Int. J. Econ. Environ. Geol. Vol. 12(2) 45-49, 2021

Journal home page: www.econ-environ-geol.org

Open Access

ISSN: 2223-957X

Fault Control on Groundwater Flow in An Alluvial Aquifer, Chaman and Khojak Basins, Balochistan, Pakistan

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Received: *11 December, 2020* ***Accepted:*** *17 May, 2021*

Abstract: Geological structures such as faults play a critical role in the flow of fluids in a reservoir by affecting its permeability. This study explores the role of the Chaman Fault in the distribution of hydrological division, groundwater separation of the aquifer systems of Khojak and Chaman basins. The Chaman Fault is a left-lateral strike-slip transform plate boundary located at the border city of Chaman, District Killa Abdullah, Balochistan. The Chaman fault plays an important role in the division of groundwater in the subsurface, accommodating the structural compartment of the aquifer system. The studies showed that the strike-slip movement of the fault made the aquifer impervious along the fault line. This assertion may also be confirmed by the drastic change in the water table across the fault. Sharp changes in the groundwater table and Total Dissolved Solids (TDS) were observed during the study. The Karazes which are an indigenous method of irrigation is present in the eastern foothills of Khojak mountains called Khojak basin. Here the water table is as shallow as ≈ 6 meters in comparison to the western side of the fault, where the water table drops to ≈274 meters towards the valley of Chaman basin. The average TDS level on the eastern side of the fault line is 773 mg/L and 1361 mg/L on the western side. Therefore, the Chaman fault is acting as a groundwater barrier which is feeding the Karezes for centuries.

Keywords: Chaman fault, Karez, hydrogeology, strike-slip, Kojak basin aquifer.

Introduction

The Chaman fault is tectonically active plate boundary between the Indian and Eurasian plates. The Chaman fault is a large and active fault around 860 kilometres long, stretching along the Pak-Afghan border region (Ul-Hadi et al., 2013). It is one of the world's major terrestrial transform faults that runs back and forth between Afghanistan and Pakistan, ultimately merging with some other faults and going to the Arabian Sea in the south (Ul-Hadi, et.al, 2013).

Recent InSAR and GPS studies show slip rates of 18± 1 mm/yr in the Chaman fault (Mohadjer et al., 2010), and ~8 mm/yr slip rate according to post-seismic studies (Furuya and Satyabala, 2008). The first geomorphic-based rate derived from an actual displacement along the strand of the Chaman fault is 33.3 ± 3.0 mm/yr (Ul-Hadi et al., 2013). The Chaman and Khojak basin provide accommodation for the alluvial sediments eroded from the uplifting Khojak Pass mountains recording the interplay between this huge alluvial fan system and the Chaman Fault system (Ul-Hadi et al., 2013).

The mean annual rainfall in Chaman is 308mm with a variation of 25mm (Ali, 2015). Centuries ago, population centres have been developed near water sources including natural flowing springs. With the growth of population, springs were developed into Karezes, and subsequently, wells and tube wells were drilled, which resulted in stressing the aquifers. Two major cities in Balochistan named Chaman and Nushki are settled along the fault line because of the water availability of natural springs along the Chaman fault. The Khojak Pass mountain is the main source of sediments for Khojak and Chaman basin (Fig.1). Strike-slip and thrust fault interaction is common to be resulting in different landforms (Cowie and Scholz, 1992; Jackson et al., 1996).

Physiographically, the Chaman area can be divided into four units i.e mountain, highland, pediment plain, and valley floor (Fig. 1). The depressions developed at the foothills of Khojak mountains against the active Chaman fault became depocenter of sediments from nearby mountains. Strike-slip motion along the fault causes streams offsets which is the evidence of active fault motion (Fig. 2). Although the Khojak Pass mountains provide the bulk of the sediments in the central part of the basin, numerous boulders and framework sediments are sourced from the Khojak mountains. Reworked sediments from the Chaman fault zone contributing to the sediment budget of the Khojak and Chaman basins. The pop-up zone along Chaman fault including Roghani Ridge blocking Bostan kahol fan sediments to erode down to Chaman basin (Fig. 2). The geologic characteristics of the Chaman fault system undergo strike-slip displacement, which resulted in the juxtaposition of different aquifers with different lithology; consequently, making a drastic change in the water table on either side of the fault.

Structural geologists, especially the ones who are specializing in the mechanical association of crustal fluid and seismologists have a great interest in the fault zones where fluid pressure is active (Hickman et al., 1995). This study is aimed to study subsurface hydrogeology along the Chaman fault, its source of water including subsurface hydro-stratigraphy. It is also aimed to observe, if the Chaman fault is acting as a barrier for the subsurface water flow. The Chaman fault may have separated two different types of aquifer adjacent to each other with different watertables. The subsurface hydrogeology of either side of the Chaman fault was studied. In this paper, an original methodology is described to combine structural and hydrogeochemical information to understand the aquifer systems. It also helps to predict the capabilities that will contribute to the effective management of the water resources in future.

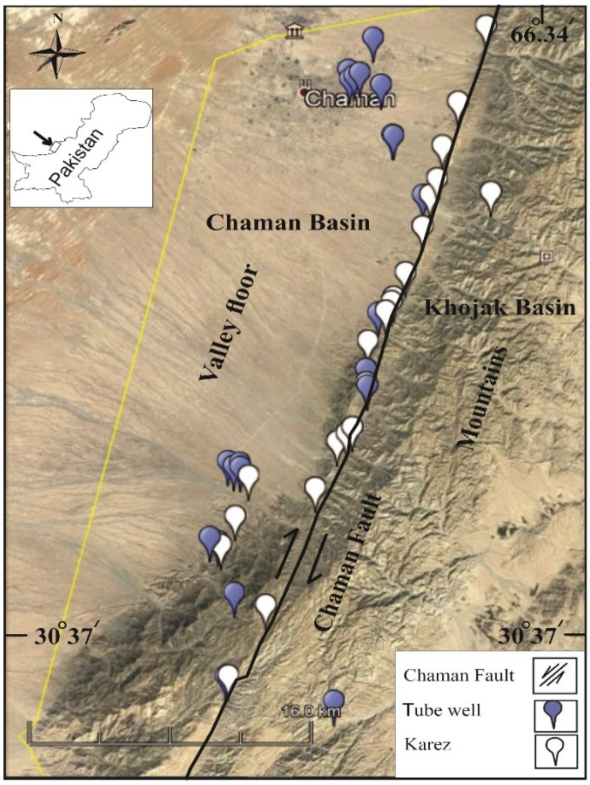

Fig. 1. Google Earth image 2021, showing physiographic features of Chaman area, location of tubewells and Karezes district Killa Abdullah.

The Chaman area is now subjected to obvious climate changes as well (Naz et al., 2020). The reduction in precipitation over the last three decades has affected the availability of water for Chaman. The scarcity of water resources has elevated by increasing water consumption for the growing population of the area since 1900 (Kummu, et al., 2016). The existing water of the Karez system could not meet the demand of the local population. Subsequently, hundreds of tube wells were drilled in Chaman basin for water, which is now a priced commodity.

Material and Methods

Geological, hydrogeological, and hydrogeochemical studies were conducted to determine the hydrogeological behaviour and the role of the Chaman fault. Water samples were collected from both aquifers on either side of the Chaman fault to recognize hydrological faces. The water chemistry is very dynamic, largely controlled, and modified by its medium of contact. An increase in Total Dissolved Solids (TDS) moving away from the Chaman fault towards the Chaman basin may be due to the contamination occurring due to water travelling in the pores of alluvium.

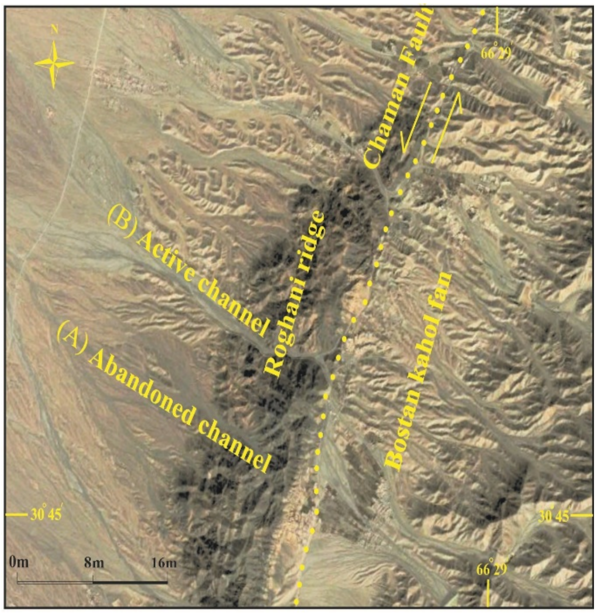

Fig. 2 Google earth image showing Roghani Ridge and Bostan kahol alluvial fan. A part of the fan has displaced left-laterally along a strand of the Chaman Fault. The evolving Roghani ridge records stream deflection from the abandoned channel A to the active channel B.

The reason for a low TDS in the Khojak basin is a very thin cover of alluvium that exists. The main aquifer is the Khojak Formation, which is a hard rock from where freshwater is entering into alluvium (Fig. 3). As water travels into the alluvium away from the Khojak basin it gets more and more contaminated. Hydrologically, the Chaman area can be divided into two main aquifers, i.e. Khojak and Chaman basins (Fig. 4). About 19 Karezes are located in the Khojak basin at the eastern side of the Chaman fault, here the water table is at ≈6 meters, while the water table of the tubewells in Chaman basin is at a deeper level of ≈274 meters.

43 water samples were collected in total from both sides of the Chaman fault to measure the difference of its TDS. Among those 43 samples, 22 were collected from Karezes while the remaining 21 samples were collected from the tubewells. Three litres of polythene bottles were used as containers. Each bottle was rinsed with distilled water before pouring the sample water. The coordinates of each water sample were determined with GPS. Physical and chemical parameters i.e. temperature, conductivity, and pH were analyzed as in-situ using a field kit. The water chemistry tests were

done by the portable kit of (Consort C931). The calibration of the portable kit was done by pH4 and pH7. Then the electrode of the portable kit was dipped and values were noted.

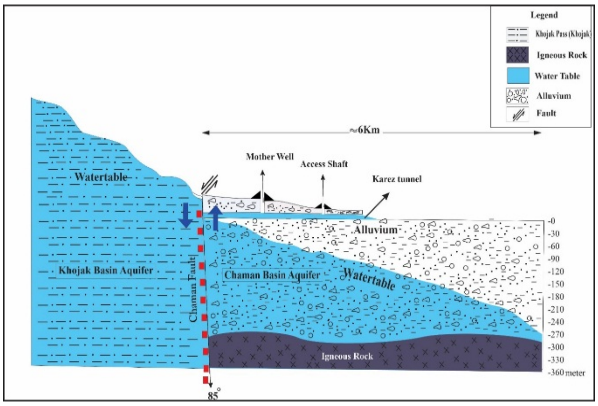

Fig. 3 Sketch showing Karez model, a centuries-old technique to tap water from a source through an excavated tunnel in the alluvium/ alluvial fan of mountain foothills. Spaced vertical shafts/wells are dug through the tunnel to remove excavated material and piled up around the shafts / open wells to protect from rainwater to flush in. Mother well is where the water table can be found, and the outlet is the last point where water can be brought to daylight to irrigate land and for domestic use.

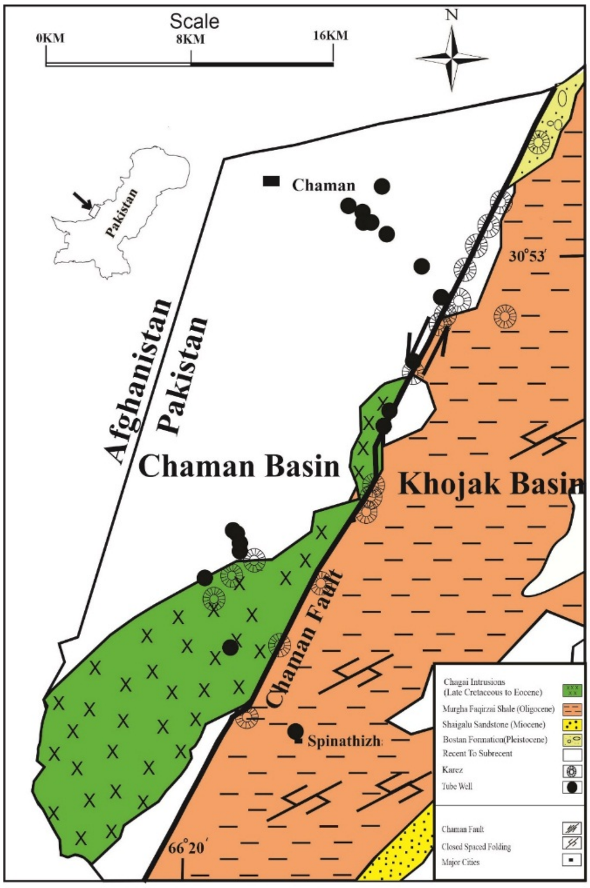

Fig. 4 Map showing Chaman fault, separating the two basins, i.e. Khojak basin and Chaman basin. Approximately all Karezes are positioned in Khojak basin on the eastern side of Chaman fault because the water table is shallow ≈6 meters and while Approximately all the tubewells are operational in Chaman Basin in the west of Chaman fault, here the water table is deeper ≈274 meters. (modified after Kakar, et al., 2016).

Results and Discussion

In Bostan area of Chaman (30˚46'21.13"N, 66˚29'2.09"E) the fault plane can be observed in a metamorphosed rock (Fig. 5). The dip of the fault plane is 75^0 and the strike is N 22^0 E. The pitch angle of the slickensides is 3^0 clockwise.

Fig. 5 Field photograph showing the slickensides of Chaman fault plane in Chagai volcanic in the Roghani igneous complex Bostan.

This outcrop suggests that the altered compacted zone is extended deep in the subsurface beneath the water level, obstructing groundwater to Chaman basin, lying at the west of the Chaman fault. However, on the surface, the rain runoff recharges the Chaman basin. The active Chaman Fault can be traced along its length by uplifted Quaternary hillocks of alluvial deposits (Lawrence et al., 1992). Observing the surface exposures and the hydrological data, it can be assumed with confidence that the same impervious materials are present beneath the water level.

When a fault system is found in the crust, it controls the hydraulic properties of that area by fault rocks, mineralization, the core of the fault, and the fractures in the damaged zone (Caine et al., 1996; Mitchell and Faulkner, 2012). From the hydrogeological perspective, a fault generally acts as a barrier for the flow but sometimes it may act as a sink if the permeability of the fault zone is higher than the surrounding sediments, and the trend of the fault zone is the same as the flow of groundwater in the host sediments (Muirwood and King, 1993).

There is a significant difference in the groundwater of Khojak ≈6 meters and Chaman basin ≈274 meters. The fault zone is acting as a barrier to the groundwater flow between both basins. The permissible limit of Total dissolved solids (TDS) in the drinking water is 1000 mg/L (WHO, 1993). However, in the study area, the TDS values of Tube well water samples indicate about 261-2200 mg/L with an average of 1361 mg/L, which is slightly higher than the permissible limit (Fig. 6, 8). In Karez water, the values varied between 242-1062 mg/L with an average of 773 mg/L (Fig. 7, 8). Total dissolved solids (TDS) can have an important effect on the taste of drinking water. The taste of water with a TDS level of less than 600 mg/litre is generally considered to be good, while drinking water becomes increasingly unpleasant at TDS levels greater than 1200 mg/litre.

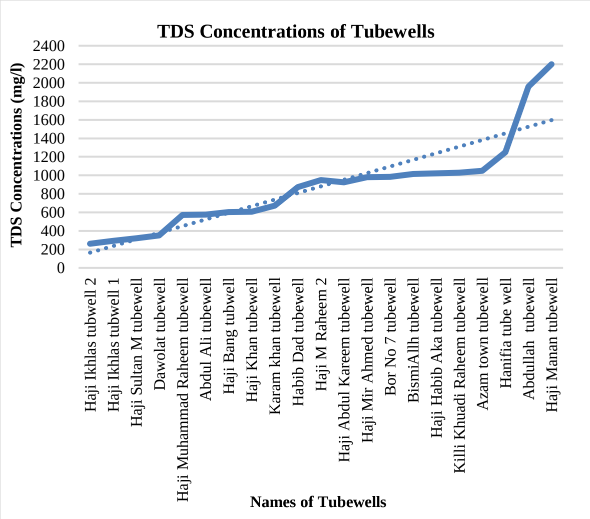

Fig. 6 Showing names of different Tube wells and TDS concentrations.

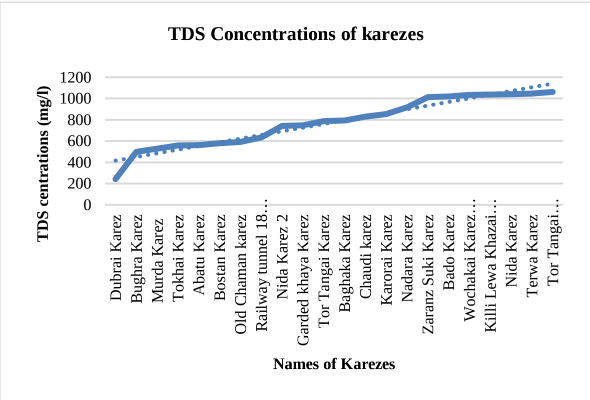

Fig. 7 Showing names of different karezes and TDS concentrations.

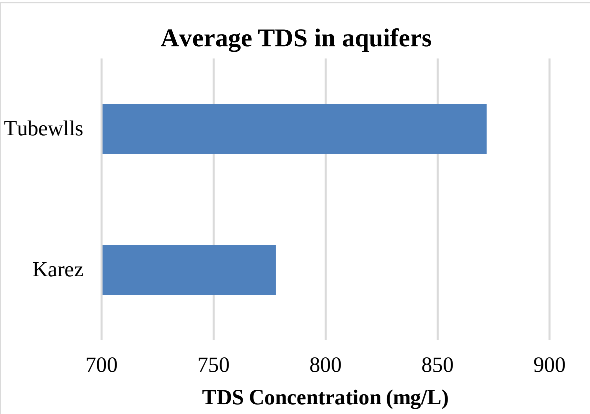

Fig. 8 The difference in TDS concentrations of Tube wells and Karezes.

Conclusion

Due to significant difference in the groundwater table of Khojak ≈6 meters and Chaman basin ≈274 meters as well as the presence of clay and silt in the fault zone, it is concluded that the fault zone is acting as a barrier to the groundwater flow between these two basins. The TDS values of Karez water varied between 242-1062 mg/L with an average of 773 mg/L. While the Tubewell water samples indicate about 261-2200 mg/L with an average of 1361 mg/L, which is slightly higher than the permissible limit (1000 mg/L). This may suggest a deep tectonic process associated with faulting. Subsurface sampling and geophysical surveys may be conducted on the Chaman fault for a more comprehensive study of these two reservoirs and their behaviour towards groundwater flow.

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