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Identification of Suitable Sites for Rainwater Harvesting Using GIS in Kandahar Province, Afghanistan

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Abstract

Objectives: This study aims to identify the potential areas for rainwater harvesting in Kandahar, Afghanistan. **Methods:** This study used GIS-based RS techniques. Satellite images were used to plan multiple thematic layers, such as lithology, slope, land use/cover, stream order, and soil texture. These layers were then converted into raster data using the raster converter feature of the ArcGIS 10.4 program. In order to come up with a site suitability map for water harvesting structure, multicriteria analysis was then carried out on the different layers, each layer's characteristics were assigned weights as provided by experts in past research reviews. Owing to their power and their respective class weights, different layers were then overlaid. **Findings:** The findings showed that the catchment was grouped into categories as 'high', 'moderate' and 'low' zones with regard to the allocated weighting of different thematic layers using weighted overlay. Twenty zones of rainwater harvesting structures were identified from the WH suitability map for the various structures for water harvesting. The suitability map helped to select water harvesting structures such as percolation tanks, storage tanks, control dams, and stop dams to be installed at the different identified sites. The potential sites of rain water harvesting identified were Shorabak, Boldak, Marrurf, Arghistan-1, Arghistan-2, Arghistan-3, Khakres, Ghorak, Maiwand-1 and Maiwand-2 in the Kandahar Province Afghanistan. **Novelty:** These findings indicate that high potential zones would play a key role in the future expansion of the production of drinking water and irrigation in the study region. The suitability map is useful to hydrologists, decision-makers, and planners for quickly identifying areas with the highest potential for harvesting rainwater.

Keywords: Rainwater harvesting; ground water; AHP approach; GIS; Kandahar; Afghanistan

1 Introduction

Water is a valuable natural resource that is essential for human health, social and economic development, food production, and environmental preservation[1]. In many parts of the world, there is serious pressure on the available water resources due to factors such as population growth, economic development, social unrest, environmental deterioration, the effects of climate change, and technological advancements[2,3]. These pressures go beyond the lack of rainfall and its erratic spatial and temporal pattern[4]. Since the beginning of time, people have inhabited regions with few rivers, where one of the best methods for securing a water supply is the direct collection of rainwater from roofs, hillsides, or rock substrates[5]. The majority of precipitation events are intense, frequently convective storms with very high rain intensities and very high spatial and temporal rainfall variability[6]. Harvesting rainwater appears to be an effective strategy for reducing the scarcity of water in developing nations[7]. The majority of the water harvested for agricultural use can be stored underground in natural systems to prevent water loss. However, rainwater collected for domestic usage may well be contaminated by bacteria and dangerous substances, necessitating careful consideration when selecting the catchment area[8].

Rainwater water harvesting is positively associated with mitigating the adverse impacts of climate change. Groundwater is one the vital natural resource maintaining life on earth[9]. Ground water declines due to its excessive use for domestic and agriculture purposes[10]. Rainwater harvesting also helps famers and local people to mitigate the impacts of droughts[11]. Droughts has devastating impacts particularly on farming communities and their livelihoods[12–14]. Farmers are confronted with natural hazards[15]. For instance, a natural hazard such as flood cause damages to farmers[16]. Most important strategy of coping with droughts is rainwater harvesting[17]. Similarly, E Saqib, Panezai[18] report that rainwater harvesting is a water conservation technique used for coping the climatic risks.

Afghanistan has ample water resources that could be used, but it lacks the necessary infrastructure[19]. Due to the inability of the economy to close gaps and make efficient use of the available resources is known as economical water shortages[20]. The country has never been able to fully develop its water resources because of internal disputes over the past forty years[21]. Research studies in the 1990s mainly concentrated on physical and biological criteria; however, those carried out after 2000 began to include sociodemographic parameters[22]. In Afghanistan, where 80% of the population lives in rural areas, about 85% of groundwater wells, 50% of springs, and 60% to 70% of traditional vast underground drains have dried up[23]. The majority of GMWs show that the groundwater level has decreased as a result of low precipitation, low recharge, and excessive motor pumping for agriculture and water delivery[24].

Afghanistan is one of the countries that is suffering significantly from the effects of climate change. Water resource degradation is one of the most detrimental outcomes. In areas with an arid-semi-arid climate, the practice of harvesting surface runoff is growing in popularity. However, there is shortage of literature on rainwater harvesting. Few studies are available that have been conducted on rainwater harvesting. For instance, Rahmani, Akramzoi[25] proposed rainwater harvesting by applying clayey dressing to the Qargha Reservoir Watershed in Kabul, Afghanistan to maximize the water harvesting potential of the area.[26] evaluated the Kabul Basin's use of artificial groundwater recharge as a management tool. This study suggested using the Kabul River's excess flow during the rainy season to artificially recharge groundwater as a management tool for Afghanistan's Kabul Basin. The technique used in this work is supported by a detailed examination of research on Afghanistan's water resources. Similarly, in a study conducted in Afghanistan's Badghis Province using GIS and multi-criteria decision-making techniques, suitable rainwater harvesting sites were found using cutting-edge technical methods that took into account several biophysical factors that were chosen in accordance with the needs of the target region's environment[27]. Another study has investigated the feasibility of a rooftop rainwater harvesting system in Kabul New City[28]. Moreover,[29] has carried out research on rainwater harvesting techniques in rangeland rehabilitation in northern Afghanistan. This study would be the first on southern Afghanistan which would have significant policy implications. This research has aimed to identify the potential areas for rainwater harvesting in Kandahar, Afghanistan through Geographical Information System (GIS), Remote Sensing (RS) techniques, and analytical hierarchy approach (AHP)

2 Methodology

2.1 Study Area

For this study, Kandahar province has been selected as a study area. Kandahar is the second largest province by region in Afghanistan, Afghanistan's southernmost province[30,31]. It is 1005 meters above sea level and is located at 65° 35′ - 65° 48′ E latitude and 31° 25′ - 31° 50′ N longitude[31] . During winter, the temperature ranges from 0 to -40 C, summers are hot. The Kandahar province has a dry climate and is one of Afghanistan's hottest provinces. The capital city Kabul is 457 km away. Kandahar Province has a total of 18 districts and a headquarter in Kandahar City. The districts include Zhari, Arghandab, Khakrez, Arghistan, Shawali Kot, Ghorak, Spin Boldak, Maruf, Daman, Panjwai, Reg, Maiwand, Shurabak, Nish, Shiga, and Takta Pool. It occupies an area of 53,500 square kilometers, with a population of 1,399,600 in 2020[32]. In Afghanistan, the ministries responsible for water governance and management include Ministry of Energy and Water (MEW), Ministry of Agriculture, Irrigation and Livestock and Authority of Urban Water Supply at national and provincial levels respectively. Similarly, the Ministry of Rural Rehabilitation and Development and Ministry of Urban Development Affairs are responsible for supply of water in rural and urban areas.

2.2 Water Sources in Kandahar Province

There are two types of water sources in Kandahar province. The main source of surface water in Kandahar Province is the Arghandab River which is located about 6 km east of the center of Kandahar. The Dahla Dam is located about 3 km northeast of the city on the Arghandab River. The initial capacity of the dam's bowl was 478.6 million cubic meters, but over time, rainwater mixed with soil and sand reduced the capacity of the Delhi dam's bowl by 30 %[33]. This dam was built for irrigation during the reign of Zahir Shah. There are two canals coming out of this dam, one is Zahir Shahi Canal and the other is the Arghandab River from which people meet their water needs. Based on previous data, the average annual flow rate of the Arghandab River is estimated at 32.9m^3per sec[31].

2.3 Groundwater Resources in Kandahar Province

Groundwater is used for drinking, industrial, and other purposes in Kandahar Province. The underground water table of the province depends on the abundance of water in the Arghandab River. Thus, the groundwater reserves also decrease with it. In particular, the Zahir Shahi Canal plays an important role in the enrichment of groundwater resources as the Zahir Shahi Canal passes through the center of the Kandahar province. Its reserves are very rich[33] .

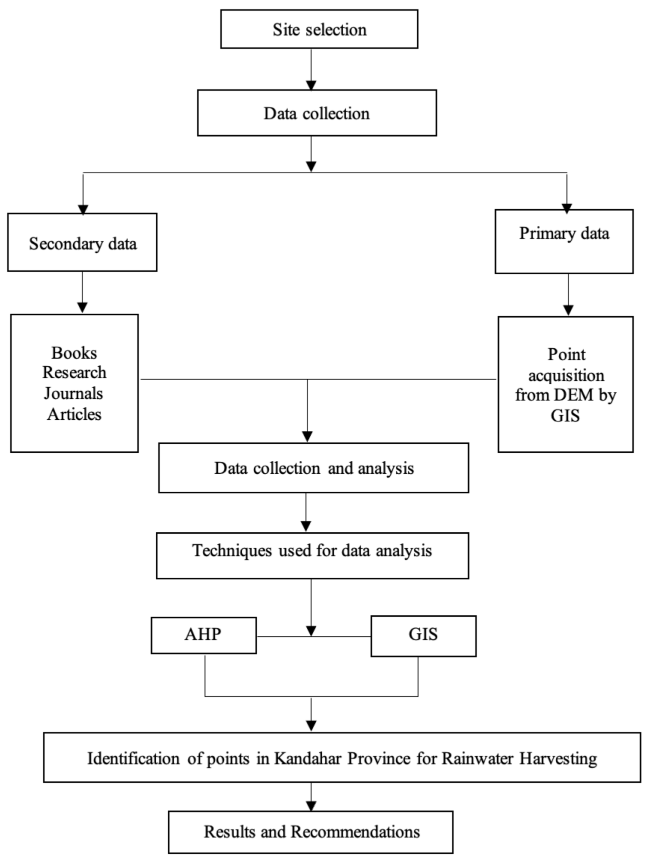

Fig 1. Flow chart of the study model

Fig 2. Map of the Study Area: Kandahar Province, Afghanistan

Each year, high amount of foreign exchange is received from the export of these fruits. There are three rivers in this province (ArghandabTarnakArghsanArghandab River and less water comes from the Tarnak River [34]

2.4 Methodology for Finding Rain harvesting Areas

In this study, the five steps were used for finding the rainwater harvesting areas which are as follows. Firstly, the option of the appropriate standard: what factors or criteria should be taken into account when determining the rainwater harvest site. Secondly, adding the weight of the factor to these parameters. Thirdly, Weight distribution for the General Parameters. Fourthly, the study focused on GIS. Fifth: the suitable areas are targeted.

The first five are used to determine the rainwater harvesting area, based on previous studies. We are now advancing on the advice of (FAO, 2003). Rainfall is called a parameter of the atmosphere and a parameter of hydrology is streamflow. And the slope of the catchment area is a topographical parameter. Lithology is also an agronomic parameter and soil texture is a soil parameter.

In this analysis, we have used the following five parameters.

1. Usage of property and covering land
2. Classes and Texture of Soil
3. Lithological or geological sciences
4. Slop
5. Density of Line

The first three data parameters were obtained from the internet in the form of the pre-surveyed shape Format. And Slop and Line Density or (Drainage Density) were accomplished in Arc GIS10.4 as a function of various DEM level commands and procedures. It was then presumed that assigning a weight factor on each criterion was on the soil or clay, giving priority to the clay soil over the grain that is, multiplying the amount of the clay by more than the soil of the sand, as well as within each criterion. Finally, in the Overlay command, a 100 percent weight factor was applied to all five parameters. As a result, the Overlay command determined the areas that were most desirable for rainwater capture and storage, taking into account both the internal (weight factor) and general (weight factor).

2.5 Data collection

This study has used the remote sensing data obtained from the Earth explorer, United States Geological Surveys (USGS) [35]. The imageries were classified through the maximum likelihood supervised classification (MLC) method in Arc GIS 10.4. [36]. In this analysis, we have used all of the open-access data, as seen in Table 2, the data form and source. In the form of Shape Files or Reconstruction Data, much of our data is from online sources.

Table 1. Types of data and Sources

No.	Data	Derived map	Source
1.	Landsat 7	Land use and land cover	http://glovis.usgs.gov
2.	Administrative map of the study area	Study area division boundary	Afghanistan Information Management Service (AIMS)
3.	DEM	Slope Stream Flow accumulation	USGS
4.	Soil		Afghanistan GIS database
5.	Watershed & river line vector data	Stream	Afghanistan GIS database

3 Results and Discussion

For producing of results and analysis, we performed following processes in this GIS-based study.

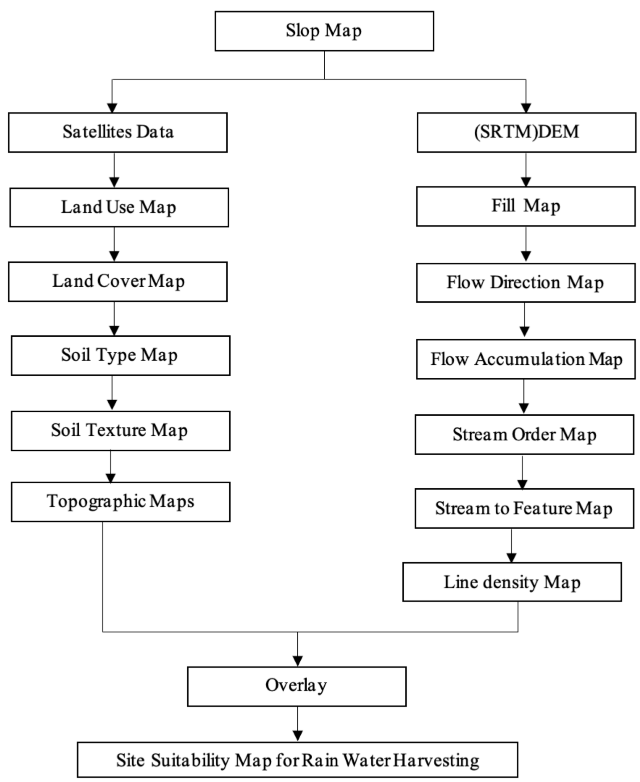

Fig 3. Diagram of the techniques used for achieving objectives of the study

3.1 Adding data

We connected the vector and raster data to GIS with this instruction. We're adding the Dem and GIS of Kandahar Province in the first phase. The DEM of the province of Kandahar, in the first position, is in the form of several parts. We used the mosaic command in GIS to combine these bits. Afterwards, added a map of the province of Kandahar until the DEM was entered or fragmented. Then opened the clip command in the Arc Tools box and then picked a map of the province of Kandahar with the option to select it. Once the DEM was selected with the province of Kandahar map, then it came to the Arc Tools Box.

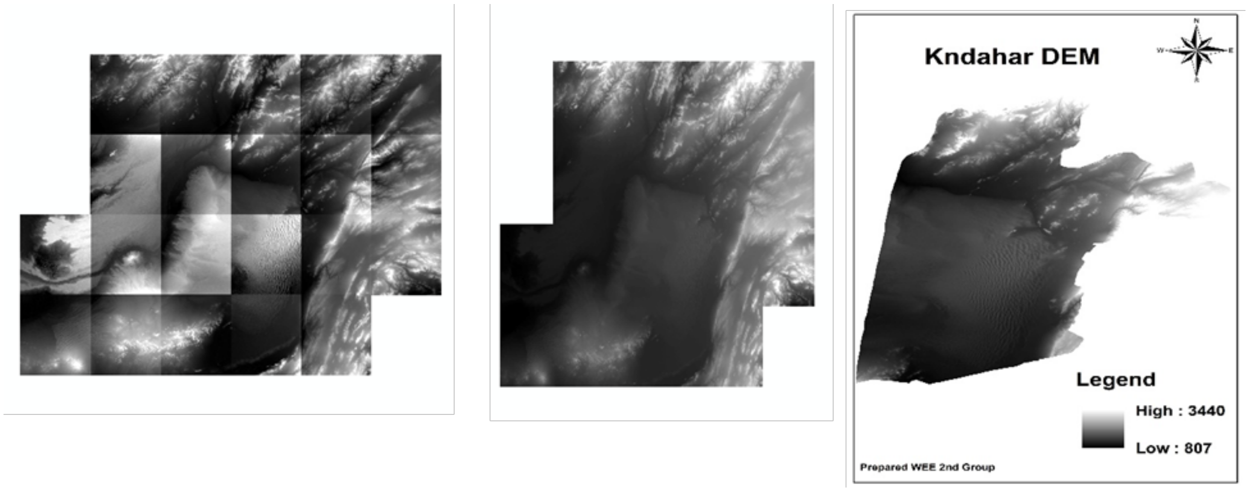

Fig 4. Digital Elevation Modeling (DEM) of the study area

3.2 Fill Process

Secondly, the filling process was applied to get the map of the province of Kandahar. The method of filling was as follows. Add to the general page of the DEM to the GIS province of Kandahar and open the Arc Tools Package. Opened the Tools Arc box. Open Special Analytics. GIS offers a table that allows one to have three choices. The input surface raster was the first option and the output surface raster was the second option, and the z limit option was the third option. Picked the completed map and selected the location or file that we wanted to save the completed map in the second option and selected a number in the third option, then selected ok.

3.3 Flow Direction

Thirdly, once we got the filled map then we got the flow direction map from the filled map. With the flow direction, we can get the inclination of each cell in the map from upstream to downstream. To achieve this, we followed the process below.

1. Open the arc tools box
2. Open special analytics tools
3. Open the hydrology box

Fig 5. Flow direction in the study area

3.4 Accumulation of Flow

We wanted to get the flow aggregation as soon as we get the flow path map. For this, we did flow aggregation. We carried out the following process to achieve flow aggregation in order to mark the places on the map where several streams and canals converged. Open the arc tools box and then opened the flow accumulation order from the hydrology box after choosing relevant analyses in the tools box. When we opened this command, a table with the options below opened and we had to fill it in. the first choice was the raster of input direction in which we carried the flow direction map and the second option was the raster of output accumulation in which we picked the position or file in which we wanted this map to be registered. The third alternative was the weight raster of the input in which we gave a figure. And the output data form was the fourth choice. This alternative had its own two choices. The first was afloat, and the second was an integer. We chose the same integer, and then we chose ok.

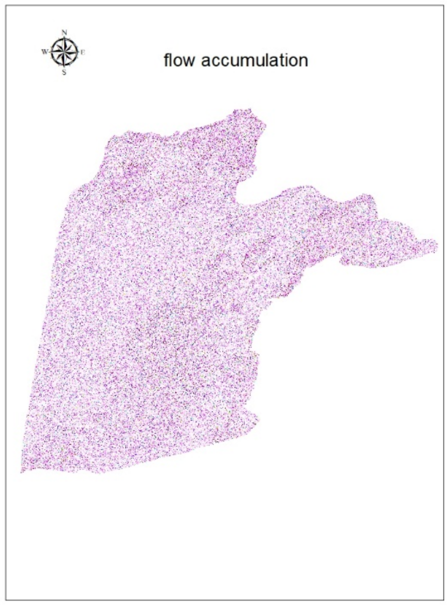

Fig 6. Flow Accumulation Map

3.5 Stream Order

When you had the accumulation of flow. After that, we also had a stream order map so that each stream or channel can be easily seen. We executed the following procedure to obtain the stream order map: open the arc tools box in GIS, choose the special analysis box in it, and then select hydrology in the special analysis tools. After that in hydrology, opened the stream order command. Selected the Input Stream Raster This alternative presented the map or map on which we wanted to construct a stream order map and the second option was the path of the input stream. We chose the position where we wanted to store or record the stream map in the selection, and the fourth choice was the stream ordering process.

3.6 Stream Link Map

streams, we followed the below method. Opened a special research box in the arc tools box and chose the stream connection command in the hydrology box. When we opened it, there was a table where three choices are available. The first choice is the raster input stream in which we sent the map in which we wanted the common points between the channels to be identified. The direction of input flow is the option under which we added the chart of flow direction and the output raster was the third option.

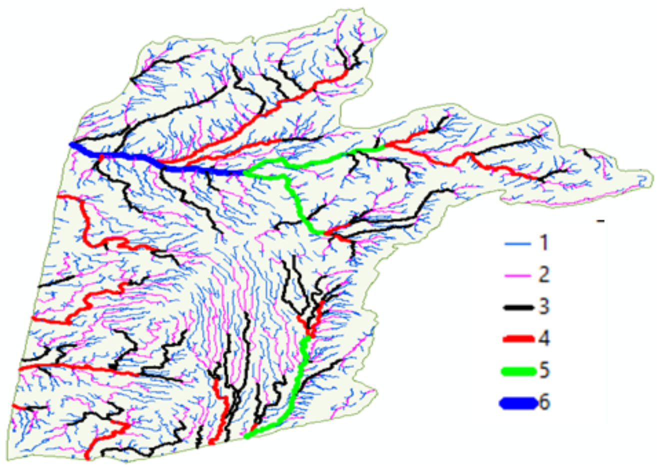

Fig 7. Stream Order Map

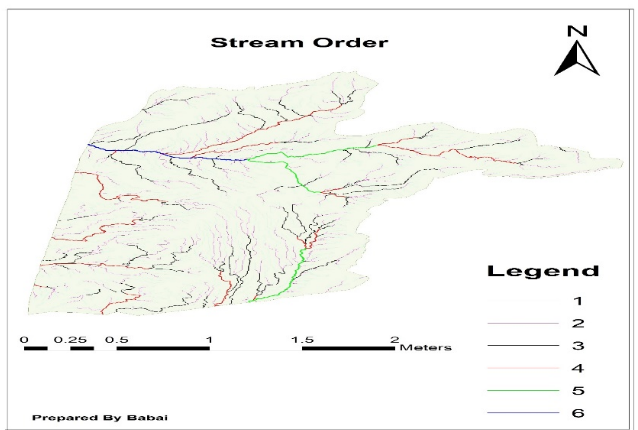

Fig 8. Stream Link Map

3.7 Density of Line

We wanted to get the line density map after we have got the Stream to Function Map. We executed the following procedure to get the line density in order to get the line density map to show us in which region the number of streams or channels is less or more. And then open the density line. This took us to a table of many choices. In the first choice, we gave the function map a stream. Document it and unite the third-choice region in this option, ok, we picked the single meter as seen below.

3.8 Slope Map

For slop map, finding the mileage on the map between each of the cells is necessary. To get the slope map, we performed the following procedure. We opened the toolbox arc in the first step, then we opened the surface in the second step. In the open table, the Enter slope order opened. The second choice was the in-point point where we had details on raster. The third choice was the output, where the location or file that we wanted to report was chosen.

3.9 Raster Polygon

Polygon to Raster guarantees that vector data can be transformed to raster data. We used the following method to execute this process: Go to the arc tools box and open the conversion in it. Opened the polygon-to-conversion command. The first choice was the input vector data in which the map we wanted to transform from a vector to a raster was introduced; the second option was the optional area in which the numbers of the cells were allocated. We chose the number six-cell and the third choice was

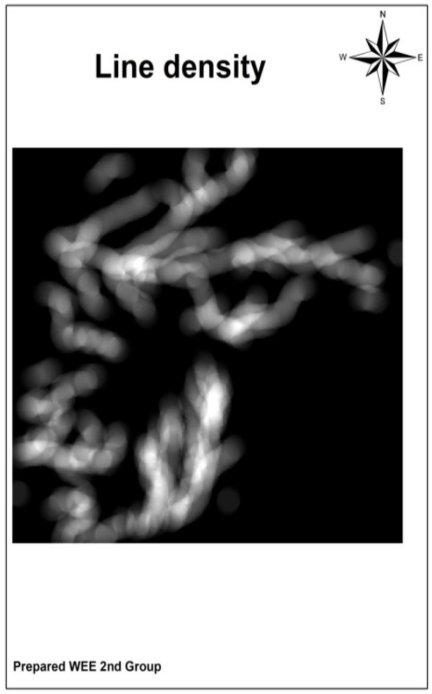

Fig 9. Line Density Map

Fig 10. Slope Map

the polygon or placing. Picked the position or file where (vector data) was to be saved, and then clicked ok as seen in the below figures.

From soil data vector to registry format

3. 10 Reclassification

For reclassification, a weight factor in proportion to its value was assigned to each criterion according to the AHP procedure. In order to minimize or increase the values in the raster results, we conducted the reclassification procedure, and if we wanted to pick the values, we used the reclassify command in the table to open the reclassify command. The other was classifying groups. Selected the regular division method in the classification method and select five digits in Groups.

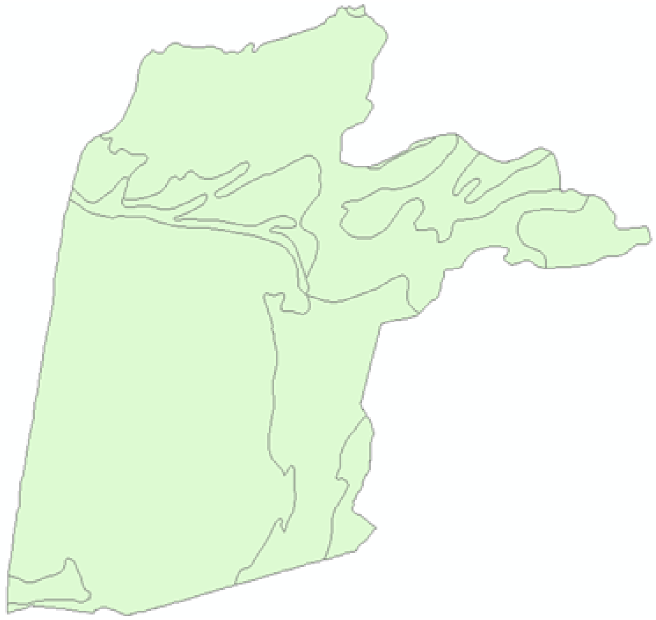

Fig 11. Soil raster data

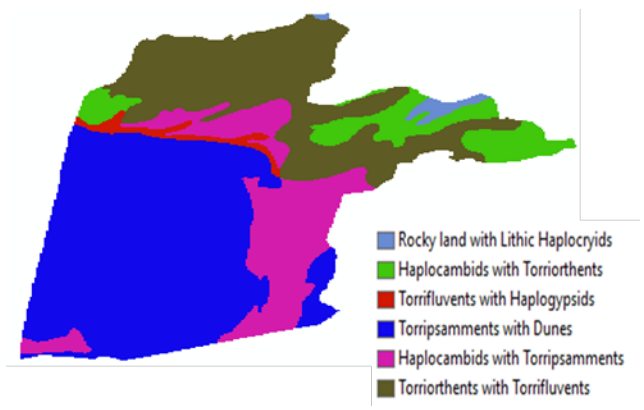

Fig 12. Soil vector data map

Geological data from vector to raster

3. 11 Map Algebra

Map Algebra allows us to perform mathematical operations on a map, such as increasing or decreasing the stream on a map, or performing other mathematical operations on a map, such as logarithmic operations. To perform the map Algebra, we performed the following procedure. Opened the arc tools box and then went to the special analysis box, opened the map algebra in it and opened the raster calculator command in the map algebra. Selected the map on which we wanted to perform mathematical operations.

3.12 Soil Texture Map

For obtaining the general soil texture map of Afghanistan we added GIS to the Afghanistan texture map. From this map, we clipped the soil texture borders of the province of Kandahar in this GIS. And then reclassified it as seen in the following figure.

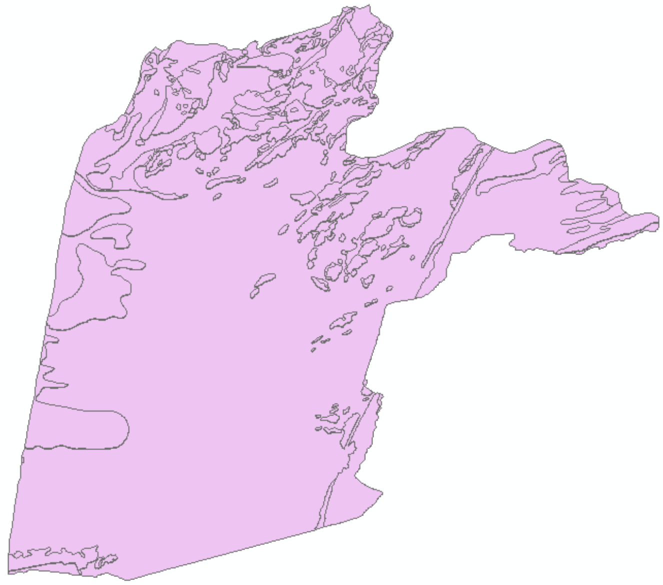

Fig 13. Soil Lithology Map

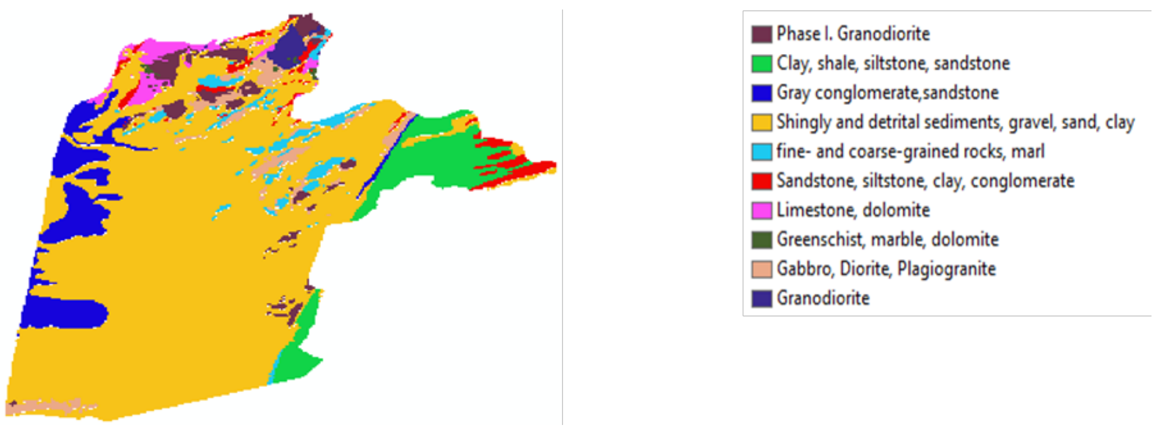

Fig 14. Lithology Raster Map

3. 13 Land Cover Map

For land cover map, the general map of Afghanistan's ground cover was added it the GIS. We then added a map of the province of Kandahar to the same map. From the Arc Tools box, we got the clip command. In the Afghanistan Boundary map, we picked the borders of the province of Kandahar and conducted the clip procedure as shown below.

3. 14 Overlay

The overlap procedure was adopted to get map mentioned below.

3.15 Suitable Locations for Rainwater Harvesting

From the analyses of results, our key goal was to identify the points or areas at which rainfalls accumulates and to identify the suitable sites for rainwater harvesting by using Arc GIS. We have been able to use Arc GIS during this research to identify particular points or places where rainwater harvesting.

In the Table 2, the locations where rainwater was collected were identified and the coordinates of these sites were provided in the UTM system.

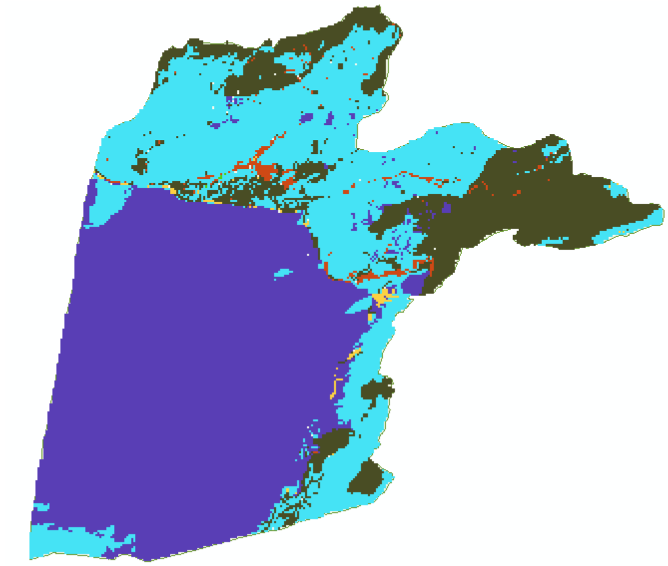

Fig 15. Reclassification map

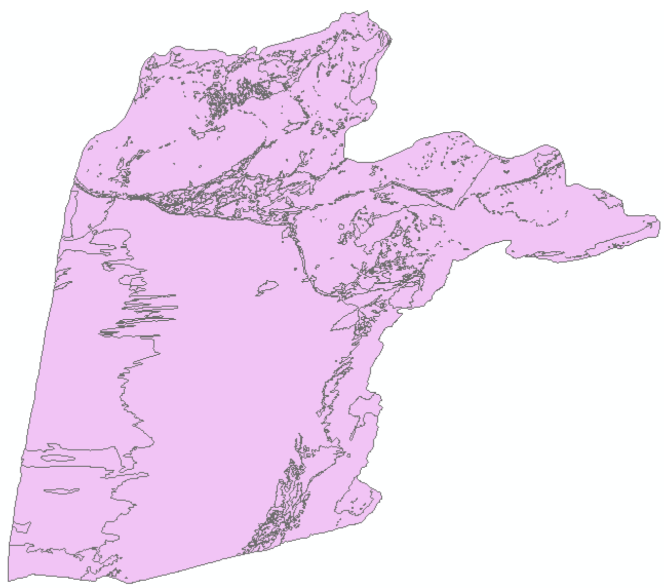

Fig 16. Victor map of soil groups

The current study has identified the rainwater harvesting locations in Kandahar Province Afghanistan. The findings showed that the catchment was grouped into categories as; 'high', 'moderate' and 'low' zones with regard to the allocated weighting of different thematic layers using weighted overlay. Ten zones of rainwater harvesting structures were identified from the water harvesting suitability map for the various structures for water harvesting. The suitability map helped to select water harvesting structures such as percolation tanks, storage tanks, control dams, and stop dams to be installed at the different identified sites.

This zoning of 'high', 'moderate' and 'low' zones would help the government agencies to invest the public money at proper places. The water harvested at 'high' zones can support the water table around the area and help farmer save water for drought seasons.

The potential sites identified for rain water harvesting include Shorabak, Boldak, Marruf, Arghistan-1, Arghistan-2, Arghistan-3, Khakres, Ghorak, Maiwand-1 and Maiwand-2 in the Kandahar Province Afghanistan.

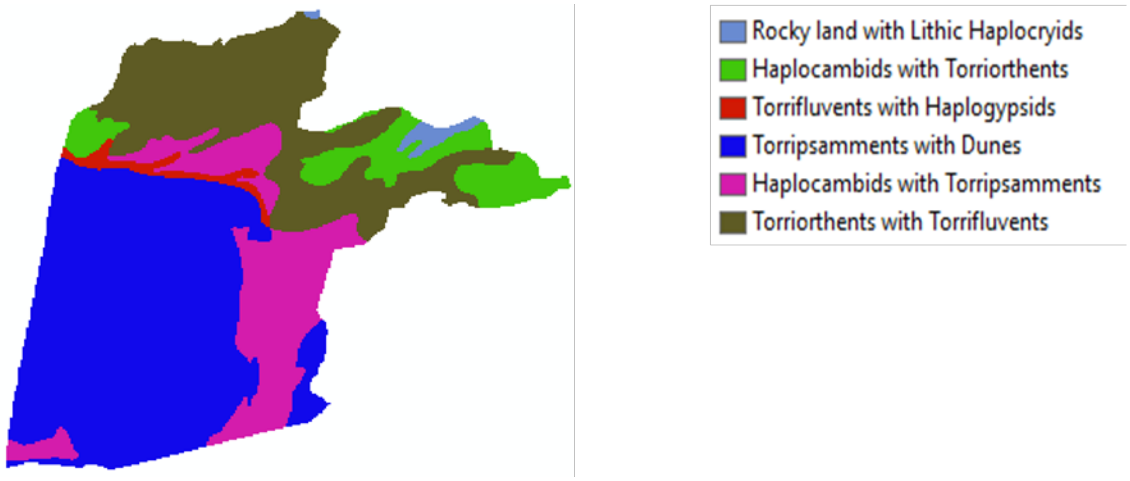

Fig 17. Raster map of soilgroups

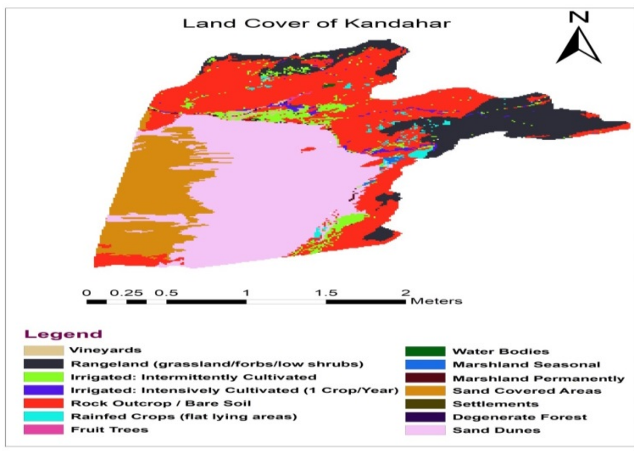

Fig 18. Land cover/use map

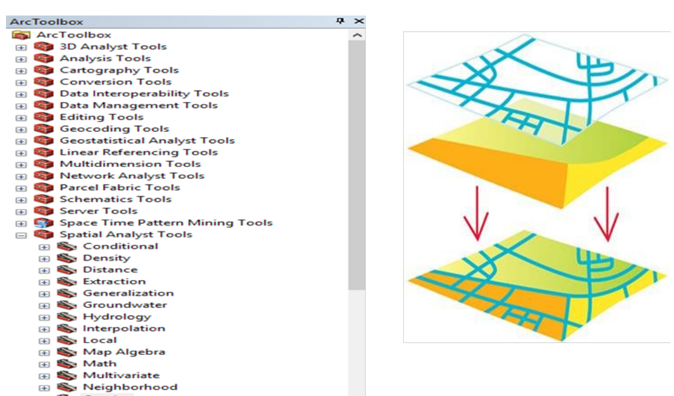

Fig 19. Overlay

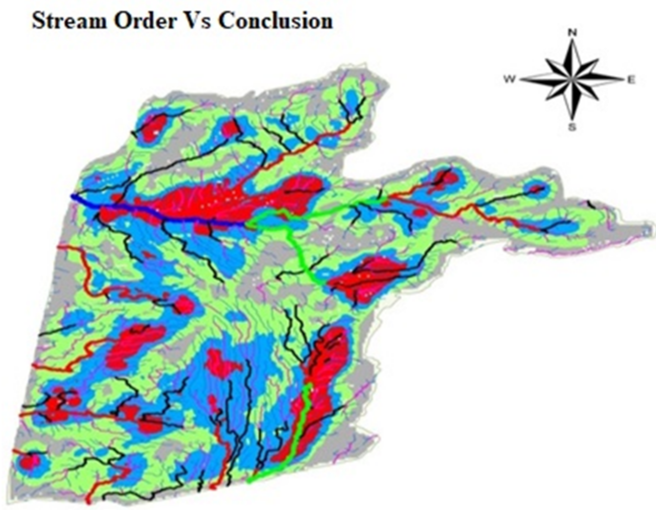

Fig 20. Stream Order Vs Conclusion

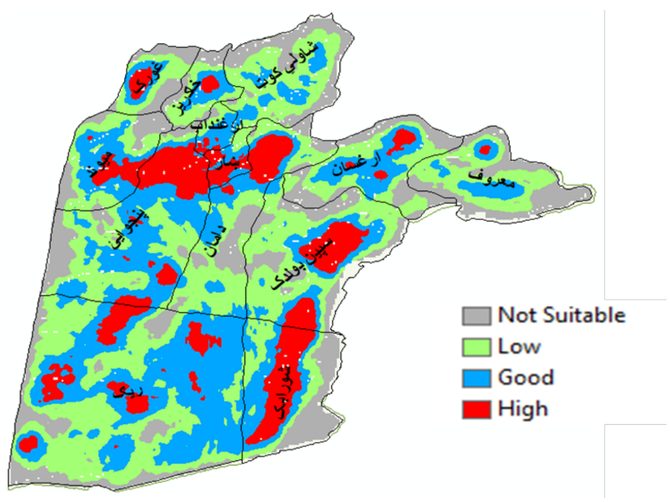

Fig 21. Final potential sitesin the study area

Table 2. Final Potential Sitesfor Rain Harvesting in the Study Area

No	Location	Latitude	Longitude	No	Location	Latitude	Longitude
1	Shorabak	66.052	30.181	11	Panjwaye	65.140	31.208
2	Boldak	66.350	31.121	12	Panjwaye	65.117	30.929
3	Marrurf	67.196	31.656	13	Panjwaye	65.369	30.867
4	Arghistan-1	66.730	31.746	14	Panjwaye	65.164	30.670
5	Arghistan-2	66.571	31.468	15	Reg	64.727	30.140
6	Arghistan-3	66.410	31.584	16	Reg	65.163	30.108
7	Khakres	65.608	32.056	17	Reg	65.560	30.493
8	Ghorak	65.203	32.093	18	Daman	65.695	31.398
9	Maiwand-1	64.901	31.765	19	Daman	65.969	31.636
10	Maiwand-2	65.034	31.573	20	the city	65.648	31.473

These findings have policy implications. For instance, in the war prone Afghanistan, very little research has been conducted in the last several decades. To the best of authors' knowledge, a study by Rahimi and Murakami [37] is the known research conducted rainwater harvesting that has investigated the feasibility of a rooftop rainwater harvesting system in Kabul New City. Contrary to it, the current study is the first of its kind that has revealed that rainwater harvesting sites in the Southern part of Afghanistan. The irrigation and agriculture departments with support of federal government can take help from these findings in establishing the rainwater harvesting infrastructure in the province that can mitigate the adverse impacts of climate change. This will help the farmers to mitigate the impacts of droughts too [11]. Because studies have reported that droughts have severe impacts on farming communities and their livelihoods [12–14]. If rainwater is harvested through established techniques such as construction of delay actions dams, then it will also help mitigate the adverse impacts of floods. Research studies report that the naturals hazards such as flood cause damages to farmers. Similarly, research studies have also shown that rain harvesting is a most important coping strategy used for mitigating the impacts of droughts [17]. E Saqib, Panezai [18]. Also report that rainwater harvesting is a water conservation strategy used for coping the climatic risks.

The rainwater harvesting can help maintain and improve the groundwater in the area. Similar has been recommended by [38]. Research studies report that groundwater is vital natural resource essential for maintaining life on earth [9] is declined due to its excessive use for domestic and agriculture purposes [10]. Thus, rainwater harvesting would help recharge the ground water reservoirs. It would also help provide water for domestic and agricultural purposes as per needs. Lastly, the specific sites identified for rainwater harvesting in Kandahar province will help promote the agriculture and rangeland management in the province which will help promote livestock too.

4 Conclusion

Basically, this study was aimed to identify the potential rainwater harvesting areas. The analysis concluded with identification of the potential rainwater harvesting areas in Kandahar province. For the optimal utilization of water, it is mandatory to harvest the rainwater during rainy season. The findings of this study are of significant importance for the policymakers of Government of Afghanistan in general and the Irrigation and Agriculture departments in particular. It is also pertinent to mention that Afghanistan has been war prone country for the last four decades. Thus, the Government has not been able to conduct research on research and development projects in the country. That is the reason this study is considered as vital contribution into research and development in the province. In conclusion this study suggests that policymakers and relevant departments of the Government of Afghanistan to construct delay action dams in the potential areas highlighted in this study. The construction of dams would on the one hand reduce the waste of water in the rainy seasons while on the other hand, it would improve the ground water table and provide water for farming as and where needed. Similarly, through rainwater harvesting agriculture, livestock and range lands for livestock would be developed. This would also help in mitigating the adverse impacts of climate change. Consolidated efforts are required from the ministries and departments responsible for water governance and management such as Ministry of Energy and Water (MEW), Ministry of Agriculture, Irrigation and Livestock and Authority of Urban Water Supply at national and provincial levels respectively for utilization of the findings of current study for rehabilitation of water resources in the country in general and Kandahar province in particular. Moreover, the Ministry of Rural Rehabilitation and Development and Ministry of Urban Development Affairs are also suggested to establish strong coordination with the other water-related ministries for making development strategies for rainwater harvesting in rural and urban areas of the country.

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