Int. j. econ. environ. geol. Vol:7(2) 10-19, 2016

Open Access
ISSN: 2223-957X
www.econ-environ-geol.org

Land Subsidence Caused by Groundwater Exploitation in Quetta Valley, Pakistan

Najeebullah Kakar[1], Din Mohammad Kakar[2], Abdul Salam Khan[3], Shuhab D. Khan[4]

[1]Irrigation Department, Government of Balochistan, Pakistan.
[2]Department of Geology, University of Balochistan, Quetta, Pakistan.
[3]Centre of Excellence in Mineralogy, University of Balochistan, Quetta, Pakistan.
[4]Department of Earth and Atmospheric Sciences, University of Houston, USA.

*Email: najeebullahkakar991@gmail.com

Received: *17 June, 2016* ***Revised:*** *14 July, 2016*

Abstract: Land subsidence is affecting several metropolitan cities in developing as well as developed countries around the world such as Nagoya (Japan), Shanghai (China), Venice (Italy) and San Joaquin valley (United States). This phenomenon is attributed to natural as well as anthropogenic activities that include extensive groundwater withdrawals. Quetta is the largest city of Balochistan province in Pakistan. This valley is mostly dry and ground water is the major source for domestic and agricultural consumption. The unplanned use of ground water resources has led to the deterioration of water quality and quantity in the Quetta valley. Water shortage in the region was further aggravated by the drought during (1998-2004) that hit the area forcing people to migrate from rural to urban areas. Refugees from the war torn neighboring Afghanistan also contributed to rapid increase in population of Quetta valley that has increased from 0.26 million in 1975 to 3.0 million in 2016. The objective of this study was to measure the land subsidence in Quetta valley and identify the effects of groundwater withdrawals on land subsidence. To achieve this goal, data from five Global Positioning System (GPS) stations were acquired and processed. Furthermore the groundwater decline data from 41 observation wells during 2010 to 2015 were calculated and compared with the land deformation. The results of this study revealed that the land of Quetta valley is subsiding from 30mm/y on the flanks to 120 mm/y in the central part. 1.5-5.0 m/y of groundwater level drop was recorded in the area where the rate of subsidence is highest. So the extensive groundwater withdrawals in Quetta valley is considered to be the driving force behind land subsidence.

Keywords: Land subsidence, water depletion, GPS, Quetta, GIS, Pakistan.

Introduction

Quetta is the capital city of Balochistan located in the Quetta valley. The total watershed area of the valley is 1757 km^2 out of which 792 km ^{2} is covered mainly by alluvium (Fig. 1). Quetta valley falls in the southern basin watershed also known as Quetta Pishin sub basin which is part of North East Pishin Lora Bain (NEPL). The hills of Mian Ghundi and Landi divide the valley into two basins namely Quetta valley to the north and Dasht plain in the south (WAPDA, 1988; Kazmi, 1973). Quetta valley is formed by three kinds of distinguishing landforms. The first landform is valley floor which is present in the central part of the valley. The second landform is Piedmont areas which is the zone between valley floor and mountains. Here the groundwater is mainly recharged due to high hydraulic conductivity (WAPDA, 1986). The third landform is the elevated mountains with steep inclinations that include Zarghoon, Takatu, Daghari, Chiltan and Murdar mountain ranges (Haque, 1986).

The aquifer system of Quetta valley is divided into four types. The uppermost aquifer is called the alluvial fan, this zone has high porosity and high permeability due to coarse grained sediments. The hydraulic conductivity is very high in this zone and groundwater is mainly recharged from this zone. Currently this zone is dry due to water depletion of the valley. The second aquifer of Quetta valley is called alluvium. This zone has intermediate porosity and permeability and is composed of gravels, sand and clay particles. The third zone is called the Boston Formation which has very low hydraulic conductivity due to the presence of silt and clay particles. The fourth zone of Quetta aquifer system is the Chilton Limestone. The primary porosity of this zone is low but due to high tectonic activity the fractures are developed making the secondary porosity very high. This zone is composed mainly of limestone. The depth of Chilton Limestone varies in the valley. In the northern end of Quetta valley the depth of this bed rock is about 1500 meters and about 1058 meters to the southern end (Alam and Ahmed, 2014). The unconsolidated alluvial aquifer and the bed rock are hydraulically connected to each other (Halcrow and Cameos, 2008; TCI, 2004; Kazmi et al., 2005).

The active Left-Lateral Chaman fault on the western side of Quetta valley splits the Eurasian and Indian plates making the geology of the area very complex. The stratigraphic sequence starts from Early Jurassic to Quaternary deposits in Quetta valley (UNDP, 1982; Kazmi, 1973; Hunting, 1961; Kazmi and Reza, 1970).

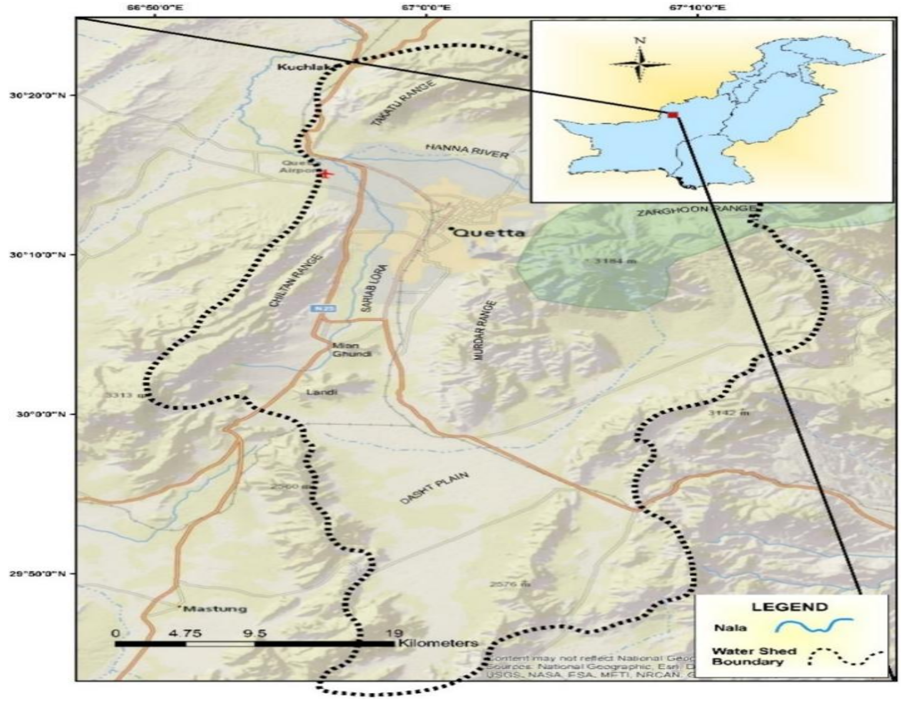

Fig. 1 Showing the location of the study area. The watershed boundary of Quetta sub basin is shown by the dotted lines whereas rivers are shown by blue lines.

The population of Quetta valley has increased several folds in the past 30 years. Groundwater is the main source for domestic and agricultural consumption. The Quetta valley alluvium aquifer is under substantial stress due to decreasing groundwater resources (WAPDA, 1989). Overexploitation of groundwater has created several problems in the valley that include significant groundwater decline in several parts of the valley, deterioration of water quality and subsidence of land (TCI, 2004; Khan et al. 2013; Khan et al., 2010). Land subsidence due to urbanization is reported in several metropolis around the world that include Shanghai in China (Yin el al., 2006), Tokyo in Japan (Hayashi el al., 2009) and Santa Clara valley in United States (Galloway et al., 1999).

Fissures were being developed in the central part of the Quetta valley, where the unconsolidated material is thick. These fissures cover an area of about 1000 meters long and 200 meters wide. They were 3 meters deep and 1 meter wide at some places and have damaged several buildings in its path (Fig. 2). These fissures may be developed due to the compaction of sediments after the withdrawal of the groundwater. GPS data also suggest increased subsidence in the central part as compared to the flanks of the Quetta valley where the rate of subsidence is minimum.

The objective of this study was to evaluate the groundwater decline in Quetta valley, to identify land subsidence in specific zones of the valley, to find out the causes of groundwater decline and to quantify the land cover over time using remote sensing in ArcGIS.

Materials and Methods

Groundwater decline data of the year (2010-2015) was obtained from Irrigation Department and Water and Sanitation Authority (WASA). These data were collected from 41 observation tube wells installed throughout the city. Land subsidence was measured using GPS units installed at five locations throughout

Fig. 2 Left photograph showing the fissures in Kechi Baig area, whereas the right photograph shows the damage caused to Dr. Sarfaraz hospital, Gai Khan Chowk, Quetta.

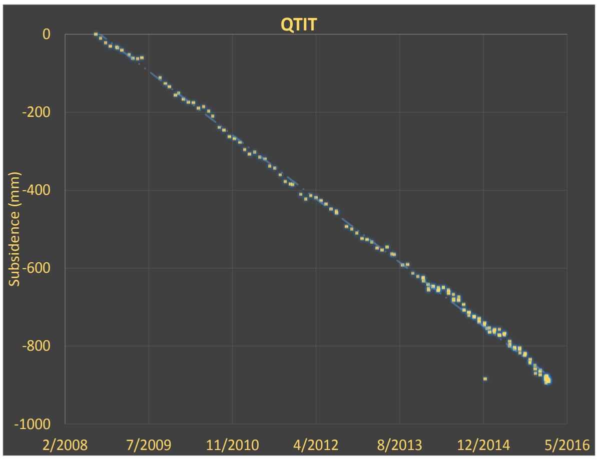

Fig. 3a Graph of GPS data for QTIT station, 120 mm/y subsidence recorded on this site.

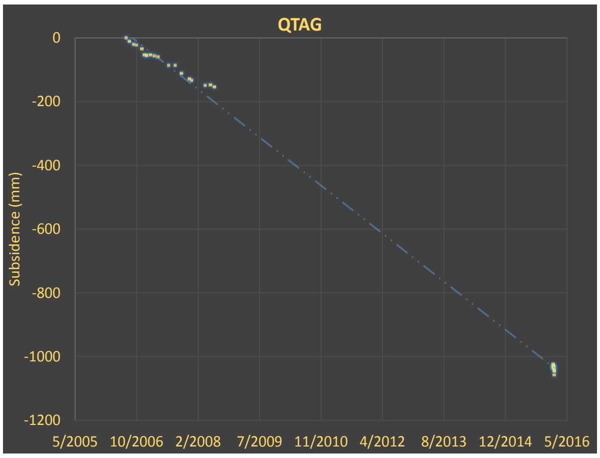

Fig. 3b Graph of GPS data for QTAG station, 106 mm/y subsidence recorded on this site.

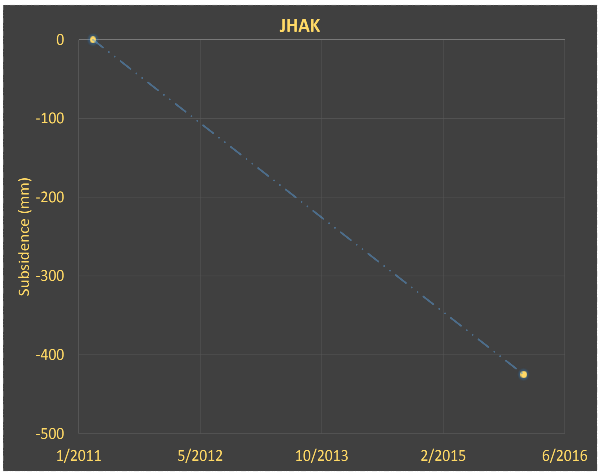

Fig. 3c Graph of GPS data for JHAK station, 88.3 mm/y subsidence recorded on this site.

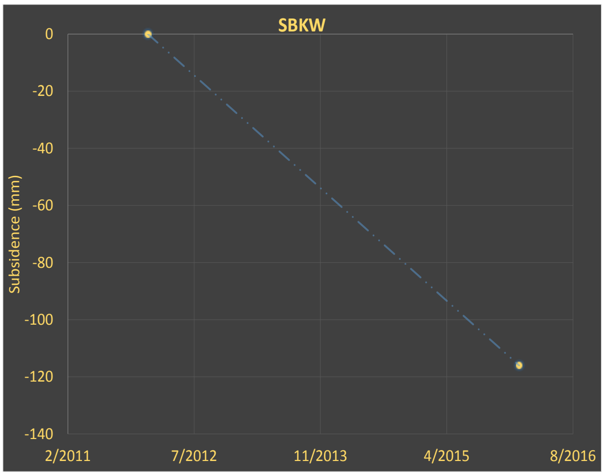

Fig. 3d Graph of GPS data for SBKW station, 29 mm/y subsidence recorded on this site.

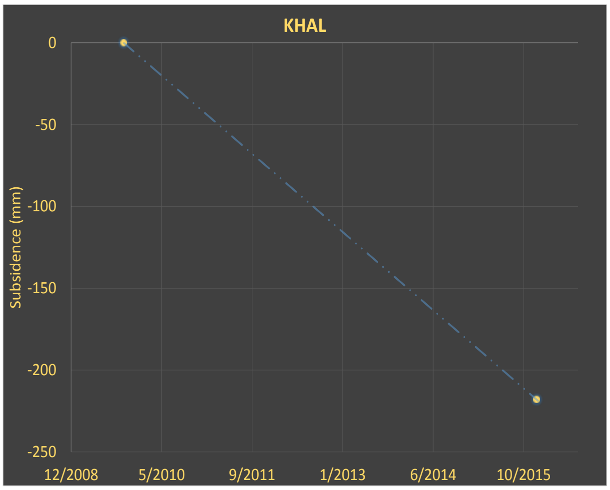

Fig. 3e Graph of GPS data for KHAL station, 35.1 mm/y subsidence recorded on this site.

the city. The GPS data were collected using Trimble Net Rs 5700 and R7 receivers that download data after every 30 seconds. The accuracy of GPS unit was 1 mm in X, Y and Z axis. Its antenna is placed on a concrete flat floor which needs at least 4 satellite connections to work properly. GPS data were processed in GAMIT software that was referenced in ITRF2008 frame, then linear trend was fit into the result to get the rate. These data were processed in Department of Earth and Atmospheric Sciences, University of Houston. Field survey was done to assess the damages caused by land subsidence. Water Decline data were processed in ArcGIS 10.2 and contour maps were made using (IDW) inverse distance weighted interpolation

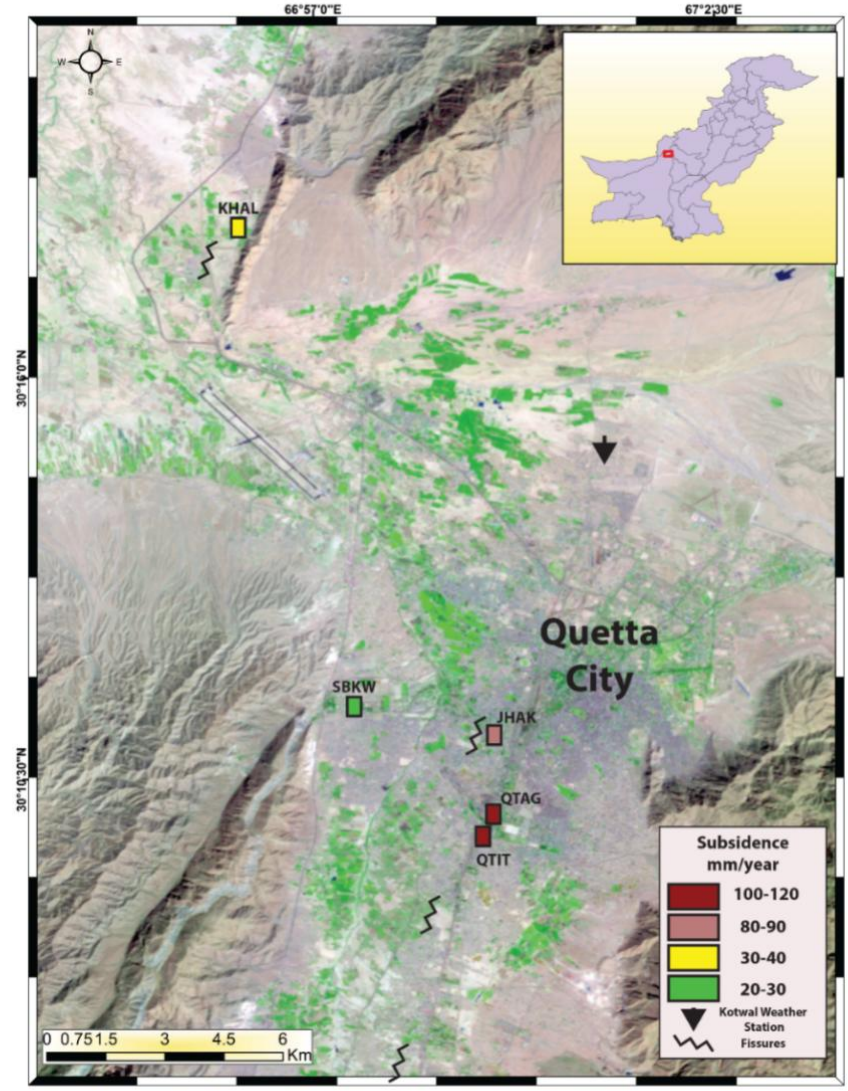

Fig. 4 Map showing subsidence in the Quetta valley. The dark brown color shows subsidence of 100-120mm/y, the light brown color shows subsidence of 80-90 mm/y, the yellow color shows subsidence of 30-40 mm/y, the green color is showing subsidence of 20-30 mm/y. The fissures can also be seen on the map, whereas the Kotwal weather station is shown by a black arrow.

technique. Remote sensing images were processed in ArcGIS 10.2 to assess the increase in vegetation over time. The precipitation data were obtained from the surface water monitoring wing of the irrigation department.

Land Subsidence

Land subsidence is the sinking or lowering of land which is mostly caused by fluid withdrawal. The underground microscopic pore spaces are filled with water molecules which make up the hydrostatic pressure in a pore. When the water molecules are extracted through a tube well, a vacuum is formed and the hydrostatic pressure diminishes in the void. As a result the pore space collapses and the whole ground is subsided.

Land subsidence in Quetta valley was first reported by Khan et al. (2013) when a drop of about 10 cm/y was recorded by GPS data in the valley. The network of these GPS points was extended to five locations in the valley to get more results. Two of these sites were located in University of Balochistan that was code named as QTIT and QTAG. The other point was located at Arbab Karam Road that is code named as JHAK. The next site was located at Sardar Bahadur Khan Woman University, which is code named as SBKW. The last site is located on a gas station that is adjacent to the Frontier Corps Camp and is code named as KHAL. QTIT is a permanent station that continuously downloads data from the GPS device whereas the rest of the stations were campaign sites where GPS device was installed for one week during the field.

Results and Discussion

QTIT

The first reading on QTIT station was recorded on 25th August 2008, whereas the last reading was taken on

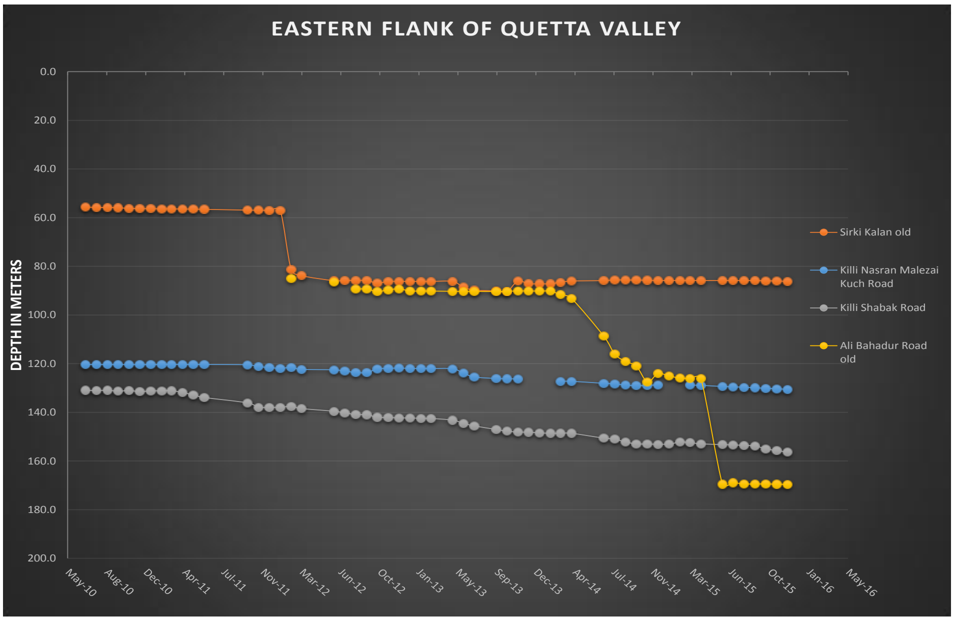

Fig. 5a Graph of water decline on eastern flank of Quetta valley. The average decline recorded in this zone is 1.5-5.0 meters/y.

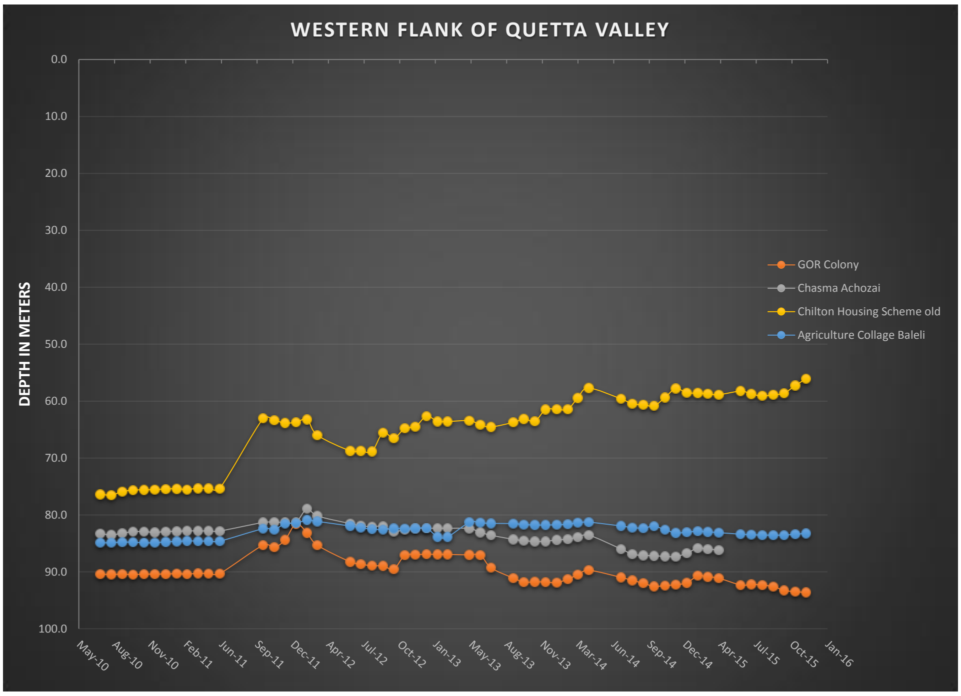

Fig. 5b Graph of water decline on western flank of Quetta valley. The average decline recorded in this zone is 0.5-1.5 meters/y. The observation well in Chilton Housing Scheme shows rise in water table.

22nd January 2016. Its latitude is 30°16'29" and longitude is 66°.98'88". The total subsidence recorded during this duration was 890 mm (0.8 m), whereas the annual subsidence recorded on this station was 120.2 mm/y (Fig. 3a).

QTAG

The first reading on QTAG station was recorded on 17th July 2006, whereas the last reading was taken on 24th January 2016. Its latitude is 30°16'6" and longitude is 66°99'0". The total subsidence recorded during this time period was 1036 mm (1.0 m), whereas the annual subsidence recorded on this station was 106.8 mm/y (Fig. 3b).

Jhak

The first reading on JHAK station was recorded on 6th June 2011, whereas the last reading was taken on 17th January 2016. Its latitude is 30.18506981 and longitude is 66°99'1". The total subsidence recorded during this duration was 430 mm, whereas the annual

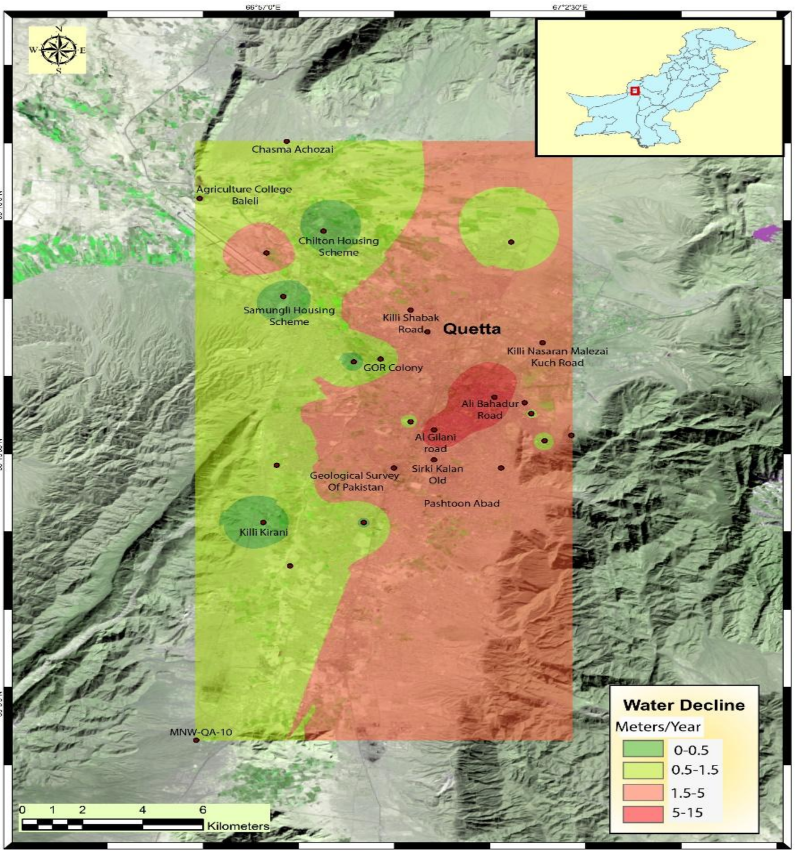

Fig. 6 Map of water decline in Quetta valley. The red and dark red color show the water decline of 1.5-15 meters/y whereas, the green and dark green color show the water decline of 0-1.5 meters/y.

subsidence recorded on this station was 88.3 mm/y (Fig. 3c).

SBKW

The first reading on SBKW station was recorded on 9th January 2012, whereas the last reading was taken on 12th January 2016. Its latitude is 30.191 and longitude is 66.959. The total subsidence recorded during this duration was 116 mm, whereas the annual subsidence recorded on this station was 29 mm/y (Fig. 3d).

KHAL

The first reading on KHAL station was recorded on 10th April 2009 whereas the last reading was taken on 9th January 2016. Its latitude is 30°30’1” and longitude is 66.933. The total subsidence recorded during this duration was 218 mm, whereas the annual subsidence

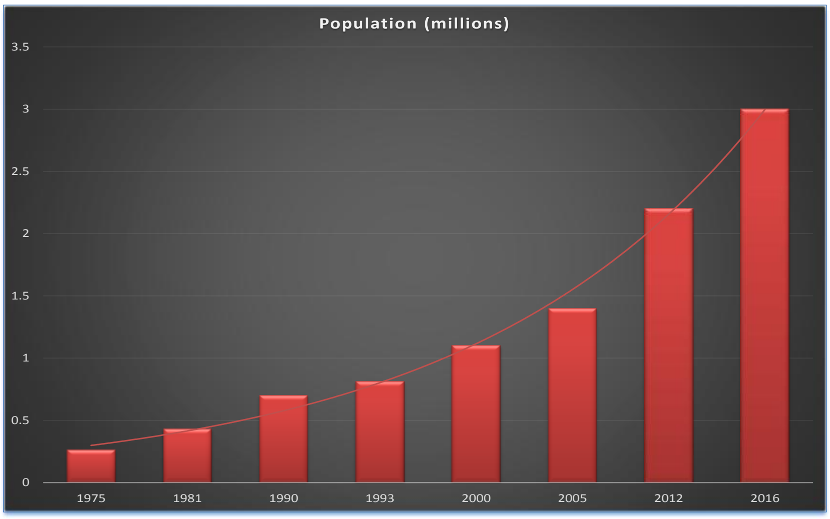

Fig. 7 Graph of population in Quetta valley which increased from 0.26 million in 1975 to 3.0 million in 2016.

recorded on this station was 35.1 mm/y (Fig. 3e).

The annual subsidence rate detected from the GPS data is shown in Figure 4. The dark brown color shows the highest rate of subsidence i.e., 100-120 mm/y, the light brown color shows the subsidence of 80-90 mm/y, the yellow color shows subsidence of 30-40 mm/y and the green color displays subsidence of 20-30 mm/y. Location of the fissures can also be seen in this figure.

Groundwater Depletion

The pioneer artesian well in Quetta valley was dug in 1889 at railway station using steam engine (Oldham, 1892). The depth of the well was 35 meters while the hourly discharge was 20,000 gallons (Oldham, 1892). But over the time water started to decline in the Quetta valley and WAPDA started monitoring of groundwater in Quetta valley in 1988. Around 177 observation tube wells were installed in the Pishin Lora Basin to observe the groundwater conditions. The depths of those wells ranged from 3.5 meters to 150 meters. Due to overexploitation of groundwater, around 123 observation wells were completely dried up and now 54 observation wells are operational. A drop of 0.25 meters per year was first observed by WAPDA in 1989 (WAPDA, 2001). Ahmad (2007) recorded decline of 1.09 meters in the 1990`s. In the 2000`s Water and Sanitation Authority (WASA) installed several new observation wells in Quetta valley to monitor the

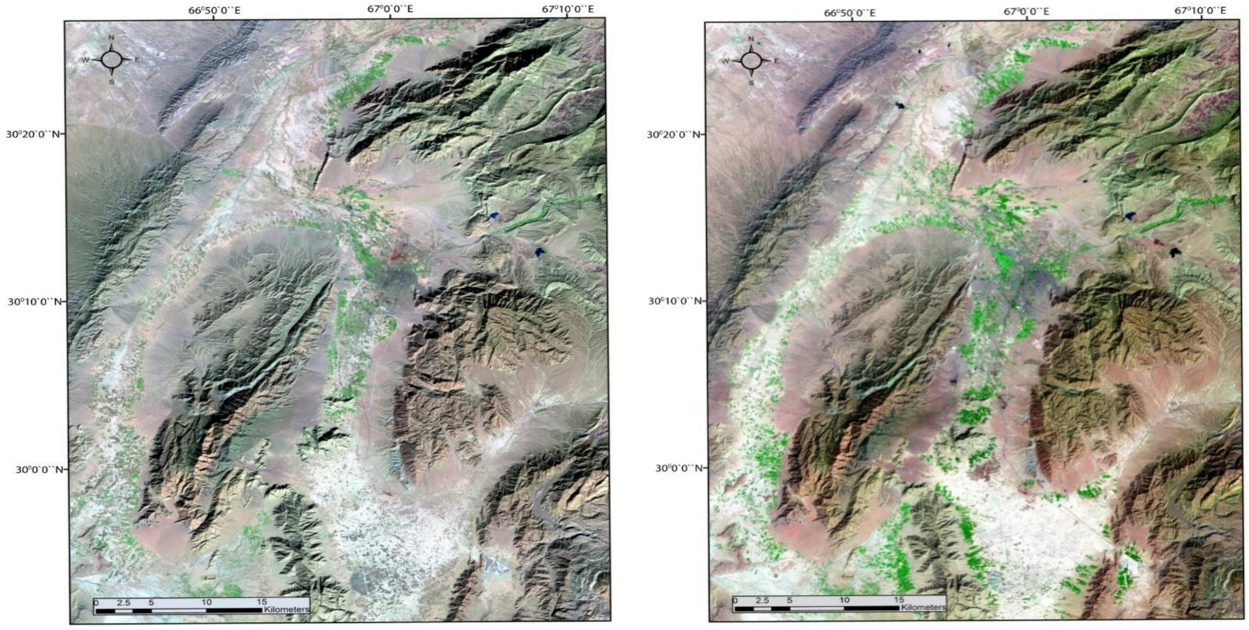

Fig. 8 Landsat Thematic Mapper bands 7, 4 and 2 displayed as red, green and blue showing the vegetation increase overtime in Quetta valley. The left image is from 21st June 1987, whereas the right image from 16th August 2011. Increase in vegetation can be seen in bright green colors in the northern and southern end of Quetta valley.

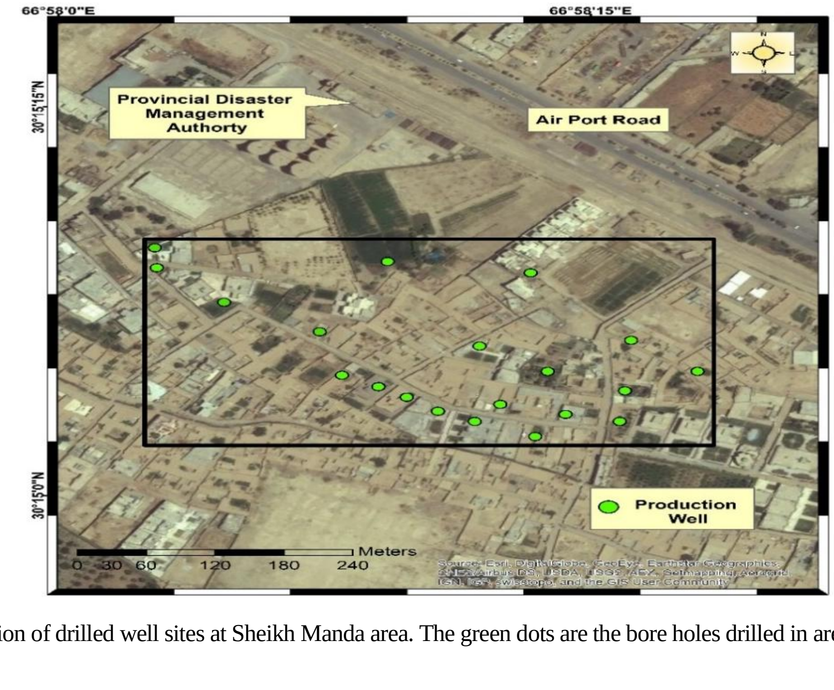

Fig. 9 Location of drilled well sites at Sheikh Manda area. The green dots are the bore holes drilled in area of 1.3 km^2.

groundwater decline. The depletion of Quetta valley water table was calculated from the year 1987 to 2010 from 55 observation wells. The average decline during this period was 1.5 meter per year in several parts of the valley (Khan et al., 2013).

To get the latest groundwater level, data from 41 observation wells were collected from WASA and Irrigation Department for the year 2010-2015. The average decline from 2010-2015 were calculated and surface was generated using Inverse Distance Weighting (IDW) interpolation technique in ArcGIS. It was observed that the average decline on the eastern side of the valley is high (1.5-5.0 m) (Fig.5a), where the population is congested, while on the western side the depletion is low (0.5-1.5m), where the population is scarce (Fig. 5b).

zone covers the whole eastern part of Quetta valley. The yellow color is showing the annual decline of 0.5-1.5 m on the location of Chasma Achozai in the north and MNW-QA-10 in the south of the valley. The green color represents the zone, where the groundwater level is rising. This zone is located on Killi Kirani and Samungali Housing Scheme.

Causes of Water Depletion and Land Subsidence

Population

According to the census of 1975, the population of Quetta valley was just 260,000 and it steadily increased and reached 430,000 in 1981. Due to urbanization and migration of refugees from Afghanistan`s civil war, the population increased to 1.1 million in 2000. Due to drought in the last decade a lot

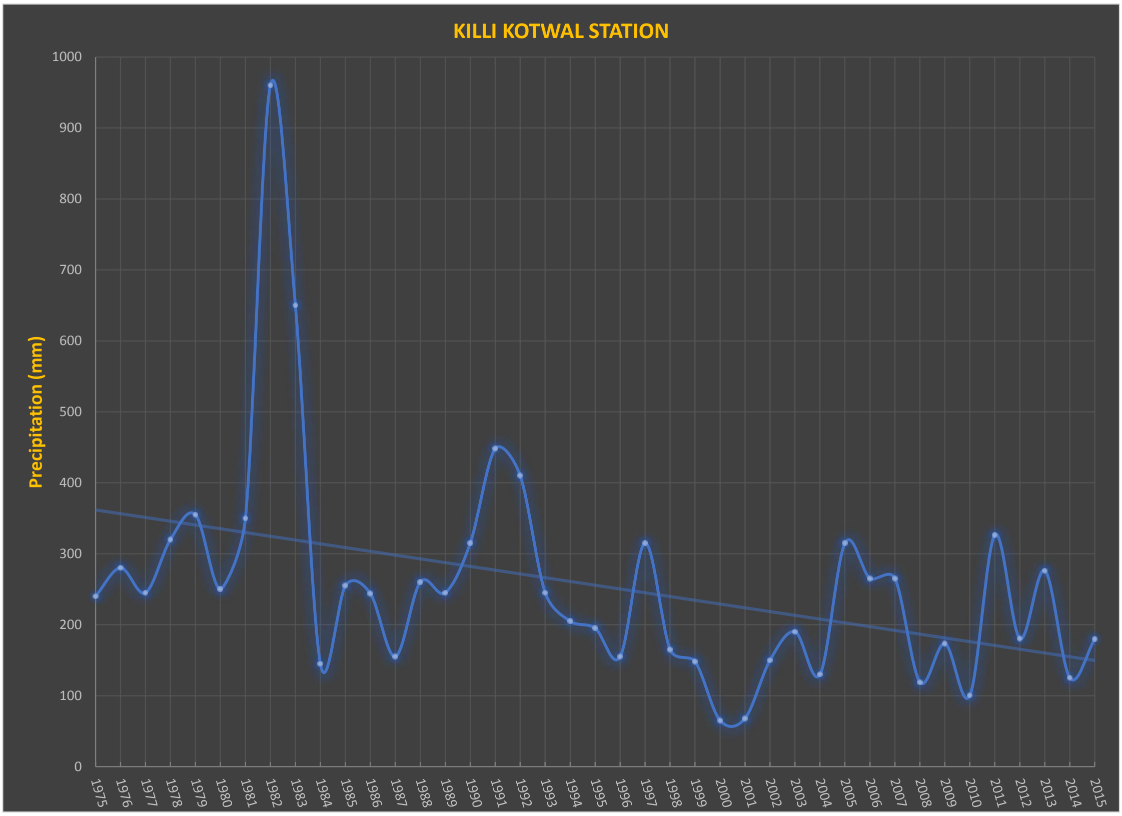

Fig. 10 Graph showing the precipitation data, precipitation gauge is located in Killi Kotwal Station in Quetta. Drought can be seen from the year 1998-2004, whereas heavy precipitation recorded in 2011.

In Figure 6, the dark red color shows the average decline of about 5-15 m on the location of Ali Bahadur and Al-Gilani road. The light red color shows the annual decline of 1.5-5.0 m on the location of Killi Shabak road and Killi Nasaran Malezai Kuch road in the north of the valley to Pashtoonabad and office of the Geological Survey of Pakistan to its south. This

Agriculture

Different crops are grown in Quetta valley that includes wheat, apricot and apples. The agriculture in

of people were forced to migrate to Quetta to earn their livelihood. According to recent estimates the population of Quetta valley is around 3.0 million in 2016 (Fig. 7). This huge population is a tremendous burden on the aquifer of Quetta valley and it is creating the problems of supply and demand in the valley due to which the aquifer is depleting at an alarming pace.

the valley has increased several folds as more people earn their livelihood from it. Groundwater is the only source used to grow these crops. Due to this phenomenon the groundwater is depleting at a faster rate. Two satellite images were processed in ArcGIS that were downloaded from USGS Global Visualization Viewer (GLOVIS) to see the land use pattern. These images were Landsat Thematic mapper at 30 m resolution from the year 1987 and 2011. Dramatic increase of vegetation can be seen in northern and southern end of Quetta valley (Fig. 8). The bands that were used to enhance the vegetation were 7, 4 and 2 displayed as red, green and blue respectively.

Illegal Drillings

Illegal drillers are drilling tube wells to extract groundwater resources without any authorization from the government. The data of illegal drilling sites is not available. To demonstrate the congestion of wells in the Quetta valley, an area of 1.3 km^2 was observed (Fig. 9). Out of the 20 wells, only one well was government owned. The illegal tube wells are supplying groundwater at unprecedented rate due to no check and balance.

Precipitation

The precipitation data of the year 1976-2015 was obtained from the Irrigation Department and plotted in Figure 10. Several fluctuations can be seen with the substantial drought which occurred during 1998-2004. During this drought the reservoirs of Spin Karez and Hana Urak which are situated to the eastern side of Quetta valley were completely dried up which resulted in significant water decline in Quetta valley aquifer.

Discussion

GPS results of Quetta valley illustrates that the subsidence is intense in the central part of the valley where the thickness of unconsolidated material is high. The average subsidence of QTAG and QTIT station has slightly increased over time. Khan et al., (2013) observed the average subsidence at QTAG station (2006-2008) as 81 mm/y and the average subsidence at QTIT station (2008-2009) as 116 mm/y, Whereas the average subsidence at QTAG station (2006-2016) has increased to 106 mm/y and the average subsidence at QTIT station (2008-2016) has increased to 120 mm/y. The subsidence at the flanks of the Quetta valley is far less than the central area e.g. the subsidence at SBKW is 27 mm/y and KHAL is 35 mm/y. In this zone the thickness of unconsolidated material is far less than the central part.

Increase in water depletion was also recorded during the study. About 1-1.5 m/y water decline was recorded at several places in Quetta valley during 1987-2010 (Khan et al., 2013; Ahmad, 2007), whereas the water depletion during 2010-2015 had reached 1.5-5.0 m/y.

Conclusion

GPS data show that the central part of the Quetta valley has subsided more than 1 meter during the last decade and continues to subside at about 120 mm per year. Whereas the subsidence at the flanks of the valley is about 30-40 mm per year. Due to land subsidence, fissures are being developed in several parts of the valley that has damaged several buildings. The groundwater is also depleting at an alarming rate that is 1.5-5.0 meters in several parts of the city. The increase in agriculture and population growth is the main cause of water depletion and subsidence in Quetta valley. The land subsidence and its associated fissures will cause damages of billions of rupees to the buildings in future, if this trend continues. The process may also mix fresh and sewerage water which will create health hazards in the city.

Acknowledgement

Najeebullah thanks his superior Syed Nadir Shah for his continued support. Author also thanks Abdullah Baryali, Jamil Ahmad Badini and Khalid Rehman for their help in collecting the groundwater and precipitation data.

References

Ahmad, S. (2007). Persistent drought of Balochistan and impacts on water availability and agriculture. *Water for Balochistan: Policy Briefings*, ***3***, 2010-2011.

Alam, K., Ahmad, N. (2014). Determination of aquifer geometry through geophysical methods: A case study from Quetta Valley, Pakistan. *Acta Geophysica*, ***62***, 142-163.

Cameos, H. (2008). Effectiveness of Delay Action/Storage Dams in Balochistan. TA-4560(PAK) Project, Asian Development Bank, Quetta.

Galloway, D., Jones, D. R., Ingebritsen, S. E. (1999). Land subsidence in the United States: U.S. Geological Survey Circular 1182, 175 p.

Haque, B. (1986). Water level behavior in northern part of Quetta valley. Hydrogeology Project, WAPDA, Quetta,Pakistan.

Hayashi, T., Tokunaga, T., Aichi, M., Shimada, J., Taniguchi, M. (2009). Effects of human activities and urbanization on groundwater environments: an example from the aquifer system of Tokyo and the surrounding area. *Science of the Total Environment,* **407**, 3165-3172.

Hunting, S.C. (1961). Hunting Survey Corporation. Reconnaissance Geology of part of West Pakistan, Balochistan, A Colombo Plan Cooperative Project, Toronto.

Kazmi, A., Abbas, G., Younas, S. (2005). Water resources and hydrogeology of Quetta Basin, Balochistan, Pakistan. Geological Survey of Pakistan, Quetta, 124p.

Kazmi, A., Reza, S. Q. (1970). Water supply of Quetta Basin, Balochistan, Pakistan. Geol. Surv. Pakistan Rec., **20**, 97-138.

Kazmi, S. (1973). Geohydrology of Quetta Valley. Hydrogeology Directorate, Reclamation Division, Water and Power Development Authority, *Pakistan*, 72p.

Khan, A. S., Khan, S. D., Kakar, D. M. (2013). Land subsidence and declining water resources in Quetta Valley, Pakistan. *Environmental Earth Sciences,* **70**, 2719-2727.

Khan, S. D., Mahmood, K., Sultan, M. I., Khan, A. S., Xiong, Y., Sagintayev, Z. (2010). Trace element geochemistry of groundwater from Quetta Valley, western Pakistan. *Environmental Earth Sciences,* **60**, 573-582.

Oldham, R. (1892). SubRecent and Recent deposits of t/te aalleT ptains of Quetta, Pishin and the Dasht-i-Bedaolat; with appendices on the Chamans of Qtetta and the Artesian water supply of Quetta and Pishin. *Rec Geol Surv lndia, **25***, 36-53.

TCI, C. ARD (2004). Techno Consult International Corporation, Cameous and Arab Resources Development. Research for water and sanitation authority, Quetta. *Quetta water supply and environmental improvement project, **2***.

UNDP. (1982). Groundwater studies in selected areas of Balochistan, Pakistan, Groundwater of Pishin Lora basin. *Technical Report,* **4,** 196 p.

WAPDA (1986). Overexploitation of groundwater in Quetta valley, Balochistan. *Hydrology Directorate General,* 26 p.

WAPDA (1988). Groundwater Level during 1967-88 in Quetta valley. *Hydrogeology project, Quetta, Basic Data Release No. 1.,* Quetta, Pakistan, 96 p.

WAPDA (1989). Groundwater mining in selected areas of Balochistan, Hydrogeology, Water and Power Development Authority, Quetta, Pakistan, 35 pp.

WAPDA. (2001). Individual Basinal Report of Balochistan, Hydrogeology Project, Quetta, 1982-2000. Water and Power Development Authority, Quetta, Pakistan.

Yin, Y., Zhang, K., Li, X. (2006). Urbanization and land subsidence in China. *Bull. Int. Assoc. Eng. Geol.,* **31**, 1-5.