West touching Afghanistan, North Waziristan and Baluchistan decreasing slowly towards South and East touching Tank and Dera Ismael Khan. The water flow is from Northwest toward towards Southeast. Wana is facing severe water shortage from past many decades, to overcome water scarcity a series of check dams is very compulsory to be built in different area and on feasible sites. Before selecting feasible sites some of the factor influencing check dams i.e., drainage density, slope percent, annual precipitation in mm, land use land cover, Geology, soil and active faults should be considered and assign appropriate weight to each criterion as per their importance in analytical hierarchy process which will gives feasible sites considering all criteria’s. For doing so, many types of data is obtained from several sources which are mentioned in Table1.

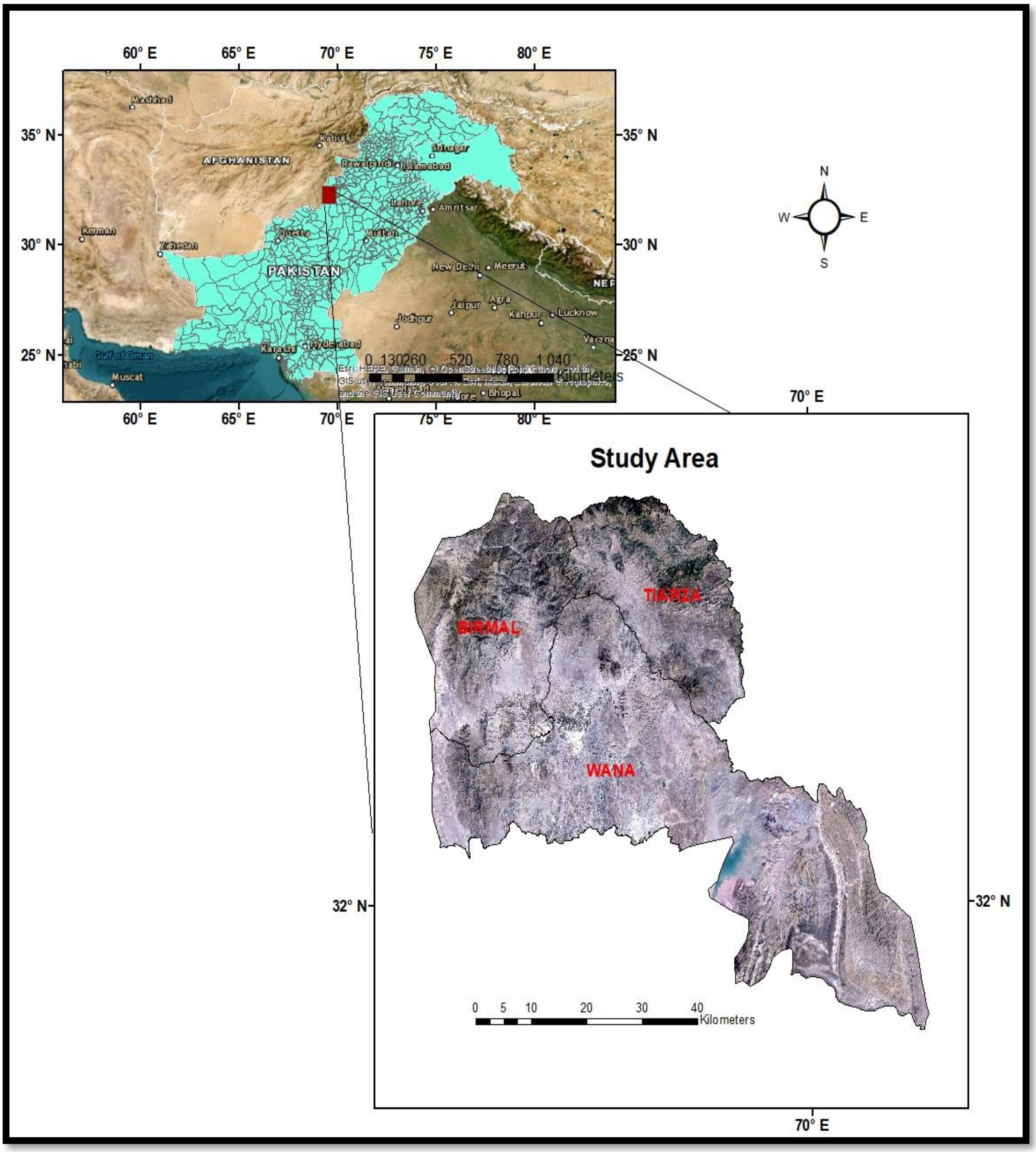


Figure 1 Study area map showing Wana, Birmal and Tiarza tehsil.

Table 1. Data and its sources used in research

| Data | Specification | Time period | Source |
|---|---|---|---|
| Active Fault from Tectonic map of Pakistan | Scanned map | 1997 | GSP |
| ESRI LULC | 2–10-meter spatial resolution | 2021 | USGS |
| SRTM(DEM) | Spatial Resolution 1-Arc | 2021 | USGS |
| Soil Data | Resolution: 250*250 meter | 2018 | FAO |
| Geology Data | Resolution: 329*329 meter | 1990 | USGS |
| Precipitation Data | 325*325 meter | 2020 | Climatic Research Unit UK |

### 3.2. Thematic layers preparation

To access, store, manipulate, display, and update vector and raster data for special applications, geographic information systems (GIS) provide the best tools. There are four ways to integrate data: planning and summing up site activities, data visualization and analysis, and data presentation. GIS is used extensively in hydrological analysis and modelling to evaluate and choose possible dam locations (Rasooli & Kang, 2015). With ArcGIS 10.8, all thematic layers, including those for slope %, geology, precipitation, soil, land use and cover, drainage density, vegetation cover, and water table were created.

### 3.3. Digital Elevation Model (DEM)

An image of 1-Arc resolution was acquired from the Shuttle Radar Topography Mission for South Waziristan from the website of the USGS (United States Geological Survey). The grids' respective DEMs were obtained and then mosaicked. The stream network and drainage density were derived. Five categories of drainage density were used. i.e. very high, high, medium, Low and very low as shown in the figure 2(A). For flow direction standard D-8 algorithm was used, This simulates the direction of flow from each pixel to its most steep neighbors The values of the grid for flow direction serve as a guide for the direction of the cells' steepest drop in this method, which compares the values of every pixel's corresponding eight neighbor’s for each center pixel in matrices of 3 by 3 pixels. Thus, while defining flow direction, slope and flow width are important parameters. For flow accumulation the flow direction was used as an input to produce the flow accumulation. The number of contents flowing through each cell is shown by flow accumulation as shown in Figure 2(B). Following that, the shape file of research area's the Digital Elevation Model was extracted from four mosaicked tiles as shown in figure 2(C). The research area's drainage and slope were generated using this imagery to develop criteria for determining whether the area was suitable for dam siteAn international research project called Shuttle Radar Topography Mission with utterly accurate high-resolution acquire digital elevation models of geographic data of Earth. Via a number of steps, including generation of the flow accumulation, flow sink, the flow direction, and ultimately drainage density was created from DEM, drainage density for this study was acquired from the DEM through a series of step using Arc Hydro tool. This was accomplished using the many tools included in the ArcGIS software's hydrological toolkit. Fill sink was developed for identifying the sites of water accumulations in a watershed since administrative borders and hydrologic boundaries, as seen in watersheds, rarely match. This output results in the generating of the flow direction map, and until the drainage network map is attained, each output becomes the input for the subsequent map. The study area slope is also derived from DEM using surface tool of ArcGIS 10.8. The research area's slope was classified into five classes as well. i.e., little slope (0-5°), gentle slope (5-7°), moderate slope (7-10°), steep slope (10-15°) and very steep slope (>15°) as shown in the figure 2(D). Stream order is shown in figure 2, and DEM of the research area is shown in the Figure 3.

### 3.4. Precipitation

The CRU TS collection of data sets contains the yearly and monthly time series for cloud cover, precipitation, daily maximum and minimum temperatures, and other factors affecting the land regions of the planet from 1901 to 2021 (CRU TS v. 4.06 is a latest release). Based on an examination of over 4000 unique weather station records, the data set is gridded to a resolution of 0.5x0.5 degrees. Annual precipitation data of 2020 was got from CRU TS for study area which ranges from 225.5 mm to 332.5 mm. Figure 3(A) showing precipitation data divided into five classes. The Northeast side touching North Waziristan and Afghanistan receives the highest annual precipitation and the South and West sides of touching Baluchistan, Tank district and Dera Ismael Khan receive least precipitation.

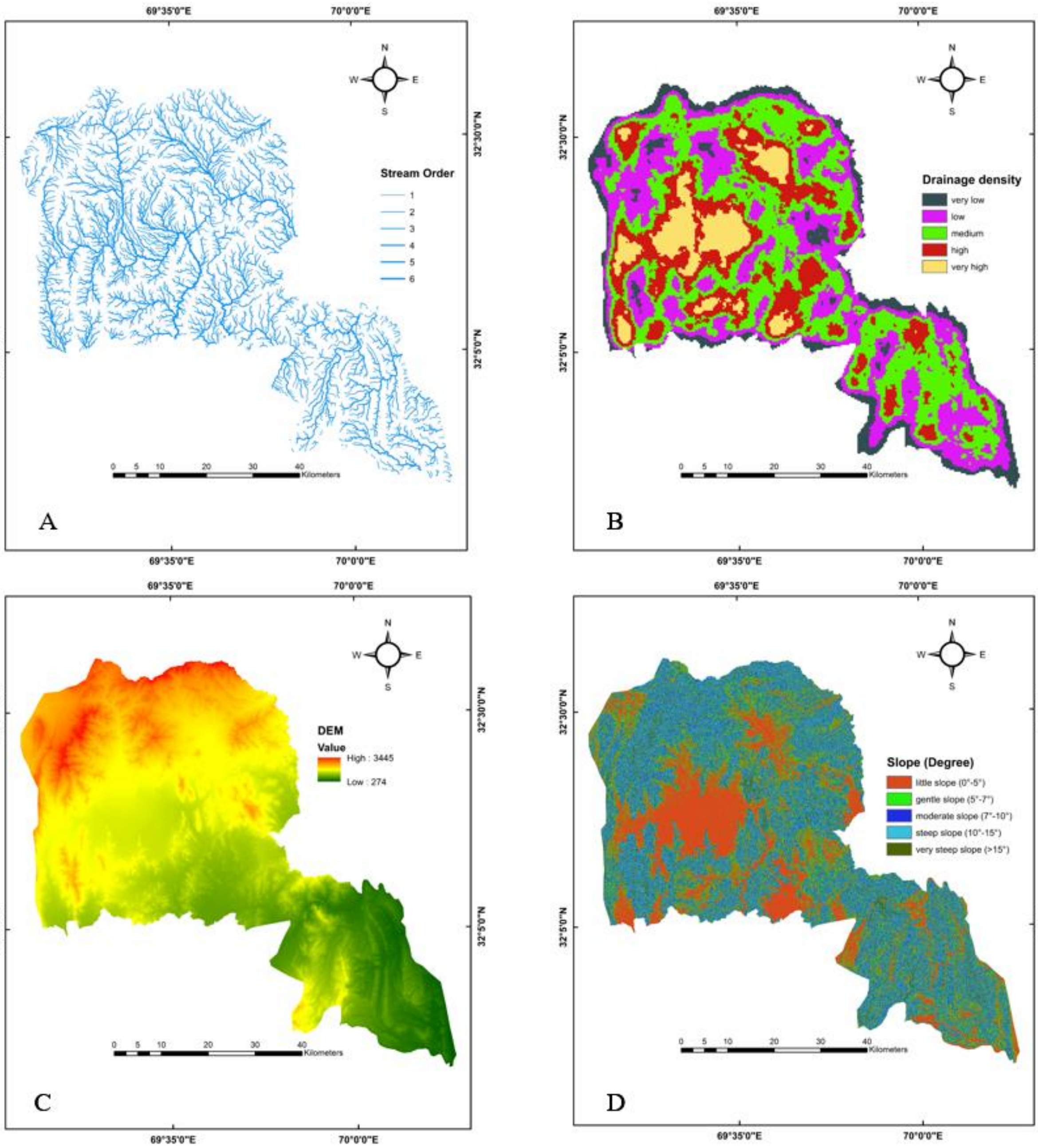


Figure 2: The main criteria for site selection: (A) stream order; (B) drainage density; (C) digital elevation model; (D) slope (Degree).

### 3.5. Land Cover

Land cover and land usage maps offer a moment in time, yet anthropogenic and natural phenomena have the power to drastically alter the landscape. These maps frequently take many years between data collecting and map release. These worldwide maps were made using a special machine learning technique that can handle a year's worth of observations in a couple of days. For decision-makers in so many industrial sectors and emerging countries, high-resolution, open, accurate, comparative, and timely land use maps are important. Esri developed improved artificial intelligence (AI) land categorization algorithms by assembling a sizable training dataset made up of billions of human-labeled picture pixels. The maps were created using over 2,000,000 Earth observations from 6 spectral bands and the whole Sentinel-2 scene collection for each year from 2017 through 2021. The land cover of the study area is based on a six-class surface map created by Esri, which depicts different types of flora, bare ground (which includes sand dunes, exposed rock or soil, deserts, quarries, and arid salt lofts, dried reservoirs, same, areas of rock or soil where there is little or no vegetation throughout the year), and water (which includes oceans, lakes, rivers, ponds, and flooded salt plains). Areas with sporadic or transient water, no rock outcrops, little to no sparse vegetation, and no man-made structures like docks may not be included in these zones.) Maize, wheat, soybeans, and void regions of organized land are examples of cereal grains, grasses, and crops that were planted or planned by people. Range land and built-up areas are also examples of massive uniform impermeable areas, like parking lots, offices, and homes. As seen in Figure 3(B), examples include homes, heavily inhabited cities, villages, towns, and pavements, and asphalt.

### 3.6. Geology

Geology plays an import role in in dam siting. If adequate geological analyses are not made, the site of a dam will pose considerable risks both during construction and during functioning. Geology data of the research area is obtained from United States Geological Survey website with a spatial resolution of 329*329 meter per pixel. There are seven types of formation in research area i.e. KJs (Cretaceous and Jurassic metamorphic rocks), Pg (Paleogene Sedimentary Rock), TKim (Tertiary and cretaceous Igneous and metamorphic rock), Jms (metamorphic and Jurassic sedimentary rocks), Ks (Cretaceous sedimentary rocks), JTr (Triassic sedimentary and Jurassic rocks) and **N** (Neogene sedimentary rock). Most of the area is covered by KJs as shown in the Figure 3(C).

### 3.7. Soil Texture

Soil is also important parameter which should be considered in selecting check dam sites. The Food and Agriculture Organization of the UN provided soil information of the research region (FAO). Research area is extracted from FAO Digital soil map of the world which consists of five classes i.e., sandy loam (49% sand content), clay (47% clay content), sandy loam (62 % sand content), loam and Clay (50% of clay content) as shown in Figure 3(D). Clayey soil was assigned more weightage because less permeable soil can store water for long time. Soil is also important parameter which should be considered in selecting check dam sites. The Food and Agriculture Organization of the UN provided soil information of the research region (FAO). Research area is extracted from FAO Digital soil map of the world which consists of five classes i.e., sandy loam (49% sand content), clay (47% clay content), sandy loam (62 % sand content), loam and Clay (50% of clay content) as shown in Figure 3(D). Clayey soil was assigned more weightage because less permeable soil can store water for long time.

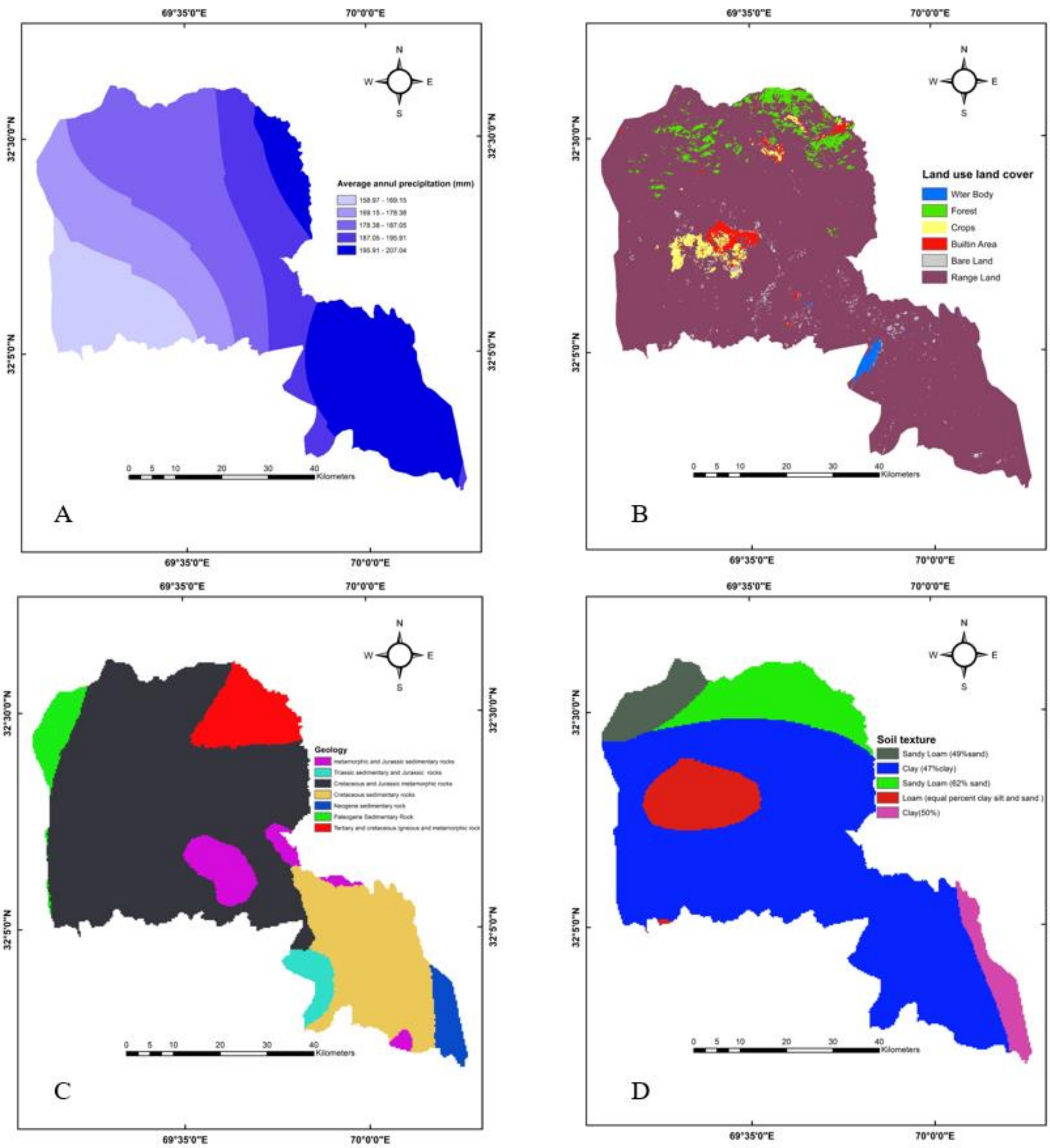


Figure 3: The main criteria for site selection: (A) average annual precipitation (mm); (B) land use land cover; (C) geology; (D) soil

### 3.8. Methodology

Several methods have been used to select excellent dam locations, and the considerations taken into account also differ significantly across different cases. (Dai, 2016). Many studies employing a variety of approaches have examined the efficient and effective selection of optimal locations for other water resource management facilities and dams. The biophysical and socioeconomic parameters make up most of the requirements for various appropriate dam locations. Most studies from the 1990s focused primarily on biophysical conditions like annual precipitation, soil type, runoff, land use, drainage network, and slope, whereas most research from the 2000s attempted to combine the biophysical characteristics with social factors as the primary criteria for choosing potential sites for rainwater harvesting structures. (Ammar, Riksen, Ouessar, Ritsema, & Research, 2016). Topography, Climate, agronomy, soils, hydrology, and socioeconomics are the six primary elements that would be taken into account when evaluating sites for soil water conservation, according to the FAO (Food and Agriculture Organization) (Adham et al., 2018). Since that decision makers' goals typically differ, that is challenging to develop a set of generic parameters for choosing a dam site. Decisions range in scope from heavy-duty hydropower consumption, like that of the Three Gorges Dam, which are the largest in the world power plant, to assistance in usage of small towns, like aquaculture or irrigation. While taking into account the regional ecosystem, A wide range of selection criteria for dam sites still causes issues for decision-makers due to their propensities towards rapid pace and viable growth in both environmental and social sides. As opposed to that, factors like hydrological conditions and slope are crucial considerations for choosing a dam location, ensuring its security, and building a dam (Ammar et al., 2016). In this research geology, soil, precipitation, land cover, drainage density, stream network, slope and fault lines were considered for selecting potential check dam sites using Analytical Hierarchy Process. The

RWH prospective suitability map of the research area was defined in this research using Geographic Information System techniques and AHP based multi criteria decision analysis. Methodology followed is given in the Figure 10. AHP gives us potential check dam zones i.e., low potential zone, medium potential zones, and high potential zones, after finding the potential zone stream network was overlaid on AHP resultant map. Check dams were marked on 3$^{rd}$ and above stream order.

### 3.9. Analytical Hierarchy Process

AHP is a decision-making methodology that uses both mathematical and psychological concepts. Developed by Thomas L. Saaty in the 1970s, it involves three key elements: defining the problem or goal at hand, identifying possible solutions or alternatives, and establishing criteria to evaluate these options. AHP offers a systematic approach to decision-making by assigning numerical values to the decision criteria and potential outcomes, which are then linked to the overall goal. The pairwise comparison is the cornerstone of AHP because it enables the decision-maker to briefly concentrate on only two options or criteria at once. Priorities are determined by first converting the verbal preference scale used to indicate each person's preference into a numerical number. In most cases, the analyst chooses the conversion table a priori without consulting the decision-maker. Weights according to their importance had been given to each chosen confined layers and their features on a scale from 1 to 9. Each thematic layer's impact and its characteristic on the probability was considered in terms of gathering rainwater while determining the weights. The allocated weights' pairwise comparison matrices were created using the AHP method following the determination of the weights of the six thematic layers and those of their features. This study's consistency ratio was 7%, which is less than 10% and shows that the factor comparisons are reasonable. The pairwise comparison matrix for locating RWH zones and the relative importance of each criterion are displayed in Table 3.

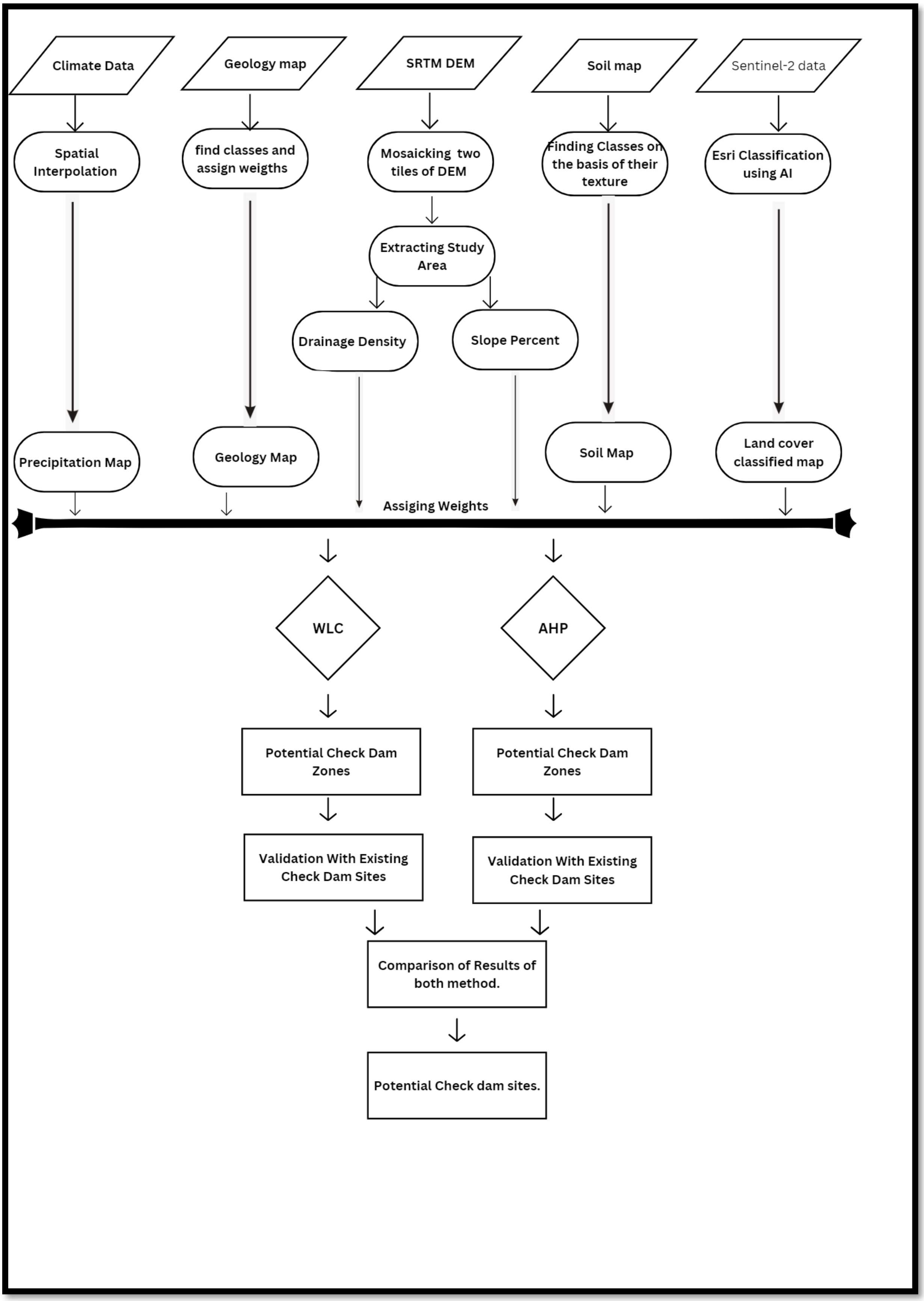


Figure 4: Methodology flow chart.

Table 2. Scale for AHP preference index.

| Intensity of Importance | Definition |
| --- | --- |
| 1 | Equal importance |
| 2 | Weak |
| 3 | Moderate importance |
| 4 | Moderate plus |
| 5 | Strong importance |
| 6 | Strong plus |
| 7 | Very strong importance |
| 8 | Very, very strong importance |
| 9 | Extreme importance |

Table 3. Pairwise comparison matrix

| **FACTORS** | **DD*** | **LULC**** | **PPT***** | **SLOPE** | **SOIL** | **GEOLOGY** | **WEIGHTS** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **DD** | 1 | 4 | 0.33 | 3 | 2 | 0.33 | 0.17 |
| **LULC** | 0.25 | 1 | 0.25 | 0.50 | 0.33 | 0.25 | 0.05 |
| **PPT** | 3 | 4 | 1 | 2 | 3 | 3 | 0.32 |
| **SLOPE** | 0.33 | 2 | 0.50 | 1 | 0.33 | 0.50 | 0.09 |
| **SOIL** | 0.50 | 3 | 0.33 | 3 | 1 | 0.50 | 0.13 |
| **GEOLOGY** | 3 | 4 | 0.50 | 2 | 2 | 1 | 0.24 |

Where: DD*= drainage density, LULC**= land use land cover, PPT***= precipitation.

## 3.10. Consistency Ratio Verification in AHP

This is referring to comparing two square matrices of the same size, where each matrix represents a set of criteria or factors. The comparison requires exact consistency, which means that the evaluation of each criterion must be accurate and reliable. This is especially important in complex situations where there are many factors to consider. As a result, the square matrix of the type (n n) must normally possess the reciprocally and consistency properties (Velmurugan, Selvamuthukumar, & Manavalan, 2011). The degree of consistency in matrices varies; one may have two or three components that are slightly out of consistency, while the other may not even come close. Calculating the consistency ratio which is a straightforward indicator for this check, Consistency ratio was obtained through equation (1) which is below

$$CR = CI \div RI \text{ ...................................... } Eq1$$

In the context of AHP, the consistency index (C.I.) is a mathematical formula expressed as Equation (2), which is used to evaluate the consistency of the pairwise comparisons made between criteria. The consistency ratio (C.R.) is a measure of how closely the pairwise comparisons align with the principle of consistency. It is used to determine the strength of the matrix in terms of its adherence to consistency.

$$CI = (\lambda max - n) \div (n - 1) \text{ ........................... } Eq2$$

The value of "n" represents the number of research criteria that are being considered. The symbol λ max refers to the largest or principal eigenvalue vector obtained by calculating the sum of the products of each element of the priority vector.

$$\lambda = 6.44 \text{ ............................................. } Eq3$$

$$Consistancy\ Index\ = 0.089 \text{ .............. } Eq4$$

$$Consistancy\ Ratio = \ 0.07 \ldots\ldots\ldots\ldots\ldots\ldots Eq5$$

All weights were given as per literature review and as per need of the research area. In Wana the only source of water is precipitation, so precipitation was given more weights comparatively, and geology is also an important parameter given second more weight comparatively which should not be ignored in dam siting and so on weights all parameter accordingly. The result gives us three zones i.e., low potential zone, medium potential zones and high potential zones as shown in the Figure 5.

After finding the potential zones, the stream network of the research area were depicted from Digital Elevation Model (DEM) and was then overlaid on the map resulting in 28 check dam sites in potential zones as shown in Figure 5.

### 3.11. Weighted Linear Combination

Weighted linear combination is a widely used technique in GIS to combine multiple layers of spatial data into a comprehensive map or index. Each layer in GIS represents a unique variable, such as land use, terrain, population, infrastructure, or climate, that characterizes a geographic phenomenon of interest.

To create a composite map or index, each layer is assigned a weight or coefficient that reflects its relative importance or contribution to the final map. The values of each layer are then multiplied by their respective weights and summed up to derive a single score or index for each location. However, the selection of weights is often subjective and may significantly impact the outcomes of the analysis. Hence, it is crucial to critically assess the justification and sensitivity of the weights chosen in the analysis to ensure that they accurately reflect the priorities and constraints of the problem at hand.

Table 4. Ranks and weights of criteria for WLC.

| **Factors** | **Weights** | **Ranks** | **Overall** |
|---|---|---|---|
| **Drainage Density** | | | |
| Very Low | 17 | 2 | 34 |
| Low | | 2 | 34 |
| Medium | | 5 | 85 |
| High | | 4 | 68 |
| Very High | | 3 | 51 |
| **Land Use Land Cover** | | | |
| Water body | 5 | 5 | 25 |
| Trees | | 1 | 5 |
| Crops | | 1 | 5 |
| Built Area | | 1 | 5 |
| Bare Land | | 4 | 20 |
| Range Land | | 5 | 25 |
| **Precipitation** | | | |
| 222.5 - 247.5 mm | 32 | 1 | 32 |
| 247.5 - 264.5 mm | | 2 | 64 |
| 264.5 - 284.5 mm | | 3 | 96 |
| 284.5 - 308.5 mm | | 4 | 128 |
| 308.5 - 332.5 mm | | 4 | 128 |
| **Slope** | | | |
| 0-5 Degree | 9 | 5 | 45 |
| 5-7 Degree | | 4 | 36 |
| 7-10 Degree | | 3 | 27 |
| 10-15 Degree | | 2 | 18 |
| >15 Degree | | 1 | 9 |
| **Soil** | | | |
| Sandy Loam (49%sand) | 13 | 2 | 26 |
| Clay (47%clay) | | 5 | 65 |
| Sandy Loam (62% sand) | | 1 | 13 |
| Loam (equal percent clay silt and sand) | | 4 | 52 |
| Clay (50%) | | 5 | 65 |
| **Geology** | | | |
| Jurassic and Triassic rocks | 24 | 2 | 48 |
| Jurassic Metamorphic and Sedimentary rock | | 3 | 72 |
| Cretaceous and Jurassic sedimentary rock | | 4 | 96 |
| Cretaceous sedimentary rock | | 3 | 72 |
| Neogene Sedimentary rock | | 1 | 24 |
| Paleogene Sedimentary rock | | 1 | 24 |
| Tertiary and cretaceous Igneous and Metamorphic rocks | | 3 | 72 |

# CHAPTER 4

## RESULTS AND DISCUSSION

The aquifer systems of the study area were to be modified by a check dam at a certain site, which was the goal of the study. This refers to a method of analyzing spatial data that combines two different techniques: the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS). AHP is used to prioritize criteria and alternatives, while GIS is used to manipulate and visualize spatial data. Weighted overlay analysis was performed, which involved assigning weights to different layers based on their relative importance and combining them to create a composite layer. The result is a spatial analysis that is guided by both AHP and GIS techniques led to the selection of those sections of the study area's stream network where human intervention can significantly increase the transport of rainwater to aquifers. These artificial recharge methods will supplement the process by which groundwater reserves are naturally refilled over time, that the replenishment process is occurring without human intervention or artificial means and is instead driven by natural factors such as precipitation, runoff, and infiltration. Therefore, a possible paraphrase could be "the natural process of refilling underground water reserves" (Ravish, Setia, Deswal, & Health, 2022). The goal of the current study was to identify more modern artificial water collecting structures and their ideal locations. When drought or moderate to severe aridity are present, few research methods, such as potential groundwater zone modelling for optimal use, delineating potential aquifers with high water recharge capacity and yield, and looking for sites suitable for artificial recharge units, offer the chances of sustainable practices (Ochir, Boldbaatar, Zorigt, Tsetsgee, & van Genderen, 2018). This form of goal-specific activity, known as suitability, allows the selection of desired characteristics or specifications against the background of a particular objective (Yeh, Cheng, Lin, & Lee, 2016). The second step in the analysis entails calculating the importance of each component or theme layer in GIS. When developing pair-wise comparison matrices and determining the weightage factors of each and every criterion, weights were primarily decided by various techniques such as rating, ranking, or the use of an analytical hierarchy process (an AHP model) (Seejata, Yodying, Wongthadam, Mahavik, & Tantanee, 2018). While ranking uses the opposite principle—greater appropriateness, higher rank—the most appropriate factors are given lower numerical values in the rating process (Suresh, Colins, & Jayaprasad, 2015). When using the AHP approach, To attain the desired objective, the weights or priority vectors of the factors or criteria were determined (Lentswe & Molwalefhe, 2020).

Taking into account the available climatic and geomorphological factors that must be examined for check dams the results of the analytical hierarchy approach fall into three categories: high potential zones, moderate potential zones, and low potential zones. These results range from high potential to low potential zones. The results showed that about 805 sq.km (21.24 %) area of the study area is covered by high potential zones, 1697 sq.km (45.35 %) area is covered by moderate potential zone and 1240 sq.km (33.13 %) area is covered by poor potential zone out of total 3742 sq.km area, as shown in Figure 5(A). After obtaining all three zones, the research area's stream order was overlaid, and the locations of the check dams were marked on the drainage channels and in accordance with local knowledge. The results of the study concluded that there are total 28 sites that are marked suitable for check dam as shown in the Figure 5(B).

It was observed that the East and Northern sides of the study area touched North Waziristan and Afghanistan and AHP assigned the high potential zones to the study's center. Check dams were marked in the upper side of the potential zones along site population and agricultural land while the high potential zone near Tank district was left unmarked though this area has high potential for check dam because there is no population and agricultural land. The northern side receive high annual precipitation and resultantly the Analytical Hierarchy Process gave high potential zones for check dams and the Western side touching Zhob and Sherani district of Baluchistan receive least annual precipitation and AHP marked it low potential zone for check dam. The results of the AHP concluded that the northern and eastern areas touching Afghanistan and North Waziristan and the central part of study area receive higher annual precipitation and was identified as high to medium potential zone while the north-western and western parts of the study area touching Baluchistan and some part of Afghanistan receive less precipitation and was identified as low potential zone for check dams.

### 4.1. Validation with existing check dam

In study area there are two existing dams one is Gomal Zam Dam, and the other is Dargai Pal Dam. Gomal Zam is hydro power generation Dam and Dargai Pal Dam is check dam. The accuracy of Analytical Hierarchy Process was checked with the already existing dams. After overlaying AHP Suitability map on research area, the results of the study showed that both the dams lie in high potential zone which gives us the accuracy of AHP 100%. Both the existing dams are shown in the Figure 7(A). The result obtained from weighted linear combination is shown in Figure 7(B) which after validating with existing check dams gave fluctuation from high to moderate potential zones.

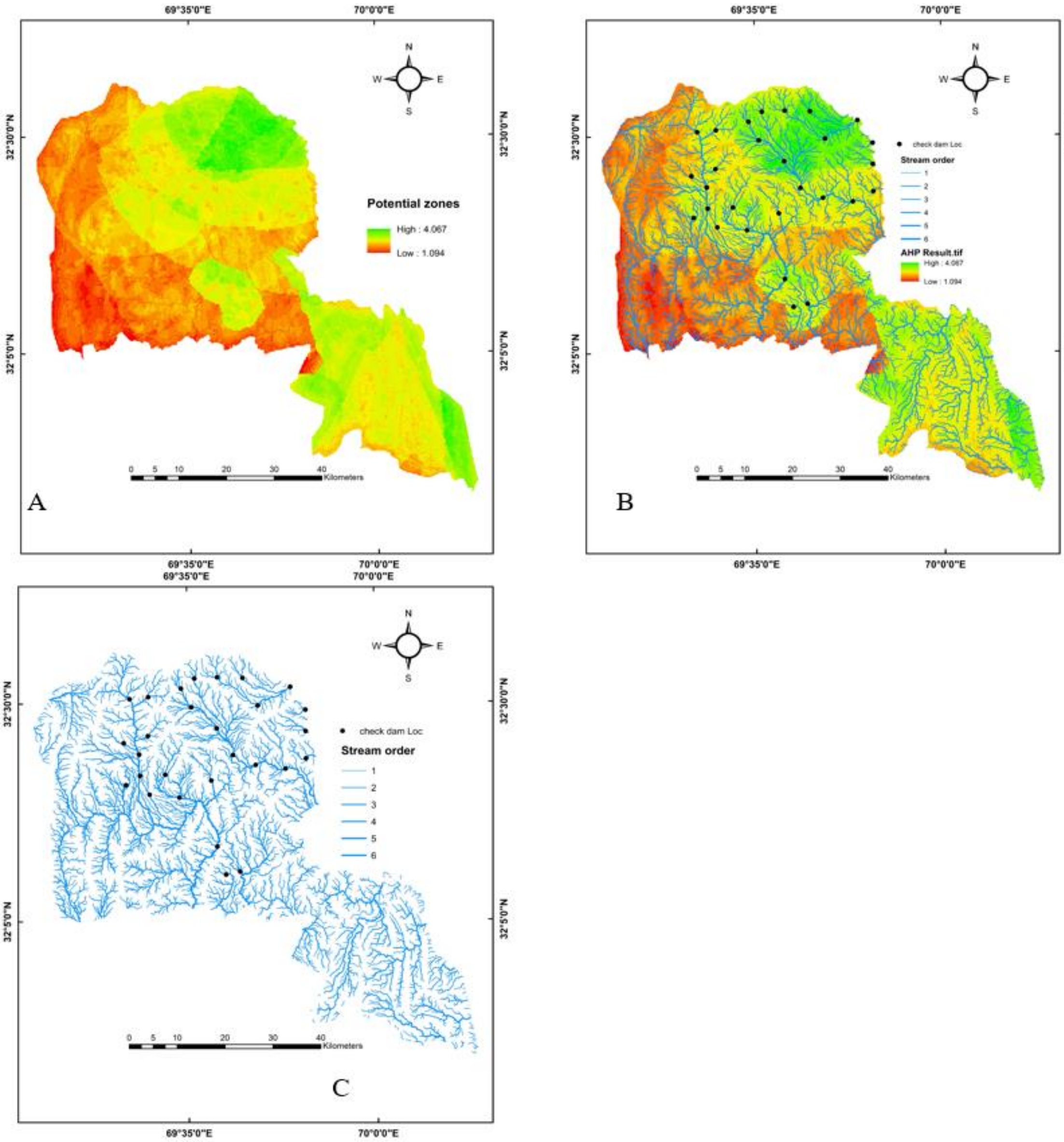

Figure 5: (A) Potential check dam zones; (B) potential check dams sites over potential zones; (C) potential check dams sites over stream order.

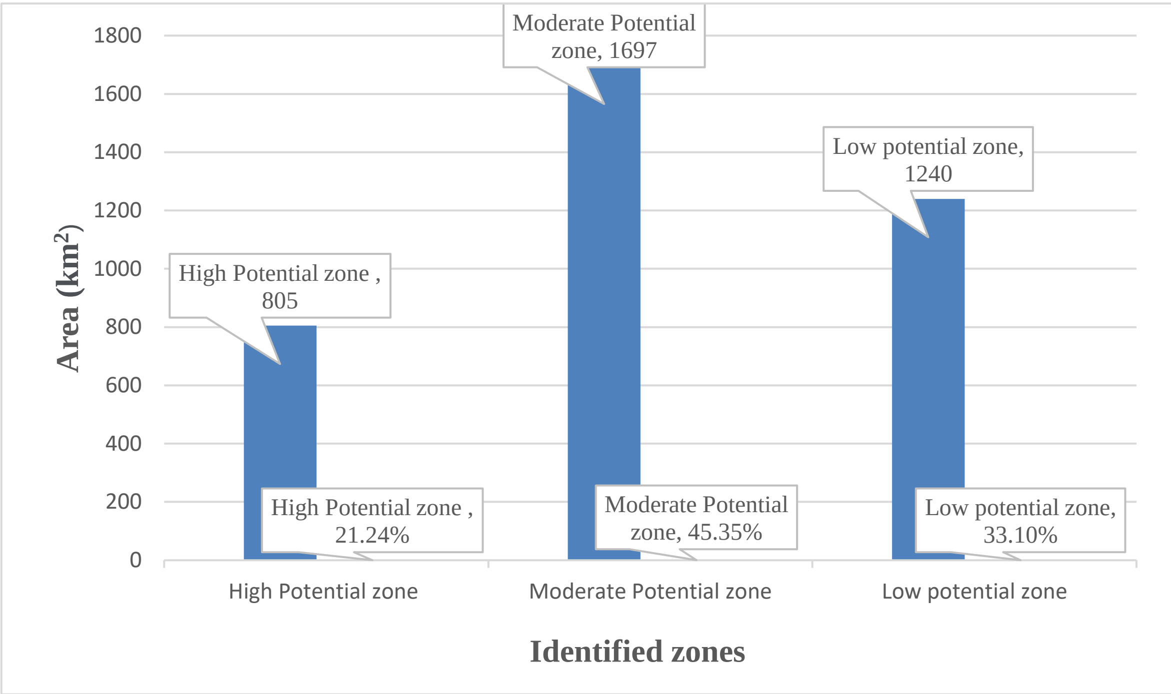


Figure 6: Percent of Zones

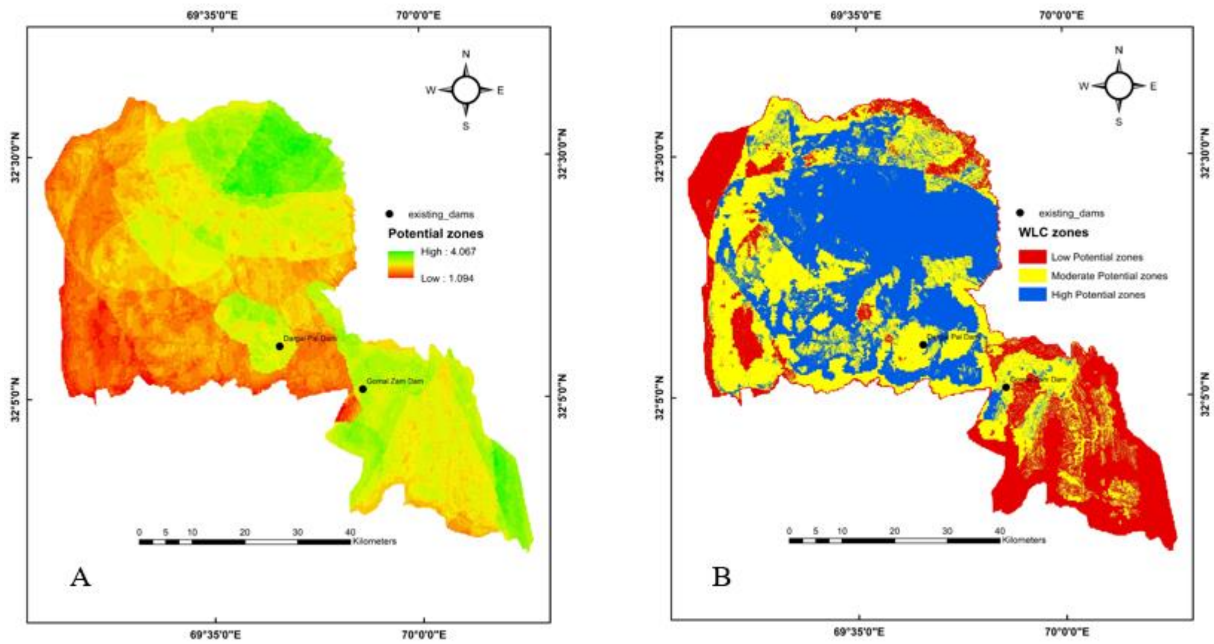


Figure 7: Validation with existing check dams: (A) existing check dam over AHP result; (B) existing check dam over WLC result.

## CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

### 5.1. Conclusion

This study focuses on introducing a software tool for spatial multi-criteria decision analysis, which is specifically designed for identifying suitable locations for managed aquifer recharge sites. The tool is intended to help with decision-making processes related to water resource management and can be used to evaluate and compare multiple criteria in a spatial context. In short, the study presents a new software tool for analyzing and selecting managed aquifer recharge sites ranking that is GIS based. A complicated selection environment is created by site identification analysis, which includes several criteria, options, and decision-making factors. With the help of this tool, the user is explicitly given the choice steps in accordance with the general analysis approach to deal with an unstructured situation. As population increases resulting in agricultural land development because people is dependent on agriculture and agriculture is dependent on ground water completely in the study area causing the drop of water table so for maintain water dynamic in the study area check dam is the need of the hour. Identification of potential check dam sites was the prime purpose of this research and analyzing the socio-economic effect of check dam on community by utilizing past data was second objective of the research. Different GIS technique is used by different authors in different area. In this research Analytical Hierarchy Process and Weighted Linear Combination were used for Identifying potential sites for check dams, after analyzing results of both techniques it was observed that Analytical Hierarchy Process give better results than weighted linear combination because the validation of existing check dams with the result of each technique was different. The validation of Analytical Hierarch Process was better i.e., the two already existing dams comes both in high potential zone of AHP, while the validation of Existing check dams with Weighted Linear Combination was not that much good i.e., both the existing check dams falls in medium potential zones. Different geographic and climatic factor i.e., drainage density, geology, soil, slope, land use land cover and precipitation were considered for identification of potential check dam sites.

## 5.2. Recommendations

Check dam site selection with the help of Analytical Hierarchy Process is integrated with Remote Sensing and GIS is the fastest and efficient way of giving better results used in many parts of the world but its results are dependent more on the quality of data and the weightage assignment. In this research, geology data, soil data, precipitation data etc. are acquired from remote sensing, however;

- the results would be better if field survey data was used.
- furthermore, before constructing check dams' geophysical investigation must be carried.

## REFERENCES


1. Adham, A., Sayl, K. N., Abed, R., Abdeladhim, M. A., Wesseling, J. G., Riksen, M., Research, W. C. (2018). A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq. *International Soil and Water Conservation Research, 6*(4), 297-304.
2. Ahmad, A., & Hussain, K. (2018). Climate change and agriculture. In *Developing Sustainable Agriculture in Pakistan* (pp. 245-265): CRC Press.
3. Ahmed, A. A., & Shabana, A. R. J. J. o. A. E. S. (2020). Integrating of remote sensing, GIS and geophysical data for recharge potentiality evaluation in Wadi El Tarfa, eastern desert, Egypt. *Journal of African Earth Sciences, 172*, 103957.
4. Ajibade, T. F., Nwogwu, N. A., Ajibade, F. O., Adelodun, B., Idowu, T. E., Ojo, A. O., Akinmusere, O. K. J. S. W. R. M. (2020). Potential dam sites selection using integrated techniques of remote sensing and GIS in Imo State, Southeastern, Nigeria. *Sustainable Water Resources Management, 6*(4), 1-16.
5. Alikhanov, B., Juliev, M., Alikhanova, S., & Mondal, I. J. G. f. S. D. (2021). Assessment of influencing factor method for delineation of groundwater potential zones with geospatial techniques. Case study of Bostanlik district, Uzbekistan. *Groundwater for Sustainable Development, 12*, 100548.
6. Aluko, O. E., & Igwe, O. J. E. E. S. (2017). An integrated geomatics approach to groundwater potential delineation in the Akoko-Edo Area, Nigeria. *Environmental Earth Sciences, 76*(6), 1-14.
7. Amalraj, A., & Pius, A. J. S. W. R. M. (2018). Assessment of groundwater quality for drinking and agricultural purposes of a few selected areas in Tamil

Nadu South India: a GIS-based study. *Sustainable Water Resources Management, 4,* 1-21.

8. Ammar, A., Riksen, M., Ouessar, M., Ritsema, C. J. I. S., & Research, W. C. (2016). Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. *International Soil and Water Conservation Research, 4*(2), 108-120.
9. Arefin, R. J. E. E. S. (2020). Groundwater potential zone identification using an analytic hierarchy process in Dhaka City, Bangladesh. *Environmental Earth Sciences, 79*(11), 1-16.
10. Arshad, A., Zhang, Z., Zhang, W., & Dilawar, A. J. G. F. (2020). Mapping favorable groundwater potential recharge zones using a GIS-based analytical hierarchical process and probability frequency ratio model: A case study from an agro-urban region of Pakistan. *Geoscience Frontiers, 11*(5), 1805-1819.
11. Basharat, M., Hassan, D., Bajkani, A., Sultan, S. J. J. I. W., Salinity Research Institute , L., Pakistan, Water, & Power Development Authority, P. (2014). Surface water and groundwater nexus: Groundwater management options for indus basin irrigation system. *299*, 155.
12. Berhanu, K. G., & Hatiye, S. D. J. J. o. H. R. S. (2020). Identification of groundwater potential zones using proxy data: case study of Megech Watershed, Ethiopia. *Journal of Hydrology: Regional Studies, 28*, 100676.
13. Dai, X. (2016). *Dam site selection using an integrated method of AHP and GIS for decision making support in Bortala, Northwest China.*
14. Gleeson, T., Wada, Y., Bierkens, M. F., & Van Beek, L. P. J. N. (2012). Water balance of global aquifers revealed by groundwater footprint. *Nature, 488*(7410), 197-200.

15. Hussain, M., & Mumtaz, S. J. R. o. e. h. (2014). Climate change and managing water crisis: Pakistan's perspective. *Reviews on environmental health, 29*(1-2), 71-77.

16. Khan, A., Govil, H., Taloor, A. K., & Kumar, G. J. G. f. S. D. (2020). Identification of artificial groundwater recharge sites in parts of Yamuna River basin India based on Remote Sensing and Geographical Information System. *Groundwater for Sustainable Development, 11*, 100415.

17. Kundzewicz, Z. W., Mata, L. J., Arnell, N., Doll, P., Kabat, P., Jimenez, B., . . . Shiklomanov, I. (2007). Freshwater resources and their management. Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 173-210. ISBN 9780521880091

18. Lee, S., Kim, Y.-S., & Oh, H.-J. J. J. o. E. M. (2012). Application of a weights-of-evidence method and GIS to regional groundwater productivity potential mapping. *Journal of Environmental Management, 96*(1), 91-105.

19. Lentswe, G. B., & Molwalefhe, L. J. J. o. H. R. S. (2020). Delineation of potential groundwater recharge zones using analytic hierarchy process-guided GIS in the semi-arid Motloutse watershed, eastern Botswana. *Journal of Hydrology: Regional Studies, 28*, 100674.

20. Lucas-Borja, M. E., Piton, G., Yu, Y., Castillo, C., & Zema, D. A. J. C. (2021). Check dams worldwide: Objectives, functions, effectiveness and undesired effects. *CATENA, 204*, 105390.

21. Ochir, A., Boldbaatar, D., Zorigt, M., Tsetsgee, S., & van Genderen, J. L. J. G. i. (2018). Site selection for water harvesting ponds using spatial multi-criteria analysis in a region with fluctuating climate. *Geocarto International, 33*(7), 699-712.

22. Ousrhire, H., Jarar, A., & Ghafiri, A. J. A. S. T. E. S. J. (2020). Multi-criteria decision analysis coupled with GIS and remote sensing techniques for delineating suitable artificial aquifer recharge sites in Tafilalet Plain (Morocco). *Advances in Science, Technology and Engineering Systems Journal, 5*, 1109-1124.
23. Pathmanandakumar, V., Thasarathan, N., & Ranagalage, M. J. I. I. J. o. G.-I. (2021). An Approach to Delineate Potential Groundwater Zones in Kilinochchi District, Sri Lanka, Using GIS Techniques. ISPRS International *Journal of Geo-Information, 10*(11), 730.
24. Qureshi, A. S. J. W. (2020). Groundwater governance in Pakistan: From colossal development to neglected management. *Water*, *12*(11), 3017.
25. Rasooli, A., & Kang, D. J. A. (2015). Assessment of potential dam sites in the Kabul river basin using GIS. *International Journal of Advanced Computer Science and Applications(IJACSA), 6*(2).
26. Ravish, S., Setia, B., Deswal, S. J. E. G., & Health. (2022). Classification of groundwater using multivariate statistical methods: a case study from a part of Haryana, northwestern India. *Environmental Geochemistry and Health,* 1-35.
27. Renganayaki, S. P., & Elango, L. J. I. J. R. E. T. (2013). A review on managed aquifer recharge by check dams: a case study near Chennai, India. *International Journal of Research in Engineering and Technology, 2*(4), 416-423.
28. Sadaf, R., Mahar, G. A., Younes, I. J. I. J. o. E., & Geology, E. (2019). Appraisal of ground water potential through remote sensing in River Basin, Pakistan. *Sustainability,* 25-32.

29. Seejata, K., Yodying, A., Wongthadam, T., Mahavik, N., & Tantanee, S. J. P. e. (2018). Assessment of flood hazard areas using analytical hierarchy process over the Lower Yom Basin, Sukhothai Province. *Procedia Engineering, 212,* 340-347.

30. Sener, E., Davraz, A., & Ozcelik, M. J. H. J. (2005). An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. H*ydrogeology Journal, 13*(5), 826-834.

31. Senthilkumar, M., Gnanasundar, D., & Arumugam, R. J. S. E. R. (2019). Identifying groundwater recharge zones using remote sensing & GIS techniques in Amaravathi aquifer system, Tamil Nadu, South India. *Sustainable Environment Research, 29*(1), 1-9.

32. Shenbagaraj, N. J. F. Identifying Appropriate Location for Water Harvesting Structures Using Remote Sensing and Geographical Information System. *Remote Sensing, 14(19),* 5008. MDPI AG. Retrieved from http://dx.doi.org/10.3390/rs14195008

33. Siebert, S., Burke, J., Faures, J.-M., Frenken, K., Hoogeveen, J., Döll, P., . . . sciences, e. s. (2010). Groundwater use for irrigation–a global inventory. *Hydrology and Earth System Sciences, 14*(10), 1863-1880.

34. Suresh, D., Colins, J., & Jayaprasad, B. J. I. J. R. S. G. (2015). Identification of artificial recharge sites for Neyyar River Basin. *International Journal of Remote Sensing & Geoscience (IJRSG), 4*(3), 20-27.

35. Velmurugan, R., Selvamuthukumar, S., & Manavalan, R. J. D. P.-A. I. J. o. P. S. (2011). Multi criteria decision making to select the suitable method for the preparation of nanoparticles using an analytical hierarchy process. Die *Pharmazie, 66*(11), 836-842.

36. Yeh, H.-F., Cheng, Y.-S., Lin, H.-I., & Lee, C.-H. J. S. E. R. (2016). Mapping groundwater recharge potential zone using a GIS approach in Hualian River, Taiwan. *Sustainable Environment Research, 26*(1), 33-43.