INVESTIGATING THE POTENTIAL RUNOFF WATER HARVESTING SITES IN D.I. KHAN ROD-KOHI AREAS USING GEO INFORMATICS

Shanzeela Farooq

211-FBAS/MSES/F14

Supervisor

Dr. Rukhsana Tariq

Co- supervisor

Dr. Arshad Ashraf

Department of Environmental Sciences
Faculty of Basic and Applied Sciences
International Islamic University Islamabad

(2014-2016)

Harvesting

Spate irrigation system

Agricultural system - Pakistan.

بسم الله الرحمن الرحيم

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Dated: 02-03-2017

FINAL APPROVAL

It is certified that I have evaluated the thesis report "Investigating the potential runoff water harvesting sites in D.I. Khan rod-kohi areas using geo informatics" submitted by Shanzeela Farooq (Registration # 211-FBAS/MSES/F14), found the thesis and its report of sufficient standard to warrant its acceptance to complete the course of studies of Master's Degree in Environmental Science of the International Islamic University, Islamabad.

COMMITTEE

Supervisor

Name: Dr. Rukhsana Tariq

Designation: Assistant Professor

Department: Environmental Sciences

University: International Islamic University, Islamabad.

Internal Evaluator:

Name: Dr. Maliha Asma

Designation: Assistant Professor

Department: Environmental Sciences, IIUI

External Evaluator:

Name: Dr. Rohama Gill

Designation: Assistant Professor

Department: Environmental Chemistry, FJWU, Rawalpindi

Countersigned by:

Chairperson, DES

Name: Dr. Rukhsana Tariq

International Islamic University, Islamabad

Co-supervisor

Dr. Arshad Ashraf

Designation: Principal Scientific officer

Dean, FBAS

A thesis submitted to Department of Environmental Sciences,

International Islamic University, Islamabad as a partial fulfillment of requirement for the award of the degree of MS Environmental Science

DEDICATION

"This thesis is dedicated to my parents for their undue support and encouragement"

DECLARATION

I hereby declare that the work presented in this report is my own effort, except where otherwise acknowledged and that the report is my own composition. No part of this thesis report has been previously presented for any other degree.

Date: 5th January, 2017

Shanzeela Farooq

Table of Contents

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Shanzeela Farooq

LIST OF ABBREVIATIONS

D.I. Khan: Dera Ismail Khan

DEM: Digital Elevation Model

GIS: Geographic Information System

KPK: Khyber Pakhtunkhwa

LULC: Land Use Land Cover

RS: Remote Sensing

RWH: Rainwater Harvesting

LIST OF FIGURES

LIST OF TABLES

Abstract

Spate/ Rod kohi Irrigation system is a unique rainwater harvesting system in which water is harvested from the mountains and diverted to the agriculture fields by traditionally made sand diversion barriers through the torrent. After the Indus Basin irrigated agricultural system Pakistan has the largest area under spate irrigation which is the source of food and livelihood to millions of people. Spate irrigation is found in all four provinces. Dera Ismail Khan is the district located in southern part of Khyber Pakhtunkhwa has the largest rod kohi area. The chief problem of the rod kohi areas is the variability in amount and distribution in the use of flood flow. The annual rainfall is very low, patchy and inexact but brings large amount of water with each event. The flood water is loaded with high amount of silt. Despite of water shortage in the area heavy amount of flood water is lost due to mismanagement. But the major issue of these areas is poverty. Options for improvement of livelihood and income generation is also less. Through reliable resource assessment and information the future planning and development of rod kohi areas is possible. The RS technique provides an efficient way of studying the land use and natural resources of the earth. It provides a synoptic view of the large portion of the earth surface thus monitoring of the existing land resources, whether in the inaccessible areas, is feasible through visual analysis of the image data. It is cost effective and minimizes the expenses involved in regular field surveys. The aim of the research work was to investigate surface runoff potential and land use in Rod-kohi areas of D.I. Khan, to identify potential RWH sites and to propose effective management strategies. It is important for developing better water management strategies for productivity enhancement of rod-kohi agriculture in the country.

About 48% of the total rod kohi area is rangeland. 26 sites were selected for RWH in the rod kohi part of D. I. Khan and the total runoff water potential in these sites was 7515m^3. The selected sites could be used for RWH by building flood management structures/ reservoirs/ponds through coupling ground realities like political, cultural and physiographic conditions, water rights, socioeconomics, and water needs of the local communities. It is recommended that Rangeland management programs should be introduced in the area and establishment of a separate and an independent institution for the conservation and management of hill torrent water.

CHAPTER 1

INTRODUCTION

INTRODUCTION

After the Indus Basin irrigated agricultural system Pakistan has the largest area under spate irrigation which is the source of food and livelihood to millions of people. Spate Irrigation system is a unique system of rainwater harvesting in which water is being harvested from the mountains and diverted to the agriculture lands by traditionally made sand diversion barriers through the torrent. Pakistan being agrarian society, pre-dominantly dictated by inherent arid to semi-arid climate has a big challenge in the context of climate change. Spate irrigation is found in all four provinces. In Khyber Pakhtunkhwa and Punjab it is called as rod kohi, in Baluchistan as Sailaba and in Sindh as Nai (Ashraf *et al.*, 2013).

About 65% of the total area of Pakistan is rod kohi traversed by hill torrents and this include province of Baluchistan, district D.G Khan in Punjab, D. I Khan in KPK, AJK and FATA. Spate Irrigation is locally known as Rod-Kohi. Rod means water channel and Kohi refer to mountains. The chief problem of the rod kohi areas is the variability in amount and distribution in the use of flood flow. The annual rainfall is very low, patchy and inexact but brings large amount of water with each event. The flood water is loaded with high amount of silt. Despite of water shortage in the area heavy amount of flood water is lost due to mismanagement. Mostly in dry and remote areas, this rod kohi system of irrigation takes place. But the major issue of these areas is poverty. Options for improvement of livelihood and income generation is also less. The poverty in the area is miserable along with heavy flood flows calls for the rational and systematic flood water management. ("*Rajanpur District*")

Rod-Kohi is a different kind of agriculture system which is practiced throughout Pakistan. In Khyber Pakhton Khwa, Rod kohi system of D. I. Khan is very large and is fed by the five large tributaries locally called as "Zams". In Punjab major part of rod kohi is in D. G Khan, Jampur and Rajanpur districts. In Balochistan, this system is spread in Barkhan, Loralai, Zhob, Bolan, Masakhel and Lasbela. In Sindh this system falls in Larkana and Dadu districts. However the biggest area under Rod-kohi agriculture system lies in Baluchistan ("*Rajanpur District*")

Hill torrent cultivation is a conventional method used to divert hill torrents into cultivable command areas to grow crops. By extreme floods and droughts events farming system is characterized. Typically it involves the construction of earthen diversion weir across torrent with large channel on one or both sides of the river to carry flood water across huge distances. Traditionally by making the use of conventional practices the communities themselves construct these earthen diversion structures and water conveyance system. As the storing of water depends on type of soil, share in water and other factors, the farmers construct fields by making embankments of about 3-6 feet (1.8m) high. Upon drying, crops are sown which grow well on the amount of moisture deposited in the soil. There would be no further irrigation except if rain occurs. The economic worth of rod kohi irrigation agriculture depends upon subsistence agriculture and livestock raising which are the main source of income. Occurrence of perennial water is also one of the aspect of Spate irrigation, and this is available throughout the year. (*"Rajanpur District"*)

Through reliable resource assessment and information the future planning and development of rod kohi areas is possible. The agriculture here is totally dependent on rainfall, although affected by floods but most of the times remains without water. It is unfortunate that most of the flood water is lost due to the mismanagement i.e. unavailability of any kind of storage and modernized engineering structures to control the torrent flows. There is a need to identify resource potential and suitable water management strategies in order to enhance agricultural productivity and economic growth in the Rod-kohi areas (Ashraf *et al.*, 2013).

The Remote Sensing technique provides an efficient way of studying the land use and natural resources of the earth. It provides a synoptic view of the large portion of the earth surface thus monitoring of the existing land resources, whether in the inaccessible areas, is feasible through visual analysis of the image data. It is cost effective and minimizes the expenses involved in regular field surveys. Land use change can be monitored using temporal satellite remote sensing (SRS) data. For rapid analysis of spatial data integration of several thematic layers is possible in GIS environment. Currently, with most of the digital available data that is digital elevation model (DEM), remote sensing images, Global positioning System (GPS) field data, data integration has become effective technique for study and analysis. (Conitz, 2000; Larsen, 1999 and Nogales, 2000).

Rod Kohi Irrigation System is more than a century old and is the vital component of the local economy, social set up and the environment (Zia & Hasnain, 2010). Rod kohi system of KPK is unique because of established rules and procedures. Since long time it is able to provide livelihood to lots of people. At present rod kohi irrigation is prevailing in Tank district, Kullachi Tehsil and upper part of D.I. Khan District ("Spate irrigation", 2003).

Farmers of Rod Kohi area face some problems. The 'sad/gandis' are improperly built and usually break due to the flow of flood water before the required irrigation is accomplished. These create problem in irrigation because mostly these are not completely constructed. The floodwater frequently cut out new channels and ravines. Therefore, the entire area gets affected by the flood water. The other problems that are faced in the Rod kohi system is the unavailability of the earth moving machinery at the required time and also inadequate man power for the construction of temporary diversion dykes in the months of June and July when sufficient water, shelter and fodder are not readily available. This leads to higher irrigation costs every year. The short-lived flows of floodwater do not conform to the crop water requirements of the area.

The flood flows are generally impregnated with a high silt charge, which preclude the possibility of economic management through reservoirs. The banks of channel are irregular in height and width, which create over-ban flooding phenomenon in various reaches of a channel. Generally the major zams have a number of tributaries and offshoots which run into each other and complicate the entire management system. (Water Harvesting in Mountain Areas of Pakistan: Issues and Options)

Dera Ismail Khan is in southern part of Khyber Pakhtunkhwa. The governance and administrative structure of tribal culture in that area make it difficult for professionals to pursue for development projects and this is the reason that area faces developmental problems. (*Bangash H. D*).

The Environmental aspects of Spate irrigation are that these seasonal storage sites would help in ground water recharging. All crops are grown as organic farming under spate irrigation. Pesticides and chemical fertilizers are not used. Some of the permanent *sadds* in rod kohi area are the excellent water pool on which human and animal population depend for drinking water. These are also favorable sites for migratory birds. By the use of less expensive local material the spate structures are made. Vegetation like bushes, trees, shrubs and grasses grown through the natural flooding of spate irrigation are the basic source of livelihood of local community ("Spate irrigation", 2003).

The primary purpose of irrigation cum flood control scheme should be to control and manage the flood flow more efficiently and cautiously. Through this not only the flood damages could be reduced but also a smoother and enhanced irrigation system of the area could be assured. The intensity of flood water would be broken and only water of manageable quantity would flow into their channels and on to the lands so people would be able to utilize this water in a much better way. (Gandapur, 2010).

The aim of the research work is the assessment of spate irrigation potential of rod-kohi region of D.I. Khan through application of GIS and remote sensing techniques. It is important for developing better water management strategies for productivity enhancement of rod-kohi agriculture in the country. The spatial and attribute databases to be generated would help field managers to select suitable sites for surface runoff harvesting in D.I. Khan rod-kohi area.

1.1 Objectives of the study

- To investigate surface runoff potential and land use in Rod-kohi areas of D.I. Khan
- To identify potential water harvesting sites by using high resolution Digital Elevation Model and ancillary data
- Propose strategies for effective management of surface runoff for agriculture development.

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

Agriculture is the largest employing sector that involves 44.7% of manpower of Pakistan's total population and participates about 23% in GDP of Pakistan but on the other side, country is facing the shortage of water. To overcome the shortage of irrigation water for agriculture, there was a need to move towards water storage techniques like rainwater harvesting (Ghani *et al.*, 2013).

The key benefit of using GIS for flood analyses is that it not only generates a visualization of flooding, but also creates potential to further analyze these events to estimate probable damage due to floods (Malik & Ahmed, 2014).

Bakir et.al (2008) worked on the GIS and Remote Sensing applications for rainwater harvesting in the Syrian Dessert, Al-Badia. They concluded that rainwater harvesting is particularly important in the arid and semi-arid region. NESPAK (1998) has identified major hill-torrent regions over 65 percent areas of the country in order to identify water conservation potential in Pakistan. Their study was mainly focused on selecting small dams on main rivers of the hill-torrent regions (Mustafa *et al.*, 2013).

Spate irrigation in Pakistan has a large potential but is also largely unknown and not well understood. In the system, water from short duration flash floods is diverted to irrigate land and fill drinking water ponds, water rangelands and forest ranges. Traditionally water is diverted from free intakes (on the piedmont zones) or (further down in the plains) with the help of earthen diversion bunds build across the ephemeral rivers.

Spate irrigation is usually pre-planting and hence soil moisture conservation is very important as there is a time-lag between the timing of watering and seeding. Another special feature of spate irrigation is the management of sediment. As sediment loads of spate flows may be as high as 10%, spate irrigation is as much about managing water and it is about managing sedimentation (Ahmad & Steenbergen).

There are two types of rain water harvesting techniques. In-situ and Ex-situ techniques. In-situ RWH is a technique which involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain where it falls (Alamerew et al., 2002; Ngigi, 2003).

Water harvesting ponds and roof harvesting are the types of Ex-situ rain water RWH techniques. In-situ water harvesting methods that concentrate soil water in the rhizosphere for more efficient use by plants are critically needed for moisture stress areas. It means rainwater is conserved where it falls, whereas ex-situ water harvesting systems involve transfer of runoff water from a "catchment" to the desired area or storage structure (Critchley and Siegert, 1991).

Rainwater harvesting is accumulating and storing of rainwater for future use and is the best tool for both surface water and ground water management. It has been used to provide water for drinking, livestock and for irrigation or to refill aquifers in the process called groundwater recharge. Rainwater harvesting can also be seen as the deliberate collection of rainwater from surface known as catchment and its storage in physical structures or within the soil profile. Water harvesting can also be used to minimize water loss and to augment water supplies in watershed systems. RWH systems are important in managing scarce rainfall and success of these systems mainly depends on identification of suitable potential sites and technologies. (Isioye et al., 2012)

Andrew Lo et al., (2016) in their research focused on assessing the hydrologic environment in the karst areas and identified best suitable sites for harvesting rainfall by using SWAT model. They had done temporal analysis by using the data of three different years and combine the results of SWAT model and selected the common sub basins of the years. The water of these selected sub basins could be used for many purposes. Treated water could be used for drinking purpose and untreated water for landscape, groundwater recharge and irrigation etc.

As the land and water are the basic components of agricultural production. their proper utilization is a prerequisite for achieving sustainable agriculture. A knowledge-based system would be helpful for better resource planning and decision making. The understanding of runoff water harvesting is essential not only for better resource utilization but also for efficient planning and development of agriculture in the country (Mustafa *et al*., 2013).

The best and most obvious solution, from the point or view of agriculture, as well as flood control, will of course be the construction of a series of small and medium size dams on some of these torrents; to store the flood water of these torrents in the Monsoons and then release it in a small perennial flow throughout the year, through small canal/channels (Gandapur, 2011).

Pakistan being agrarian society, pre-dominantly dictated by inherent arid and semi-arid climate has a big challenge in the context of climate change. The Ten Years Perspective Development Plan prepared by the Planning Commission, Government of Pakistan emphasized the aspects of overcoming drought and reviving agriculture through sustainable water resources development and management in the country by focusing on fragile environments like Rod-kohi and Sailaba areas. The objectives outlined in this Plan demand overcoming water scarcity through augmentation and conservation means (Ashraf *et al.*, 2013).

CHAPTER 3

MATERIALS & METHODS

MATERIALS AND METHODS

3.1 Study Area

Dera Ismail Khan is district located in southern part of Khyber Pakhtunkhwa, lies between longitudes 70° 11′ and 71° 20′ east and latitudes 31° 15′ and 32° 32′ north. According to the Pakistan Bureau of Statistics total area of Dera Ismail Khan is 7326 Square kilometers. It is located on the west bank of River Indus. Tank and Lakki Marwat districts are located on the north, Bhakkar and Mianwali in the east, Dera Ghazi Khan on the south and South Waziristan and Tank on west. (Qadir, 2013) Principal Zams of D.I. Khan include Tank, Gomal, Choudhwan, Daraban and Shaikh Haider. Population according to 1998 census was 852995 persons, Male population of 53% and female 47%. The population density of the area is 116 per Sq. Km.

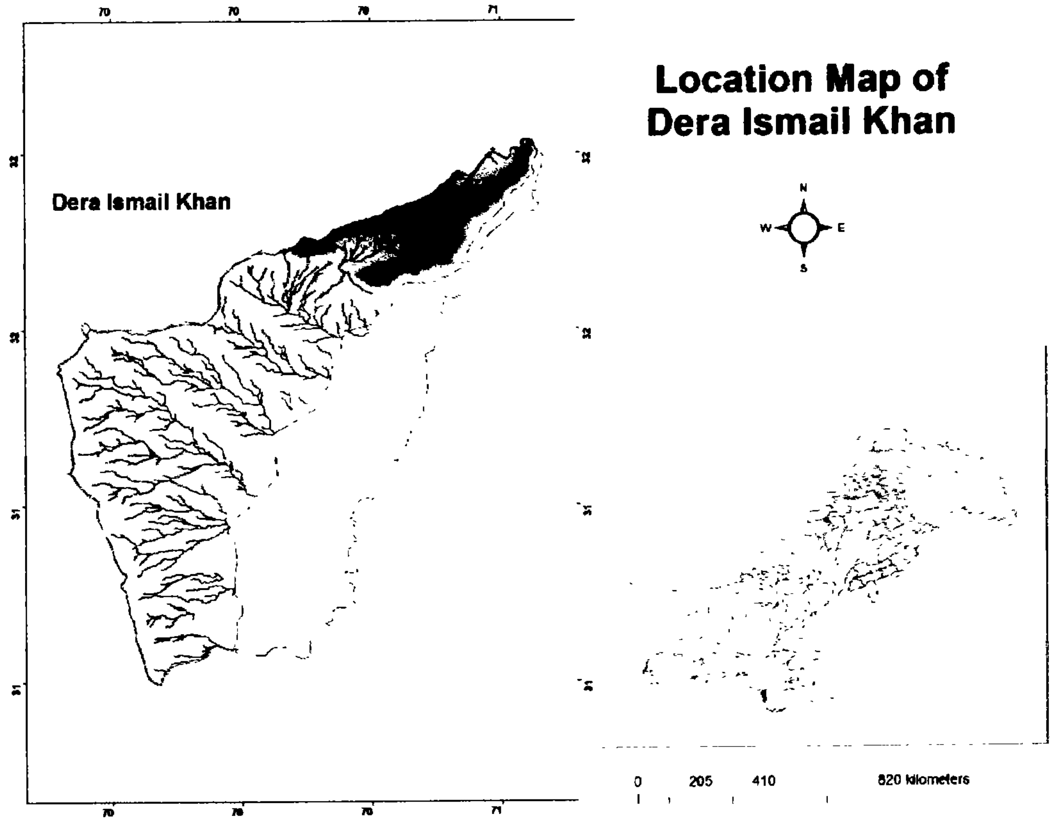

Figure 1: Location Map of Dera Ismail Khan

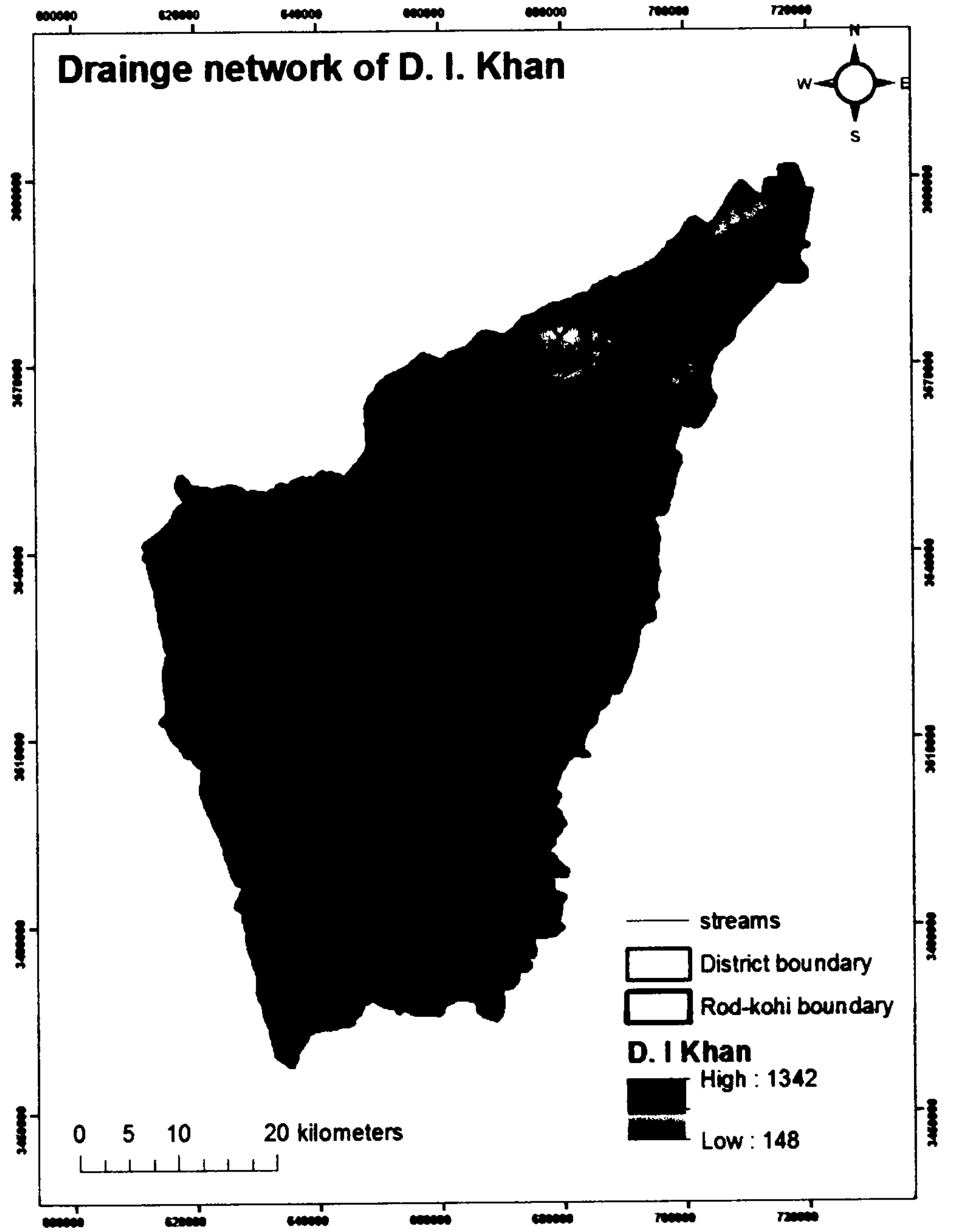

Figure 2: Drainage network Map of D.I. Khan

Drainage network helps in watershed delineation and for suggesting the water storing structure according to the water flow. Figure 2 shows the drainage network of Dera Ismail Khan.

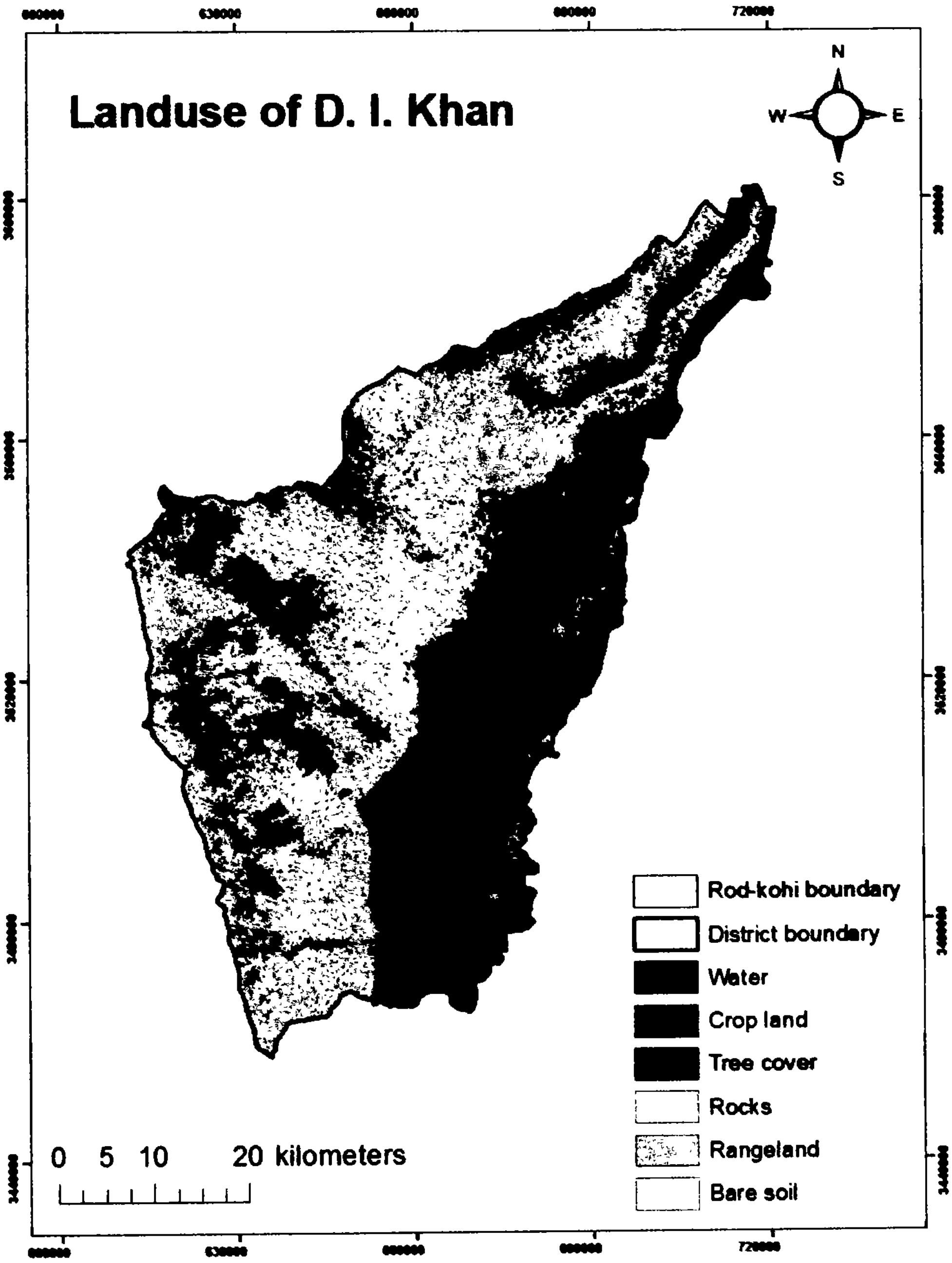

Figure 3: Land use map of D. I. Khan

Figure 3 shows the land use of Dera Ismail Khan. It depicts that the eastern part is irrigated land and water body is present whereas the western side is mostly consist of rangeland, bare soil and exposed rocks. Major land cover/land use classes in D. I. Khan were rangeland over 16%, exposed rocks over 27% area, bare soil on 9% area, tree cover on 29% and cropland over 4% area and waterbody over 15%.

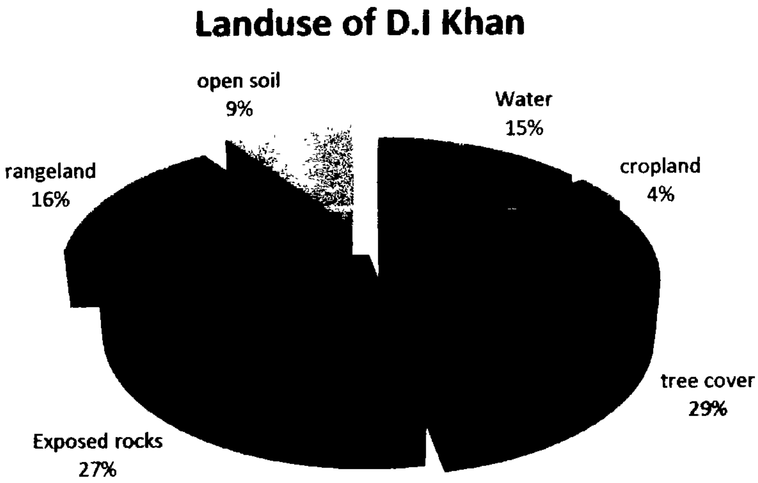

Figure 4: Land use/land cover estimated in target area

3.1.1 Climate

Dera Ismail Khan has hot summers and moderate winters. The climate is arid to semi-arid with mean annual precipitation from 180 to 305 mm. Mean annual rainfall during 1980-2009 period was about 273mm (Figure 5). More than 50 percent rains are received during monsoon period (July-September). The temperature varies from 26^{0}C to 44^{0}C in summer and 4^{0}C to 20^{0}C in winter. High temperatures and low rainfall are major factors of low natural vegetation in the area (www.parc.gov.pk/index.php). Rainfall occurs in two different period; in late winters and early spring from February to April, and in Monsoon in the months of June and July. (D. I. Khan, n.d.).

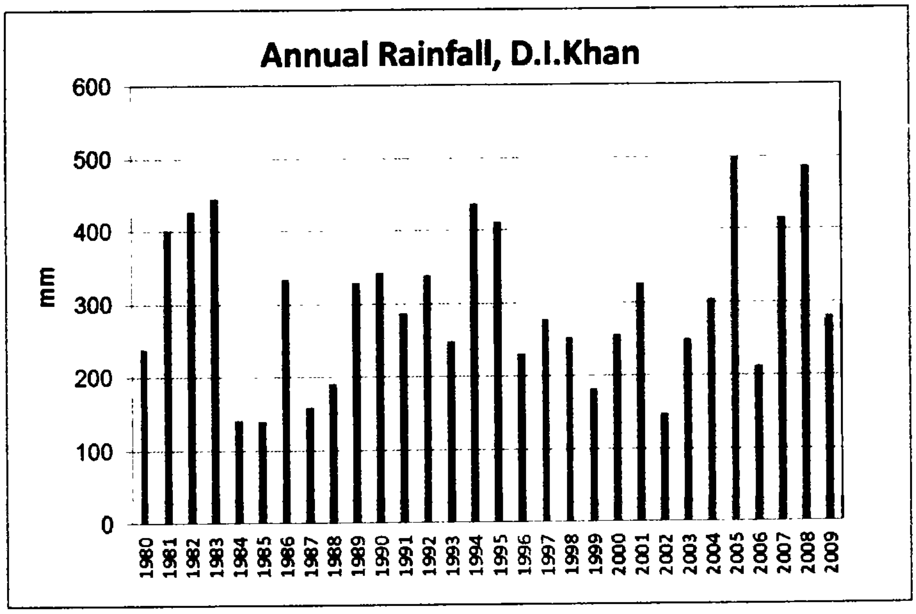

Figure 5: Time series of Annual rainfall at D.I. Khan meteorological station

3.1.2 Agriculture

The principal crops grown are wheat, sorghum, millets, gram and pulses. In major part of the Rod-kohi region Wheat is sown. The land use is mainly subsistence torrent water cropping and livestock grazing. Some irrigated faming also exists in areas where perennial water of springs is available for irrigation. In upper reaches Perennial water or locally known as Kalapani is available all the year round. This water is used for high valued crops like fodder, vegetables and fruits and contributes significantly towards the sustainable farming in the rod kohi area. Mainly fruit orchards like of apple, peach, plum, apricot and grapes, and crops like wheat, maize and alfalfa are grown here (Mustafa *et al.*, 2013).

The general methodology for the research is as follows:

- Data collection and preparation
- Data processing
- Results Interpretation

3.2 Materials:

3.2.1 Data Used:

Landsat Thematic Mapper OLI (Operational Land Imager) images from January to December for the year 2013. The image has 11 spectral bands and was downloaded from http://glovis.usgs.gov/ site. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of 90m resolution was used in the study. The DEM downloaded from www.jpl.nasa.gov/ site was resampled to 30m resolution for delineation of catchments at micro level. The soil map acquired from Soil survey of Pakistan was used in the study.

3.2.2 Software used:

The software used in the study were ESRI's ArcMap 10.1, ERDAS Imagine 2013, Arc Swat and MS-Office.

ArcGIS:

ArcGIS is Geographic information system software developed by ESRI. GIS can be used for map making, storing geographic data and analyzing spatial data.

ERDAS Imagine:

ERDAS imagine is a remote sensing software with enabled raster graphics editor facilities for geospatial applications. It is designed by ERDAS. The software allow the user to prepare, display and enhance digital images for mapping in Geographic Information System (GIS) and Computer Aided Design (CAD) software.

Arc Swat:

Arc Swat is tool which is used for hydrological modelling. The main advantage of SWAT model is its ability to model poorly gauged and ungauged watersheds. It makes it attractive to be used where the infrastructure is inadequate to measure the required inputs for hydrologic modelling like in developing countries. The principle of SWAT model is that the water balance is the driving force behind everything that happens in watershed.

MS-Office:

It was used for report writing, making graphs and tables. Microsoft word was used for writing report and for preparing manuscript for power point presentation. Microsoft excel was used for graphs, tables and required statistical analysis.

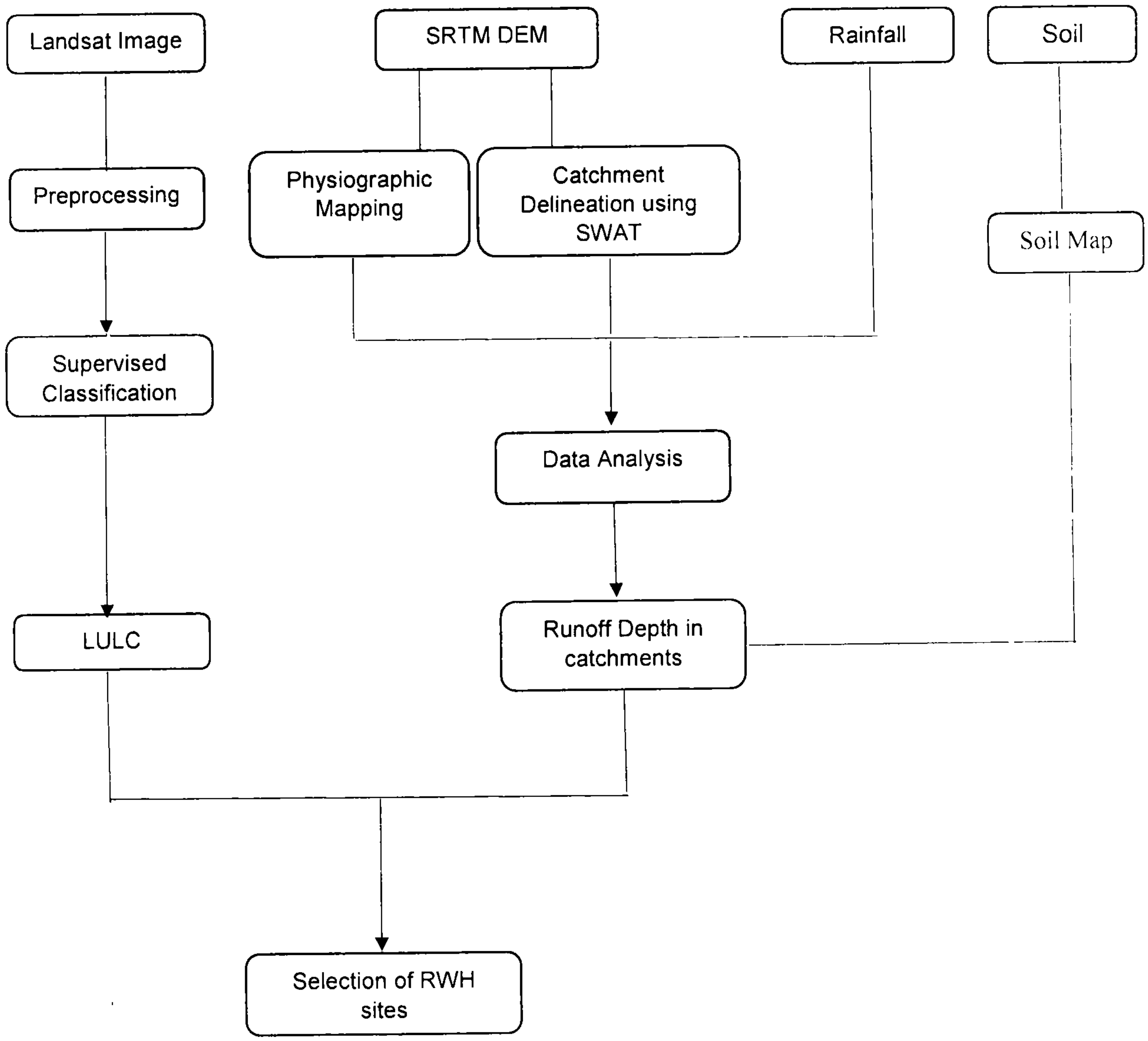

Figure 6: Flow chart showing General methodology

3.3 Methodology

3.3.1 Stacking:

The layer stack function is used for placing layers one on top of the other. This process is used to stack the layers in one image. Stacking the band layers give a composite image by combining separate base layers. Landsat image obtained from USGS was first stacked in ERDAS imagine. The layers from band number 2-7 were stacked.

3.3.2 Sub setting:

The second step after the stacking is sub setting of the Landsat image to get the required study area. Create subset tool was used to clip D.I. Khan from the tile. Image sub-setting was also done in ERDAS imagine.

3.3.3 Image Classification:

The remote sensing data of Landsat-8 was processed and analyzed through visual as well as digital interpretation to analyze land cover/land use of the study area. For better results whole image of D.I. Khan was classified and at the end the rod-kohi area was then separated by sub-setting of image. Supervised Classification was performed in ArcMap through Iso cluster tool. It was categorized into 6 classes: Water, forest, Cropland, Rangelands, Rocks and Bare Soil. Settlement was included into the class of bare soil as the area is sparsely populated. Later quantitative analysis was performed to assess the extent of different land use classes.

3.3.4 DEM:

The resolution of the DEM was 90m. The study area was extracted from it in ArcGIS through extract by mask tool.

3.3.5 Physiography Mapping:

Physiographic maps are the cartographic depiction of the broad-scale physical regions of an area, often based on terrain, sediment and rock types, and geologic structure and history (Salisbury, 1909; Raisz, 1931). Physiography mapping was prepared using DEM of the study area.

3.3.6 Slope:

The incline, or steepness, of a surface is known as slope. Slope can be measured in degrees from horizontal (090), or percent slope. A slope of 45 degrees equals 100 percent slope. As slope angle approaches vertical (90 degrees), the percent slope approaches infinity. Slope map for the study area was developed by using DEM. It was calculated in spatial analyst tool in ArcGIS. The degree of slope is represented by a color map.

3.3.7 Drainage network:

Drainage plays a significant role in RWH. Drainage network like soil, elevation etc. is also an important feature for selection of rainwater harvesting sites. Drainage network of the study area were calculated using Digital Elevation Model in SWAT Model.

3.3.8 Soil Map:

Soil data was obtained from soil survey of Pakistan. The digitizing and geo referencing of the soil map was performed in the ArcGIS software. The resulting soil map was then converted into a vector layer.

3.3.9 Catchment Delineation:

River network was generated and outlet of the sub-basins were marked that served as base to generate catchment boundaries on micro scale in Arc Swat through its Watershed delineation tool. For accurate result DEM of 90m resolution was first resampled into 30m resolution through ArcGIS and then introduced into Arc Swat for processing. Projection of DEM was defined into Transverse Mercator WGS 84. The threshold value was set at 500ha.

3.3.10 Data Analysis:

NESPAK has developed the equation for D. I. Khan by using which rainfall, runoff volume and water potential can be calculated. The analysis was performed in the raster calculator of map Algebra in spatial analyst tool by using DEM.

1. To calculate rainfall at 50% DEM of D.I. Khan was multiplied with the 0.26 and then by adding 103. The equation was: $y = 0.260x + 103.0$

Where y is the rainfall and x is the digital elevation model of study area

2. The Rainfall volume was calculated by multiplying rainfall with 8100 (cell size of DEM) and dividing it with 1000. The resultant rainfall volume is in m^3.
   The equation was [Rainfall volume_50%] = 8.1 * [rainfall_50%]
3. Runoff was also calculated by multiplying the coefficient 0.26 with the rainfall volume at 50%. The equation used was [Runoff] = [rainfall volume] * 0.26.
4. Water potential is the water which is left after runoff for use. It was calculated by subtracting rainfall volume from runoff and then by multiplying with the coefficient 0.047.
   The equation was [water potential] = [runoff] - ([rainfall volume] * 0.047).

Rainfall, runoff and water potential in each sub basin was measured by applying zonal statistics on the sub basin boundary separately with rainfall, runoff and water potential map. Then zonal statistic table of each category was generated and exported to MS excel for analysis.

3.3.11 Final Map:

Final map was developed by combining land use map and sub basin layer. Cross tabulation is comparing attributes in different coverages or map layers according to location. For final output cross tabulation function was applied on sub basins and land use map. Then the most favorable sites were selected for rainwater harvesting. Strategies for harvesting potential of surface water resource for irrigation and domestic use were proposed.

CHAPTER 4

RESULTS & DISCUSSION

RESULTS AND DISCUSSION

a) Physiographic mapping

Physiographic maps and mapping are important because they delineate areas that are relatively uniform with respect to key physical attributes. Base map layers like of infrastructure, physiography, soils, drainage network and climate were prepared in GIS using topographic and thematic maps of D.I. Khan District.

Physiography map of the D.I. Khan area was generated from Digital elevation model data which consists of three elevation zones. Physiographic zones were delineated based on elevation (Hubert, 1995). The zones include: Lowland (<300 m); Hilly area (300-700m) and Middle mountains (700-2000m). High mountains (>2000m) are absent in this area.

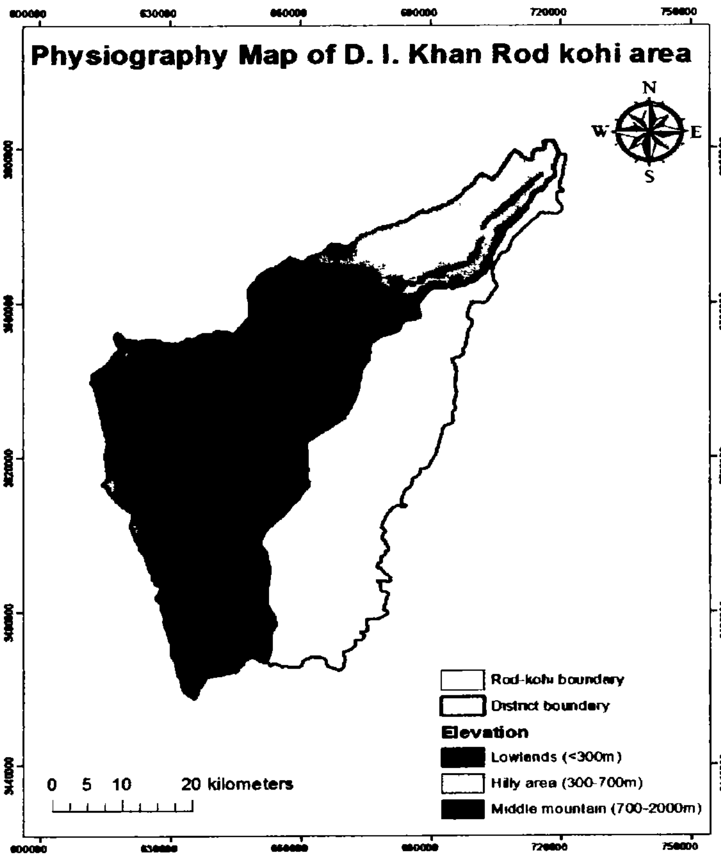

Figure 7: Physiographic Map of D.I. Khan Rod kohi area

Physiography	Area (sq. km)	Percentage
lowlands	754.77	90.1%
hilly area	82.11	9.8%
middle mountain	0.83	0.10%
Total	837.71	100%

Table 1: Number of sites in D.I. Khan by physiographic zones

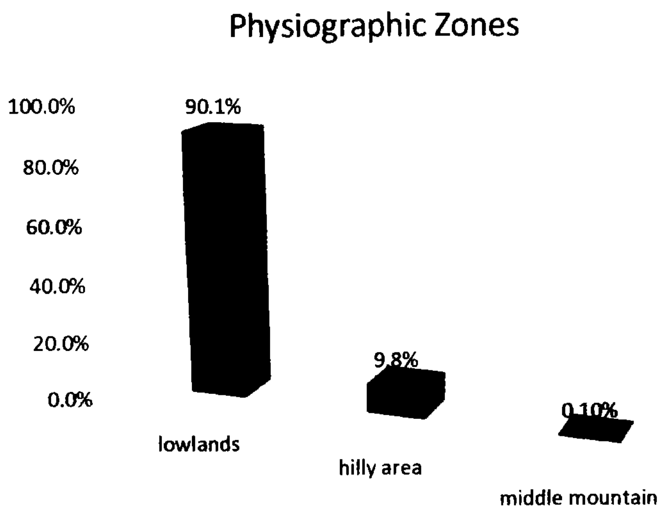

Figure 8: Percentage coverage of physiographic zones in D. I. Khan

The figure 7 shows that 90% area comes under the category of lowlands. 9.8 % area is hilly and mountains are only 0.1%.

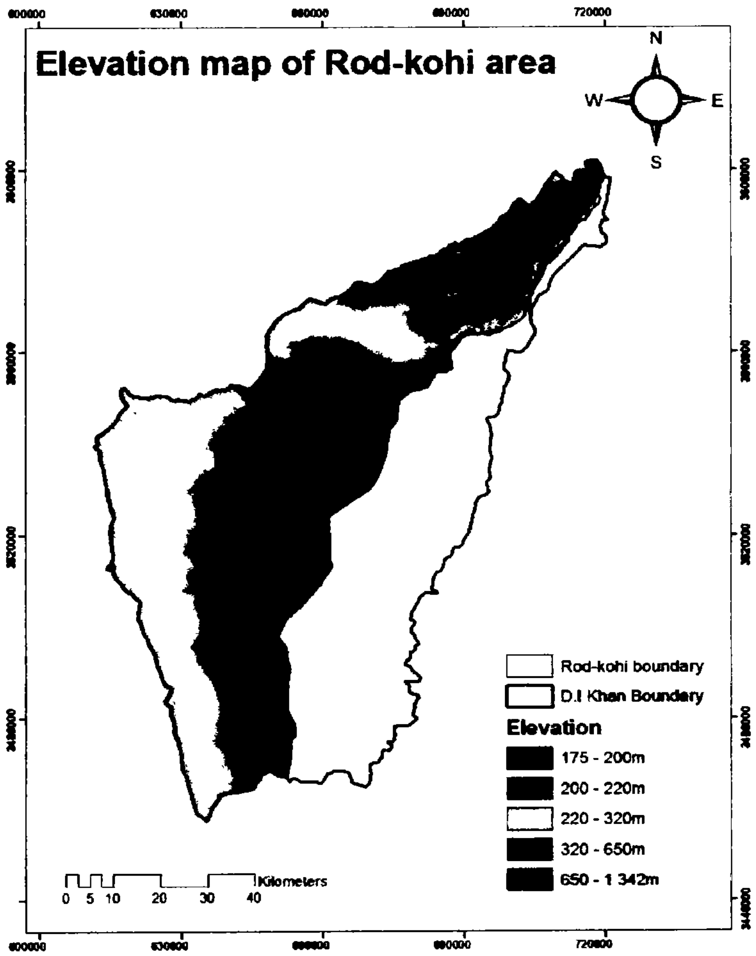

Figure 9: Elevation Map of D.I. Khan Rod kohi area

About 84% of the rod kohi area of D. I. Khan has the elevation less than 300m and 16% is above 300m as shown in the figure 9. Northern part has high elevation values while western and southern part has low elevation values.

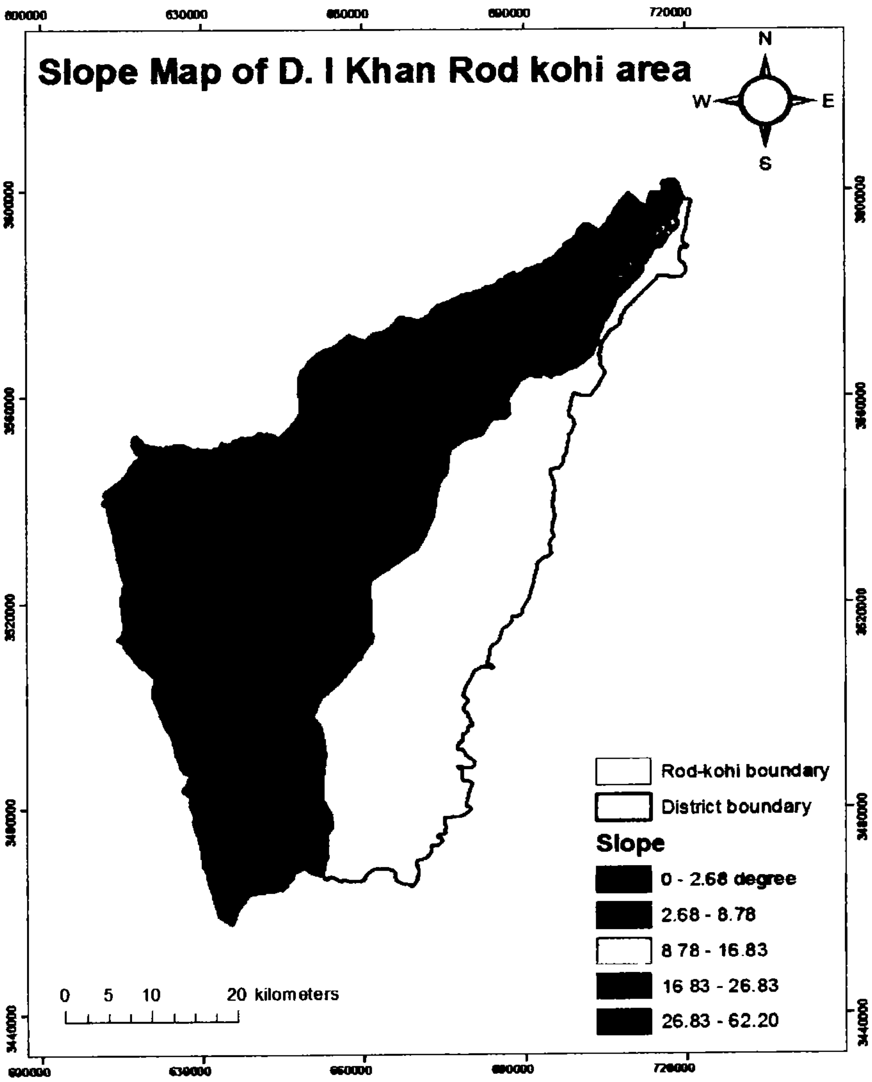

Figure 10: Slope Map of D.I. Khan Rod kohi area

Slope is an important criterion for mapping and executing RWH technology. According to the literature, the suitability of zones for RWH increases when land slope decreases, and vice versa. DEM was used to calculate the slope and the measure of its angle was in Degree. The output showed that major part of the area is flat and lies between the slope ranges of 0-3 degrees. The highest value of slope was found to be 62.20 degrees which is present in insignificant area.

According to FAO slope can be classified into 6 categories:

Slope values	Classes
<7 ^{O}	Flat to gentle slope
7 ^{O} – 15 ^{O}	Moderate Slope
15 ^{O} – 20 ^{O}	Strong slope
20 ^{O} – 25 ^{O}	Very strongly slope
25 ^{O} – 30 ^{O}	Steep
>30 ^{O}	Very Steep

Table 2: Classes of slope

As most of the rod kohi area lies in flat to gentle range of slope, cultivation in these areas is possible. Areas with <7 slope are highly cultivable lands that require no, or very few intensive conservation measures, such as strip cropping, contour cultivation, vegetative barriers, rock barriers and in larger farms, broad base terraces.

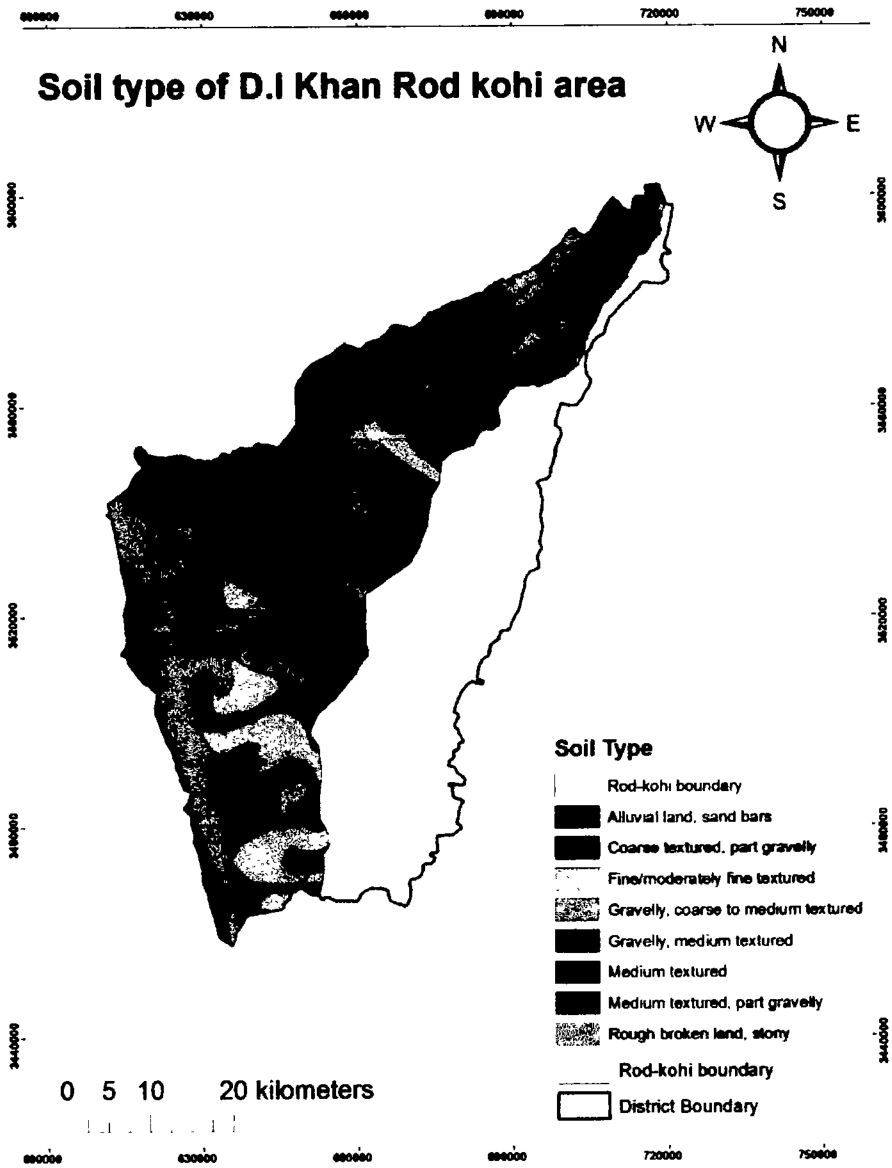

Figure 11: Soil Map of D.I. Khan Rod kohi area

Soil Texture is also an important characteristic which should also be taken into consideration while proposing RWH structures. Not all methods of water harvesting are favorable for all soil types. The study area have different types of soil texture as alluvial, coarse textured, fine textured, gravelly, and rough broken land or stony as shown in figure 11.

b) Land cover assessment and mapping

LULC is the main criterion for the selection of RWH sites. Extent of land cover/land use was estimated using remote sensing data of Landsat 8 of the target areas. The figure 12 shows the LULC of the D. I. Khan rod-kohi region. About 48% of the area is rangeland, 33% is rocks, 10% is bare soil and only 9% is tree cover.

For final selection of sites Land Use pattern of the region was taken into consideration, because rain water could not be harvested at all the sub-basins of the rod-kohi area. The land use/ land cover map is important for identification of RWH sites.

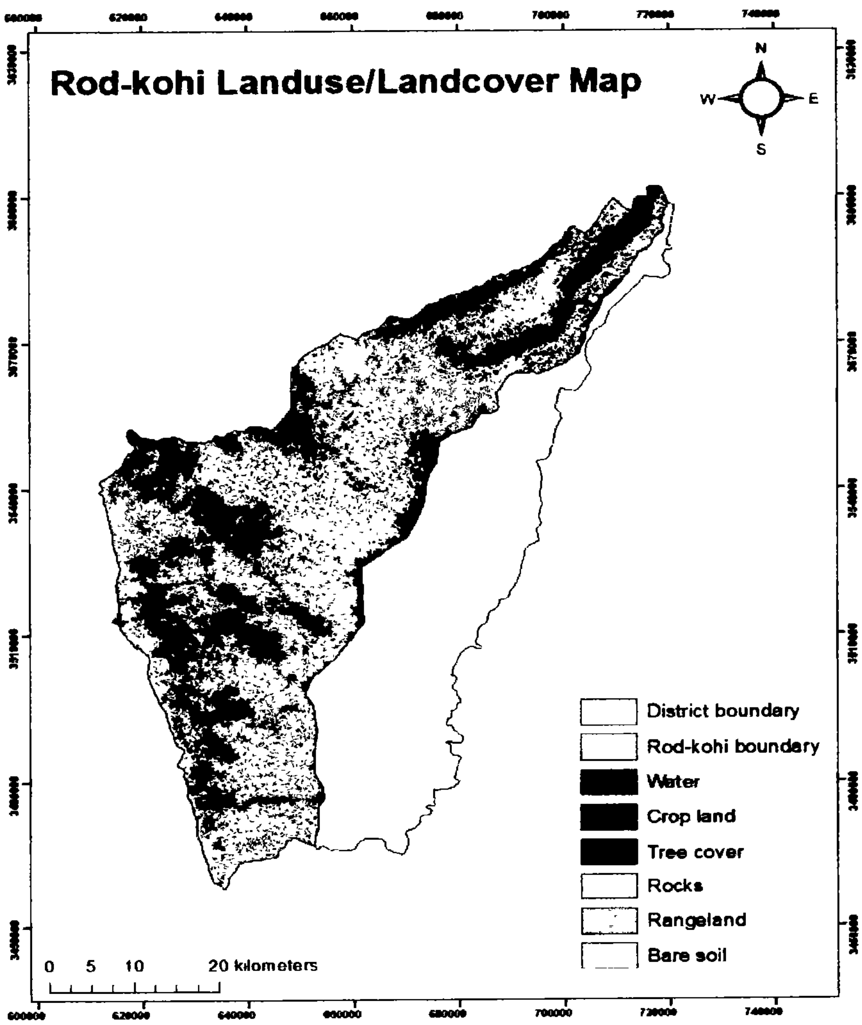

Figure 12: Land use Map of D. I. Khan Rod Kohi Area

Land use	Number of sites	Percentage
Tree cover (3)	48	9%
Rocks (4)	175	33%
Rangeland (5)	258	48%
Bare soil (6)	52	10%
Total	533	100%

Table 3: Number of sites in D.I Khan by various land use

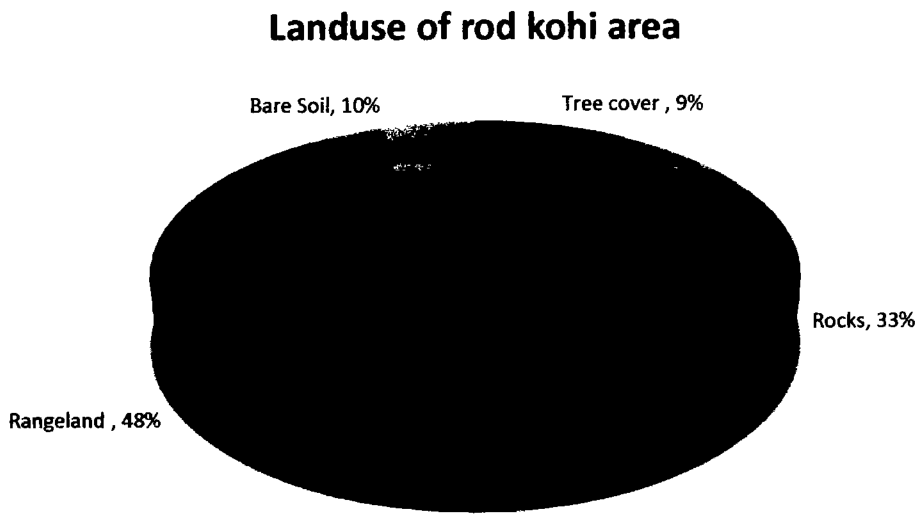

Figure 13: Land use chart of Rod-kohi area

c) Identification of Potential RWH sites

Overall 533 sites were identified in the rod kohi area. About 84% of the total sites lie below 300m elevation and 16% within the elevation range of 300-700m. Total runoff water potential in 533 catchments at 50% rainfall probability was about 155282m^3.

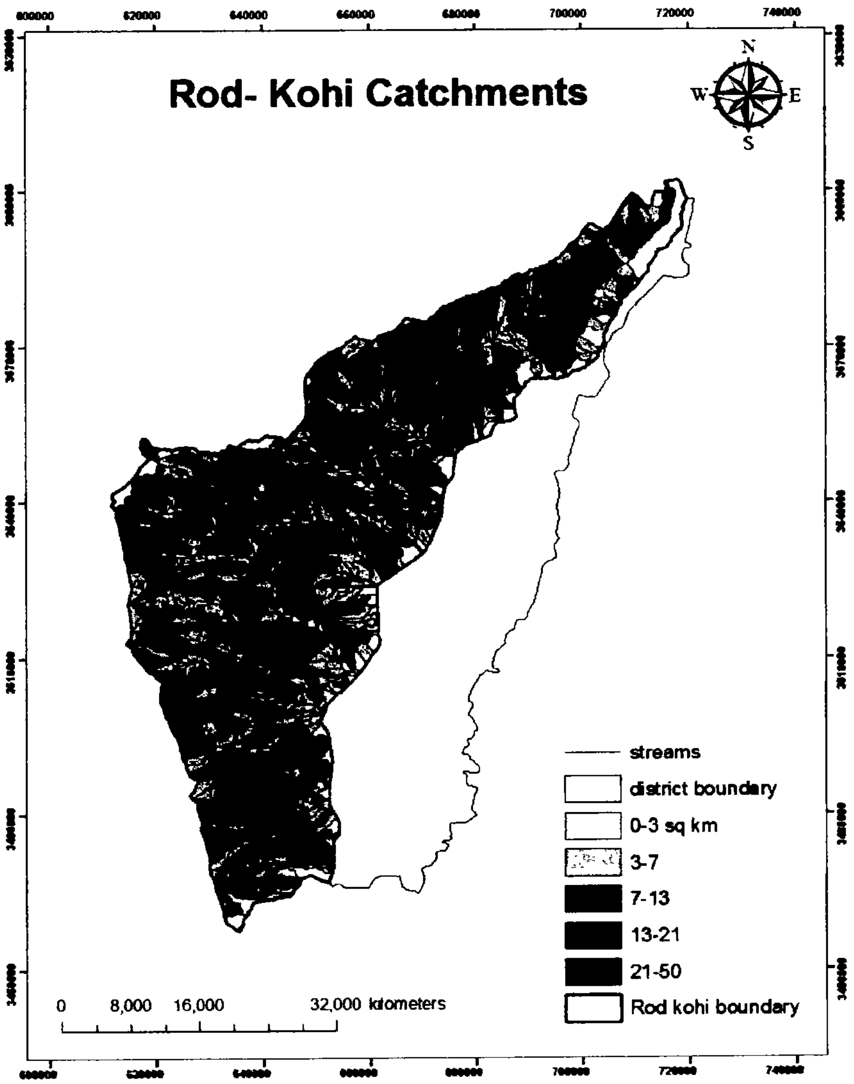

Figure 14: Rod- kohi Catchment Map

Area (sq. km)	Number of sub-catchments	Percentage sites in each area	Water Potential (cubic meter)
0 - 3	200	37.7%	58290m^3
3-7.0	131	24.7%	38184 m^3
7.0-13	119	22.4%	35373 m^3
13-21	56	10.5%	16884 m^3
21-50	25	4.7%	6551 m^3
Total	531	100%	155282 m^3

Table 4: Water potential in sub catchments according to the area

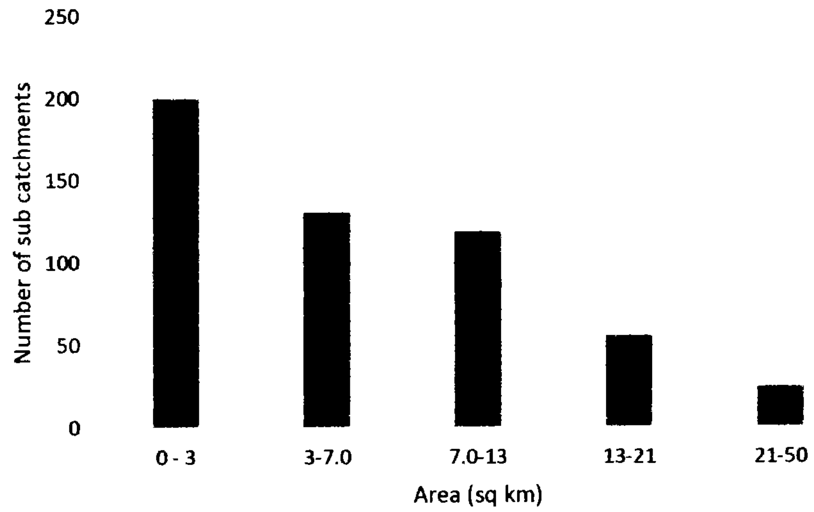

Figure 15: Number of sub-catchments according to area

Rainfall is the primary factor that generates runoff depth along with other factors. Runoff depth is an important factor in identifying RWH sites. It is used to estimate the water supply during a water event.

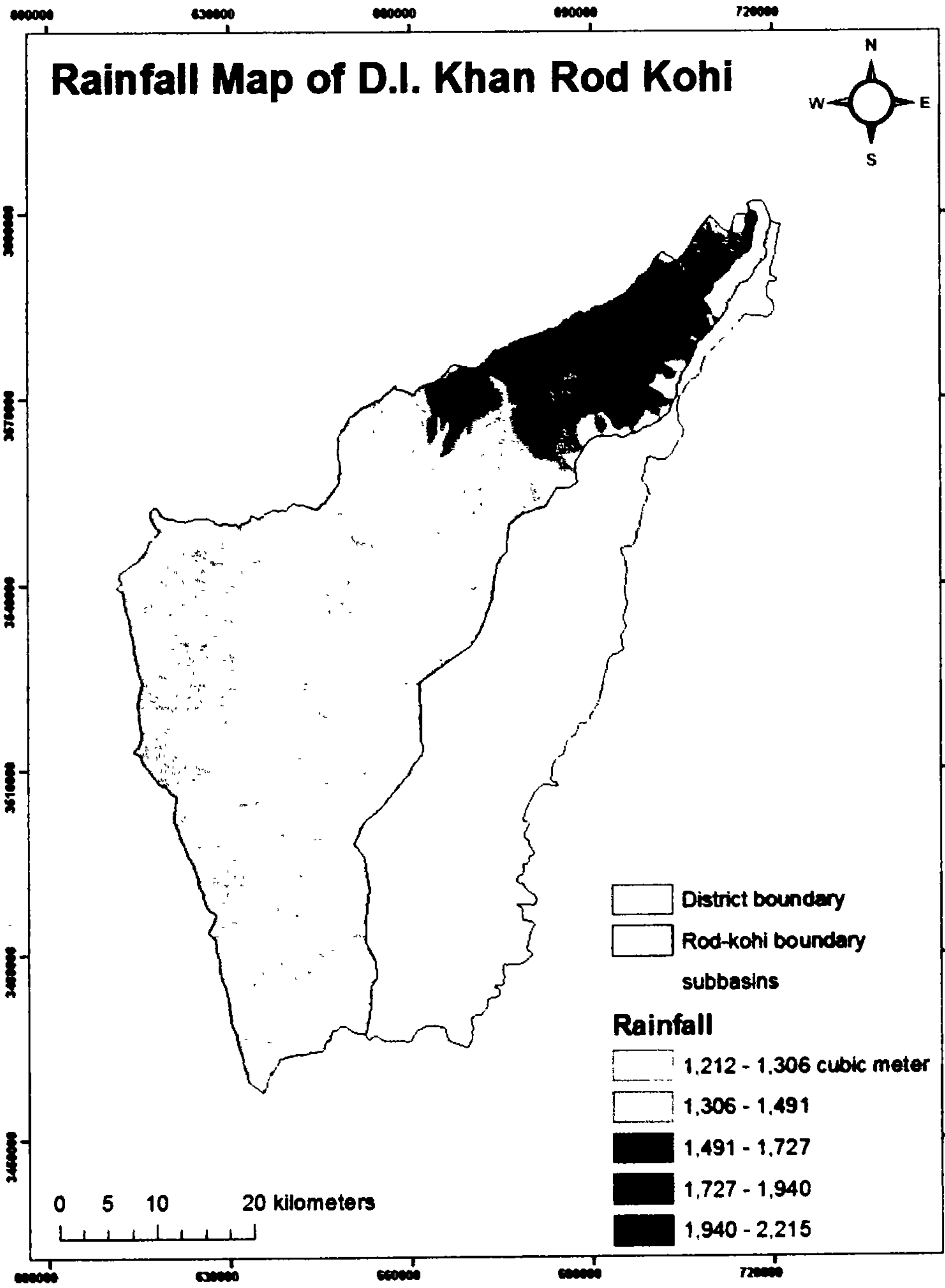

Figure 16: Rainfall Map of D.I. Khan Rod kohi area

Figure 16 shows the rainfall volume of the D.I. Khan Rod kohi areas. The highest rainfall value is 2215 m^3 and lowest is 1212m^3. North eastern part have high rainfall value range of between 1940-2215m^3 while the lowest rainfall values were observed in south eastern part.

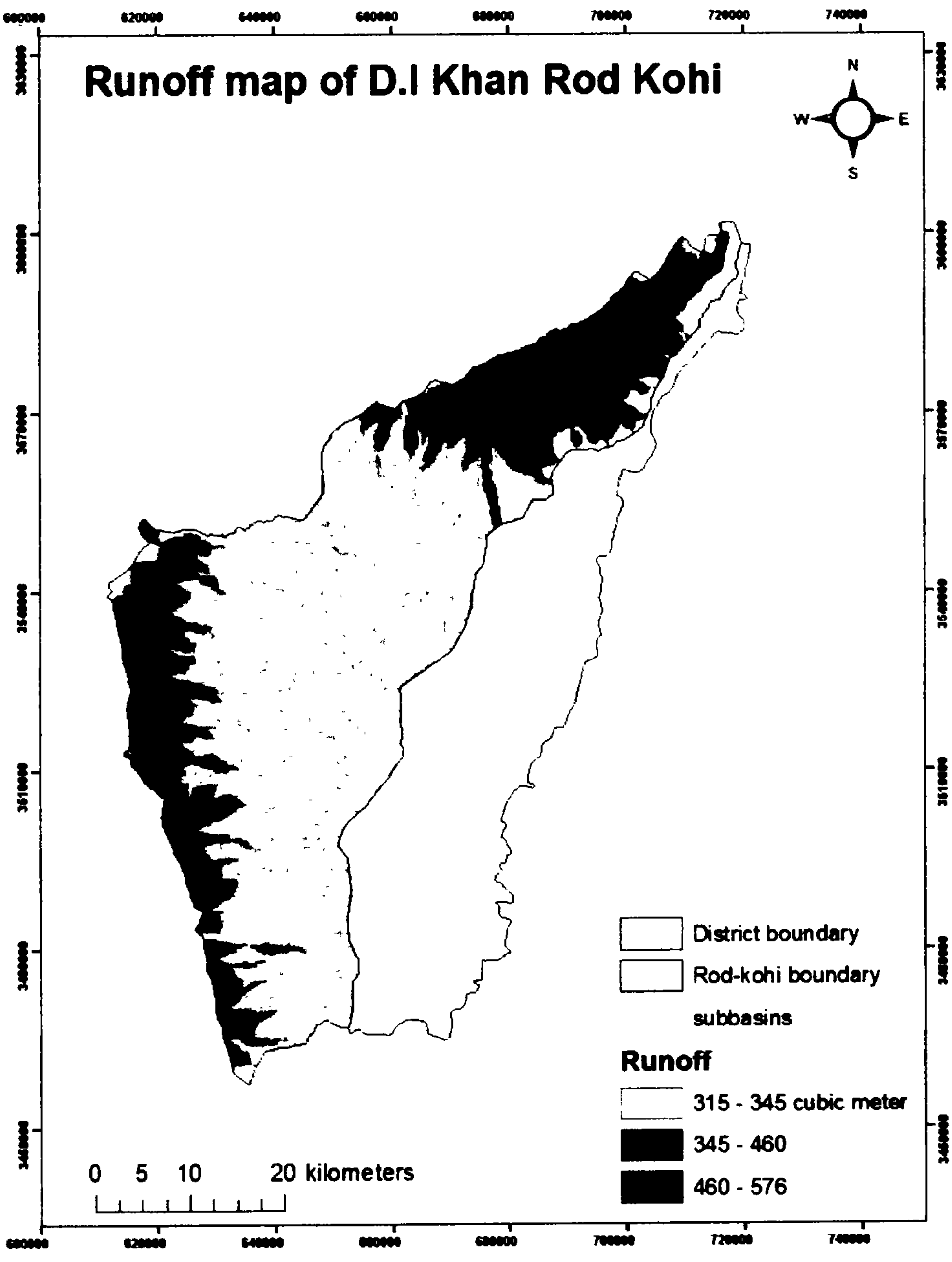

Figure 17: Runoff Map of D.I. Khan Rod kohi area

Similarly like rainfall the maximum runoff values were observed in northern part of the area while the south eastern part have low runoff values. The highest runoff value is 576m^3 in the areas of high rainfall volume and lowest runoff value is 315m^3 in the areas of low rainfall values. The areas with high rainfall have high runoff values and vice versa.

d) Assessment of RWH potential of Major hill-torrents

Using the available data thematic layers were selected for identifying suitable RWH sites. In this study, the criteria that were adopted to determine the suitable RWH sites are: physiography, slope, soil, and LULC.

The potential water harvesting sites are shown in figure 18. These are the sub basins in which more than 80% of the area is rangelands. The total number of outlets on these sub catchments are 28 on which water storing reservoirs can be constructed. The basic reason of selecting sites on rangeland is that most of the rod kohi part, about 48% is rangeland. As rangelands are unused land features and these could be made productive by taking proper measures. These sites can be called as highly suitable sites. Vegetation and livestock grazing is possible. The soil of this land features is also favorable for water harvesting and slope is gentle. However medium suitable sites could be selected on bare soil as the slope of these area is also gentle but the problem of erosion exist in this area. Least suitable sites for RWH can be made on mountains. As the slope of the hilly area is steep so only water storage is possible as this water might not be used for crop production.

Cost effective earthen water reservoirs could be developed in the area for rainwater harvesting and to use this water for livestock, domestic use and irrigation.

Check dams or farm ponds can be built on the selected water harvesting sites after ground surveys. Check dams are small devices made of rocks, gravel bags, sediment retention fiber rolls, sand bags, etc., placed across natural or manmade channel or drainage ditch. These structures can recharge groundwater and supplement surface storage in the study area. A well designed, and maintained check dam will reduce channel erosion. Areas with gentle slope are proposed for check dams and most of the selected RWH sites lies in this range. These structures can used for the efficient planning and management of water resources in the study area, which in turn can ensure a sustainable water supply in the context of climate change.

Storage tank is also an option for surface water storage. These structures are very beneficial for RWH. Storage tanks are mostly cylindrical in shape, flat bottoms, and vertical to ground with fix of floating roof. But the most favorable areas for storage tanks are open lands without scrub with sandstone and where steep slope are found.

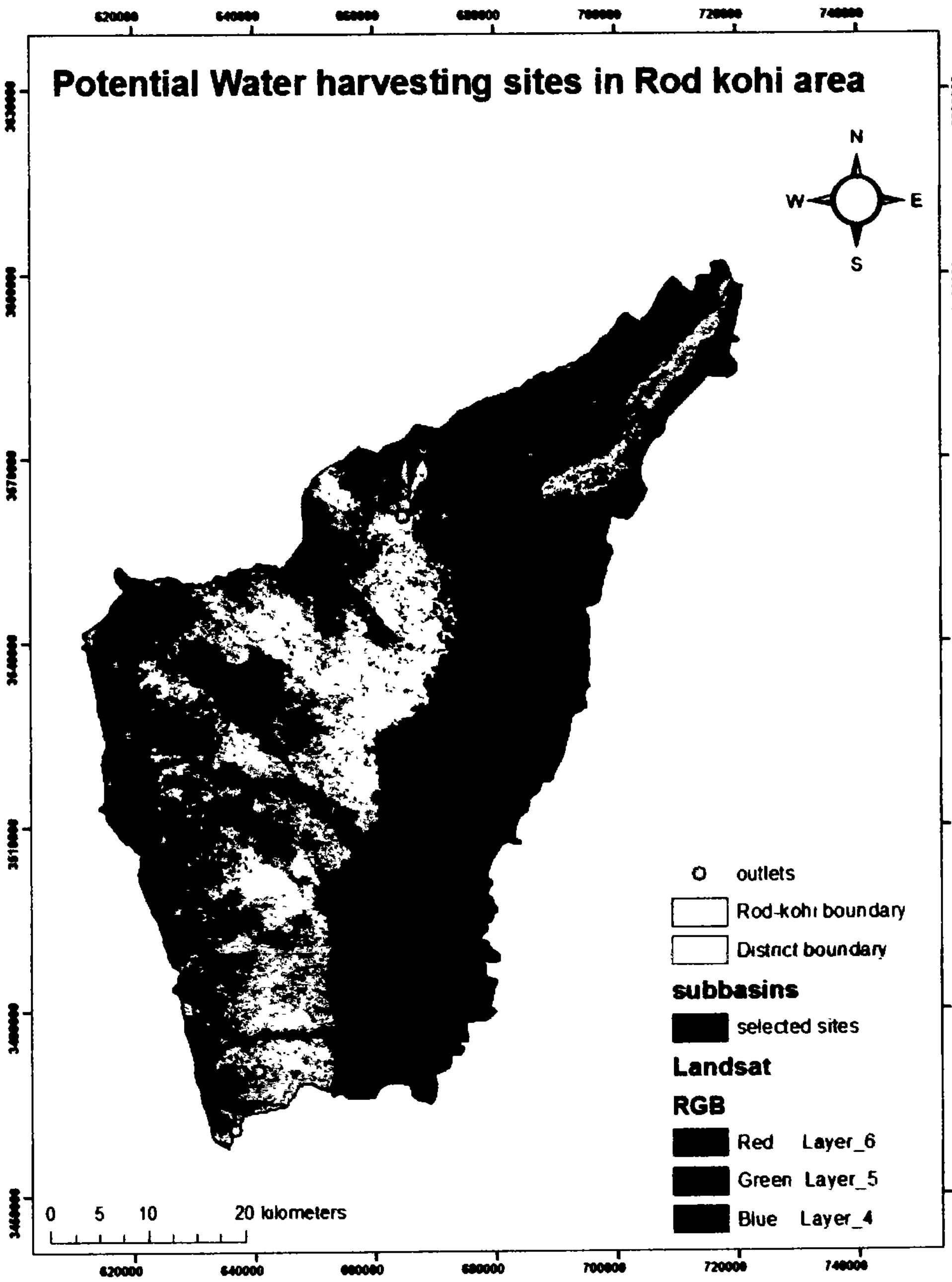

Figure 18: Potential water harvesting sites

ID	Longitude	Latitude	Sub catchment Area (sq. km)	Water potential (m^3)
1.	70.38335800	31.64535	35.50	261
2.	70.43605840	31.17832	11.75	261
3.	70.26145971	31.68336	5.38	262
4.	70.30669313	31.71843	21.51	265
5.	70.38091206	31.33268	7.74	267
6.	70.42472361	31.48964	18.05	268
7.	70.27788863	31.76967	3.80	271
8.	70.32077089	31.52701	13.96	271
9.	70.98589212	31.94353	49.53	273
10.	70.34233480	31.41939	13.17	274
11.	70.23936519	31.78589	10.98	275
12.	71.00047825	31.96983	13.37	276
13.	70.82055498	31.96869	6.14	276
14.	70.79608911	32.00337	18.59	279
15.	70.75195348	32.01038	5.67	280
16.	70.317137	31.714145	9.64	280
17.	70.41628475	31.22651	6.96	281
18.	70.44837677	31.17862	10.96	282
19.	70.88267098	31.87787	37.95	287
20.	70.33533542	31.72368	8.92	290
21.	70.36856601	31.37447	5.14	292
22.	70 47899291	31.09504	9.81	295
23.	70.23936882	31.78616	8.44	307
24.	70.64880092	32.03028	5.67	353
25.	70.74742693	31.97381	24.16	372
26.	70.73016943	31.98712	25.25	417
Total Water Potential				7515m^3

Table 5: Final selected water harvesting sites showing area and water potential

About 50% of the catchment area is less than 10 square kilometer. 30% area lies in the range of 20 square kilometer and the rest of the 20% catchments consist of the area above 20 square kilometers. 22 catchments possess water potential less than $300m^3$. Only 15% catchments possess water potential of above $300m^3$.

Agriculture programs should be introduced in these selected RWH sites. On high elevation area agriculture is not possible however the reservoirs for storage of water could be built. Aqua culture could be promoted by building ponds on rocky surfaces. Fishes can be kept that would generate income. Orchards and fruit tress could be grown through extensive farming system.

CONCLUSION

&

RECOMMENDATIONS

CONCLUSION

Rod kohi areas have a tremendous potential for the development due to the fertility of land and presence of abundant water which remains unutilized and go into the Indus waste. But unfortunately this system is less understood and being ignored. Up to now, there is hardly any effort that has been made to introduce improved technique of water management. The Remote sensing and GIS techniques are valuable in assessing the potential sites for rainwater harvesting. About 48% of the total rod kohi area is rangeland. 26 sites were selected for RWH in the rod kohi part of D. I. Khan. Total runoff water potential in these sites was 7515m^3. The selected sites need to be prioritized for developing flood management structures/ reservoirs/ponds through coupling ground realities like political, cultural and physiographic conditions, water rights, socioeconomics, and water needs of the local communities. The surface runoff potential can be harvested effectively for irrigation purpose through construction of ponds, reservoirs and small/mini dams, and establishing a network of diversion and dispersion structures. 10% of the rod kohi area is bare/open soil which can be developed for agriculture purpose through proper management of flood water. There is a vast potential of solar energy for uplifting water from existing reservoirs and groundwater pumping for irrigation and domestic use in the rod-kohi areas. In conditions of uncertainty in flood water availability, relatively limited public support programs and social complexity of the system, there is a need of mass awareness of the importance of the system and new interventions necessary for the agriculture development in the area.

RECOMMENDATIONS

- Perennial flow should be conserved by adopting upgraded techniques of conveyance, diversion and application.
- Improved methods of irrigation should be extended.
- Efficient system of irrigation (trickle and sprinkler) must be familiarized in the area for promoting of high valued horticulture crops.
- Associations for water users can be formed to ensure justice and equity for the use of rain and perennial water.
- Agriculture extension services are lacking in area, they must be extended.
- Range management programs should be introduced in the area for rangeland conservation and to avoid overgrazing of the watersheds.
- A separate and independent institution like Rod kohi Development Authority must be established for the conservation and management of hill torrent water.
- At small level Non-Governmental Organizations/Community Based Organizations should be encouraged for the uplift of the local community.

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