SPATE IRRIGATION POTENTIAL AND DISTRIBUTION OF WATERSHEDS OF ROD-KOHI ARES OF PAKISTAN USING GEOINFORMATICS

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Abstract

There is insufficient knowledge and data available for developing better water management strategies for rod-kohi areas at various levels in the country. Such gap in knowledge and baseline data is very crucial for sustainable development of Rod-kohi agriculture. The future planning and development of rod-kohi areas depend on reliable assessment of resources and availability of information. The assessment of water resource is important in context of increase in its demand and changing climate conditions in this part of the country. There is a need to investigate resource potential of Rod-kohi region in order to enhance and sustain agricultural productivity and economic growth in these areas. The present work is focused on assessing spate irrigation potential of Rod-kohi region of the country 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 distribution of landuse of rod-kohi region has been analyzed qualitatively and quantitatively through integrated use of remote sensing (RS) and Geographic Information system (GIS) techniques. The Landsat ETM plus image data (1999-2001) was analyzed to develop landuse classes in the present study. There were 10 major landuse classes identified in the rod-kohi region, which were further divided into 18 sub-classes. Overall, rangelands and exposed rocks (serve as degraded rangelands in wet season) were found dominant over 70 percent of the Rod-kohi region. Rangelands were found in all physiographic regions particularly in the Middle Mountains (700-2000m) covering about 7.5 M.ha. The land provides fair opportunities for livestock rearing. Forest mostly of scrub type covers about 0.9 M.ha in various parts of the region. Overall, crop cover was found over 1.5 M.ha including some rainfed crop over 0.3 M.ha. The bare soil or culturable waste was over 6.5 M.ha. This area can be developed for cultivation through adopting proper flood management techniques.

Overall about 14.6 BCM (11.8 MAF) of surface runoff is generated in the Rod-kohi region of the country, out of which 4.3 BCM (3.5 MAF) is utilized for irrigation and domestic purpose. There exists surface water potential of about 10.2 BCM (8.3 MAF) in the region, which if properly utilized for irrigation purposes would be able to bring an estimated 1.0 million ha of land under cultivation. More than 1.0 BCM of water potential exists each in Suleiman Rod-kohi belt, Zhob and Kurram River basins. There is a need to increase awareness among communities regarding efficient use of surface/subsurface water especially in drought condition in order to sustain agriculture productivity.

The spatial and attribute database generated in the present study can help planners, field managers and policy makers for developing better management strategies for sustainable development of the rod-kohi

areas. The study would provide base for detail planning and management of rod-kohi resources besides awareness for utilizing new techniques for monitoring such resources in future.

1. INTRODUCTION

Pakistan has a single largest area under spate irrigation after Indus basin irrigated agricultural system. If utilized and managed properly it can feed not only its increasing population but can export resources like food, fodder, fuel and livestock to deficit regions of the country. The future planning and development of rod-kohi areas depends on reliable assessment of resources and availability of information. At present, the country is facing severe problem of shortage in irrigation water supplies, which could impact agriculture production and economic growth in future. Since 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 monitoring of landuse is essential not only for better resource utilization but also for efficient planning and development of agriculture in the country.

The rod-kohi region of the country has not been investigated thoroughly for landuse before though some efforts had been undertaken on localized bases. In one of the feasibility study for flood management of hill torrents, NESPAK (1998) had identified major hill-torrent regions in the country and described its physical characteristics like soils, landuse, agriculture and hydrology along with statistical analyses. Landsat TM image data was used to identify and map sparse natural vegetation and tree covers over hill slopes, valley plains and alluvial fans, besides seasonal crop cover in the target rod-kohi area (Roohi et al. 2003). There is a need to explore optimum landuse of the rod-kohi irrigation region in order to develop agriculture sector to sustain livelihood in future. The base information of landuse can be helpful in areas like: pasture and rangeland management; landuse and agriculture planning; preparation of flood management plan; selection of check dams/flood control sites; watershed management; land resource management and conservation etc.

This necessitates that all potential unutilized resources of water and land be used to increase agriculture production. Pakistan has already utilized major part of its conventional water resources. According to PARC (1980), three agro-ecological regions where rod-kohi irrigation is practiced are Western dry mountains, Suleiman piedmont range and Balochistan plateau. Reliable estimates can be achieved through integrated approach of using RS, GIS and field survey techniques.

The RS technique provides an efficient way of studying the landuse and natural resources of the earth. This technique has successfully been used for monitoring of landcover and landuse in many countries. 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. Landuse change can be monitored using temporal satellite remote sensing (SRS) data. Integration of different thematic layers is possible in GIS environment, which helps in rapid analysis of spatial data. Today, with most data available in digital format i.e. remote sensing images, digital elevation model (DEM), field data of Global positioning System (GPS), data integration is a common method used for interpretation and analysis (Conitz, 2000; Larsen, 1999 and Nogales, 2000). The present work is aimed at assessment of spate irrigation potential of rod-kohi region of the country 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 generated in digital form and methodology adopted can help planners, field managers and policy makers for developing better strategies for sustainable planning of rod-kohi landuse in future.

1.1 Geographical Setup

The rod-kohi region of the country mainly lies between longitude range of 60° 50′ to 72° East and latitudes 24° 42′ to 34° 3′ North in various parts of the Khyber Pakhtunkhwa, Punjab, Sindh and Balochistan provinces (Figure 1). The region stretching over 49 percent area of the country is drained by rivers and hill-torrents originating from mountain ranges some of which lie out side international borders i.e. Afghanistan and Iran (Ashraf and Ahmad, 2008). The drainage system is typical development due to extreme aridity, geology and structure of the area. Some of the important mountain ranges are Suleiman Range, Kirthar Range, Pub Range and Makran coastal Range etc. The consolidated rocks exposed in the area are mostly of sedimentary origin consisting of various types of limestone, shale, sandstone, clay and conglomerate.

It comprises areas of western dry mountains, Suleiman Piedmonts and major part of Balochistan plateau in the west of the country. The region is characterized by heterogeneous physiography including low hills, gravelly fans and terraces, level piedmont plains of Suleiman Mountain Range sloping gently towards the Indus River and steeply dissected mountain slopes with intervening narrow and broad valleys. The Suleiman Mountain Range runs for a distance of about 480 kms in a north-south direction, Takhte Suleiman being the highest peak (3,700m) (Kazmi and Jan 1997). Major part of the valleys comprises gravelly fans and terraces made in course mountain outwashes. The region is mainly dry with implications on environmental fragility, minimum recharge of aquifers and slow vegetative recovery. The main sources of the income are livestock rearing and agriculture production based on perennial flows and hill-torrent flood irrigation.

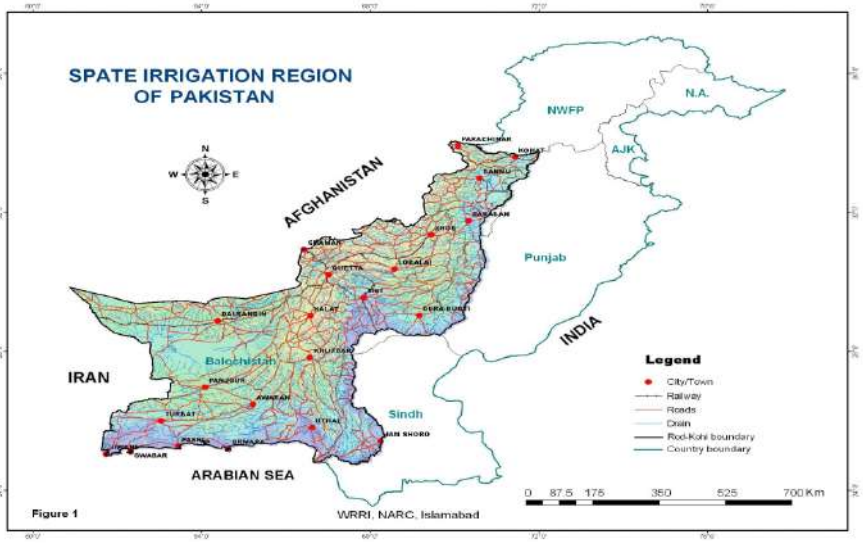

Figure 1: Geographic setup of Spate irrigation region of Pakistan

1.2 Climate

Most of the area is arid to hyper-arid with very low precipitation. The climate of the region has wide variations. The hilly areas in the north have bracing cool dry climate, whereas coastal belt of Makran is hot and humid. Kachhi plain and Kharan desert are the hottest places in the country. The rainfall is patchy and erratic in nature. However, at times, a single rainfall storm exceeds the average annual in amount and intensity; and generates flash runoff. Maximum annual rainfall (>800mm) receives in Kurram district of KPK while minimum (<100mm) in the western parts of the Balochistan province (Figure 2). The 50% probability map showed maximum rainfall range 500-700mm in the northern parts while minimum range of less than 100mm in the western and eastern parts of the Rod-kohi region. Most of the area in lower half was found under less than 200mm range. The central part of rod-kohi area is dominated by rainfall within 100-400mm range. Mean seasonal rainfall of Rabi indicates major area under less than 200mm range while of Kharif under less than 100mm rainfall range. In general, the rainfall follows the trend of topographic variations. Most of the rainfall occurs in summer from the summer monsoon originated from Bay of Bengal, but when these monsoons reach Balochistan and Sindh they become dry. The monsoon, which originates from Arabian Sea in summer are not effective in Sindh and Balochistan because most of Balochistan is out of the route of these winds and in Sindh they pass over without raining due to high temperature. The winter rains are the results of movement of cyclonic winds which originate from the Mediterranean Sea.

Mean annual temperature is more than 25°C in the central and coastal plains whereas less than 17°C in the northwestern parts comprising high mountains. Mean seasonal temperature of Kharif indicated major area under greater than 26°C range. June is the hottest month in the plains and July in the mountainous areas. On the hottest days the temperature may exceed 50°C. There is a marked variation in temperature between the coastal areas and the interior. In coastal areas the maximum temperature in summer is considerably lower than those in the interior while in winter these areas are warm because the sea and land breezes blow round the year and keep the temperature approximately constant during all the months of the year.

1.3 Agriculture and Landuse

The principal crops grown are wheat, sorghum, millets, gram and pulses. Wheat is sown in major part of the Rod-kohi region. The landuse is mainly subsistence torrent water cropping and live stock grazing. Some irrigated faming also exists in areas where perennial water of springs is available for irrigation. Mainly fruit orchards like of apple, peach, plum, apricot and grapes, and crops like wheat, maize and alphalfa are grown here. In some parts in Balochistan, water is harvested for irrigation, which is known as ‘Khushaba’. On higher altitudes, there are forests of juniper and wild olive, which merge with barren lands with scanty bushes and grasses in low-lying areas. Vegetation is xerophytic and is characterized by thorny scrubs and poor grasses in the lower regions. In the south sorghum and millets are the important crops. Along the coast, castor bean is grown wherever water is available from springs or ‘karezes’.

The main sources of income are livestock rearing and agriculture production based on perennial flows and hill-torrent flood irrigation. The natural vegetation provides an ample source for livestock grazing.

1.4 Hydrology

There are large number of rivers and streams draining different parts of the Rod-kohi region. Some of the major rivers and their tributaries flowing in the region are Kurram River, Gomal, Zhob R., Pishin Lora R., Nari, R., Mula R., Dasht, Hingol, Rakhshan, Gaj, Porali River. Most of the hill-torrents are ephemeral in nature and form a secondary network of natural drainage system. The ephemeral hill-torrents become active for a short period during limited heavy showers. Some of the streams get absorbed within the land or drain into depressions. Very few rivers remain active for along time. Each river system drains a particular basin. The duration and quantum of available flows entirely depend upon local precipitation. Basin irrigation is practiced by constructing earthen diversion bunds across the channels for diverting flood flows. However, during high floods, only a small part of the runoff is utilized for agriculture while the major part enters into river Indus unused.

Major sources of groundwater are karazes, tubewells, open wells and springs. Tubewells are increasingly used for tapping groundwater to meet domestic as well as agricultural needs of the local communities. In areas where electricity is available, the number of deep tubewells is growing tremendously. The farmers are converting low value crops to high value orchards and cash crops. Although tubewells pumpage has advantage to provide assured supplies of water at critical times of crop growth with full farmer control, some valleys like Nari, Pishin and Zhob are now facing a serious problem of groundwater shortage due to overexploitation. Also, during a year of low rainfall, groundwater table goes enormously low and the wells become dry. This affects the quantity as well as quality of the agricultural produce. Due to complex geology and variable topographic, climate and surface hydrological conditions, the quality and quantity of groundwater varies greatly in different parts of the region. In the valley floor and at some piedmont formation the groundwater exists within shallow depths of 5 to 10 meters. Areas of Human-e-Mashkel and Pishin Lora are highly saline.

MATERIALS AND METHODS

2.1 Data Used

The Remote Sensing data of 34 number scenes of Landsat ETM plus image data mainly of 1999-2001 period were used as primary data in the present study. The images are (Appendix-A). The full scene of LANDSAT covers about 185x175 km of ground surface on earth. The image has seven plus spectral bands which possess distinct spectral characteristics useful for vegetation type and health discrimination, soil moisture, water-bodies delineation, rock type discrimination, etc. The secondary data include toposheets of 1:50,000 and 1:250,000 scales, landforms, physiography, infrastructure, hydrology and soils etc. collected from various source departments like Survey of Pakistan (SoP), Water and Power development Authority (WAPDA) and Soil Survey of Pakistan (SSP). Also statistical data of agriculture and landuse, climate available in literature and data collected from field surveys were used to supplement the landuse analysis work.

2.2 GIS Database Development

The secondary data of topography, infrastructure, administrative and watershed boundaries, etc. were developed and transformed in vector form for input in GIS. The topographic features like drainage, locations and boundaries were extracted from toposheets through scanning and on-screen digitization in

GIS software. The elevation zones and relief information were derived from DEM data of SRTM available on 90m resolution. GPS survey was carried out to collect ground control points (GCPs) and validation of landuse classes in limited areas. The stepwise methodology used for landuse mapping is shown in Figure 2.

2.3 Image processing and Analysis

Initially, the RS image data were geometrically rectified and subsets of the Area of Interest (AOI) were developed. Image analysis was performed following a hybrid analytical approach (visual and digital). There were 18 classes of landcover/landuse defined for thorough investigation of landuse in the rod-kohi region. Major landuse classes were defined for landuse mapping after consulting landuse/landcover classification of USGS (Thomas and Ralph 2002) and Colombo plan Report (1958). The visual interpretation was performed for qualitative analysis while digital interpretation for quantitative analysis of the image data. Delineation of man-made features like built-up land, plantation and orchards etc. was carried out through on-screen digitization in GIS. For image classification, initially unsupervised classification was performed using ERDAS imagine software. The classes were identified and delineated by the computer on the basis of similar spectral characteristics of the group of pixels. It helped in defining more specific classes for supervised classification method. In supervised classification, suitable band combination was used and training-sample sets were selected from known areas on the image to form set of signatures (statistical criteria for proposed classes) for classification. The signatures were evaluated using contingency matrix. The maximum likelihood rule was followed for the classification that commonly provides reliable classification results. The schematic diagram of methodology followed is shown in Figure 2.

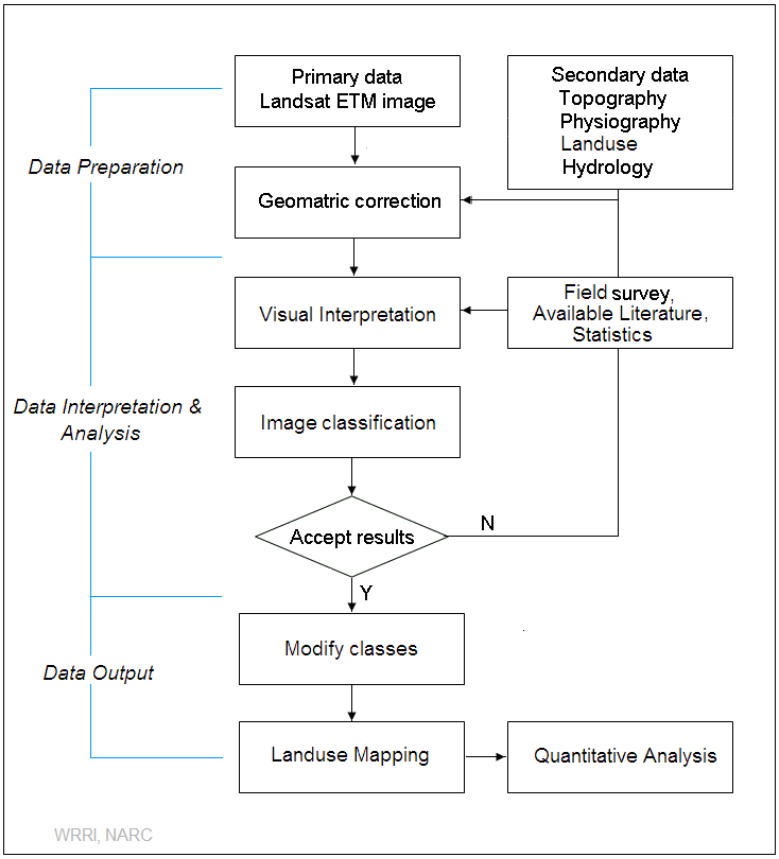

Figure 2: Methodology followed for landuse assessment

2.1 Geo-spatial Modeling

The thematic data of topography, administrative boundaries, hydrology, physiography and hydrogeology were used as input data in GIS for overlay analysis. The data were acquired from different source departments like Survey of Pakistan (SoP) and Water and Power Development Authority (WAPDA) etc. The hydrolgeological maps prepared by WAPDA at scales of 1:500,000 and 1:250,000 were used to extract information related to surface and groundwater resource of the Rod-kohi region. The historical climatic data of meteorological stations lying within and vicinity of Rod-kohi region was acquired from Pakistan Meteorological Department (PMD), Islamabad.

The GIS was used to develop geo-databases and spatial data layers of topography, hydrology, soils and landuse etc. in ArcGIS software. The thematic data layers were geo-referenced using Geographic coordinate system i.e. Lat./Long. WGS84. The Remote Sensing image data integrated with digital elevation model (DEM) and topographic maps have been used to identify and delineate 20 rod-kohi basins in the Rod-kohi region (Figure 5). The river basin boundary and drainage network were generated from 90m SRTM DEM using Hydrological Modeling Software HEC-Geo HMS in Arcview software.

It is important to estimate surface water potential at various probabilities level for development of better planning and water management strategies. Rainfall probabilities at 25%, 50% and 75% were determined from historical rainfall data of last 50 years available of meteorological stations lying within and vicinity of Rod-kohi region. The location of these stations is shown in Figure 6. About 15 such stations lie within the Rod-kohi region area. The average annual rainfall was determined from isohytal map interpolated from 25%, 50% and 75% probabilities rainfall data in Arcview 3.2 software (ESRI, 1998). The Inverse Distance Weight (IDW) method (polynomial power 4) was used for the interpolation. Later rainfall equivalent was determined for assessment of total volume of water available at regional and basin level.

2.3 Water Balance Assessment

Quantitative evaluation of available flows is essential for irrigation planning and it requires adequate hydrologic information. At present, there are very few hill torrents where periodic or continuous flow measurements are being carried out. Therefore, the runoff occurred in rod-kohi region was estimated from annual volume of water (rainfall equivalent) using rainfall-runoff coefficients determined by NESPAK (1998) for different hill-torrent regions of the country. During high intensity rainfall, a part of flows is evaporated, major part of it infiltrates into the bed while the surplus flows move in the form of runoff. The runoff water is utilized for irrigation and to some extent for domestic purpose through number of irrigation and flood management schemes developed in different parts of the rod-kohi areas. The estimates of this water use were taken for water balance analysis of the Rod-kohi region and water conservation potential was determined at basin and regional levels.

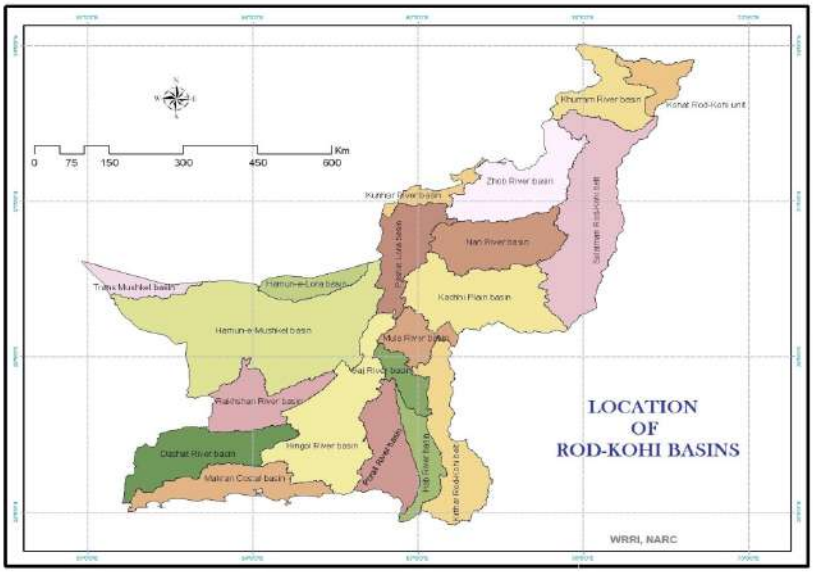

Figure 3: Location of Rod-kohi basins/units in the country

3. RESULTS AND DISCUSSION

Landuse Analysis

Overall, crop cover was found over 1.5 M.ha under sailaba and rod-kohi cultivation including some rainfed crop over 0.3 M.ha. The rod-kohi area of the country is mentioned by various sources like Food and Agriculture Organization as 1.4 M.ha (FAO 1999); 2.0 M.ha by Khan (1987) and PARC (2001), and 1.23 M.ha by Waterinfo.net.pk.com. It may depend on the technique and quality of the data used. The crop cover varies with season, availability of soil moisture & flood water management practices adopted for Rod-kohi irrigation. The bare soil, which is culturable waste land, was found over piedmont plains, along river banks and alluvium in inter-mountain valleys. This land which is unused due to lack of water management practices, investment and uncertain availability of flood water for irrigation, can be brought under rod-kohi cultivation through appropriate flood management techniques i.e. diversion of flood flows to irrigate these areas. It may also includes some fallow land. In wet season it serves as minor grazing land.

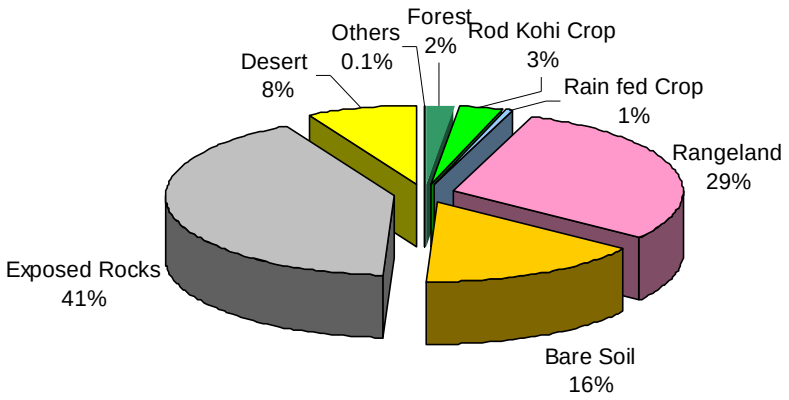

Figure 4: Percentage Share of Landuse in Rod-kohi Region

In Khyber Pakhtunkhwa province, about 10 percent area was found under rod-kohi crop while 7 percent under rainfed crop cover. The bare soil was found over 18 percent land lying mostly over piedmont plains in the east of Suleiman Mountain Range. Major portion of this area lies in Bannu, D.I. Khan, Lakki Marwat, Tank and Karak districts (Figure 5a). In Punjab, about 6 percent area was found under rod-kohi crop while 2 percent under rainfed crop cover. The bare soil or culturable waste covers about 0.76 M.ha (44%) over the Suleiman piedmont plains in D.G.Khan and Rajanpur districts (Figure 5b). The rod-kohi crop was found over 4 percent area in Sindh. The bare soil or culturable waste covers about 0.79 M.ha (38%) over the piedmont plains lying on eastern and southern fringes of Sindh rod-kohi region (Figure 5c). In Balochistan, about 2 percent area was found under crop cover. Orchards were also found over 0.05 M.ha within cultivated area (Appendix-B). These provide a good source of income for the local communities. The bare soil covers about 4.27 M.ha (13%) mainly in the intermountain valleys, piedmont plains and some coastal areas that can be developed for rod-kohi cultivation through appropriate flood management techniques.

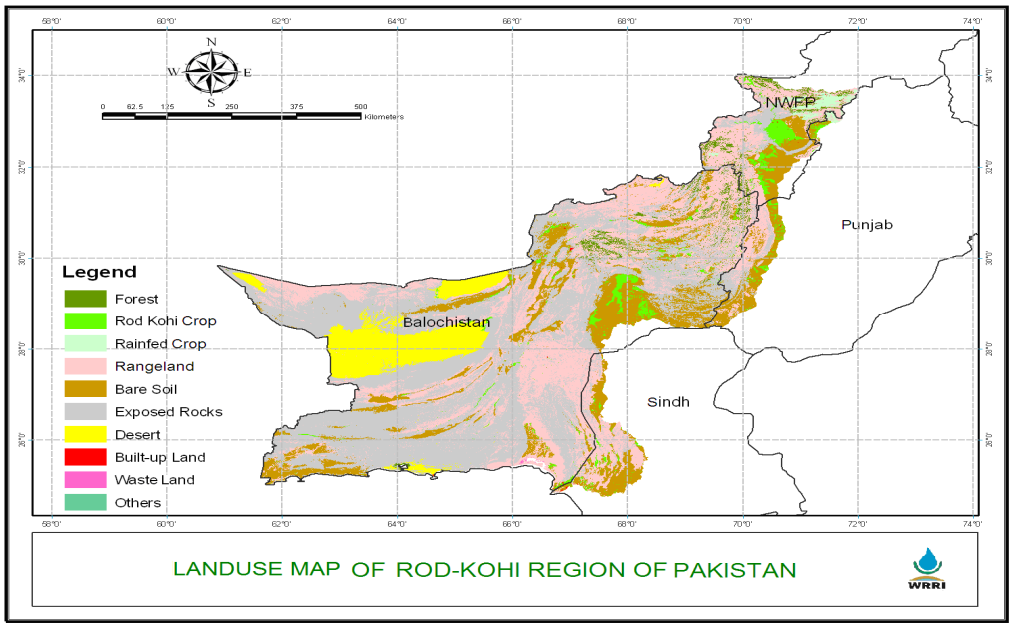

Figure 5: Major landuse classes of Rod-kohi region of the country

S.No	Landuse	Khyber Pakhtunkhwa	Punjab	Sindh	Balochistan	Total (000' ha)
1	Forest	359.0	1.0	0.9	503.5	864.5
2	Rod-kohi crop	384.8	104.2	92.0	598.5	1179.5
3	Rain fed crop	266.4	36.9	-	0.4	303.7
4	Rangeland	1588.0	538.1	1002.1	9135.5	12263.7
5	Bare soil	695.9	762.7	789.4	4272.4	6520.4
6	Exposed Rocks	537.4	308.2	195.7	16268.2	17309.5
7	Desert	-	-	-	3160.4	3160.4
8	Built-up Land	3.9	0.5	3.8	6.7	14.9
9	Waste lands	-	0.2	-	6.9	7.2
10	Water bodies	2.1	0.1	1.6	1.7	5.5
	Total	3837.6	1751.9	2085.6	33954.1	41629.3

Table 1: Summary of Landuse Classes identified in Rod-kohi Region

Major area of this class was found in Balochistan over 4.2 M.ha followed by Sindh about 0.79 M.ha. In Punjab and Khyber Pakhtunkhwa, it covers about 0.76 M.ha and 0.7 M.ha, respectively.

3.2 Surface Water Potential

The Rod-kohi region of Pakistan is characterized by three broad hydrological components on the basis of drainage distribution: a. Indus Basin drainage, b. Coastal Basin drainage and c. Closed Basin drainage. The Rod-kohi region that has drainage linked with Indus River system stretches over 184,240 sq km in the north-western part (Table 1). Major rod-kohi areas of the four provinces lie in this component. About 107,258 sq km of Rod-kohi region has coastal drainage system i.e. drain directly into the Arabian Sea. It comprises the central and coastal Makran ranges, the Pab hills and the sub mountainous area of southwestern Rod-kohi region. The Hub, Porali, Hingol and Dasht are the principal rivers flowing in this component. In the northwestern part of Balochistan between Siahan Range and Raskoh belt, an area of about 124,792 sq km constitutes closed drainage system. It is an area of low land possessing two great playas or shallow lakes known as Hamun-e-Mashkel and Hamun-e-Lora. The Surface run-off of the closed basin component adds into the lakes. This area possesses minimum population density. The proportion of three hydrological components in the Rod-kohi region is shown in Figure 3.

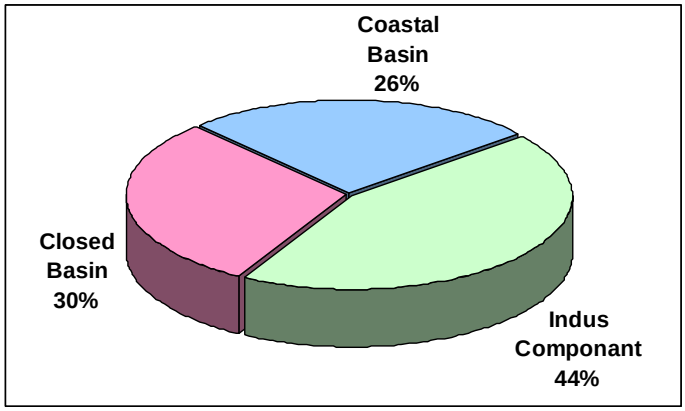

Figure 6: Proportion of Hydrological components in Rod-kohi region

Component	Area (sq km)	% Area	Popul den (person/km^2)
Indus Basin	184240	44	140
Coastal Basin	107258	26	109
Closed Basin	124792	30	33
Total	416290	100	-

Table 1: Hydrological Components of Rod-kohi Region

Total volume of water assessed from 50% probability rainfall in the Rod-kohi region was about 72 BCM out of which 14.6 BCM (11.8 MAF) was found as surface runoff (Table 2). The total water use is about 4.3 BCM (3.5 MAF) which is utilized mainly through irrigation and flood management schemes developed in rod-kohi areas. There exists water potential of about 10.2 BCM (8.3 MAF) in the Rod-kohi region, which can be utilized to bring approximately over 1.0 million ha land under irrigation (assuming average irrigation depth of 1m). Among hydrological components, about 7.4 BCM of water potential exists in Indus Basin, 1.5 BCM in coastal basin and 1.3 BCM in closed basin component (Annexure-C).

Total volume of rainfall water estimated from average annual rainfall is about 47.8 BCM in Balochistan and 15.7 BCM in KPK province. In Punjab and Sindh the rainfall equivalent is about 5.5 BCM and 27 BCM respectively (Table 2). Maximum runoff of about 8.5 BCM is generated in the Balochistan province followed by 4.2 BCM in KPK, 1.4 BCM in Punjab Rod-kohi region. In Sindh, total runoff estimated is about 0.47 BCM. Water use was found maximum in KPK i.e. about 4.2 BCM followed by 1.67 BCM in Balochistan province. The minimum water use was found in Sindh i.e. about 0.1 BCM. The water balance had indicated about 6.8 BCM water conservation potential in Balochistan, 2.1 BCM in KPK, 0.95 BCM in Punjab and 0.37 BCM in Sindh Rod-kohi regions. The respective water potentials can be utilized to bring about 0.68 M ha land in Balochistan, 0.2 M ha land in KPK, 0.09 M ha land in Punjab and about 0.04 M ha land in Sindh under irrigation.

Province	Volume (BCM)	Runoff (BCM)	W-use (BCM)	Balance (BCM)
KPK	15.729	4.201	2.103	2.099
Punjab	5.484	1.410	0.462	0.948
Sindh	2.734	0.473	0.102	0.371
Balochistan	47.767	8.491	1.670	6.821
Total	71.714	14.575	4.337	10.238

Table 2: Water Potential in Rod-kohi Region by Provinces

3.3 Water Potential by Rod-kohi Basins

The water balance of rod-kohi basins indicated maximum runoff of about 3.2 BCM generated in Suleiman Rod-kohi belt followed by 2.3 BCM in Kurram River basin (Table 7). Mean annual rainfall in these basins is more than 250mm. There are six Rod-kohi units that generate more than 1.0 BCM of surface runoff each annually. Minimum runoff is generated in Hamun-e-Lora and Trans Mushkel basins i.e. less than 0.1 BCM, which have closed drainage system. In Kirthar Rod-kohi belt, Kohat unit, Hamun-e-Mushkel and Porali, surface runoff ranges between 0.5 BCM and 1.0 BCM. Maximum utilization of water is in Kurram basin i.e. about 1.17 BCM followed by Kohat unit about 0.81 BCM and Suleiman Rod-kohi belt about 0.80 BCM. In most of the closed drainage basins like RRB, TMB, HLB and PLB, it was found less than 0.01 BCM each. The population density in some of these units is below 12 persons/ sq km.

The water balance analysis of Rod-kohi units had shown surface water potential of over 1.0 BCM each in Suleiman Rod-kohi belt, Zhob and Kurram River basins. Such potential was found within range of 0.5 – 1.0 BCM in Hingol, Hamun-e-Mushkel, Kachhi plain and Nari River basins. This water potential can be utilized for development of culturable waste land for agriculture use through adopting appropriate flood management techniques i.e. diverting flood water for irrigation or developing storage/check dams and ponds etc in these areas. In Trans-Mushkel, Hamun-e-Lora and Kohat Rod-kohi unit, the water potential was found in less than 0.1 BCM range. The population densities in these units are 15, 4, 4 and 434 persons/km^2, respectively. The annual per capita provision of surface water potential is shown in Figure 9. More than 2000 m^3 per capita of water potential was found in Mula, Gaj and Hamun-e-Lora basins. It is in the range of 1000-2000 m^3 in the Zhob, Nari, Hamun-e-Mushkel, Trans-Mushkel, Hingol and Porali River basins. In Suleiman Rod-kohi belt, per capita potential lies within 500-1000 m^3 range while in the Kirthar it is in less than 500 m^3 range.

3.4 Water Availability at Various Rainfall Probabilities

Water balance analysis at 25%, 50% and 75% probabilities of rainfall indicated surface water potential of over 16 BCM, 10.2 BCM and 2.3 BCM in the Rod-kohi region (Table 5). These potentials can brought about 1.6 M.ha, 1.0 M.ha and 0.59 M.ha land under irrigation. At 50% rainfall probability, major land potential (>= 0.1 M.ha) was found in Suleiman Rod-kohi belt, Kurram, Nari and Kachhi plain (Table 6 and Figure 10). It is maximum i.e. about 0.24 M.ha in Suleiman Rod-kohi belt followed by about 0.12 M.ha each in Zhob and Kurram River basins. It was least in the Trans-Mushkel and Hamun-e-Lora basins (i.e. <0.01 M.ha). The detail of land potential at three rainfall probabilities of water availability is shown in Table 6.

The conservation of flood flows of hill torrents offers great prospects for development of orchards and other crops which require water round the year. It is unfortunate that in spite of scarcity of water, major part of flood flows is lost due to mismanagement. The major problem is the unavailability of any kind of storage and modernized engineering structures, though lot of efforts and money were spent in order to control the torrents flow floods but storage is never considered important which might be considered the main drawback of the previous studies. If proper storage facility and modernized structures are provided in these areas then not only the flood is controlled but also the drought conditions can be mitigated and the crops which have very less yield due to the unavailability of water can be enhanced.

S.No.	Name	Area (sq km)	Popul. Density (person/km^2)	Elev. Range (masl)	Annual Rainfall (mm)	Volume (BCM)	Annual Runoff (BCM)	Water Use (BCM)	Water Balance (BCM)
1	Makran Coastal basin	18,171	15	0-1172	71	1.291	0.258	0.153	0.105
2	Dasht River basin	23,318	17	0-1470	64	1.492	0.298	0.195	0.103
3	Hab River basin	10,135	488	0-2169	149	1.507	0.292	0.079	0.213
4	Porali River basin	18,260	15	0-2280	150	2.739	0.548	0.155	0.393
5	Rakhshan River basin	16,929	9	555-1848	67	1.128	0.113	0.006	0.107
6	Gaj River basin	6,803	11	0-2280	141	0.960	0.216	0.033	0.183
7	Kirthar Rod-Kohi belt	23,092	403	11-2137	127	2.933	0.501	0.106	0.396
8	Hingol River basin	37,375	11	0-2883	135	5.041	1.008	0.311	0.698
9	Mula River basin	8,701	11	41-2819	148	1.286	0.279	0.040	0.239
10	Trans Mushkel basin	6,389	4	475-1905	64	0.409	0.041	0.002	0.039
11	Hamun-e-Lora basin	7,611	4	845-1936	95	0.720	0.072	0.003	0.069
12	Hamun-e-Mushkel basin	72,057	4	555-2748	81	5.824	0.582	0.025	0.557
13	Kachhi Plain basin	32,453	76	48-2819	164	5.333	1.013	0.129	0.884
14	Pashin Lora basin	16,856	81	1236-3458	220	3.708	0.371	0.006	0.365
15	Nari River basin	22,186	25	118-3458	244	5.407	1.011	0.088	0.923
16	Kundar River basin	4,950	98	1232-2829	250	1.238	0.175	0.007	0.168
17	Zhob River basin	25,619	24	344-2840	257	6.585	1.387	0.212	1.175
18	Suleiman Rod-Kohi belt	42,011	103	84-3168	294	12.363	3.189	0.802	2.387
19	Kohat Rod-Kohi unit	7,401	434	202-2613	471	3.485	0.904	0.818	0.085
20	Kurram River basin	15,974	173	207-4660	517	8.264	2.316	1.167	1.149
	Total	416,290	Avg: 100	0-4660	Avg: 185	71.714	14.575	4.337	10.238

Table 3: Physical Characteristics of Rod-kohi Basins/units of Pakistan Water Balance Analysis of Rod-kohi Basins/Units of the Country

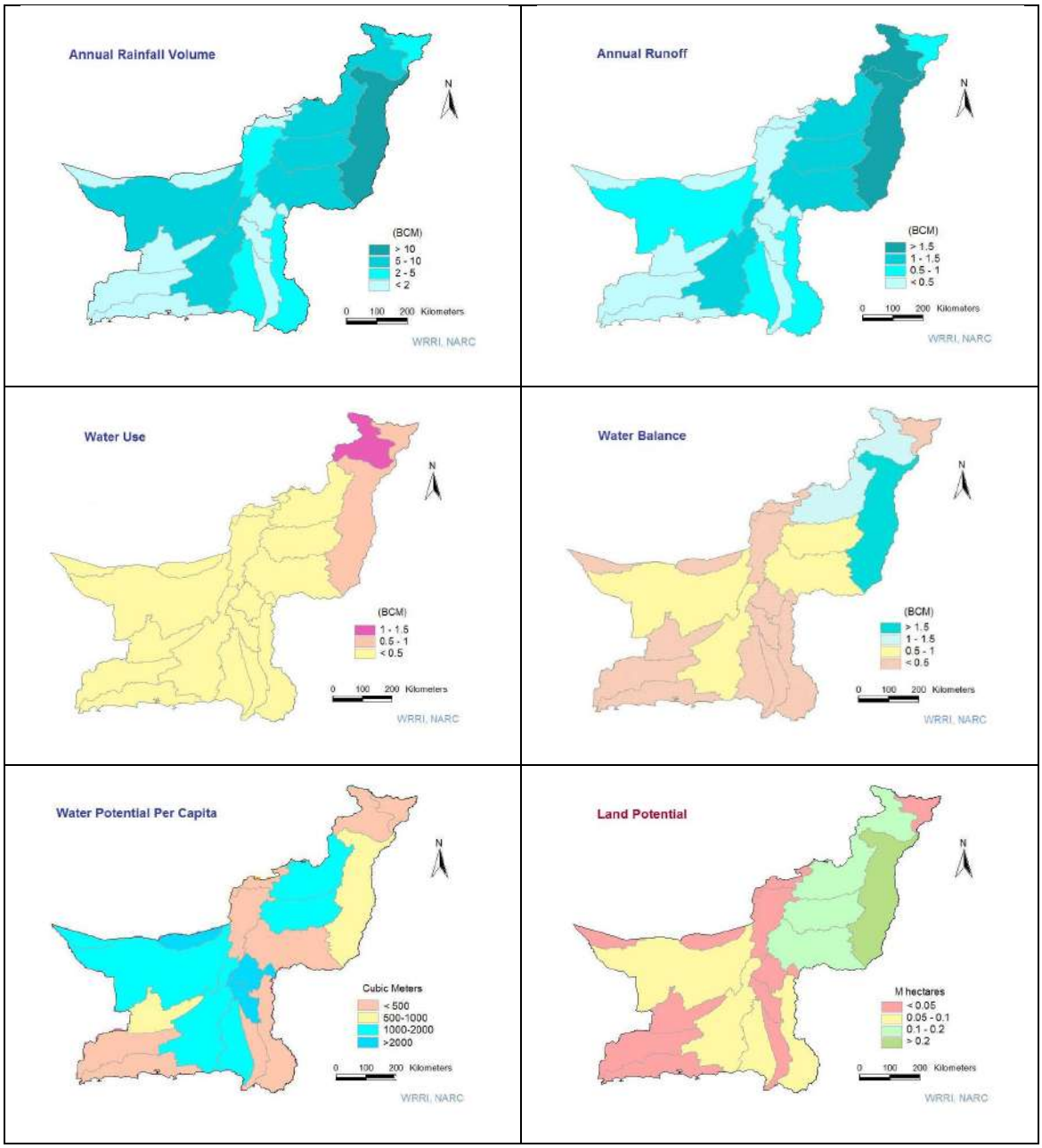

Figure 7: Water balance analysis indicating surface water potential and use in the region at 50% rainfall probability

4. CONCLUSION

There exists surface water potential of about 10.2 BCM (8.3 MAF) in the region, which if properly utilized for irrigation purposes would be able to bring over 1.0 million ha of land under cultivation. Valuable potential of surface water exists in different Rod-kohi basins i.e. more than 1.0 BCM in Suleiman Rod-kohi belt, Zhob and Kurram River basins, within 0.5-1.0 BCM range in Hamun-e-Mushkel, Kachhi plain and Nari River basins. In rod-kohi basins like Trans Mushkel, Hamun-e-Lora and Kohat Rod-kohi unit, the water potential was found in less than 0.1 BCM range. In order to cope with future changes in environment and socio-economic needs, the water resource behavior should be investigated in detail in different water stressed basins of the Rod-kohi region. The surface water potential of the rod-kohi areas should be utilized through construction of small dams and farm ponds for enhancing agriculture productivity and economic growth in these areas. A regular monitoring of agriculture landuse is needed using advance remote sensing techniques which can also be utilized for flood water management for irrigation use. The surplus water can be conserved through construction of reservoirs and series of ponds. A regular monitoring of Rod-kohi landuse is essential for effective landuse planning and resource conservation in future.

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