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RESEARCH PAPER

Observed Long-Term Climatic Variability and Its Impacts on the Ground Water Level of Quetta Alluvial

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Abstract Water is an important natural resource. Groundwater is one of most vital and consistent source of renewed water globally containing areas which have extreme rainfall and abundant of surface water. This study assesses the climate impact on groundwater level using the precipitation, temperature data from 1946 to 2015, evapotranspiration, and monthly groundwater levels from 1987 to 2013 in Quetta Valley, Balochistan. The annual precipitation analysis identifies decreasing trends at all the gauging stations. The sharp increase in maximum temperature was observed during the late 90s. Similarly, mean monthly minimum temperature was observed well below normal 1947–1987, and afterwards, a sharp increase in minimum temperature was observed which was well above normal. The annual evaporation data analyzed which identified increasing trends at all the stations except Quetta city, where it has been decreased. The trends are found to be statistically significant at all the stations except Quetta city. Similarly, the rain data of different time periods have also been examined with the perspective to study its impact on the groundwater levels. The analysis explores the fact that the groundwater is continuously depleting due to variability in rainfall. The result also illustrates that groundwater level is decreasing day by day and the rainfall temporary influences for a very short time period on the groundwater level depending upon the consumption.

Keywords Rainfall · Evapotranspiration · Groundwater levels · Temperature · Declining

1 Introduction

The environment from place to place plays dominant effects on our lives. The departure of rain and sun affects the judgment of the people and has a deep relation with their daily lives behavior. However, when looking to the importance of the atmosphere, we know little about it (Ter kuile 2009). Most of the countries globally are continually facing acute shortage of water and cannot meet the irrigation, industrial, and domestic water demands. Climate change has additionally affected the situation by reducing precipitation in several countries, while the temperatures have been increased which further aggravated the situation

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by lessening the availability of water for all sectors (Holman 2006; Bates et al. 2008). The climate change in comparison with the socioeconomic assessments gets more importance and has direct impacts regionally (Holman et al. 2007). Hydrological systems are being affected by the climatic variables and any fluctuation in the precipitation patterns, changes in the evapotranspiration, increase or decrease in the snow may have an impact on the groundwater storage (Kløve et al. 2014a, b). Pakistan Water Partnership (PWP 2001) has reported that 59 billion cubic meter of groundwater is being extracted for agriculture, domestic and industrial sectors. Wet wintertime and dry warm weather in summer owed to seasonal fluctuations in precipitation and yearly increasing potential evapotranspiration and put some direct impacts. The water-level variation of the wetted areas is dependent on the meteorological fluctuations regionally and in the catchment areas (House et al. 2016). The depletion of groundwater level has been increased, since the beginning of the 20th century. Since 1900–2000, it is due to the reason that the water demand has been increased. However, the predicted increase from 2001 to 2050 is generally because of climate change which has arisen due to the decline in the availability of surface water and renewal of the groundwater and because of high rate of evaporation (Wada et al. 2012). To study spatial and temporal effects due to the climate change over the groundwater recharge, it is mandatory to adopt a physically based methodology (Jyrkama and Sykes 2007). Several studies have been conducted on the climate change effects on the surface water, but a slight consideration has been given to the climate change impacts on the groundwater. Despite of the fact that groundwater is main source for the drinking water in many countries of the world and is one of the important sources to preserve the environmental values of any area (Kumar 2015). The research results in the western Europe reveals groundwater reduction in the late summer season and slightly decreased in winter and spring in most of the upstream catchment areas (Dams et al. 2012).

Pakistan Meteorological Department (PMD) has measured temperature changes in the light of Intergovernmental Panel on Climate Change (IPCC) emission scenarios (A1, A2, B1, and B2) and observed that the surface air temperature in Pakistan has been raised by 0.099 °C/decadal from the period 1960–2010 with the total change of 0.47 °C (GoP 2013). The climate of Quetta features a continental and arid with significant variations between summer and winter temperatures. The highest temperature recorded in Quetta is 42 °C (108 °F) on 10th July 1998. The lowest temperature in Quetta is −18.3 °C (−0.9 °F) which was recorded on 8th January 1970.

Quetta Sub-basin is a part of Pishin Lora Basin (PLB) which is the one of thirteen major groundwater basins of Balochistan. The area of sub-basin extends from Latitude 29°40′ to 30°25′ N and longitude 66°50′ to 67°20′ and covers an area of 1860 km. Quetta itself is the district of Balochistan; which is the biggest province of the Islamic Republic of Pakistan in area. Quetta city is situated at about 30°–10′N and 67°–01′E, about 600 km north of Karachi and 700 km-west of Lahore. Quetta has an elevation of 1680 m above mean sea level. Table 1 shows the geographical location of the study area.

The research area consists of the Quetta North Basin, which is part of the Pishin Lora regional basin. It extends over an area of about 1300 km^2, with a maximum length and width of about 70 and 36 km, respectively (Sultan et al. 2013). The water table maps are constructed using measured water table data which indicate that the elevation of the water table decreases from the east and north towards the west. Figure 1 presents a satellite image of the study area.

1.1 Groundwater Resources Quetta Valley

The Quetta valley is located in an arid zone and is largely dependent on the groundwater resources for domestic, commercial, and agriculture use. The alluvial aquifer is the main source for the abstraction of water for all uses to the inhabitants of Quetta city. The studies reveal that there are more than 2300 tube wells and dug wells in operation installed by the government as well as privately in and around the valley. Most of these wells have been scheduled for operating between 20 and 24 h. Thus, over-pumping from the aquifer and the extraction rate exceeds the natural recharge rate which is probably one of the main factors to cause a steady depletion of the aquifer. This has been observed by the continuous monitoring of the observation as well as operational wells which showed drop of water levels in the wells. The thermal sensitivity scenarios result that climate change and other surface disruption will warm the shallow ground water, but this depends upon the duration and magnitude, surface conditions, aquifer bulk density, and groundwater speed (Kurylyk et al. 2015). The groundwater flow in the deep and shallow aquifers shares the hydrological cycle and climate variability has affected the process of recharge (Chen et al. 2002). In the hydrologic cycle studies, it is essential to consider the probable

Table 1 Geographical location of the study area

S. no.	Station	Longitude (E)	Latitude (N)	Elevation (m)
1	Quetta City	66°57′20.3″	30°11′09.0″	1695
2	Samungli	66°56′20.7″	30°15′46.6″	1585
3	Killi Kotwal	67°00′21.0″	30°14′05.5″	1660
4	Sariab	66°58′03.3″	30°06′22.0″	1715

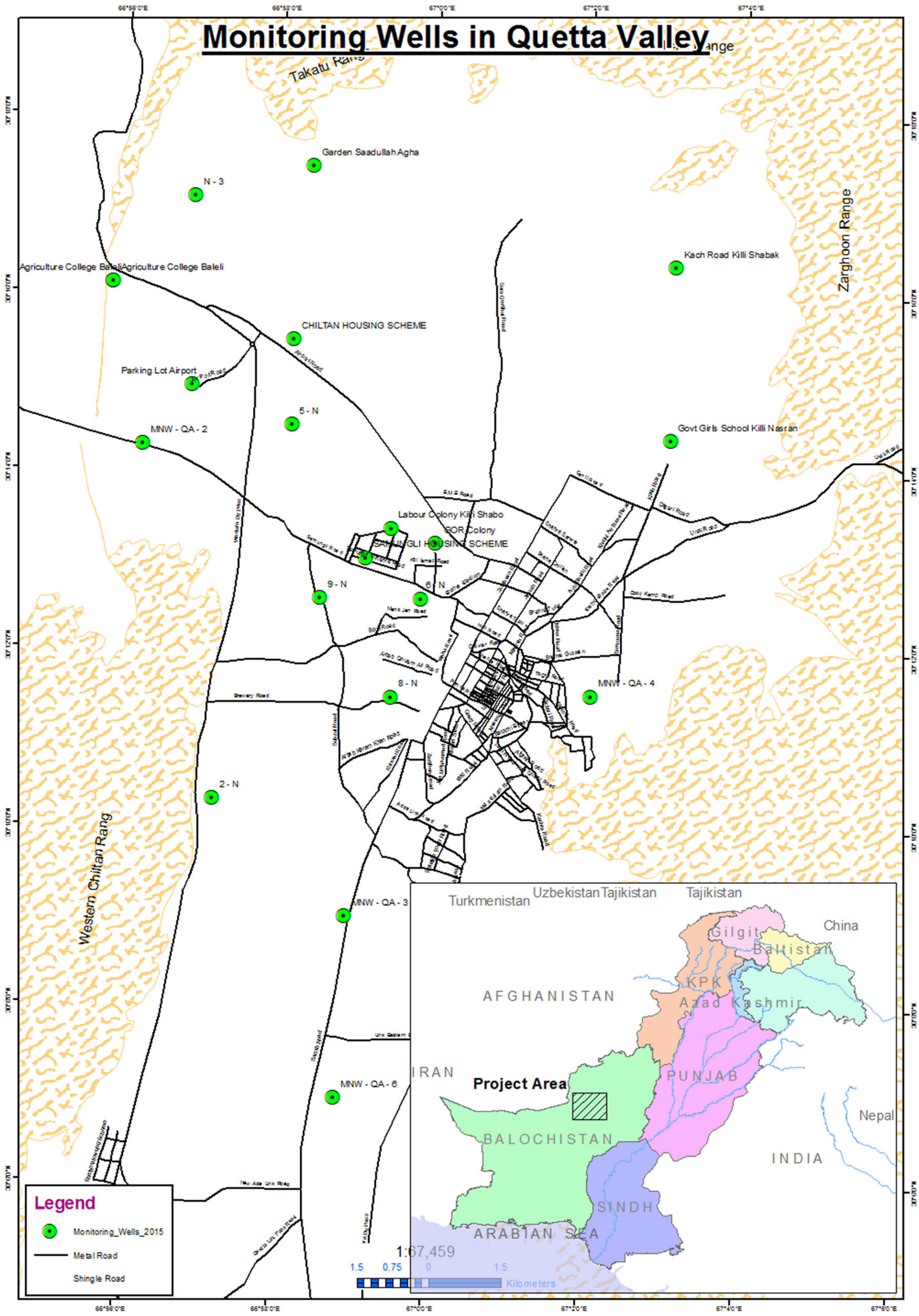

Fig. 1 Location and distribution of the monitoring wells of Quetta area

impacts of climate change on groundwater. It can be predicted that any change in the recharge will directly affect the groundwater that includes variations in precipitation and evapotranspiration, with a possible changes in the interactive behavior, naturally regulated among the groundwater, surface water systems, and irrigation (Kumar 2012). The irrigation water consumption along with the climate change impacts put pressure on ground water and ecosystem which ultimately damage the aquifer and groundwater ecosystem (Kløve et al. 2014a, b). The study conducted in Ghir Plain south of Iran to find out the relationship between the water table, temperature, and the rainfall. It has been proven that rainfall and the water table are directly linked, i.e., increase in rainfall raises the water table, while the temperature and the water levels are in reverse as the water table lessens with the increase in temperature (Naseri Ghiri et al. 2013).

Second, the prolonged periods of the drought in the recent past have also contributed in unbalancing the natural recharge, and resulted in worsening the situation. The estimated population of Quetta in 2005 based on the national population census was just over a million. Quetta's population including persons of Afghan origin which was 1.3 million and every fourth resident was an Afghan (Gazdar et al. 2010). This migration once again caused dramatic growth in the urban population and current estimates for Quetta are over 2.00 million. Precipitation is the main source of natural recharge to the aquifer (Majeed 2000) which falls over the catchment areas of Quetta subbasin. The surface water potential is almost negligible in Quetta as the ephemeral streams are found in southern parts, while most of the developments have been observed in northern regions of the valley. The ground water depends upon the texture, thickness, structure of saturated alluvial formation. The permeability and porosity of saturated formation depend upon size, shape compaction, and concentration of the particles. The aquifer porosity determines the water stored quantity. The hydrogeology attributes of Quetta valley, e.g., permeability and porosity and limestone, sandstone, and conglomerate beds of Eocene-Pliocene strata, are more significant (Umar et al. 2014). The mean annual rainfall in the valley is about 210 mm, over 80% of which falls during winter months from November to April. The rise in water levels is also observed during January to mid of April due to the recharge.

This study contributes to indicate the significant trend analysis regarding precipitation, temperature, and evaporation and identify the impacts of precipitation on the groundwater levels in alluvial of Quetta Valley. Furthermore, the details also benefit the water managers, politicians, and the government to take appropriate decisions for short-, medium-, and long-term measures to satisfy the consumers with the proper and continuous availability of water for them. Moreover, the results of the study may provide a gateway to the scientists for further investigation and exploration for surface water availability instead of dependence only on the groundwater.

2 Materials and Methods

The precipitation, temperature data for the period 1946–2015 have been collected from Pakistan Meteorological Department. Similarly, the evapotranspiration has been calculated from the temperature records and the groundwater-level data from the 17th observation wells were collected from the Water and Sanitation Authority (WASA) for the period of 1987–2013. These data sets were sorted out, categorized and organized in Microsoft Office (Excel) for different homogeneousness tests. The geographical Information System 8.2 was used to develop the study area maps and GPS to record the locations of the tube wells. Primary data were collected from 2007 to 2015 using water-level meter—model 1010, flat tape water-level meter.

The modified Hargreaves equation is used to calculate ET for Pakistan region (Eq. 1). The same equation is used in different climate locations in India (Subburayan et al. 2011; Patel et al. 2015):

$$\mathrm{ET}_{(\mathrm{MH\ arg})} = 0.0023R_a(T_{\max} - T_{\min})^{0.162}\left(\frac{T_{\max}+T_{\min}}{2}+17.8\right) \tag{1}$$

where ET $_{(\mathrm{M\ Harg})}$ is the estimated evapotranspiration using modified Hargreaves equation for Pakistan region. R_a is the extraterrestrial radiation (mm/day); $T_{\max}$ and $T_{\min}$ are the minimum and maximum temperature, 0.0023 and 0.162 are the Hargreaves coefficient and exponent, respectively, and 17.8 is the temperature coefficient as defined by Hargreaves (1994).

The water recharge is estimated by the multiplication of specific yield of the aquifer to the water-level rise in the tube well (Rasmussen and Andreasen 1959). The same approach of water table fluctuation (WTF) was used by many hydrologists in their study to measures ground water recharge (Meinzer and Stearns 1929; Gerhart 1986). This approach is simple and works well to estimate the water recharge in Tube well (Healy and Cooke 2002; Risser et al. 2005). The equation to calculate the ground water recharge of an aquifer is as follows:

$$R = \Delta h \times Y_s \tag{2}$$

where R is the water recharge Δh is the altitude of water table in inches, and Y_s is the specific yield of the aquifer, whose value is 0.20 for alluvium soil and 0.14 for bedrocks in Quetta region (Khurshaid 2011). Two statistical tests are used on annual precipitation and minimum and maximum temperature, i.e., Mann–Kendal test for linear trend (Mann 1945), and Sen's Slope test (Sen 1968) for slope magnitude at $\alpha = 0.05$ significance level. The partial correlation analysis (PCA) has been conducted among rainfall, evapotranspiration, mean temperature, ground water level (GWL), and ground water recharge (GWR). The PCA measures the linear relationship and strength among the variable along with the adjusting the effect of other variables.

3 Results and Discussion

The time series analysis has been conducted over a long period of 70 years (1946–2015), as shown in Fig. 2. The observed rainfall remained below normal during the two long periods, i.e., 1958–1979 and 1988–2000. However, two extreme amounts of rainfall 949.8 and 633.3 mm were observed during 1982 and 1983, respectively. The 5 year moving average also shows a decreasing trend over the period.

The mean monthly maximum temperature was remained well below normal during 1946–1969, 1973–1987, and 1990–1999. The sharp increase in maximum temperature was observed during the late 90s. Similarly, mean monthly minimum temperature was observed well below normal during 1947–1987. Afterwards, a sharp increase in minimum temperature has been observed which was well above normal. The linear trend shows sharp increase both in minimum and maximum temperature which may put a pressure in evapotranspiration rate in Quetta region.

The time series trend and magnitude of annual precipitation, temperature (maximum, minimum), and evapotranspiration are determined using non-parametric Mann–Kendall and Sen's slope approach, respectively. The annual precipitation analysis identifies decreasing trends at all the gauging stations. The trends are found to be statistically significant at all the stations except Quetta city. The magnitude of the significant trends is -5.53 mm/year at Samungli, -5.36 mm/year at Sairab, and -4.51 mm/year at Killi Kotwal. A significant increasing trend in the maximum temperature has been observed at all the stations except Killi Kotwal. The magnitude of maximum temperature has significantly increased (0.07 °C/year) at Samungli. The minimum temperature shows increasing trends at all the stations except Killi Kotwal, where it has decreased insignificantly. A significant increasing magnitude trends of 0.08 °C/year and –0.09 °C/year is observed at Quetta and Samungli, respectively.

The annual evapotranspiration analysis identifies increasing trends at all the stations. The trends are found to

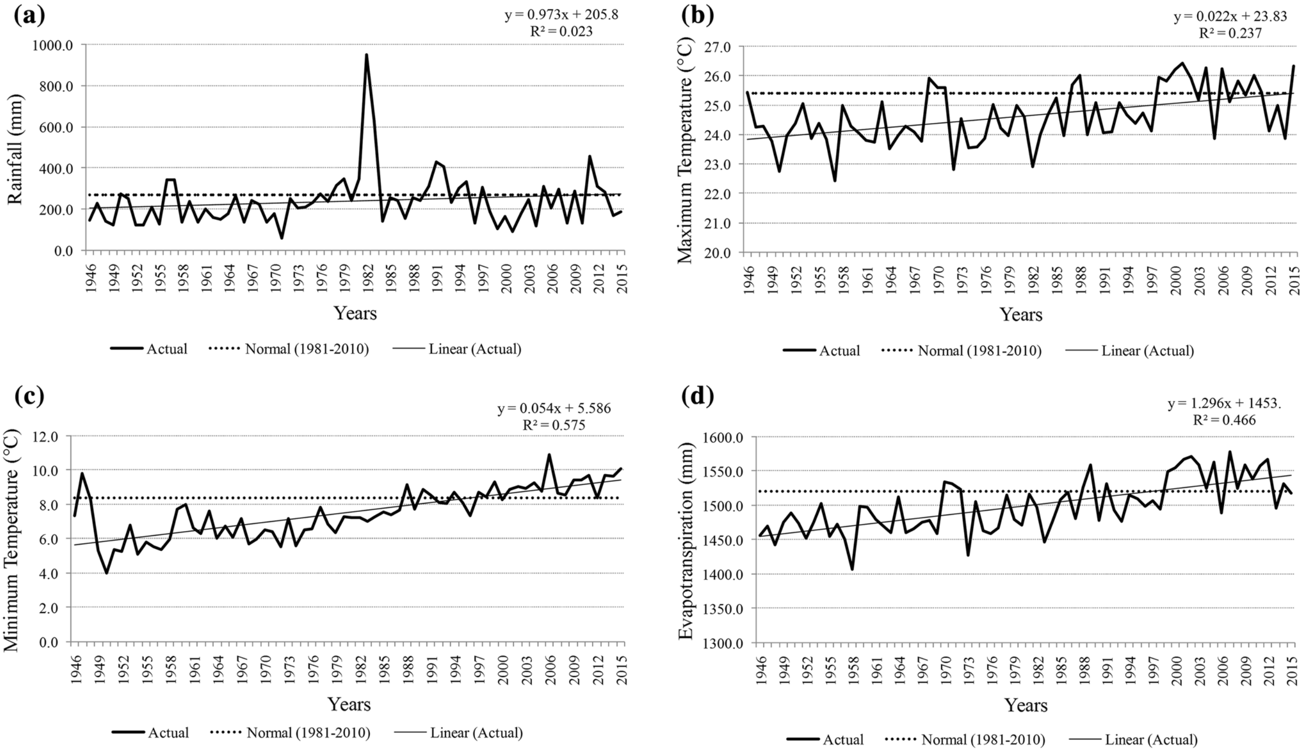

Fig. 2 Annual time series analysis of Quetta during 1946–2015. **a** Rainfall (mm), **b** maximum temperature (°C), **c** minimum temperature (°C), **d** evapotranspiration (mm)

Table 2 Significant analysis of precipitation, temperature (maximum, minimum), and evapotranspiration of study area

Parameters	Station	Quetta	Samungli	Killi kotwal	Sariab
Precipitation (mm)	Z	−1.51	**−2.03**	**−2.29**	**−2.59**
	Q	−2.41	−5.53	−4.51	−5.36
Maximum temperature (°C)	Z	**3.03**	**3.18**	−0.39	**1.81**
	Q	0.05	0.07	−0.02	0.05
Minimum temperature (°C)	Z	**5.26**	**5.00**	−0.21	1.23
	Q	0.08	0.09	−0.01	0.03
Evapotranspiration (mm)	Z	**5.50**	**4.74**	**4.73**	**5.04**
	Q	1.39	1.33	0.34	0.93

Bold letter represents 95% significant level

Z Mann Kendal, *Q* Sen Slope

be statistically significant at all the stations. The magnitude of the significant trends is 1.39 mm/year at Quetta, 1.33 mm/year at Samungli, 0.93 mm/year at Sairab, and 0.34 mm/year at Killi Kotwal (Table 2). The significant increase in temperature (max, min) and decrease in precipitation may enhance the evapotranspiration of that area and put a pressure on the water budget conditions and water demands of the crops (Fig. 3).

3.1 Rainfall Impact on the Groundwater

The rainfall and groundwater data since 1987–2005, i.e., was collected to evaluate the rainfall impacts over the groundwater fluctuations in study area. The various tube wells were selected from different sites of north, east, west, central, and south of Quetta Valley (Fig. 4).

The main objective of this research is to find out the deviation rate of water declining from the average values for each year. The values with the (−ve) sign shows the deviation of the decline of water below the average rate, and similarly, the (+ve) values indicate that the decline exceeds the average rate of water level. The formula to calculate the percentage departure of rainfall and ground water is as follows:

$$D = \frac{(X_j - \overline{X})}{\overline{X}} \times 100 \tag{3}$$

where D is the departure in percentage, X_j is the actual data, and $\overline{X}$ is the average. Figure 5a further explains that since 1995–2005, the water level declined rapidly and the rainfall impact is not reflected.

During the period 1989–2002, the water levels of different tube wells situated in the north of Quetta Valley 2-N, 5-N, 6-N, 8-N, and 9-N were considered to identify the relationship of rainfall and ground water levels. Figure 5b shows the declining of groundwater behavior remains similar low as there is low rainfall in some of the stations. However, it exceeded in the years from 1995 to 2002, even the rainfall departure was negative.

Another primary data set of tube wells and the rainfall was considered which lies in main city area, i.e., Gor colony, Government Girls School Killi Nasaran, Kuch Road Killi Shabuk, Parking lot area Airport and Samungli Housing Scheme. The departure of the water levels in (Fig. 5c) shows high deviations from the average values both above and below. The rainfall during these eight years remains low except 2008 and 2010.

In Fig. 5d, primary data of water levels have been collected from different tube wells for the period 2006–2007 to further rectify the behavior of fluctuations in the water levels in the valley. These tube wells are located in the North and the North east of Quetta Valley. The water-level departure in relation with the rainfall almost reflects the same pattern of declining of groundwater as projected in Fig. 5.

The partial correlation analysis of rainfall (R), evapotranspiration (ET), means temperature (T), ground water level (GWL), and ground water recharge (GWR) has been conducted of different tube wells installed in Quetta valley (Tables 3, 4). The results show that temperature and evapotranspiration are directly proportional to each other and inversely proportional to rainfall. The negative relation between rainfall and some tube wells shows that rainfall does not impact the ground water level/recharge of aquifer. The significant change (water level decreasing with the increase of rainfall) is observed in MNW-QA-2, MNW-QA-4, and Samungli housing scheme at 95% confidence level, where as the rest of the stations, i.e., 2-N, 9-N shows increasing trend with respect to rainfall. The negative value of recharge shows aquifer that is depleting and water table is gradually decreasing with the passage of time.

The ground water budget of aquifer of Quetta valley is calculated using the following equation:

$$\Delta S = P - \mathrm{ET} \pm \mathrm{RO} \pm \mathrm{GF} \tag{3}$$

where R is recharge, P is precipitation, ET is evapotranspiration, RO is runoff, and ΔS is change in storage. The values are calculated in inches.

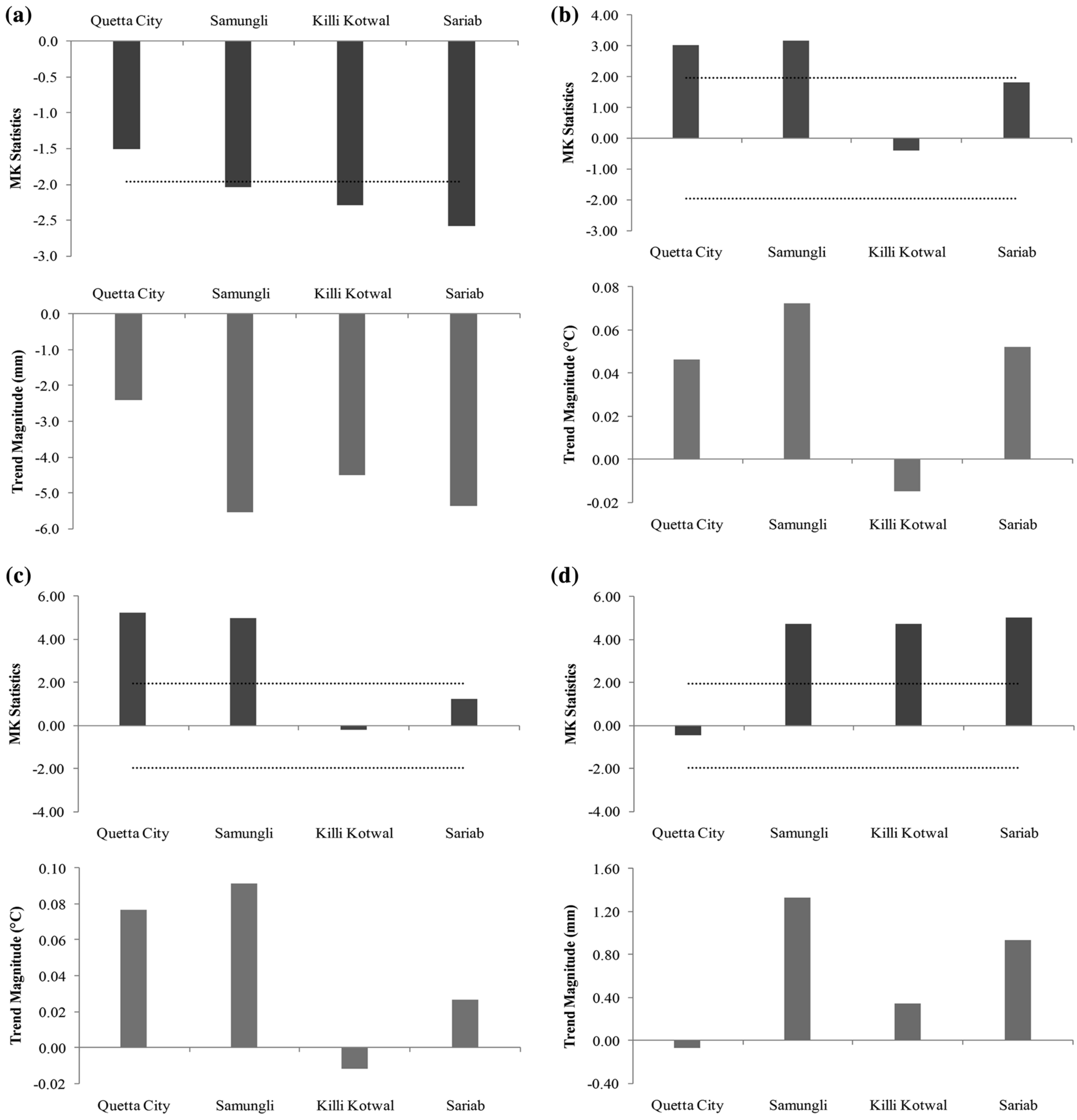

Fig. 3 Result of the trend test for **a** annual precipitation, **b** maximum temperature, **c** minimum temperature, and **d** evapotranspiration

The alluvial aquifer is the main source for the abstraction of water for all uses to the inhabitants of Quetta city. The natural inflow and discharge of Quetta alluvial aquifer was 54.9–103.0 mm^3 with no return/back flow during 2000–2015. The last fifteen year data (2000–2015) show that the domestic losses gradually decreased, but it was maximum (9.66 mm^3) in 2015, whereas irrigation needs were 7.0 mm^3 in 2000 which are reduced to 3.0 mm^3 in 2015. The total abstraction from alluvial aquifer was 74.99 mm^3 which has been reduced to 49.98 mm^3 in 2015. The maximum deficit of total hydrological balance was observed in 2000 which was −35.48 mm^3 whereas maximum surplus 13.94 mm^3 in 2005. However, afterwards, it starts to decrease to −24.49 mm^3 in 2010 and −0.34 mm^3 in 2015. The rainfall was below normal and drought conditions prevailed in Quetta valley during 2000 and 2010 which was one of the major reasons for deficit of water balance. The good amount of annual rainfall is one of the

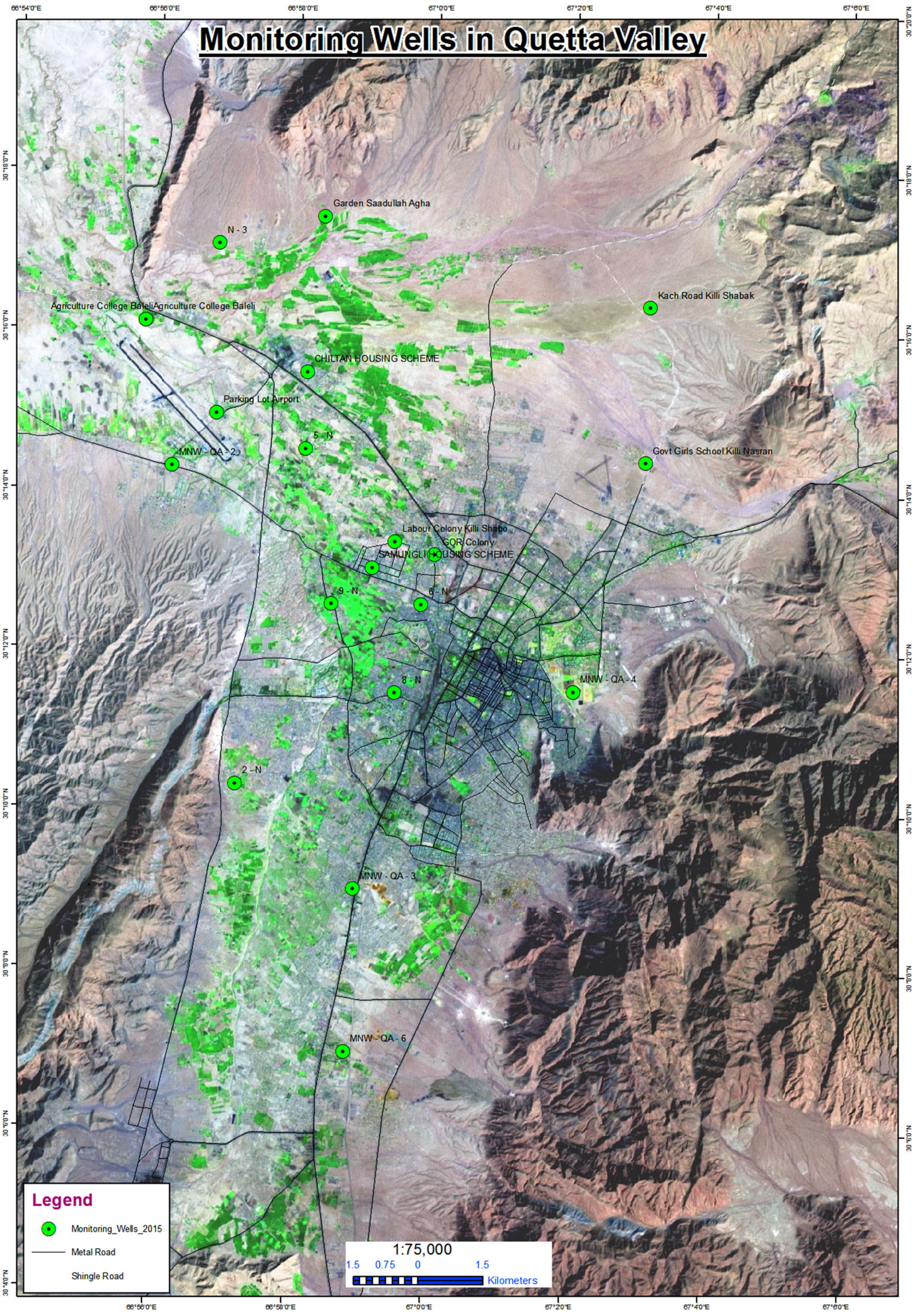

Fig. 4 Network of monitoring wells in study area of Quetta alluvial

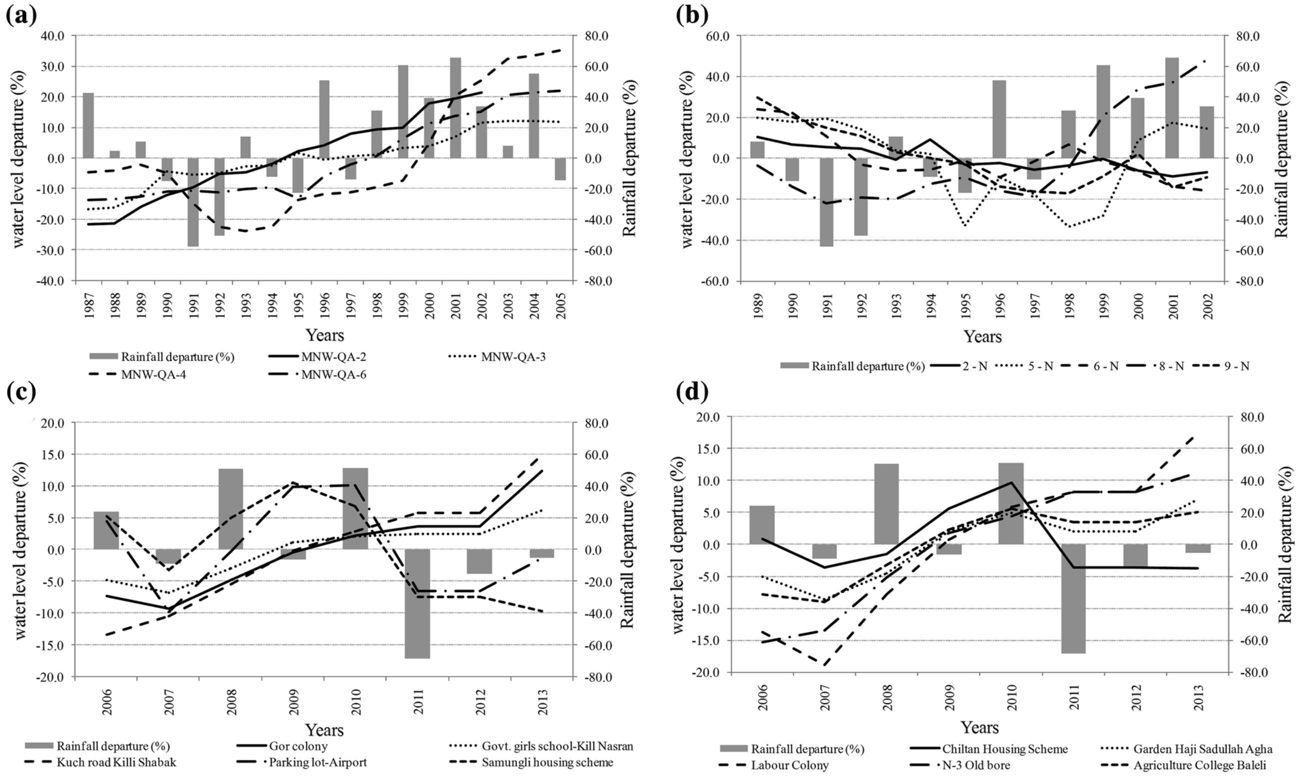

Fig. 5 **a–d** Percentage departures of rainfall and water level in different regions in Quetta valley

Table 3 Partial correlation analysis of *R*, ET, *T*, GWL, and GWR of different tube wells

	R	ET	*T*	GWL and GWR			
				MNW-QA-2	MNW-QA-3	MNW-QA-4	MNW-QA-6
R	1.00	−0.69	**−0.56**	**−0.44**	−0.29	**−0.57**	−0.61
ET	−0.69	1.00	0.96	**0.46**	0.37	0.67	0.70
T	**−0.56**	0.96	1.00	0.41	0.35	0.62	0.66
GWL and GWR							
MNW-QA-2	**−0.44**	**0.46**	0.41	1.00	0.96	**0.48**	0.90
MNW-QA-3	−0.29	0.37	0.35	0.96	1.00	0.41	0.81
MNW-QA-4	**−0.57**	0.67	0.62	**0.48**	0.41	1.00	0.74
MNW-QA-6	−0.61	0.70	0.66	0.90	0.81	0.74	1.00

Bold values represent correlation is significant at 0.05 level

GWL ground water level, *GWR* ground water recharge

major reasons for the surplus of hydrological balance during 2005. The study identifies that a large number of tube wells and dug wells (more than 2000) are installed by the government as well as local people in and around the valley during 2000–2005, and most of these wells have been scheduled for operating between 20 and 24 h thus over-pumping from the aquifer and the extraction rate exceeds the natural recharge rate which is probably one of the main factors to cause a steady depletion of the aquifer. This has been observed by the continuous monitoring of the observation as well as operational wells which showed drop of water levels in the wells. Second, the prolonged periods of the drought period in the recent past have also contributed in unbalancing the natural recharge, and resulted in worsening the situation (Table 5).

4 Conclusion

To ensure and quantify the availability and quality of the water resources for the future generations, it is mandatory to study the influence of probable changes as appeared in

Table 4 Partial correlation analysis of *R*, ET, *T*, GWL, and GWR of different tube wells

	R	ET	*T*	GWL and GWR				
				2-N	5-N	6-N	8-N	9-N
R	1.00	−0.74	−0.64	**0.56**	0.20	0.41	−0.68	**0.53**
ET	−0.74	1.00	0.96	−0.62	−0.07	−0.40	0.81	**−0.47**
T	−0.64	0.96	1.00	**−0.54**	−0.07	−0.37	0.79	−0.45
GWL and GWR								
2-N	**0.56**	−0.62	**−0.54**	1.00	0.34	0.69	**−0.57**	0.80
5-N	0.20	−0.07	−0.07	0.34	1.00	0.14	0.14	0.62
6-N	0.41	−0.40	−0.37	0.69	0.14	1.00	**−0.46**	0.72
8-N	−0.68	0.81	0.79	**−0.57**	0.14	**−0.46**	1.00	−0.31
9-N	**0.53**	**−0.47**	−0.45	0.80	0.62	0.72	−0.31	1.00

	R	ET	*T*	GWL and GWR				
				Gor colony	Govt, girls school-Kill Nasran	Kuch road Killi Shabak	Parking lot Airport	Samungli housing scheme
R	1.00	−0.23	1.00	0.31	0.28	0.35	−0.57	**0.64**
ET	−0.23	1.00	−0.23	−0.27	−0.23	−0.36	0.42	0.45
T	1.00	−0.23	1.00	0.31	0.28	0.35	−0.57	**−0.63**
GWL and GWR								
Gor colony	0.31	−0.27	0.31	1.00	0.98	0.98	0.04	−0.51
Govt, girls school-Kill Nasran	0.28	−0.23	0.28	0.98	1.00	0.97	0.17	−0.37
Kuch road Killi Shabak	0.35	−0.36	0.35	0.98	0.97	1.00	−0.04	−0.54
Parking lot Airport	−0.57	0.42	−0.57	0.04	0.17	−0.04	1.00	0.81
Samungli housing scheme	**−0.64**	0.45	**−0.63**	−0.51	−0.37	−0.54	0.81	1.00

	R	ET	*T*	GWL and GWR				
				Chiltan Housing Scheme	Garden Haji Sadullah Agha	Labour Colony	N-3 Old bore	Agriculture College Baleli
R	1.00	−0.23	1.00	−0.54	0.17	0.30	0.37	0.20
ET	−0.23	1.00	−0.23	0.33	−0.15	−0.24	−0.33	−0.21
T	1.00	−0.23	1.00	−0.54	0.17	0.30	0.37	0.20
GWL and GWR								
Chiltan Housing Scheme	−0.54	0.33	−0.54	1.00	0.26	0.01	−0.02	0.25
Garden Haji Sadullah Agha	0.17	−0.15	0.17	0.26	1.00	0.96	0.92	0.96
Labour Colony	0.30	−0.24	0.30	0.01	0.96	1.00	0.97	0.95
N-3 Old bore	0.37	−0.33	0.37	−0.02	0.92	0.97	1.00	0.96
Agriculture College Baleli	0.20	−0.21	0.20	0.25	0.96	0.95	0.96	1.00

Bold values represent correlation which is significant at 0.05 level

GWL ground water level, *GWR* ground water recharge

the hydrological cycle due to climate change. The study of temporal characteristics of climate change guides in the present and future water resource strategy and its management, while quantification of the spatial impact analysis is somehow critical to guard the underground water assets, and in the framework of land use sharing and its development process. It is evident through several climate change studies that the groundwater resources are linked to

Table 5 Preliminary hydrological balance for Quetta alluvial aquifer

Component	Yearly volume (mm^3)			
	2000	2005	2010	2015
Natural inflow and recharge of aquifer	54.9	103.0	44.1	62.5
Backflow	–	–	–	–
Domestic (losses)	8.39	8.33	7.94	9.66
Irrigation	7.00	7.00	4.00	3.20
Total abstraction from alluvial aquifer	74.99	73.73	56.65	49.98
Total balance	−35.48	13.94	−24.49	−0.34

climate change impacts either directly or indirectly, through the stored water in the surrounding water bodies as well as through the renewal of water from precipitation. The renewal of the groundwater process is not only dependent on the main climate variables, precipitation, temperature, and evapotranspiration spatially and temporally, but also reliant on the spatial land-surface properties distribution as well as deepness and soil properties.

In this study, three major aspects precipitation, temperature, and evapotranspiration have been considered to estimate their response against the groundwater levels on the alluvial of Quetta Valley. Using 30 years of actual historical weather and groundwater-level data set was considered to assess the variations in the past and present changes in these variables. The results of this study reveal that changing in the rain patterns and overall rise in minimum and maximum temperature and evapotranspiration have drastically affected the recharge of the Quetta alluvial aquifer. In South and South East of Quetta valley, the groundwater decline for the period 1987–2005 has been recorded up to 30.66 m. About 2.8 m of water-level decline has been observed for the period 1989–2002; in west and in city area, the decline remains 2.8 and 4.37 m since 2006–2013. Similarly, up to 29 m of water levels has been declined in the Northern part of Quetta valley during 2006–2013. The partial correlation analysis reveals that water table is decreasing as the number of tube has increased over the last decade which may put the pressure on ground water recharge and water budget of the aquifer. This study also shows that Quetta aquifer water budget has a deficit of −35.48, −24.49, and −0.34 mm^3/year during 2000, 2010, and 2015, respectively.

The results reveals that the groundwater levels which vary significantly in western part may be supported with some extra shower or due to the slope of the Valley towards west. In other areas of the Quetta valley, the groundwater variation is not responding directly to the rainfall due to a large gap in winter rainfall. The groundwater level in the western part of the Quetta is much better than rest of the valley.

References

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (2008) Climate change and water: Technical Paper VI. Geneva, Switzerland. UNT Digital Library. http://digital.library.unt.edu/ark:/67531/metadc11958/. Accessed 25 March 2016

Chen C, Ji R, Schwab DJ, Beletsky D, Fahnenstiel GL, Jiang M, Johengen TH, Vanderploeg H, Eadie B, Budd JW, Bundy MHA (2002) Model study of the coupled biological and physical dynamics in Lake Michigan. Ecol Model 152:145–168

Dams J, Salvadore E, Van Daele T, Ntegeka V, Willems P, Batelaan O (2012) Spatio-temporal impact of climate change on the groundwater system. Hydrol Earth Syst Sci 16:1517–1531

Gazdar H, Kaker SA, Khan I (2010) Buffer zone, colonial enclave or urban hub? Quetta: between four regions and two wars. Crisis States Research Centre working papers series 2, 69. Crisis States Research Centre, London School of Economics and Political Science, London, UK

Gerhart JM (1986) Ground-water recharge and its effect on nitrate concentrations beneath a manured field site in Pennsylvania. Ground Water 24:483–489

Government of Pakistan (2013) Frame work for implementation of Climate change policy 2014–2030. http://www.pk.undp.org/content/dam/pakistan/docs/Environment%20&%20Climate%20Change/Framework%20for%20Implementation%20of%20CC%20Policy.pdf. Accessed 24 March 2016

Hargreaves GH (1994) Defining and using reference evapotranspiration. J Irrig Drain Eng 120:1132–1139

Healy RW, Cooke PG (2002) Using groundwater levels to estimate recharge. Hydrogeol J 10:91–109

Holman IP (2006) Climate change impacts on groundwater recharge-uncertainty, shortcomings, and the way forward? Hydrogeol J 14:637–647

Holman IP, Ferreira JP, Vieira JM (2007) Regional hydrological impacts of climate and socio-economic change in North West England. IAHS Publ 310:49–56

House AR, Thompson JR, Acreman MC (2016) Projecting impacts of climate change on hydrological conditions and biotic responses in a chalk valley riparian wetland. J Hydrol. doi:10.1016/j.jhydrol.2016.01.004

Jyrkama MI, Sykes JF (2007) The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). J Hydrol 338:237–250

Khurshaid A (2011) Evaluation of aquifer system in Quetta Valley through geophysical methods and groundwater flow modeling (Doctoral dissertation, University of the Punjab, Lahore). http://eprints.hec.gov.pk/7579/1/1055S.htm. Accessed 24 May 2016

Kløve B, Ala-Aho P, Bertrand G, Gurdak JJ, Kupfersberger H, Kværner J, Muotka T, Mykrä H, Preda E, Rossi P, Uvo CB (2014a) Climate change impacts on groundwater and dependent ecosystems. J Hydrol 518:250–266. doi:10.1016/j.jhydrol.2013.06.037

Kløve B, Ala-Aho P, Bertrand G, Gurdak JJ, Kupfersberger H, Kværner J, Muotka T, Mykrä H, Preda E, Rossi P, Uvo CB (2014b) Climate change impacts on groundwater and dependent ecosystems. J Hydrol 10:250–266

Kumar CP (2012) Climate change and its impact on groundwater resources. Int J Eng Sci 1:43–60

Kumar CP (2015) Modelling of groundwater flow and data requirements. Int J Mod Sci Eng Technol 2:18–27

Kurylyk BL, MacQuarrie KT, Caissie D, McKenzie JM (2015) Shallow groundwater thermal sensitivity to climate change and land cover disturbances: derivation of analytical expressions and implications for stream temperature modeling. Hydrol Earth Syst Sci 9:2469–2489

Majeed A (2000) Natural and artificial recharge techniques for Balochistan. IUCN Balochistan programme, water programme document series http://www.waterinfor.net.pk/pdf/nartb.pdf

Mann HB (1945) Nonparametric tests against trend. Econometrica: J Econom Soc 1:245–259

Meinzer OE, Stearns ND (1929) A study of groundwater in the Pomperaug Basin, Connecticut with special reference to intake and discharge. US Geol Surv Water Supply Pap 597B:73–146

Naseri Ghiri A, Aref F, Amiri B, Khosropour A, Naseri Ghiri R (2013) Influence of climate changes and geological features on water table changes in Ghir Plain, Iran. N Y Sci J 6:39–49

Pakistan Water Partnership (2001) Supplement to the framework for action (FFA) for achieving the Pakistan Water Vision 2025. http://www.pwp.org.pk/

Patel J, Patel H, Bhatt C (2015) Modified Hargreaves equation for accurate estimation of evapotranspiration of diverse climate locations in India. Proc Natl Acad Sci India Sect B Biol Sci 85:161–166

Rasmussen WC, Andreasen GE (1959) Hydrologic budget of the Beaverdam Creek Basin, Maryland. U.S. Geological Survey Water-Supply Paper 1472

Risser DW, Gburek WJ, Folmar GJ (2005) Comparison of methods for estimating ground-water recharge and base flow at a small watershed underlain by fractured bedrock in the eastern United States. US Geol Surv Sci Investig Rep. 2005-5038

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63:1379–1389

Subburayan SI, Murugappan A, Mohan S (2011) Modified Hargreaves equation for estimation of ETo in a hot and humid location in Tamilnadu State, India. Int J Eng Sci Technol 3:592–600

Sultan A, Rahman NA, Ramadan TM, Salem SM (2013) The use of geophysical and remote sensing data analysis in the groundwater assessment of El Qaa Plain, South Sinai, Egypt. Aust J Basic Appl Sci 7:394–400

Ter Kuile BJ (2009) The relation between temperature and precipitation. http://www.srderoode.nl/Students/benjamin_internship_report.pdf. Accessed 24 March 2016

Umar M, Waseem A, Kassi AM, Farooq M, Sabir MA, Faridullah (2014) Surface and subsurface water quality assessment in semi-arid region: a case study from Quetta and Sorange Intermontane Valleys, Pakistan. Glob NEST J 16(5):938–954

Wada Y, Beek LP, Sperna Weiland FC, Chao BF, Wu YH, Bierkens MF (2012) Past and future contribution of global groundwater depletion to sea-level rise. Geophys Res Lett. doi:10.1029/2012GL051230