Composite Analysis of Landuse and Groundwater Resources of Rod-Kohi Region of Pakistan using Geoinformatics

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ABSTRACT

Rod-kohi system of irrigation is often generally referred to as flood irrigation or spate irrigation system in which floods of the hill torrents are diverted into plain area for irrigation purpose. In rod-kohi region where uncertainty exists in flood water availability for irrigation use, groundwater is a valuable resource used mainly as supplement source of irrigation. The region, being rich in natural resources, is remained far behind in terms of data availability and data quality, the situation that has affected incredibly the needs of future planning and development. In the present study, major landuse/landcover classes of the region were identified and delineated using Landsat ETM+ (Enhanced Thematic Mapper Plus) image data and related with groundwater potential for interactive analysis in GIS (Geographic Information System). The potential groundwater zones were delineated and assessed on the basis of aquifer characteristics in the region. Rangeland and exposed rocks were identified over 70% of the rod-kohi region i.e. total area about 42 Mha (Million hectares). Share of cropped area and bare soil or culturable waste was about 3.5 and 15.4%, respectively. High and medium potential of groundwater were estimated in about 2.3 Mha out of which 60% exist under bare soil, 16% under cropped area and the rest underneath other landuse classes. High efficiency irrigation techniques like drip and rain-gun system need to be adopted in areas having substantial groundwater potential in order to sustain agriculture production. The study would provide base for detail investigation of the rod-kohi resources in context of increase in future needs for agriculture and water resource planning and development in the region.

Key Words: **Spate Irrigation, Geoinformatics, Landuse, Groundwater, Rod-Kohi.**

1. INTRODUCTION

Pakistan has a single major area under rod-kohi irrigation system after Indus basin irrigated agricultural system. The rod-kohi region in the country comprises parts of southern Khyber Pakhtunkhwa, southwestern Punjab, western Sindh and almost entire Balochistan province. The future planning and development of this region depends on reliable assessment of resources and availability of information. The increasing population and shrinking resources are the driving forces for improving the planning process

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[1]. At present, the country is facing severe problem of shortage of 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. Landcover plays a key role in controlling the hydrologic response of watersheds in a number of important ways [2-5]. Changes in landcover can lead to significant changes in soil moisture content and infiltration [6], surface and subsurface flow regimes [7] and recharge to groundwater [8]. The rod-kohi region of the country has not been investigated thoroughly for natural resource before though some efforts had been undertaken on localized bases [9-12]. In one of the feasibility study for flood management of hill torrents, NESPAK (National Engineering Services Pakistan) [13] had identified major hill-torrent regions in the country and analyzed its physical characteristics like soils, landuse, agriculture and hydrology.

The rod-kohi areas which are flooded less frequently or inadequately are generally irrigated with private tubewells and open wells [14]. The last drought (1998-2004) had forced the farmers to introduce supplemental irrigation using groundwater resources through springs, wells, tubewells and Karazes [15]. The perennial irrigation system in the region is largely based on groundwater which oozes out in the form of springs. The other irrigation sources in the region are tubewells/open wells, channels, Karazes, infiltration galleries, springs and river diversions. Karazes and infiltration galleries exist mainly in Balochistan and are used for irrigation since 16^{th} century. The main issues now relate to environmental sustainability and long-term availability of the groundwater resource in the rod-kohi region. This requires development of a baseline database and methodology for better monitoring and management of the existing resources; evaluate all recharge/discharge sources and their interaction with groundwater potential; delineate and assess areas of varying potential of groundwater for effective planning and development of groundwater resource in the region.

A knowledge-based system would be helpful for better resource planning and decision making. Integration of different thematic layers is possible in GIS which helps in rapid analysis of spatial data. GIS technology provides suitable alternatives for efficient management of large and complex databases [16]. The strength of this technology is its ability to integrate data from various disciplines using a common geographical boundary of reference [17]. RS (Remote Sensing) data provides synoptic view of a large area, which by other mean may be difficult to approach. It has advantages of spatial, spectral and temporal availability, covering remote and inaccessible areas within short time. It is rather an inexpensive mean for carrying out regional studies.

The main objective of this paper is to evaluate groundwater resource potential under various landuse/landcover conditions to meet future needs of water use in the rod-kohi region using geoinformatics application. Interactive analysis between the groundwater potential zones delineated from aquifer characteristics of the region and the landuse/landcover data generated using RS technique was performed using analytical tools of GIS in the present study.

2. GEOGRAPHICAL SETUP

The rod-kohi irrigated region of Pakistan stretches over an area of about 41.6 Mha within longitudes 60° 50′ - 72° 0′ E and latitudes 24° 42′ - 34° 3′ N in the western territory of Pakistan (Fig. 1). It is bounded in the west by Iran and Afghanistan and in the south by Arabian Sea. The agro-ecological regions where rod-kohi-irrigation system is practiced include western dry mountains, Suleiman piedmont plains and Balochistan plateau [18] (Table 1). Major rivers flowing in this region are Gomal, Kurram, Tochi, Porali, Hangol, Dasht, Baran, Nari and Gaj, and some of the major hill-torrents are Vehowa, Sanghar, Kaha, Gud, and Luni, etc. The hill-torrents are generally ephemeral in nature. The climate of the region has wide variations as the hilly areas in the north have bracing cool dry climate, whereas coastal belt of Makran is hot and humid. 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. During a year of low rainfall, groundwater table goes enormously low and the wells become dry. The main sources of income are agriculture and livestock. The principal crops grown are wheat, jawar, gram, bajra, cotton, pulses and fruits. Wheat is sown on large area of the region.

Major part of the valleys comprises gravelly fans and terraces made in course mountain outwashes. In the valley floor and at some piedmont formation the groundwater exists within shallow depths of 5-10m. The quality and quantity of groundwater also varies

with geology, climate and hydrological conditions. The groundwater occurs in two broad systems: (a) Porous aquifer system which exists in the plains, valleys and desert areas, and (b) Fissured aquifer system which exists in the hard rocks and mountainous terrain. In areas of favorable structure with high rate of rainfall a number of springs are developed in fissured rocks. These springs provide perennial source of water locally called 'Kalapani' in rod-kohi areas which can be properly managed for irrigation and domestic use [11].

FIG. 1. LOCATION OF ROD-KOHI REGION IN PAKISTAN

TABLE 1. MAIN AGRO-ECOLOGICAL ZONES OF ROD-KOHI REGION

Zone	Physiography	Climate	Soils	Landuse
Western dry mountains	High mountains, hills, valleys filled with alluvium and loessic material	Major part comprises semi-arid high land with mild summer and cold winter	Main soils of valleys are strongly calcareous but deep and loamy	Predominant landuse is grazing. Main crops grown are wheat, maize and fruits
Dry western Plateau	Mountainous areas with intermountain basins and plateaus including Kirthar range	Arid (desert) tropical type of climate with constantly dry season	Soils in plains are deep, strongly calcareous silt loams	Predominant landuse is grazing. Vegetation is xerophytic. Wheat is the main crop. Sorghum, millets and fruits are also grown.
Suleiman Piedmont	Piedmont plains of Suleiman Range, sloping towards Indus River	Arid and hot, sub-tropical continental	Loamy in gently sloping areas but clayey away, strongly calcareous	Rod-kohi cultivation is the main landuse. Main crops grown are wheat, sorghum, millets and grams.

3. DATA AND METHODOLOGY

The remote sensing data of Landsat ETM+ from 1999-2001 (N=34) were used as primary data in the present study (Table 2). Landsat ETM+ image has six bands of 30m, one band of 60m resolution and a panchromatic band of 15m resolution. The multispectral bands possess distinct spectral characteristics useful for vegetation type and health discrimination, soil moisture, water-bodies delineation and rock-type discrimination. The mosaic of the imageries indicating the study area in band combination of 5, 4, 2 (Red, Green, Blue) is shown in Fig. 2. The secondary data of topography, hydrology/hydrogeology, soils and climate were acquired from SOP (Survey of Pakistan), WAPDA (Pakistan Water and Power Development Authority), SSP (Soil Survey of Pakistan) and PMD (Pakistan Meteorological Department), respectively. The hydrogeological maps prepared by WAPDA at 1:250,000 and 1:500,000 scales were used to extract information related to subsurface lithology and groundwater resources. DEM (Digital Elevation Model) data of SRTM (Shuttle Radar Topography Mission) at 90m resolution was used to study the topography and physiography of the region. GPS (Global Positioning System) survey was carried out for collection of GCP (Ground Control Points) and field validation at different locations.

The thematic data layers of topography, physiography and hydrology were developed using Transverse Mercator coordinate system for data integration and modeling in ArcGIS 9.3 software. The landuse/landcover of the region was studied through visual and digital interpretation of the Landsat image data. For image classification, supervised method was adopted and training samples were collected from the representative landcovers in the image based on ground information and experience. The signatures were evaluated using contingency matrix. Image classification was carried out in ERDAS imagine software following maximum likelihood rule, commonly used to acquire reliable classification results. Later quantitative analysis was performed to assess the extent of different landuse classes. The flow chart of methodology followed for landuse mapping and analysis is shown in Fig. 3.

Physiographic zones were delineated based on elevation [17] and related with landuse and groundwater zone layers for spatial analysis. The zones include: Lowland (<300m); Hilly area (300-700m); Middle mountain (700-2000m) and High mountain (>2000m). About 50% of the rod-kohi region

comprises of middle mountain zone and 22% hilly area, also called sub Himalaya zone, Siwaliks or plateau region [17, 20]. Lowland stretches over 8.95 M.ha area mainly comprising of piedmont plains of the Suleiman and Kirthar ranges slopping towards Indus River in the east and the coastal area sloping towards Arabian Sea in the south (Fig. 4).

TABLE 2. LANDSAT IMAGERIES USED IN THE PRESENT STUDY

No.	Path-Row	Dated	No.	Path-Row	Dated
1.	151-037	11-10-2000	18.	156-043	14-10-2000
2.	152-037	18-10-2000	19.	152-040	18-10-2000
3.	151-040	23-09-1999	20.	153-040	23-09-2000
4.	151-038	11-10-2000	21.	156-041	10-05-2001
5.	151-039	23-09-1999	22.	154-041	12-05-2001
6.	152-038	17-11-1999	23.	155-041	03-05-2001
7.	152-039	18-10-2000	24.	153-038	09-10-2000
8.	152-042	18-10-2000	25.	153-039	09-10-2000
9.	152-043	06-11-2001	26.	154-038	29-06-2001
10.	153-042	25-10-2000	27.	154-039	29-06-2001
11.	152-041	18-10-2000	28.	154-042	12-05-2001
12.	153-041	25-10-2000	29.	154-043	03-12-2000
13.	154-040	29-06-2001	30.	155-042	01-04-2001
14.	155-039	03-05-2001	31.	156-039	10-05-2001
15.	155-040	03-05-2001	32.	156-040	10-05-2001
16.	155-043	01-04-2001	33.	157-039	19-09-2000
17.	156-042	10-05-2001	34.	157-040	04-07-2001

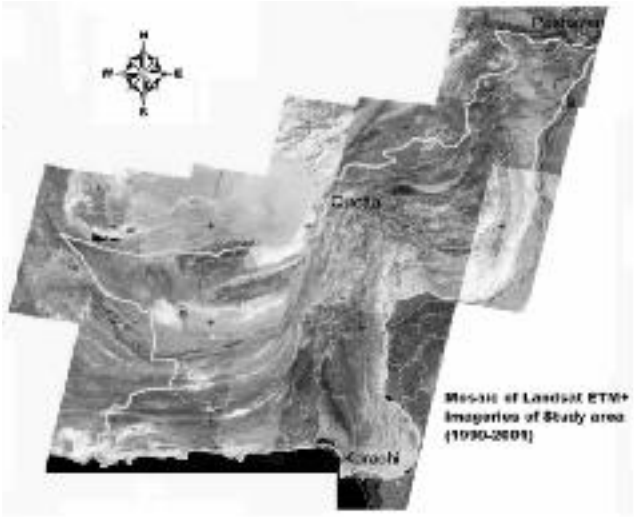

FIG. 2. RGB COMPOSITE (542) OF LANDSAT MOSAIC DATA OF THE ROD-KOHI REGION

The groundwater potential zones of the rod-kohi region were delineated through on-screen digitization of the hydrogeological maps in ArcGIS. The five groundwater potential zones defined after WAPDA [19] include: High (groundwater yield 100-300m^3/hr or more down to 150m depth, fairly thick and extensive aquifer); Medium (50-100m^3/hr yield down to 150m, moderately thick and extensive aquifer); Low (10-50m^3/hr yield down to 150m, aquifer of limited thickness and extension); Poor (less than 10 m^3/hr yield down to 150m, patchy, hard rock, discontinuous aquifer) and NA (no potential aquifer). Finally, GIS was used to integrate and model spatial data layers for overlay analysis.

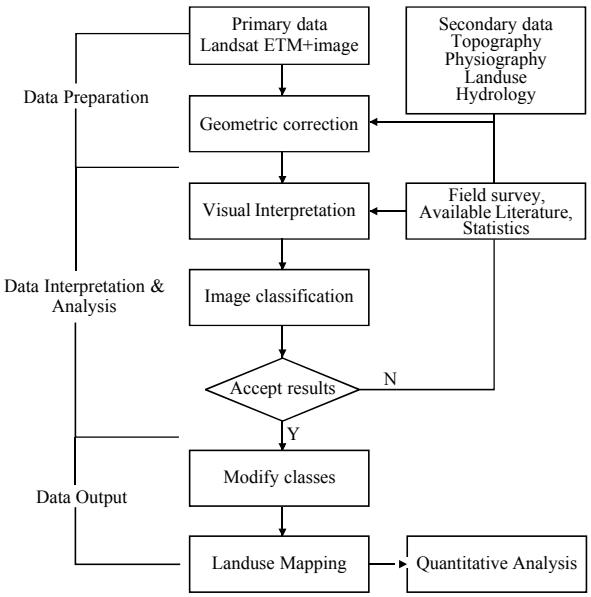

FIG. 3. FLOW CHART OF LANDUSE MAPPING AND ANALYSIS

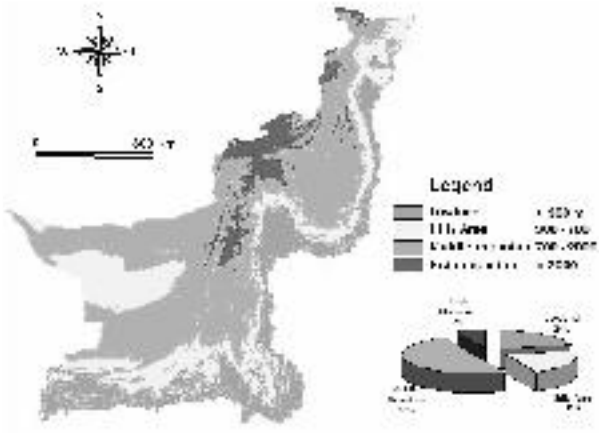

FIG. 4. PHYSIOGRAPHIC ZONES OF ROD-KOHI REGION

4. RESULTS AND DISCUSSION

4.1 Landuse Mapping and Analysis

The landuse/landcover mapped and assessed through image interpretation and analysis revealed rangeland and exposed rocks collectively over 30 Mha in the rod-kohi region (Table 3 and Fig. 5).

Forest cover of various types e.g. coniferous, scrub, tree plantation and mangroves exists over 0.9 Mha mainly in the middle and high mountain zones. Overall cropped area was identified over 1.5 Mha which is in conformal with the figure of 1.4 Mha of spate irrigation area estimated and compiled by FAO [10]. Maximum rod-kohi crop was identified over lowlands whereas rainfed crop was dominant over hilly area (Table 4). The bare soil or culturable waste was identified over 6.5 Mha, dominantly in the lowlands within Suleiman and Kirthar piedmont plains and in parts of Makran coastal area. This land can be brought under rod-kohi cultivation through adopting appropriate means of water conservation and management. The rangeland and exposed rocks (serve as grazing land during wet season) exist more or less in all the physiographic zones. The western part of the Balochistan rod-kohi region consists of barren sandy land within 300-700m elevation range. There are minor landuse classes like settlements, wasteland (saline, marshy areas) and water bodies which possess less significant coverage in the rod-kohi region.

4.2 Analysis of Groundwater Zones

Overall low to high potential of groundwater was identified over 8% of the rod-kohi region (Fig. 6). Such potential of groundwater exists in piedmont plains of Suleiman and Kirthar ranges and in patches within alluvium of intermountain valleys of Khyber Pakhtunkhwa and Balochistan rod-kohi regions. High potential of groundwater (100-300 m^3/hr or more groundwater yield) exists in about 0.6 Mha, dominantly in Sindh rod-kohi region i.e. over 0.37 Mha. Major pockets of this zone also exist in Khuzdar, Lasbella, Qilla Saifullah and southwest of Zhob area in Balochistan. The medium potential zone (50-100 m^3/hr yield) was identified over 1.7 Mha while low potential was dominant in about 1 Mha (Table 5). The former zone was dominant over 0.67 Mha in Punjab, 0.54 Mha in Khyber Pakhtunkhwa and 0.49 Mha in Balochistan. Watertable generally exists in shallow environment in piedmont plains in this zone. The poor potential zone (less than 10 m^3/hr yield) exists over 30% of the rod-kohi region (Fig. 6). The aquifers in this zone are generally patchy and discontinues. Physiographically, high and medium potential zones cover 0.39 and 1.23 Mha areas in the lowlands respectively (Table 6). In hilly areas (also called plateau or Siwaliks), the high potential zone was identified over 0.15 Mha.

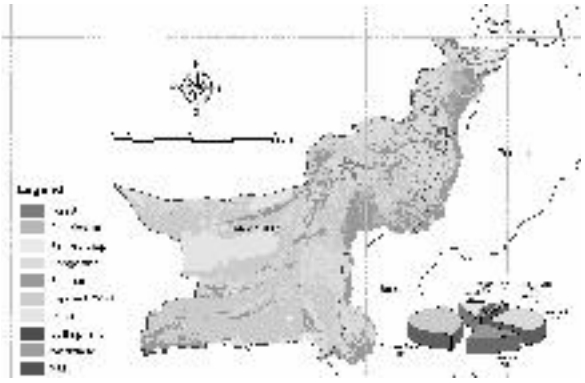

FIG. 5. LANDUSE/LANDCOVER DISTRIBUTION IN ROD-KOHI REGION

TABLE 3. LANDUSE CLASSIFICATION IN ROD-KOHI REGION BY PROVINCES

Landuse Class	Khyber Pakhtunkhwa (000' ha)	Punjab (000' ha)	Sindh (000' ha)	Balochistan (000' ha)	Total (000' ha)
Forest	359.0	1.0	0.9	503.5	864.5
Rod-kohi crop	384.8	104.2	92.0	598.5	1179.5
Rain fed crop	266.4	36.9	-	0.4	303.7
Rangeland	1588.0	538.1	1002.1	9135.5	12263.7
Bare soil	695.9	762.7	789.4	4272.4	6520.4
Exposed rocks	537.4	308.2	195.7	16268.2	17309.5
Desert	-	-	-	3160.4	3160.4
Built-up land	3.9	0.5	3.8	6.7	14.9
Wasteland	-	0.2	-	6.9	7.2
Water bodies	2.1	0.1	1.6	1.7	5.5
Total	3837.6	1751.9	2085.6	33954.1	41629.3

4.3 Analysis of Landuse Vs Groundwater Zones

High and medium potential of groundwater exist maximum under bare soil or culturable waste land i.e. over 0.27and 1.09 Mha respectively (Table 7 and Fig. 7). The bare soil area, which remains unused due to non-availability of surface runoff, can be developed for agricultural use to meet the future food requirements of the local communities. Low to high potential of groundwater was identified over 0.59 Mha under cropped area. The groundwater potential in these areas can be utilized for raising delta crops and fruits through adopting high efficiency irrigation techniques.

In rangelands, high potential of groundwater lies in about 0.12 Mha whereas medium and low potential exist over 0.19 and 0.24 Mha, respectively. This potential of groundwater can be harnessed through availing solar and wind energy resources available abundantly in parts of Balochistan and Sindh rod-kohi areas. About 2% of the desert area possesses low to high groundwater potential. Similarly, 2% of exposed rocks area possesses low to high potential of groundwater. The groundwater at some places in these areas usually discharges in the form of springs, the perennial flow of which can be harnessed for irrigation and domestic purpose through adopting appropriate water management techniques.

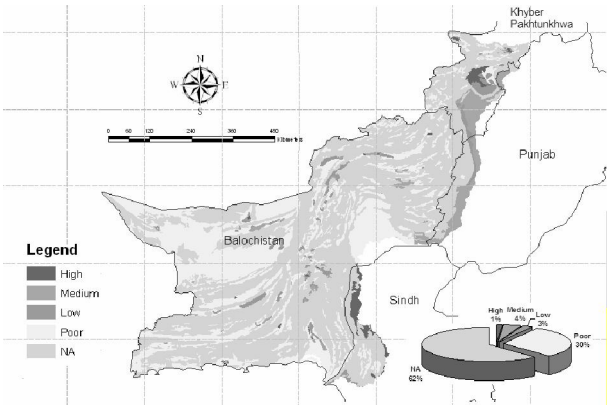

FIG. 6. GROUNDWATER POTENTIAL ZONES IN ROD-KOHI REGION

TABLE 4. DETAIL OF LANDUSE CLASSES BY PHYSIOGRAPHY

Landuse Class	Lowland (000' ha)	Hilly area (000' ha)	Middle mountain (000' ha)	High mountain (000' ha)	Total (000' ha)
Forest	20.4	62.4	488.1	290.2	861.1
Rod-kohi crop	737.9	198.9	264.5	9.7	1210.9
Rainfed crop	9.9	202.6	96.8	0.0	309.3
Rangeland	1695.2	1532.3	7490.3	1490.0	12207.9
Bare soil	3865.0	725.0	1974.9	77.1	6642.0
Exposed rocks	2491.6	4169.5	9618.2	952.8	17232.2
Desert	108.5	2113.3	914.6	1.3	3137.7
Built-up land	6.7	2.1	6.2	0.0	15.0
Wasteland	7.4	0.0	0.0	0.0	7.4
Water bodies	3.4	1.0	0.4	0.8	5.6
Total	8946.0	9007.0	20854.0	2822.0	41629.0

TABLE 5. AREA UNDER DIFFERENT GROUNDWATER ZONES BY PROVINCES

Zone	Khyber Pakhtunkhwa (000' ha)	Punjab (000' ha)	Sindh (000' ha)	Balochistan (000' ha)	Total (000' ha)
High	183	-	369	45	597
Medium	543	670	2	488	1,702
Low	353	103	71	543	1,070
Poor	514	15	230	11,868	12,627
NA	2,245	965	1,414	21,009	25,633
Total	3,838	1,752	2,086	33,954	41,629

TABLE 6. DETAIL OF GROUNDWATER ZONES BY PHYSIOGRAPHY

Zone	Lowland (000' ha)	Hilly Area (000' ha)	Middle mountain (000' ha)	High mountain (000' ha)	Total (000' ha)
High	395	155	47	-	597
Medium	1,235	133	334	-	1,702
Low	351	225	493	2	1,070
Poor	3,215	3,756	5,338	318	12,627
NA	3,593	4,848	14,663	2,529	25,633
Total	8,788	9,117	20,875	2,849	41,629

TABLE 7. GROUNDWATER ZONES BY LANDUSE IN ROD-KOHI REGION

Zone	Forest (000'ha)	Crop area (000'ha)	Rangeland (000'ha)	Bare soil (000'ha)	Desert (000'ha)	Exposed rocks (000'ha)	Total (000'ha)
High	-	157	122	269	8	41	597
Medium	1	218	188	1089	22	184	1,702
Low	1	217	244	437	41	129	1,070
Poor	56	576	2573	2848	2712	3862	12,627
NA	829	287	9236	1750	278	13253	25,633
Total	889	1456	12362	6393	3060	17468	41,629

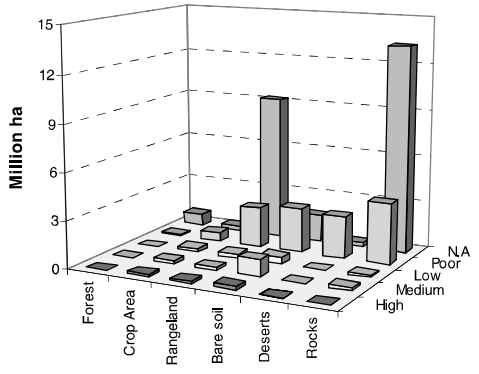

FIG. 7. ANALYSIS OF LANDUSE VS GROUNDWATER ZONES IN ROD-KOHI REGION

5. CONCLUSIONS

In the present study, we evaluate relationship of landuse/landcover delineated through image processing with groundwater zones developed from aquifer characteristics of the rod-kohi region using analytical tools of GIS. Major landuse of the rod-kohi region is characterized by rangeland and exposed rocks (serve as grazing land during wet season) which collectively covers about 70% of the rod-kohi region. Overall, cropped area was identified over 1.5 Mha and bare soil or culturable waste over 6.5 Mha in the region. The low to high potential of groundwater lies over 3.37 Mha out of which 0.59 Mha exists under cropped area.

The high potential was dominant in 0.27 Mha under culturable waste. High efficiency irrigation techniques like drip and rain-gun irrigation system should be adopted in areas having substantial groundwater potential in order to enhance agriculture productivity. Overexploitation of groundwater needs to be controlled in order to reduce negative impacts in different overdrawn basins like Zhob, Nari and Pishin. A detail investigation of the groundwater resource in the region is required in context of increase in water use and changing climatic conditions in future. The findings of the study would provide a decision support tool for evaluating better management options for sustainable development of land and water resources in the rod-kohi region.

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