Investigating Potential Artesian Aquifers in Rod-Kohi Area of DI Khan, NWFP using GIS and Geo-Processing Techniques

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ABSTRACT

The artesian aquifers provide economical and sustainable source of groundwater for irrigation and domestic use. GIS (Geographic Information System) was used for development and integration of spatial databases, analysis and visualization of spatial data in two- and three-dimensional views. The aquifer system of Daraban Rod-Kohi area of DI Khan was analyzed to identify potential artesian aquifers using geological sections of the observation wells representing detail of subsurface lithology and strata encountered. According to an estimate, about 1,700 million m3 of extractable volume of groundwater exists in this part of rod-kohi area. Different profile sections were drawn to analyze the subsurface condition of the study area using Rockworks GIS-based software. The geo-processing technique of horizontal litho-blending was utilized for lithological modeling. Based on stratigraphic information of the area, three distinct aquifers were identified down to a depth of about 200 meters among which two are semi-confined to confined having prospects of artesian water. The 2D and 3D analysis show that characteristics of the confined aquifers vary spatially with the subsurface lithology and structural setup of the area. The depth range of confined layer-1 is found between 118 and 133 meters while of confined layer-2 between 182 and 195 meters. The output data indicated a close agreement with the observed data of the artesian wells. The study results can provide base for detail investigation of artesian resource and selection of potential sites for installation of artesian wells in the target area.

Key Words: **Artesian Aquifer, Groundwater, GIS, Lithological Modeling, Rod Kohi Area, DI Khan.**

1. INTRODUCTION

The artesian aquifers form a valuable source of groundwater in arid areas of Pakistan. This important resource which sustain yield even during drought conditions, has not been investigated fully yet for irrigation and domestic purposes. The recent drought forced the farmers to introduce supplemental irrigation using groundwater resources through springs, wells, tubewells and Karezes [1]. In rod-kohi (or 'Sailaba') areas of the country, uncertainty exists in flood water availability for irrigation use. The rod-kohi areas which are flooded less frequently or inadequately, are generally irrigated with private tubewells and open wells [2]. The groundwater pumpage through tubewells is also becoming costly due to increase in fuel and electricity prices. Among over one million tubewells in the country being operated using electric or diesel prime-movers, around 87% are being

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operated by diesel fuel [3]. The price of diesel fuel in future may further affect the agriculture productivity and profitability. In such situation, artesian wells are providing a reliable, sustainable and an economical source of groundwater supply to many rural communities in parts of NWFP and Balochistan province. Often the water in artesian streams flows hundred of miles, from the place of descended into the earth as rain to the point where it emerges again from wells. For this reason - since they are not dependant upon local conditions of rainfall, artesian wells usually supply an endless source of water, even in times of extreme drought, when other wells in the vicinity go dry [4]. The groundwater investigations and research on aquifer systems are mainly undertaken by WAPDA which provide information of subsurface aquifer characteristics and groundwater potential [5-6]. A number of groundwater studies made by other agencies have been limited in scope and purpose.

The GIS technology provides suitable alternatives for efficient management of large and complex databases [7]. Integration of different thematic layers is possible in GIS environment which helps in rapid analysis of spatial data. Efficient management of groundwater resources relies on a comprehensive database that represents the characteristics of the natural groundwater system [8]. The GIS can be used as additive tool to develop supportive data for numerical groundwater modelling, integration and presentation of image processing and modelling results [9]. It should be realized that by just using last century's schemes no longer solves challenges related to today's groundwater situation [10]. There is an urgent need for expansion in the knowledge of user and research-base of institutions through utilizing geoinformatics and geo-processing tools for better investigation and management of groundwater resource. In the present study, potential artesian aquifers were identified in Daraban rod-kohi area of DI Khan and their physical characteristics were assessed through application of GIS and geo-processing techniques. The spatial data along with related information of the wells was collected through GPS (Global Positioning System) survey carried out in the targeted area.

1.1 Study Area

Daraban command area in DI Khan is stretched over an area of about 490 sq. km within longitudinal range 70 12 00-70 40 40 E and latitudinal range 31 37 44-31 49 44 N in the northwestern territory of Pakistan (Fig. 1). The area is bounded in the west by Suleiman mountain range and in the east by CRBC (Chashma Right Bank Canal) emerging from Chashma barrage near Kalabagh. The elevation ranges between 180-417 meters above mean sea level. The general slope is towards southeastward. Major land use of the area is rod-kohi agriculture. The rod-kohi cultivation is done by diversion and spreading of intermittent flow of hill torrents. Well-irrigation using artesian groundwater is used as supplement irrigation and in some areas as primary source of irrigation in the command area. According to an estimate, about 1,700 million m^3 of extractable volume of groundwater exist in this part of rod-kohi area [11].

The Suleiman Mountains in the west of command area are part of the south western extension of the Himalayas known as Balochistan Arc. They form both past and present source of sediments that make up the western and central parts of the alluvial fill of the plain and also have a great influence on the chemical quality of both surface and groundwater [11].The Suleiman-Kirthar fold belt is characterized by east-west trending arcuate, convex to the south folds in which Jurassic to Recent sedimentary rocks are exposed [12]. The mountains of Suleiman range are almost bare rocks and the valleys are fertile having good moisture holding capacity. Major landform is sub-recent piedmont plains with eroded and severely eroded land [13]. The foothill region is commonly covered with gravel fans which form distinct piedmont zones. These are followed by sub-piedmont zones characterized by gentle slope and finer sediments [12]. The slopes of the piedmont and sub-piedmont plains range from 10-20 and 2 to about 5 m/km. The average slope is 2 percent ranging from Indus River to the foot of Suleiman range [14]. A large number of intermittent and perennial streams enter the DI Khan from the western Suleiman Mountains. The major streams which sustain perennial flow in DI Khan area are Tank Zam, Gomal River and Khora River (Daraban Zam). The crops use moisture of the diverted flood waters which flow down onto the plains from the mountains carrying fertile organic matter.

The climate of the area is arid to semi-arid sub-tropical continental with seasonal fluctuations in temperature and rainfall. The average monthly temperature shows a hot period from May to September with mean exceeding 30C. In winter the average monthly temperature drops below 12C during December and January [11]. Annual rainfall is low, uncertain and patchy. Mean annual rainfall varies between 180 and 305mm. Westerly waves carrying moisture from Mediterranean Sea bring rainfall in winter. The Monsoon rains in summer often result in occurrence of torrential floods which bring heavy sediments downstream.

1.2 Characteristics of the Artesian Wells

The artesian wells are mainly concentrated in the southwestern part of the study area between longitudes 70 18 30 E and 70 21 E, and latitudes 31 41 40 and 31 44 50 N within elevation range of 213-233 meters above mean sea level (Fig. 1). The groundwater from artesian wells is mainly abstracted from more than 90 meters depth. The discharge of the wells ranges within 1-2 liters/sec and may be utilized for irrigation up to 10 hectares of agricultural land. There are seasonal variations in the wells discharge which depend mainly on the rainfall recharge taking place in the folding and faulting zone of Suleiman range lying in the catchment of Daraban area. The fluctuations in the groundwater discharge vary from well to well. The discharge of some of the wells increases in the wet season i.e. during months of August and September and may decrease in the dry season. Generally the wells in deep

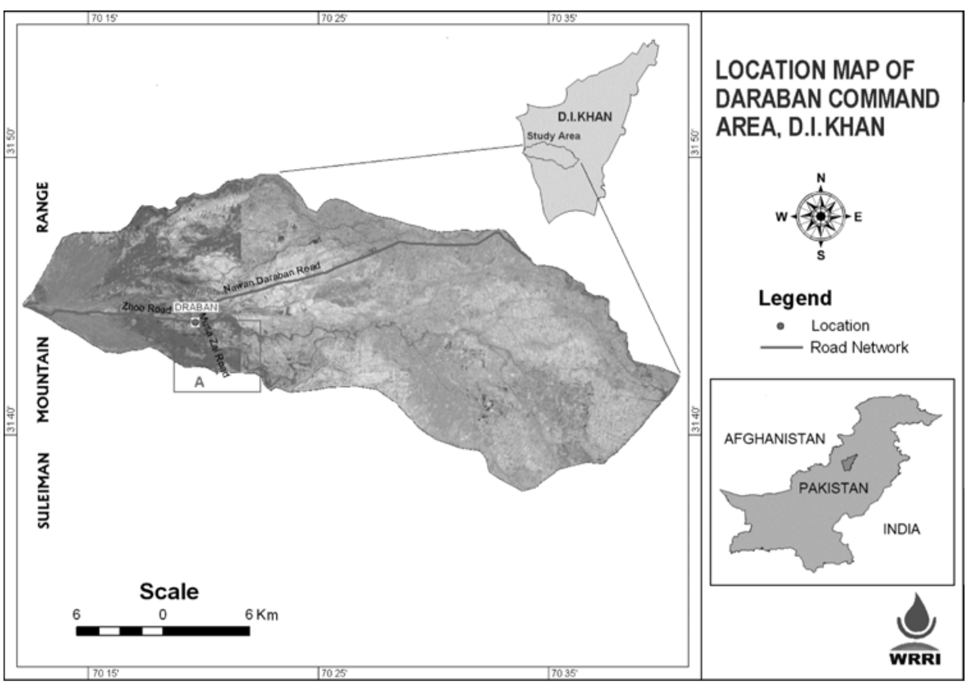

FIG. 1. DARABAN COMMAND AREA INDICATING LOCATION OF ARTESIAN WELLS IN BOX-A

aquifers are less affected by the climatic variations and thus sustain their yield throughout the year.

The major components of recharge of the groundwater aquifer in DI Khan are sub-surface inflow of groundwater from the mountainous area, infiltration of surface runoff mainly of streams and rivers entering the area from the adjacent mountains and overland flow during heavy rains. The components of discharge are evapo-transpiration and groundwater abstraction from number of public and private tubewells/open wells present in the area.

At present, the installation of artesian wells is not based on proper investigations of aquifer potential which may result in loss of cost and efforts. There is a need to investigate potential sites of artesian aquifers based on the lithological, hydro-geological and hydrological characteristics of the area using multiple thematic data. The main objective of carrying out the present study is to identify potential artesian aquifers and suitable sites for installation of new artesian wells in the target rod-kohi area using GIS and geo-processing techniques. The other objective is to provide baseline information and data for detail geological and geophysical investigations of such aquifers in future.

2. MATERIALS AND METHOD

The thematic data of topography, geomorphology, soils, hydrology and climate was acquired from different source departments like Survey of Pakistan, Soil Survey of Pakistan, WAPDA and Pakistan Meteorology department. A GPS survey was carried out to collect ground control points, wells data and related field information. The detail of each well was collected through its owner's interview. The geological sections of the observation wells developed by WAPDA [11] were used to get insight of the subsurface lithology. Lithological and structural geological conditions determine the spatial distribution and extent of hydrogeological bodies (aquifers, aquitards). The remote sensing data of SPOT-5 having spatial resolution of 2.5 m was acquired from Satellite ground station Islamabad to demarcate land features and land cover of the study area (Table 1).

The development and integration of spatial data, analysis and visualization of spatial data in 2D and 3D views was carried out in Geographic information system. The thematic layers of artesian wells, surface hydrology, infrastructure and landforms were developed in GIS using UTM (Universal Transverse Mercator) projection system. The attribute data was linked to the respective thematic layer for analytical purpose. The remote sensing image and topographic map data were used for delineation of command area boundary in GIS. The spatial data was input and analyzed in Arcview GIS 3.1 software [15].

TABLE 1. DATA OF ARTESIAN WELLS COLLECTED FROM STUDY AREA

Well No.	Longitude	Latitude	Surface Elev. (masl)	Well Depth (m)
1.	70° 18' 57"E	31° 44' 09"N	231	126
2.	70° 18' 49"E	31° 44' 15"N	233	127
3.	70° 18' 33"E	31° 44' 16"N	232	127
4.	70° 20' 16"E	31° 43' 10"N	220	137
5.	70° 20' 06"E	31° 42' 52"N	225	125
6.	70° 20' 33"E	31° 41' 53"N	223	168
7.	70° 20' 33"E	31 ° 41' 47"N	224	198
8.	70° 20' 25"E	31° 41' 52"N	224	126
9.	70° 20' 11"E	31° 43' 12"N	218	91

The subsurface lithology and strata encountered were investigated using geological sections of the observation wells. The profile AA' stretches over a distance of 32 km in NW-SE direction, whereas profile BB' over a distance of 26 km in NE-SW direction. The profiles AA' and BB' were drawn to cover major command area of Daraban (Fig. 2(a-b)). The profiles were plotted through lithological modeling using horizontal litho-blending technique of Rockworks 2006 software [16].

Approximate depths and thicknesses of the underlying aquifers were determined using the surface elevation and the well data collected from the field. The model results were verified with the observed data of wells depth collected during field survey.

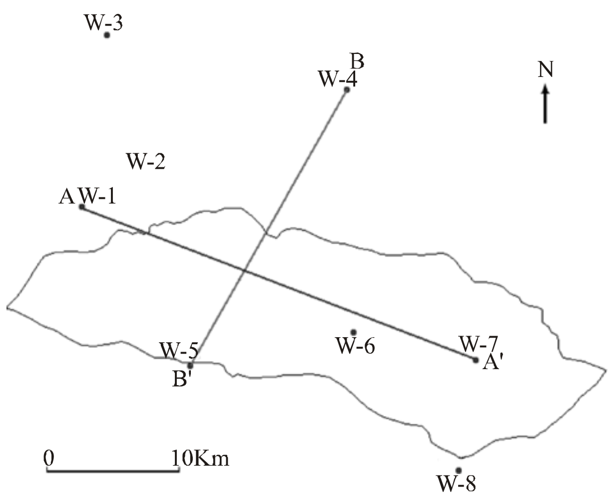

FIG. 2(a). LOCATION OF BOREHOLES AND PROFILES AA' & BB'

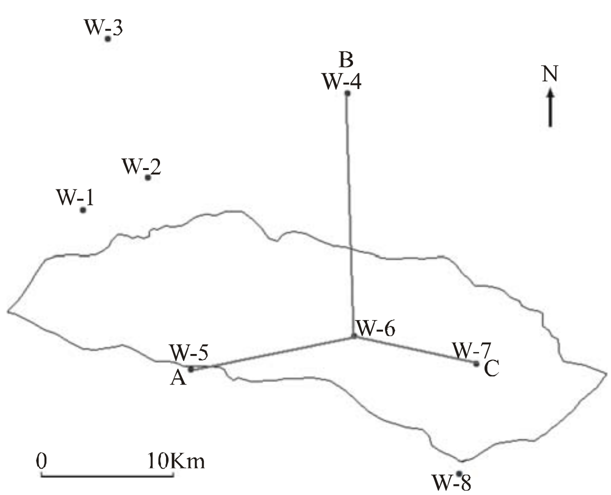

FIG. 2(b). LOCATION OF PROFILE ABC

3. RESULTS AND DISCUSSION

Overall the depth of artesian wells was found within range of 90-200 meters. The profile sections shown in Fig. 3(a-e) indicate distribution of subsurface lithology underneath the study area. The subsurface lithology is predominated by clay material consisting of layering of variable thickness of sand and gravels. Most of the unconsolidated deposits were laid down as a filling in low areas that were created by the crustal downwarping [11]. The gravel deposits are dominant in the northwestern mountainous terrain (Fig. 3(a)). The gravel deposits consist of minor clay and sand material. Layering of sand deposits is prominent in the northwestern side where alluvium deposits of the DI Khan basin are found in abundant. The profile BB' along NE-SW direction indicates sand deposits consisting of

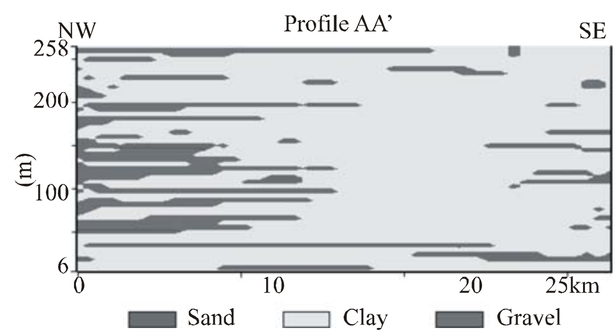

FIG. 3(a). PROFILE SECTION ALONG AA'

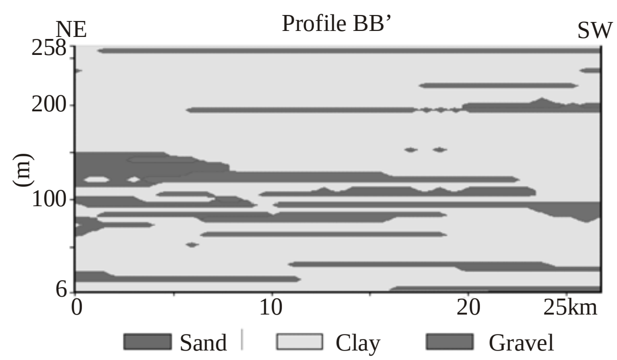

FIG. 3(b). PROFILE SECTION ALONG BB'

fine to coarse grain sand and sand mix with minor clay and gravels, which tends to decrease southward. The permeable layers of sand and gravels within confined material of clay develop a potential zone of artesian aquifer. The lithology in three dimensional view is shown along profile ABC (Fig. 3(c-e)). The gravel deposits gradually lessen down towards east in the plain as distance from the mountainous area increases. In the western part of the piedmont plain along the mountains the alluvial fill generally consists of coarse material i.e. coarse sand, gravels and boulders derived from the adjacent rocks. Eastward away from the mountains the fill gradually becomes fine grained with extensive layers of clay alternating with fine sand layers. In piedmont plain the clay section was more difficult to be defined especially near the mountains.

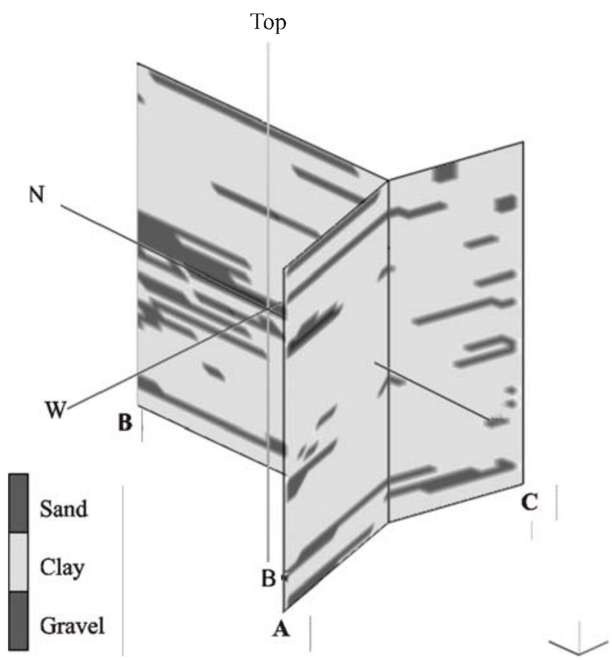

FIG. 3(c). PROFILE SECTION ALONG ABC

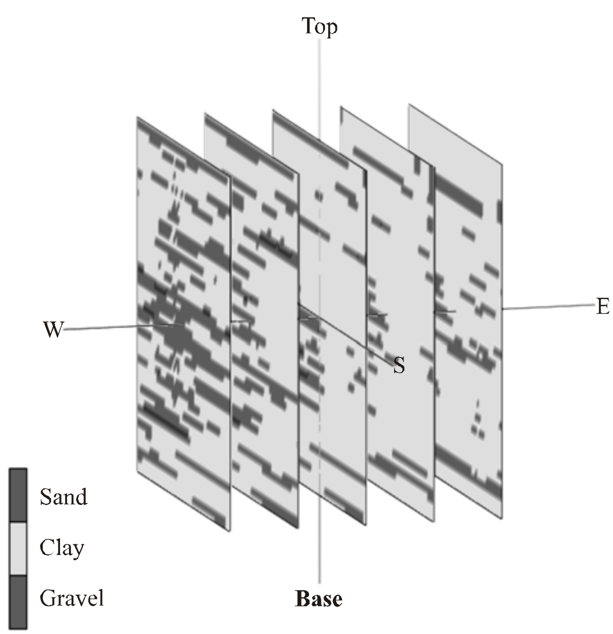

FIG. 3(d). FENCE SECTION IN W-E DIRECTION

4.1 Analysis of Aquifer Layering

Based on stratigraphic information of the area, three distinct aquifers were identified down to a depth of about 200 meters in the target area (Fig. 4). The physical characteristics of these aquifers vary spatially with the characteristics of the subsurface lithology and structural setup of the area. The first aquifer which is unconfined lies within depth range of about 3-67 meters (Table 2). This aquifer comprises of unconsolidated valley-fill deposits principally composed of weathered material

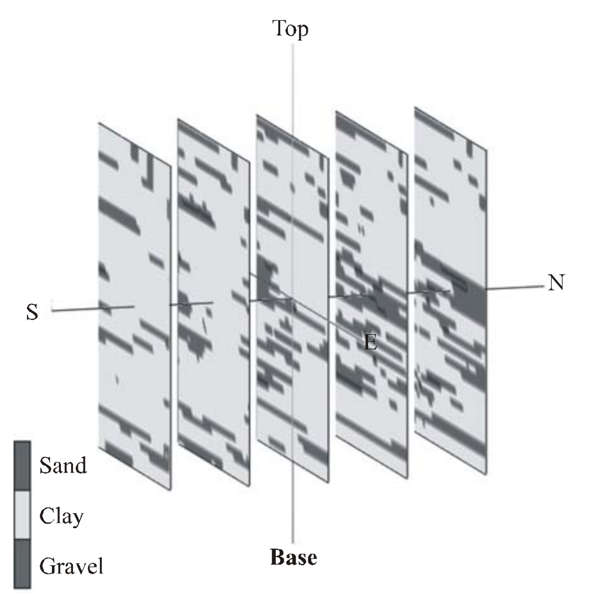

FIG. 3(e). FENCE SECTION IN N-S DIRECTION derived from the adjoining mountain ranges and have been laid down in structural depressions. According to [12], present day ephemeral or intermittent streams draining the outer hill ranges around the Indus plain carry heavy silt load, which are deposited as wide and thick silt and clay deposits in the piedmont zone. The unconsolidated deposits of clay, sand, gravel of various grades and their admixture have variable distribution both laterally and vertically. The thickness of this aquifer may vary from 2 to 46 meters. The watertable depth in the floodplain area is generally less than 20 meters, while in the piedmont plain it ranges from 2 meters to over 100 meters [11]. The second aquifer is confined due to presence of an overlying aquatard layer (Fig. 5). The depth of this aquifer (Confined Layer-1) ranges between 76 and 133 meters and thickness within 2-19 meters. The third aquifer is also confined being separated from the first confined aquifer through an aquatard layer. This second confined aquifer (confined layer-2) lies within depth range of about 109-181 meters and possesses thickness between 1 and 9 meters range (Table 2). According to [11], the groundwater beneath 120-200 meters occurs under (semi) confined conditions. The permeable layers of the alluvial fill have been reported to extend over depths more than 260 meters in the piedmont plain. The stratigraphic profile developed along AA' shows a probable extent of artesian zone underneath the study area (Fig. 5). The situation shows some higher prospects of artesian groundwater in the western side of the piedmont plain than in the eastern side. The confined aquifer layers possessing artesian conditions are separated from the floodplain deposits of Indus River by a transition zone [11]. The flood plain deposits which are much more homogeneous and consist of very thick sand layers interfering with the piedmont deposits in this transition zone.

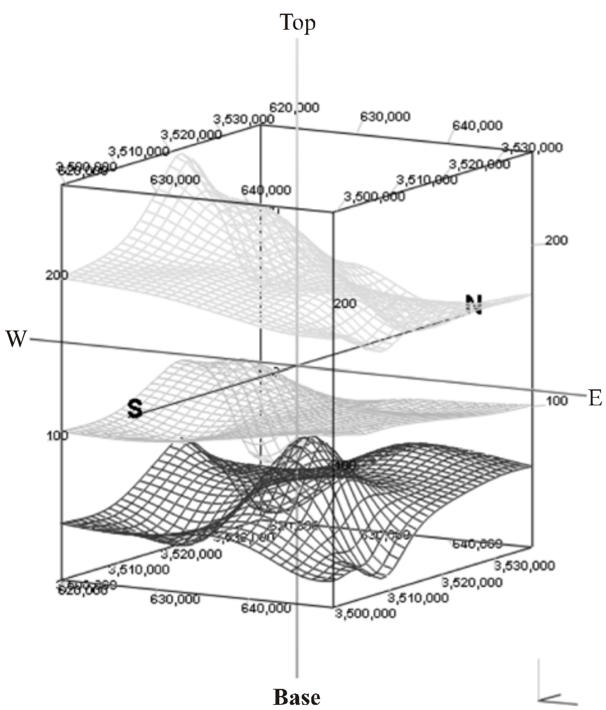

FIG. 4. THREE-DIMENSIONAL VIEW OF AQUIFER LAYERS

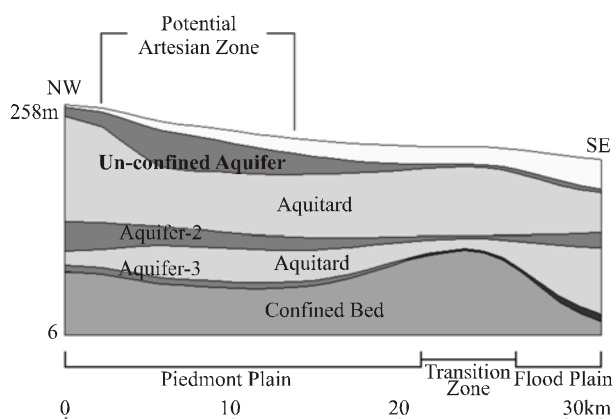

FIG. 5. AQUIFER SECTION INDICATING POTENTIAL ARTESIAN ZONE ALONG PROFILE AA'

TABLE 2. PHYSICAL CHARACTERISTICS OF UNDERLYING AQUIFERS IN PIEDMONT PLAIN OF D.I.KHAN

Aquifers	Minimum Depth (m)	Maximum Depth (m)	Minimum Thickness (m)	Maximum Thickness (m)
Unconfined	3	67	2	46
Confined Layer-1	76	133	2	19
Confined Layer-2	109	181	1	9

3.2 2D Analysis of Aquifers

The top elevation of confined Aquifer-1 shows a depression region in the central part of the command area (Fig. 6(a)). The elevation range of this region lies between 105 and 110 masl (meters above sea level). A low depression of elevation range 95-100 masl is found in the lower left side of Daraban command area, which appears to be a potential site of groundwater aquifer. In confined Aquifer-2, low elevation ranges less than 50 masl is found in lower left and right corners of the Daraban command area (Fig. 6(b)). The former side may form a potential site of confined aquifer (artesian nature) and the later of an un-confined aquifer. A patch of elevation range 100-105 masl exists in the lower central part of the aquifer.

The isopatch maps of aquifer thickness show decline in thickness of the confined aquifer layers from west to east direction (Fig. 7(a-b)). In Confined Layer-1, the thickness in the centre is less than 6m, whereas it is maximum in the range of 22-24m in the upper left corner of the command area (Fig. 7(a)). Similarly, in confined Layer-2, low thickness concentrates at the centre, whereas maximum thickness ranging within 8-8.5 meters lies at the upper left corner. Though thickness of Confined Layer-2 greater than 7.5m may form a potential site of artesian groundwater but overall thickness of Confined Layer-2 is smaller than that of the confined Layer-1. It is well known that transmissivity increases with thickness of aquifer. This shows that confined layer-1 may possess higher prospects of artesian groundwater than of confined Layer-2.

3.3 Aquifers Characteristics Under Well Data

Through integration of geo-processing and GIS techniques, the geometric characteristics of the confined layers underneath each well were determined for data verification. Overall the depth of confined Layer-1 ranges between 118 and 133 meters while of confined Layer-2 between 182 and 195 meters underneath the wells domain (Table 3). The thickness of confined Layer-1 varies between 18-20 meters underneath the artesian wells. The depths of most of the artesian wells (as given in Table 1) were found approximately within range of the confined Layer-1. Only one well has a depth close to the range of confined Layer-

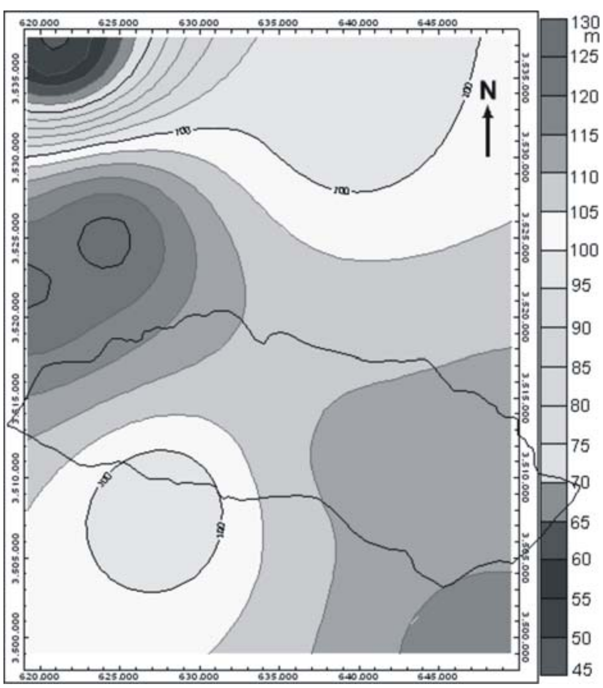

FIG. 6(a). SURFACE ELEVATION OF CONFINED LAYER-1

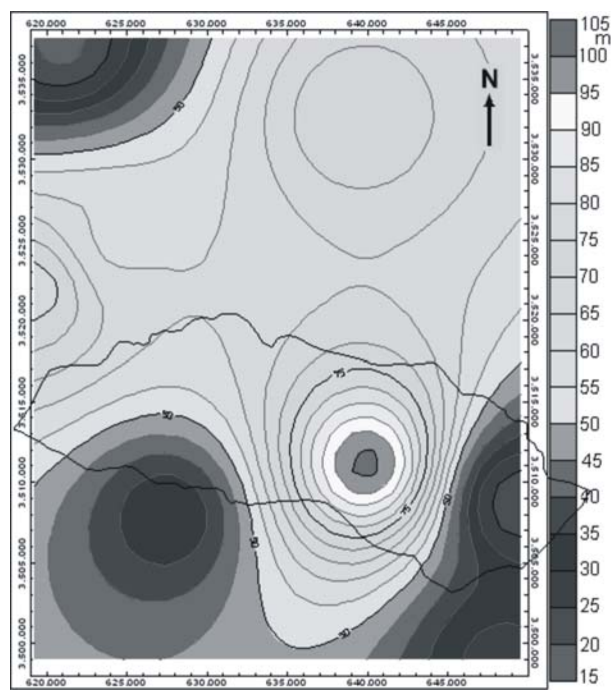

FIG. 6(b). SURFACE ELEVATION OF CONFINED LAYER-2

2. The yield of the former wells was found higher than that of later. This shows a close agreement of the calculated data of aquifers with that of the observed data of the wells.

4. CONCLUSIONS

The results of the study indicate that the rod-kohi area of NWFP possesses potential of artesian groundwater resource that can be explored for sustainable development of agriculture. Based on stratigraphic information of the area, three distinct aquifers were identified down to a depth of about 200 meters among which two were semi-confined to confined having prospects of artesian water. The depth of confined Layer-1 was found ranging between 118 and 133 meters while of confined Layer-2 between 182 and 195 meters in the study domain. The thicknesses of the two confined Layers 1-2 varied between 18-20 meters and 8-8.5 meters, respectively. Though, confined Layer-1 providssustainable yield of groundwater due to its higher thickness than of confined Layer-2, but discharge of the later would be higher due to its more confined nature. The

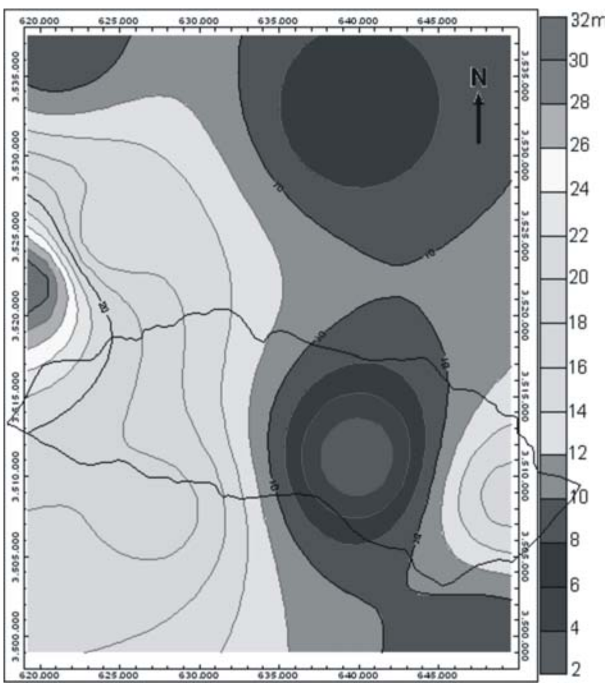

FIG. 7(a). ISOPATCH MAP OF CONFINED LAYER-1

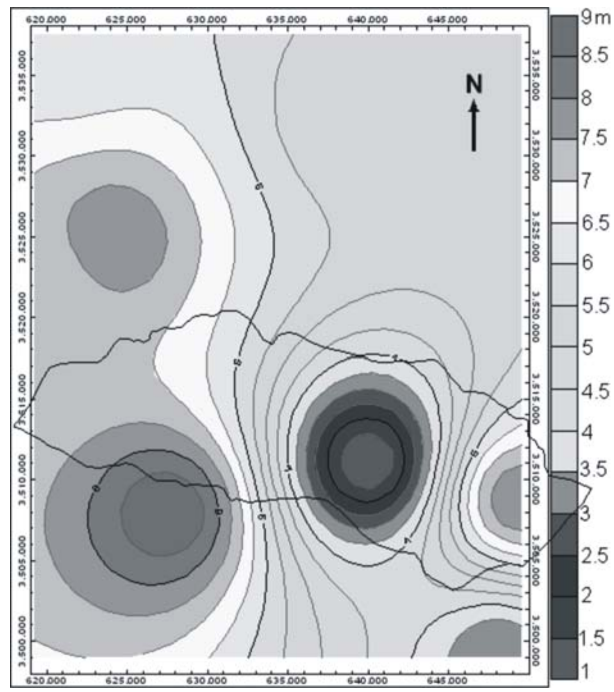

FIG. 7(b). ISOPATCH MAP OF CONFINED LAYER-2

TABLE 3. DEPTH AND THICKNESS OF CONFINED AQUIFERS UNDERLYING THE ARTESIAN WELLS

Well No.	Depth (m)		Thickness (m)	
	Confined Layer-1	Confined Layer-2	Confined Layer-1	Confined Layer-2
1.	126-131	186-191	18-20	7.5-8
2.	128-133	188-193	18-20	7.5-8
3.	127-132	182-187	18-20	7.5-8
4.	120-125	185-190	18-20	8.5-9
5.	125-130	190-195	18-20	8.5-9
6.	123-128	188-193	18-20	8.5-9
7.	124-129	189-194	18-20	8.5-9
8.	124-129	189-194	18-20	8.5-9
9.	118-123	183-188	18-20	8.5-9

physical characteristics of these aquifers varyspatially with the characteristics of the subsurface lithology and structural setup in the target area. Integration of different thematic layers is possible in GIS environment which helps in rapid analysis of spatial data. Effective management strategies based on detailed but systematic geological and geophysical investigations need to be adopted for optimum and sustainable use of artesian groundwater. Although artesian aquifers can provide a sustainable supply of groundwater, yet overexploitation of groundwater can cause negative impacts that may exceed the benefits. The possible measure to solve the overexploitation is to control the supply of ground water and increase that of surface water. In this regard it is necessary to have an integrated management of both surface and groundwater resources. Appropriate laws of groundwater use need to be developed and implemented in order to ensure safe yield and equitable use of artesian groundwater in future.

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