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Causes and effects of temporal groundwater level change in the alluvial aquifer of Dera Ismail Khan area, Pakistan

Anwar Qadir[1], Zulfiqar Ahmad[2], Tahseenullah Khan[1] and Muhammad Zafar[1]
[1]Department of Earth and Environmental sciences, Bahria University, Islamabad
[2]Earth Sciences Department, Quaid-I-Azam University, Islamabad

Abstract

The Chashma Right Bank Canal (CRBC) Stage-II Command Area lies in the Dera Ismail Khan District of Lower Indus Basin. The Indus River and tube wells were used in the past for irrigation purpose, which are now changed to the canal irrigation system. In this research the pre and post water table depths have been investigated to assess the vulnerability of the irrigated land due to water logging. To address this problem the subsurface area has been explored using the water table depth in integration with depositional unit correlation, lateral zonation of hydraulic conductivity and recharge difference calculation for 1976 and 1996. The recharge determined in 1976 using the Water Table Fluctuation (WTF) method is 6 cm. The recharge in 1996 is greater than that of 1976. The groundwater recharge difference between 1976 and 1996 is determined to be 0.64 m. Moreover, three distinct zones have been found which divide the unconfined aquifer vertically into fine to medium sand, medium to coarse sand with gravels and the medium sand. Three lateral zones namely A, B and C are identified on the basis of the water level difference and hydraulic conductivity. Zone B which occupies the middle part has been found to be more vulnerable to the water logging conditions as compared to the other two zones. The role of hydraulic conductivity in zone B is found critical in the buildup of higher water table zones leading to the land degradation in response to perched water table zones development.

Keywords: Hydraulic conductivity; Water logging; Water levels; Dera Ismail Khan.

1. Introduction

Due to global warming and scarcity of dams, the groundwater in Pakistan is under severe threat of exhaustion. In Pakistan nearly 30% canal command area is water logged and 13% highly water logged (e.g. Oosterbaan and Nijland, 1994; Qureshi et al., 2008). Some areas in the Dera Ismail Khan (D.I.K) are also water logged. The study area lies 185 m above mean sea level in the D.I.K area, part of the Lower Indus Basin, which is bounded by latitudes 31º57′51′′ and 31º36′50′′ and longitudes 70º40′22′′ and 70º 57′52′′ span over an area of 336 km^2 (Fig. 1). The Chashma Right Bank Canal (CRBC) is situated towards west and Indus in the east whereas north and south are bounded by the Takwarrah Nala and Sheikh Haider Zaman Nala (Indus tributaries). D.I.K is hot semi-arid with seasonal considerable fluctuations in temperature and rainfall. The average monthly temperature shows a hot period from May to September with mean exceeding 30ºC. In winter the average monthly temperature drops below 12ºC in December and January. Rainfall is concentrated in two wet seasons in March-April and July-August (Malik, 1985; Ullah et al., 2001). The average yearly precipitation is 261 mm.

The D.I.K area is a component of the Indus River Basin composed of alluvial sediments derived from the Indus and its tributaries. Most of the details about the hydrogeology are explored initially by Hood et al. (1970). Physiographically the area can be divided into five major units based largely on the data from the Fraser (1958) i.e. Mountain highlands, Piedmont plain, Flood plain, Aeolian deposits and Gravel fans. The study area lies in the flood plains of the basin. The detailed analysis of the canal recharges is provided by the Ahmed (1972) and Kijne and Jacob (1996).

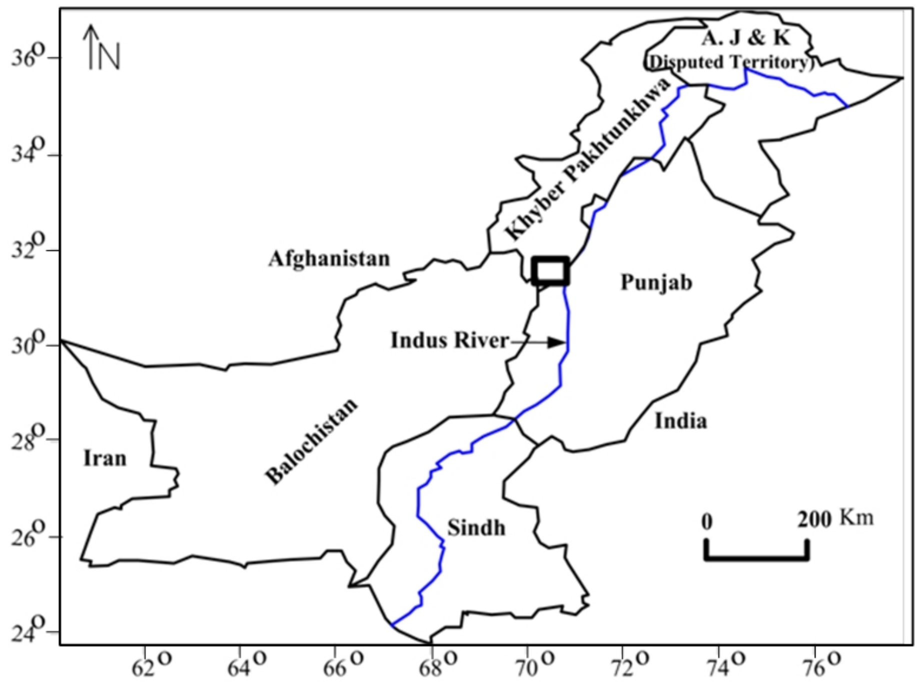

Fig. 1. Location map of the study area. Rectangle marks the Dera Ismail Khan.

The canal irrigation in D.I.K dates back to Early 1900 by the inception of Paharpur Canal originating from Indus at the Chashma Barrage. The Chashma Right Bank Canal (CRBC) is an another canal that is deriving its water from Indus and drain the barren lands of D.I.K.

The present study is meant to assess the impact of CRBC on the groundwater resources by comparing the water level depths in the D.I.K area (Figs. 2abc). The methodology adopted is the conceptualization of the hydrogeologic model, calculation of the hydraulic conductivity and its zonation. This study also describes the causes and effects of the regions under shallow water table.

2. Methodology

The groundwater level depth data for various periods were acquired from various sources, including the Water and Power Development Authority (WAPDA), Water and Salinity Investigation Department (WASID), Public Health Engineering Department (PHED) reports, on site resistivity surveys and various private tube well owners. The data was interpolated with the help of Kriging which is considered to be the most suitable method for the groundwater levels interpolation (e.g. Virdee and Kottegoda, 1984; Kumar, 1996; Kumar & Remadevi, 2006; Volpi and Gambolati, 1978) (Figs. 3abc).

The water levels represent two time periods, i.e. 1976 and 1996. These interpolated water levels were overlaid for the comparison. The points at which the contours of comparing periods cross each other were noted and the difference was calculated. The area is laterally divided into three zones i.e. A, B and C on the basis of the water table depth differences. The average was taken of all the different values to calculate the overall rise or fall of the water table in the area.

The data from wells (Fig. 3) was sorted out and checked in the field during various tube well installations to ascertain the general texture of sediments encountered in the bore holes. Based on soil texture, it has been found that the area which generally comprises of alluvium can be subdivided vertically into three zones i.e. fine to medium sand, medium to coarse sand with gravel and medium sand. All the wells in Figure 2 are correlated to check the continuity of these depositional units in the subsurface (Fig. 4). On the basis of this correlation, the whole section can be divided into three hydrostratigraphic units.

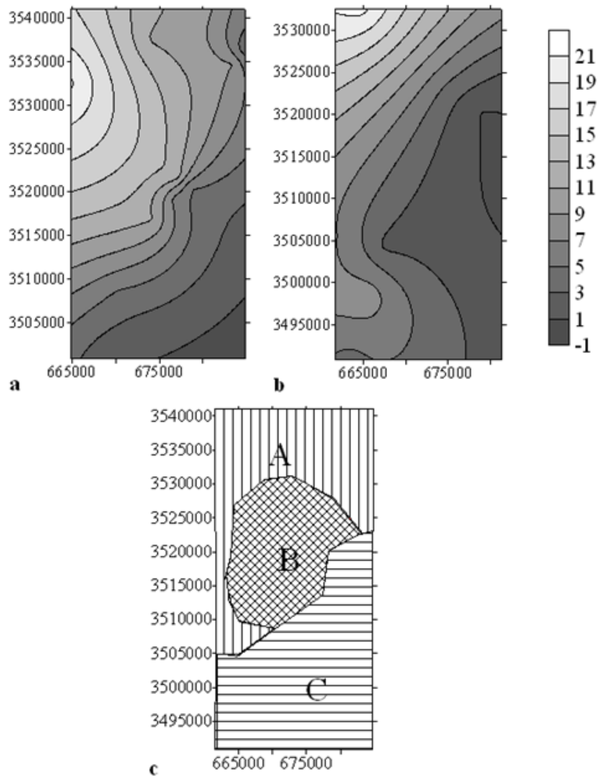

Fig. 2. Water table depth contour maps of 1976 (a) 1996 (b) aquifer lateral zonation map (c) of Dera Ismail Khan.

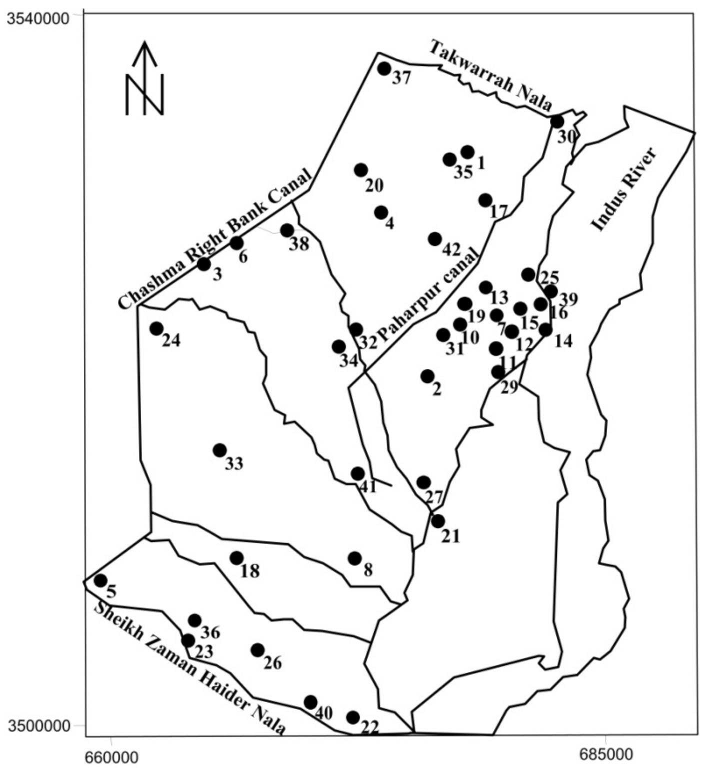

Fig. 3. Location of wells in the study area (Coordinates in Universal Transverse Mercator (UTM) meters).

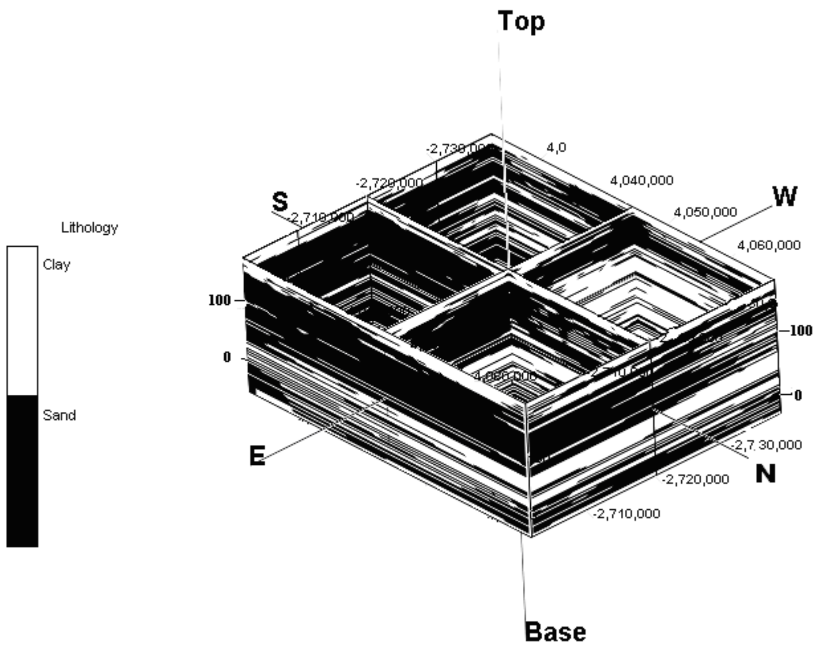

Fig. 4. Subsurface lithologic Fence diagram of the study area based on the well correlations.

The lateral zonation of unconfined aquifer on the basis of hydraulic conductivity is done by the help of an algorithm method in Figure 5 (e.g. Sun et al., 1995; Tsou et al., 2006). The mean of the hydraulic conductivities is taken for each textural unit in all the wells in Figure 3 during pumping tests (e.g. Malik, 1985) and the detailed conductivity zonation is done by the following formulae as Equations. (1) and (2).

$K_H=\sum b^n K^n/b$ (1)

$Kv=b/\sum (b^n/k^n)$ (2)

K_H Horizontal hydraulic conductivity in x and y dimensions.

Kv Vertical hydraulic conductivity.

(m) Number of depositional units in the block.

b^n total thickness of the nth depositional unit in the well.

K^n the mean hydraulic conductivity associated with the nth geological material.

The lithologic model and the conductivity distribution map are compared with the general physiography of the area. The same maps are also compared with the water table zone maps of the area to determine the factors involved in the changing water table levels. An attempt has been made to assess the groundwater recharge with this data using the method described by Healey and Cook (2002).

Recharge by Water Table Fluctuation (WTF) method can be estimated using the equation (3)

$R(t_j) = Sy \times \Delta H(t_j)$ (3)

where $R(t_j)$ (cm) is recharge occurring between times t_0 and t_j, Sy is specific yield (dimensionless), and $\Delta H(t_j)$ is the peak water level rise attributed to the recharge period (cm).

3. Discussion

On the basis of this study an unconfined and confined aquifers are found in the area of investigation (Fig. 4). Due to enormous usage of the shallow unconfined aquifer, attention has been focused to know the response of this aquifer in water logging and perched water table formation. As already stated that the unconfined aquifer contains three layers (Table 1). The aquifer thickens eastward due to the deposition of sediments by the Indus River. Sand is the most prominent depositional unit. The clays form lenses and at some places networks leading to partial confinement of the aquifer. However, there are areas where clay lenses at the shallower depths may create perched water table contributing to water logging (e.g. Cox and McFarlane, 1995) (Fig. 4).

Table 1. General statistics of the data set for unconfined aquifer layer's textures and hydraulic conductivities (K).

Serial No.	**Layers**	**Number of wells utilized**	**Texture of the layer**	**Average layer top (m)**	**Average Grain size (mm)**	**Mean K (m/d)**	**Max. K (m/d)**	**Min. K (m/d)**
1	L 1	45	Fine to medium sand	5	0.125-0.3	7.588	16	1
2	L 2	45	Medium to coarse sand with gravels	42	0.3-0.5	15.449	25	2
3	L 3	45	Medium sand	60	0.3-0.4	28.281	69	1

Abbreviations: m= meter; mm= millimeter; m/d= meter per day; Max= maximum; Min= minimum and K= hydraulic conductivity.

The temporal change of groundwater levels from years 1976 to 1996 is due to increase in utilization and recharge of the groundwater (Figs. 2abc). In general the groundwater table depth is decreasing in the northeast and increasing towards southwest (Figs. 2ab). The comparison between the two years reflects a rising trend in year 1996. On the basis of water level change the study area can be divided into three zones (Fig. 2c). The A and C zones possess very minor or no change in water level at all, whereas the B zone has a major rise of water levels up to 2m. The recharge estimated using WTF is a change of 30 cm in between the wet and dry season. This change multiplied by the specific yield (S_{y}) gives the recharge value of 6 cm during 1976. This value of the recharge is quite coherent with the previous calculations of recharge (e.g. Naqvi, 1977). The 6 cm of recharge is the normal change interpreted in 1976. Subtracting the 6 cm out of 0.7 m recharge calculated for the 1996, the remaining recharge of 0.64 m is an additional input from various other sources including the irrigation and tube well decrease.

The comparisons of the water levels suggest that there was no water logging in general in the study area except where the older canal existed. The commencement of CRBC seemed to be a blessing for the area from the point of view of water table rise which otherwise be lowered in the absence of this canal in the rapidly growing urbanization with massive irrigation activities. There were 100 tube wells in 1985 and 8000 dug wells reported by Malik (1985). The extraction of groundwater is increased to about more than 10,000 tube wells and 20,000 domestic wells in 1996. There is one major problem that the water levels are continuously rising and the tube well irrigation is reducing in the Canal Command Areas (e.g. Ahmed, 1972; Kijne and Jacob, 1996).

The zonation of unconfined aquifer system has been done on the basis of the hydraulic conductivity of aquifer (Fig. 5). It has been found out that these can be classified into three classes. The hydraulic conductivity values are lower towards the western portion and near the tributaries in the area due to the presence of clay lenses in the sand brought by Indus tributaries.

Hydraulic conductivity distribution clearly shows a strong relation with the water table rise. Higher hydraulic conductivity zones show very less change. Whereas the low to medium conductivity zones show a rise of water levels and these are the areas where there is a chance of water logging.

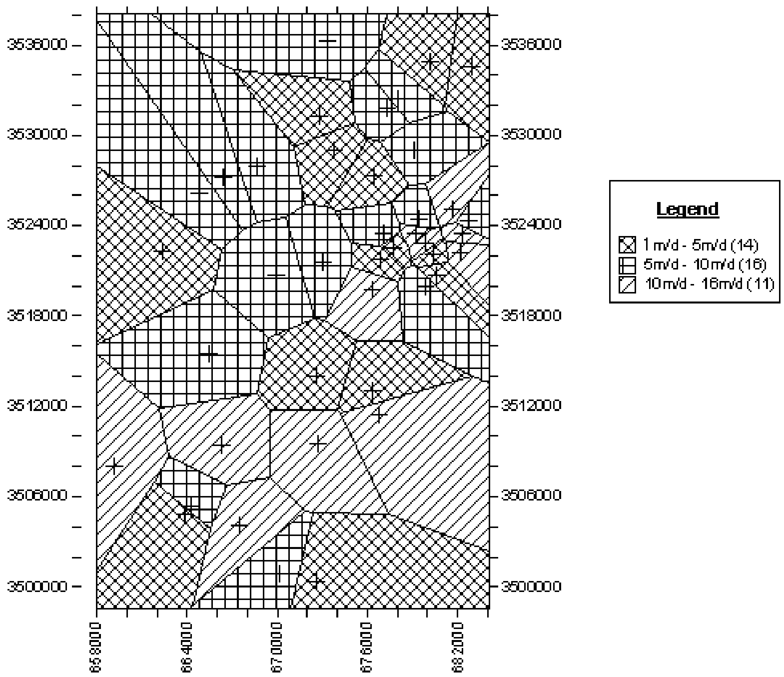

Fig. 5. Hydraulic conductivity lateral zonation of unconfined aquifer.

Apart from lesser activity of tube well irrigation the groundwater is also used for the domestic activities. The rise of water levels is linked to the land degradation that may ultimately lead to the water logging if proper measures are not taken. The important measure in this regard is to put some subsurface drainage points at the higher hydraulic points to get the groundwater levels in equilibrium.

4. Conclusions

Two aquifers an unconfined and a confined aquifer are found in the study area. The recharge calculated for the year 1976 in unconfined aquifer was 6 cm in one hydrologic year. It is also found that the groundwater levels are rising due to the more groundwater recharge available in the form of canals, distributaries and minors supported by the recharge difference determined i.e. 0.64 m in 1996.Three distinct vertical depositional units i.e. fine to medium sand, medium to coarse sand with gravels and medium sand are also determined. On the basis of changes in water level depths and the hydraulic conductivity, three lateral zones are identified. The middle B zone is having low hydraulic conductivity than the other two zones and is found more susceptible to be water logged. The presence of low hydraulic conductivity is a consequence of clay lenses.

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