

Identification of Suitable Sites for Rainwater Harvesting Using Remote Sensing and GIS: A Case Study of District Lakki Marwat, Pakistan

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ARTICLE INFO		ABSTRACT
Article History:		<i>Lakki Marwat is significantly under great threat due to water scarcity since last 2 decades. According to current scenario the most promising alternative is rain water harvesting in the monsoon season in different agro-climatic zones. This study is an innovative approach to explore the potential rain water harvesting sites in Lakki Marwat through Geospatial analysis. GIS and remote sensing methods were integrated to evaluate four parameters runoff, slope, drainage density and LULC which are significantly affecting our RWH sites. Weighted overlay analysis is used as a method to evaluate these parameters. These factors along with their individual features were assigned suitable weights to generate suitable sites for rain water harvesting. The study area was classified into four zones as most suitable covering an area of 14.5%, suitable (25.47%), moderate suitable (38.55%) and least suitable (21.4%). This research findings will not only bring positive impact on the agriculture, livestock, water and soil quality but will also enhance the ground water recharge and will reduce the ground water consumption and to increase ground water table.</i>
Received:	August 22, 2025	
Revised:	September 24, 2025	
Accepted:	October 13, 2025	
Available Online:	October 21, 2025	
Keywords:		
Rain Water Harvesting; Water Scarcity; Flood Control; Suitability Maps; Lakki Marwat		
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Introduction

The demand for water for agricultural and urban development has increased with increase in population. Besides urban areas, rural areas have also come under pressure for water resources due to increased settlements. Pakistan's arid and semi-arid areas suffer from water shortage. The concept of RWH sites has been traditionally applied in many different countries. In India at a very dry area known as Desert Gold, residents made a simple system to harvest rainwater (Juliana et al 2013). In Japan, the government made it compulsory to construct RWH for new building (Juliana et al, 2013). In Pakistan, availability and accessibility of fresh water is a major issue (Ahmad et al., 2010). As alternative sources, rainwater is highly preferred by the people and

hence, rainwater harvesting (RWH) has emerged as a widespread practice across the globe to address water scarcity and other environmental problems (Singh et al., 2017). Rainwater Harvesting (RWH) structures are better options to save water through construction of best roof top structures which are then connected through pipes with water tanks. Water conservation is imperative to reduce the water poverty during no or low rainfall (Saha et al., 2018). Most of the precipitation evaporates from the often-bare soil or from surface depressions. In Pakistan, RWH in desert area of Cholistan, Union Council level mini dams and ponds in Punjab, Pilot project of GW recharging by CDA, promotion of RWH in Earthquake Affected Areas of KPK and AJK, rain Water Conservation walk by ERRA on 10th December 2013 in Murree were the only measures taken by the government of Pakistan for RWH (Lade and Oloke, 2015). More irrigation water is needed to feed the growing population but irrigation water is very limited (Prinz et al., 1998).

RWH sites can be identified with the help of geospatial techniques. Effective rain water harvesting needs knowledge of RWH structures, simulation models, and expert opinion to solve practical problems and provide a scientific basis for decision-making at the micro scale. GIS technology provides a best computer aided tools and therefore can provide the best support in the decision making for solving problems (Shakoor et al., 2017). Precise modeling of water harvesting plays a tremendously important role in the management of the watershed. Based on above, objectives of the study were to 1, to estimate the direction and flow accumulation of rain water using Geospatial techniques and 2, to identify the possible locations for rain water harvesting.

Research Methodology

Study Area

Lakki Marwat is part of Bannu Division of Khyber Pakhtunkhwa province. Average elevation in Lakki Marwat is about 255m. The latitude is 32.6135° N, and longitude is 70.9012°E (Figure 1) (Khan et al., 2021). Lakki Marwat district is occupied by hills and sandy plains. Elevation of the hills remain 500-1000 meters above sea level. It covers an area of 3,296 square kilometers. It is a speedy growing city and has a population of almost 1.041 million. It has dry type of climate with harsh climatic conditions. The dry conditions in the district make it like a Desert. Rainfall is very scanty and occurs sometimes in months of July and August. Summers start in April and remain till October. June is the hottest month with minimum and maximum temperature ranges of 30–35C and 42–45C (Sarwar et al., 2013).

Data Sources and analysis

Digital elevation model (DEM), land use /land cover, precipitation and soil map which were later used to find the runoff at each station the data has been taken from the USGS Website were used as the data for this study. A Landsat 4-5 image (spatial resolution of 30 m) was obtained on 24 March, 2011 and March 31, 2011. The DEM of 0.5 x 0.5 degree was used in this study. Data of rainfall for 38-years (1981–2018) were collected from Climate Hazards Group Infrared Precipitation (CHIRP) data archive. The Softwares used for analysis were ERDAS Imagine and Arc Map.

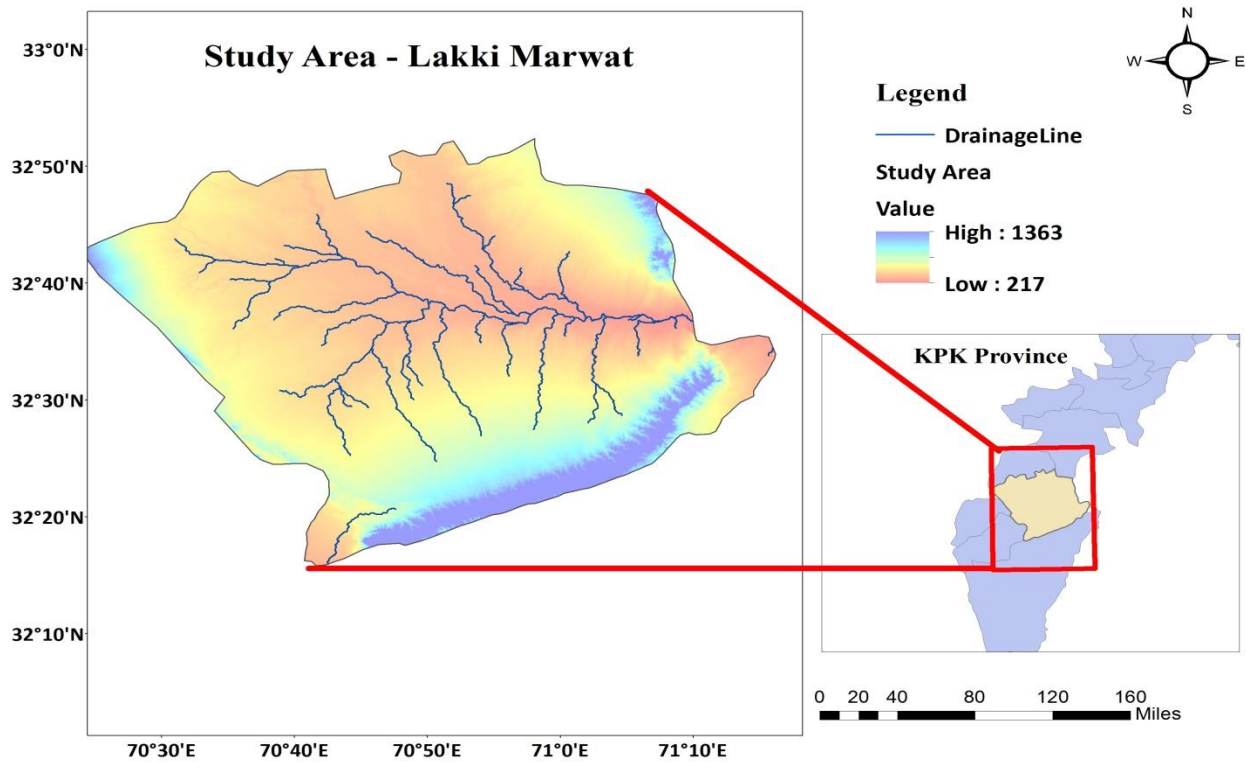


Figure 1: Study area (Lakki Marwat)

Layer Stacking and Selection of Raster Parameters

Layer Stacking method was used for combination of individual bands in this study. As we have two raster images of our study area, we used a single raster dataset from multiple raster datasets by mosaicking method. The four criteria of runoff, slope, drainage, and Land use land cover change (LULC) were used to determine the suitable RWH sites in Lakki Marwat. The surface runoff map was prepared from precipitation data along with CNs and LULC. LULC classes, such as barren soil, settlements, water, vegetation and sandy rocks differently affect the runoff depth. Slope and drainage plays an important role in selecting RWH sites.

Maximum Likelihood Supervised Classification

Image classification is the process to automatically arrange pixels into LULC classification. In this study supervised classification techniques were used to identify different LULC classes. Before classification, a shapefile has been made by extracting the study area which is Lakki Marwat District. Extract by mask tool is used for this purpose to extract the required area in ArcMap. In order to do supervised classification, the training areas were used to highlight the correct patterns of water, vegetation, barren land, settlements and sandy rocks. Then by using that signature file, supervised classification has been done on the Landsat 4-5 satellite image. After the classification has been done, all the attributes of image were extracted separately e.g. vegetation, barren land, settlements, sandy rocks and water. Then we calculated the area of each attribute by multiplying the total number of pixels in each attribute with the size of pixel. As our coordinate system was WGS 84 and cell size was in decimal degrees, we converted it to km^2 . For this we transform coordinate system to UTM zone 43 through project raster tool in data management tools. To obtain area we multiply cell count with the cell size which is 0.06387204 km^2 .

Measurement of Rainfall

Precipitation data of 38 years (1981 – 2018) from 16 stations were collected from Climate Hazards Group Infrared Precipitation (CHIRP). The average precipitation of 16 stations was calculated. For points measurement of precipitation data in the study area we used IDW algorithm from spatial analyst toolbox, which gave us the average annual rainfall (Figure 2).

Slope Map

To derive slope of study area, we filled the raw DEM using arc hydro module. Then using the SLOPE tool from spatial analyst toolbox find slope. After then slope map is classified into five different classes ranging from lower to higher elevation.

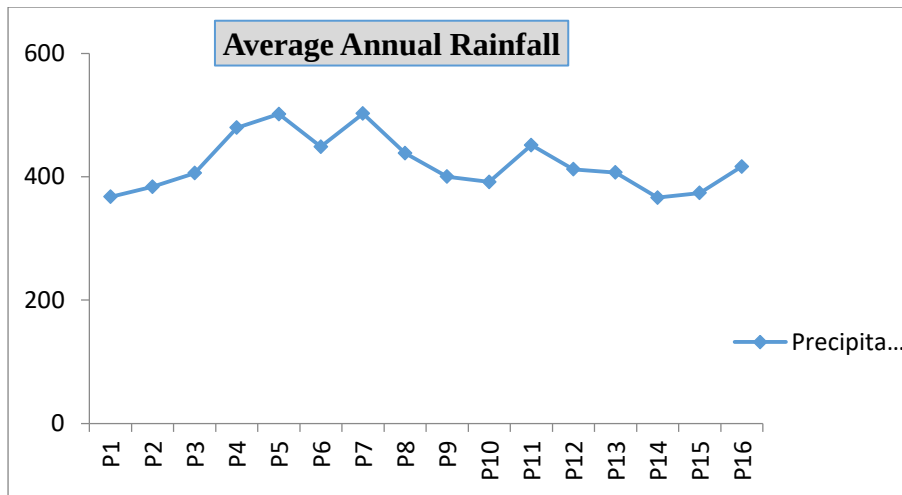


Figure 2: Average annual rainfall of different points of study area at 16 different stations for the period of 1981-2018.

Digitizing of Soil Map and Runoff Calculation

Arc GIS was used for digitization and georeferencing of the soil map. SCS curve number method to identify CN based on soil type which were later used to find the runoff at different stations. Soil Conservation Service equation was used in GIS, as:

$$Q = \frac{(P - 0.2 \times S)^2}{(P + 0.8 \times S)} \text{ --- (1)}$$

In above equation Q represent runoff depth in millimeters, P is rainfall amount in millimeters, and S show maximum potential retention in millimeters.

$$S = \frac{254000}{CN} - 254 \text{ --- (2)}$$

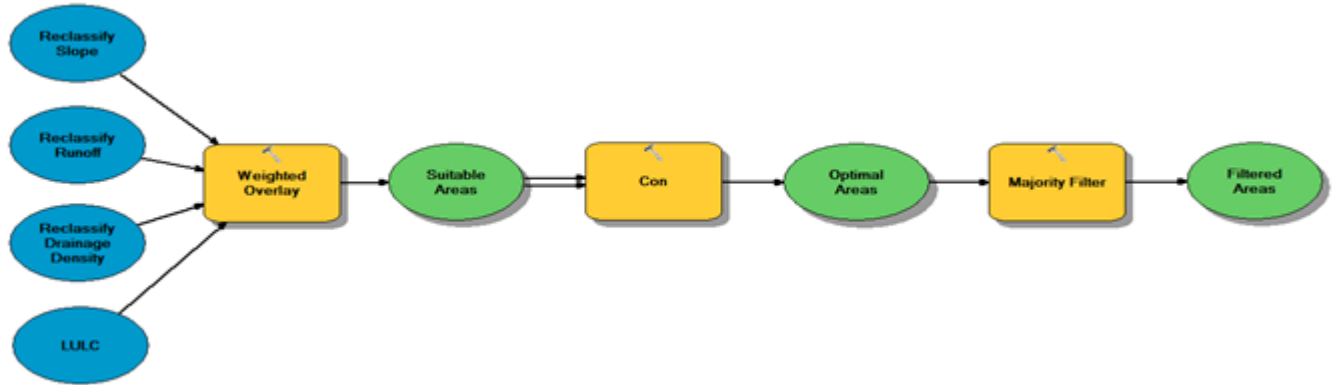
CN was estimated per pixel by matching the soil map and LULC.

Weighted Overlay Analysis (WOA)

WOA was performed to prepare RWH suitability sites map. Weights were assigned on a scale level of 0-10 to thematic layers (runoff depth, slope, drainage, and LULC). Resultant map was classified into four classes. 1 was used to represent least suitable and 4, the most suitable class with the moderate suitable areas between them. It was found that the moderate suitable region covers 38.55 %. Area “not suitable” represent 21.4%. “Most suitable areas” covered 14.5 %. This region is

mostly located within the north east and this is the region having the most appropriate conditions of slope, runoff, LULC and drainage. The suitable areas covered 25.47 percent. The model used from ArcGIS model builder was used to Identify the suitable sites for rainwater harvesting (Figure 3).

Figure 3: Model to identify RWH



Results and Discussions

The slope map of Lakki Marwat is shown in Figure 4. The northern part of the district is mostly barren and have less vegetation.

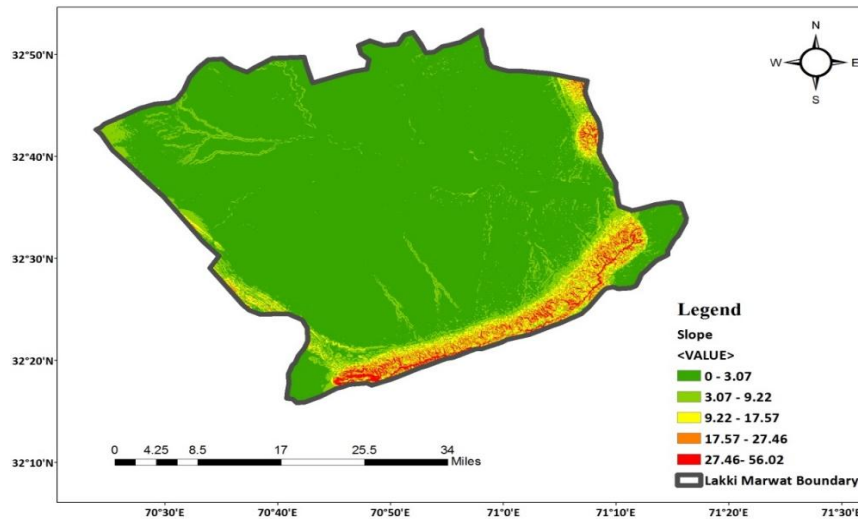


Figure 4: Slope Map of Lakki Marwat

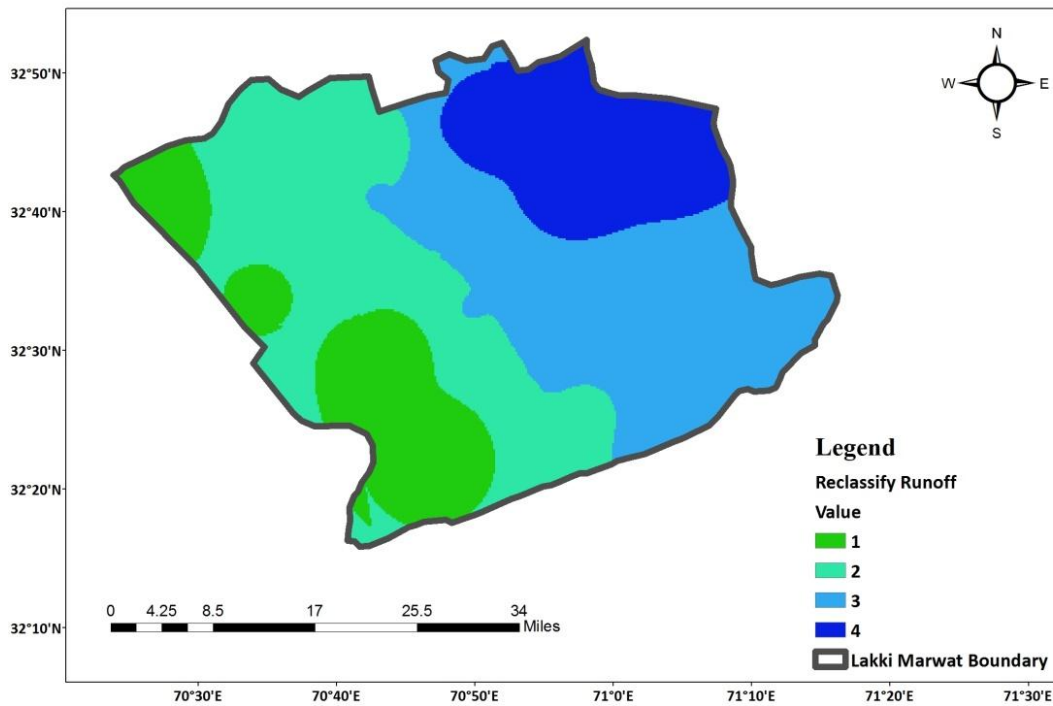


Figure 5: Runoff Map of Lakki Marwat

The study area also has highest runoff of 532.803 mm (Figure 5). The ranked value and percentage area of different land uses were identified (Table 1).

Table 1: Ranked value and % area of different LULC

S.NO	LULC	Ranked value	% area
1	Residential	1	21.1
2	Sandy Rocks	36	16.2
3	Vegetation	106	2.9
4	Water	49	19.58
5	Barren	201	24.3
6	Others	183	15.86

These different land uses are also shown throu a GIS map (Figure 6). The soil texture here is clay loam which contains more clay than other types of rock or minerals thus having very low infiltration rate (Figure 7). Four classes of RWH sites, namely most suitable, suitable, moderate and least suitable were identified (Figure 8). The north eastern part of Lakki Marwat was represented as as an excellent zone for RWH. The least suitable zones are mostly present in the south and south east part. This region is characterized by sandy rocks and have extremely steep slope.

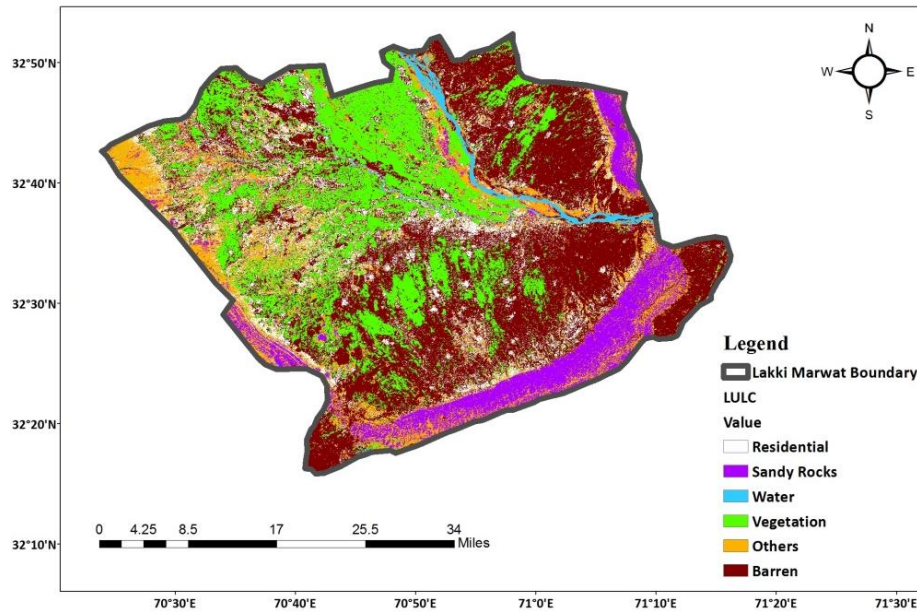


Figure 6: LULC map of Lakki Marwat

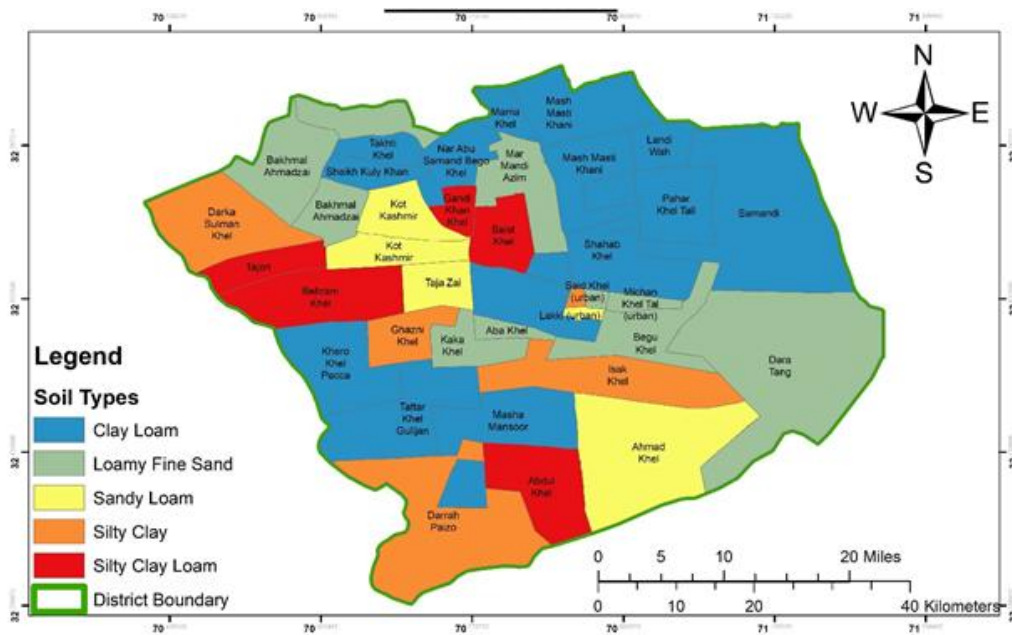


Figure 7: Soil texture map

The areas were identified as high suitable, suitable, moderate suitable and poor suitable zones cover about 14.5% (478.59 km^2), 25.47% (836.65 km^2), 38.55% (1266.26 km^2) and 14.5% (703.16 km^2). Optimal location for RWH is shown in the northern parts of Lakki Marwat (Figure 9).

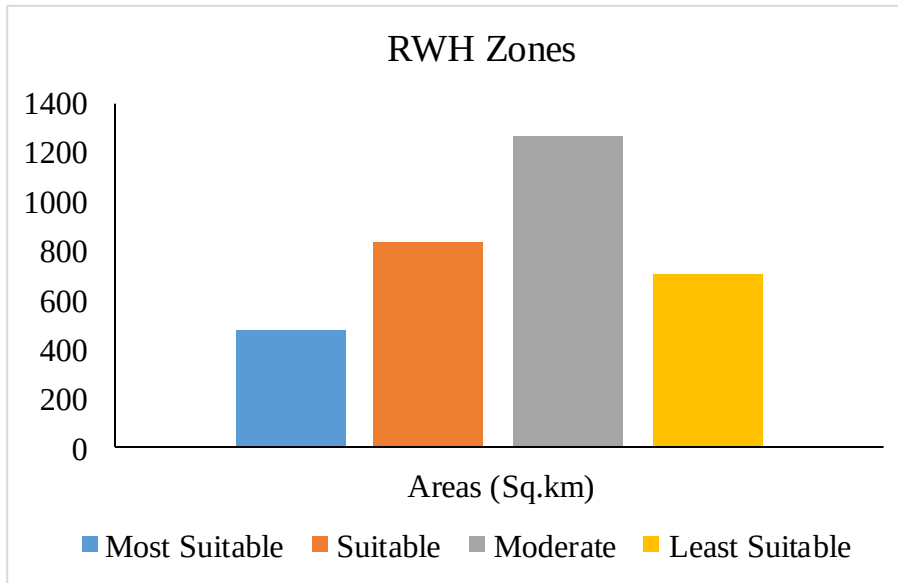


Figure 8: Area of different RWH zones in sq.km

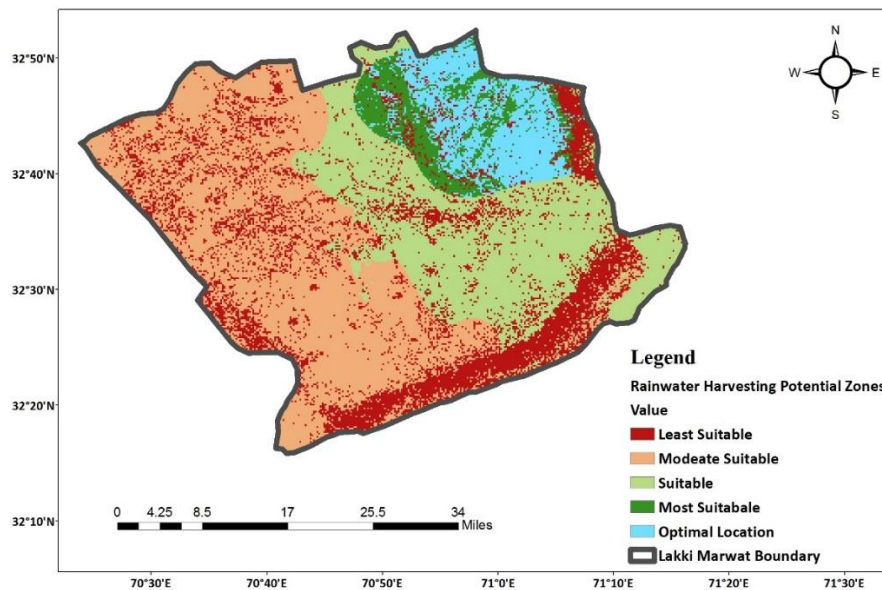


Figure 9: RWH suitability map of Lakki Marwat

Conclusion

This methodology for rain water harvesting suitability sites with the help of GIS and RS technology is more advanced and appropriate as compared to the simple survey methodologies. This is due to integration of multiple layers of parameters such as drainage, slope, LULC and soil textures. The use of curve number method to find regional runoff depth using LULC and soil parameters. The whole study area is identified with the most suitable, moderately suitable, least suitable and not suitable classes. Therefore, this study is much important and has potential for policy makers and government authorities to work on the most suitable sites for rain water harvesting structures construction. With the construction of these structures, this arid and desert

like region will provide more potential for development of agriculture. Rain water collected at identified sites can be used for domestic and agricultural purposes.

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