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Decline of Static Water Level in Quetta Sub-basin, Balochistan, Pakistan

Hameed Ullah[1], Akhtar Muhammad Kassi[2], Syed Mobasher Aftab[3], Muhammad Zahir[4], Nisar Ahmed[5]

1 Quetta Water and Sanitation Authority, Balochistan, Pakistan; hameedullah_g@yahoo.com
2 Department of Geology, University of Balochistan, Pakistan; amkcem1@gmail.com
3 Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Balochistan, Pakistan; syed.aftab@live.com
4 Centre of Excellence in Mineralogy, University of Balochistan, Pakistan; zahirkakargeo@gmail.com
5 Geological Survey of Pakistan, Balochistan, Pakistan; nakhan621@gmail.com

ABSTRACT

Background: Quetta is the most populated city of Balochistan, situated in a valley, called Quetta Sub-basin, apart of the Pishin Sub-basin, situated in northern part of the Kirthar Belt, comprising formations of Lower Jurassic through Holocene age. The Baleli River, along with its ephemeral streams, flows generally northwards, drains out of the Quetta Sub-basin near Baleli and joins the Pishin Sub-basin. It comprises two types of aquifers; 1) Alluvial aquifer, comprising horizontally-lying Quaternary alluvial succession, composed of siltstone, mudstone, sandstone and conglomerate, having primary porosity; 2) Limestone aquifer, composed mostly of Jurassic limestone, having secondary porosity. Decline of water level is detected in Sub-basin, which needs proper attention by the concerned authorities.

Objectives: The main objective was to estimate decline in the static water level in the alluvial and limestone aquifers of the Quetta Sub-basin.

Methods: Out of 430 tube wells of Quetta Water and Sanitation Authority (Q-WASA), 40 were randomly selected for monitoring for a period from April 2019 to March 2020. We selected 9 tube wells from the Limestone and 31 from the Alluvial aquifer. Decline in static water levels was estimated by taking average static water levels of both aquifers and estimating decline through formula of well-level data method. Water levels were measured by Sonic Water Level Meter and Water Level Meter Model-102 Manual.

Results: The findings show that a decline of the static water level was detected both in Limestone and Alluvial aquifers, during the period from April 2019 to March 2020, which is estimated as 0.2 m in the Limestone aquifer, and 0.99 m in the Alluvial aquifer.

Conclusions: Our results confirm that decline of the static water level dangerously continues and drastic steps are needed regarding groundwater recharge and appropriate management, in order to cope with the critical situation of water shortages in Quetta.

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Static water level; aquifer; alluvial aquifer; recharge; Quetta; sub-basin; Balochistan Pakistan;

1. INTRODUCTION

Quetta is the provincial capital and the most populated city of Balochistan, Pakistan. It is situated in the Quetta Valley, which is a part of the Quetta sub-basin (Figure 1). Hydrologically, the Quetta Sub-basin is one of the nine sub-basins of the Pishin Lora River Basin (Durrani et al., 2018).The Quetta sub-basin outspreads between Latitude: 30° 00´ to 30° 25´ N, and Longitude: 66° 50´ to 67° 15´E, covering an area

*CONTACT Hameed Ullah hameedullah_g@yahoo.com

of 603 km2. Geologically, the sub-basin is an inter-mountainous valley of the northern-most part of the Kirthar Fold-Thrust Belt, comprising rock successions of Lower Jurassic to Holocene age (Bender & Raza, 1995). The valley extends from Mian Ghundi in the south-east up to Baleli Gap in the north-west. The valley is bordered by mountain ranges of Chiltan, Murdar, Takatu, and Zarghun. Chiltan is the highest peak 3,194 m above mean sea level (masl), while the average elevation of the valley is 1,680 m. The Baleli River is flowing in the center of the valley, generally from south to north direction, and drains out of the sub-basin near the Baleli Village and joins the Pishin River (Pishin sub-basin). Small ephemeral streams from the surrounding mountains join the Baleli River.

Groundwater, in the Quetta area, is the only source for municipal supply, irrigation and industrial utilization. Recharge of groundwater resources has been reduced considerably due to climate change and mismanagement of this valuable natural resource. Over-exploitation of the groundwater resource caused continuous decline of the water table in the Sub-basin (Durrani et al., 2018).

Climate of the Quetta area is semi-arid with substantial variations between temperatures of the summer and winter seasons. Average temperatures of summers (during May and September) record between 24 to 26 °C, of autumns (during September and November) record between 12 to 18°C, of winters (during November and March) record between 4 to 5 °C, and that of springs (during April to May) record between 15 to 20 °C (Durrani et al., 2018). The maximum average monthly precipitation is recorded in January i.e. 56.7 mm while the minimum average precipitation is recorded in September i.e. 0.3 mm (Durrani et al., 2018). The semi-arid climate, scanty precipitation, prolonged droughts, heavy extraction of the groundwater from the sub-basin and drastic growth of population has disrupted the groundwater balance of the QuettaSub-basin (Durrani et al., 2018). Gradual decrease in recharge of the groundwater resources due to climate-change, mismanagement and over-exploitation (very high discharge) of the precious groundwater resource caused a continuous decline of the groundwater level of the Sub-basin (Durrani et al., 2018).

Two types of aquifers are present in the Quetta Sub-basin: i) an unconfined aquifer in the valley-fill type alluvial sediments composed of mostly siltstone, mudstone, sandstone and conglomerate, having primary porosity and hereby named as Alluvial aquifer and, ii) A limestone aquifer of the surrounding mountains, which mostly comprises limestone successions of Jurassic through Palaeocene age, mainly the Jurassic Chiltan Limestone and hereby named as Limestone aquifer (Sagintayev et al., 2011). The concept of groundwater budget requires that balance exists between the groundwater quantity entering into (recharge) and leaving out (discharge) of the aquifers. In the natural environment, groundwater is continuously flowing from the recharge to the discharge of the aquifers, establishing a balance over a considerable time. The groundwater balance means that "quantity of the recharge into the aquifer is equal to the quantity of discharge of the groundwater from the aquifer" (Thornthwaite & Mather, 1957).

Numerous studies have been conducted on the stratigraphy, structure, groundwater balance, depletion of water level, water economy, artificial recharge and surface and groundwater interaction of the Quetta and surrounding areas. Reconnaissance map and report of the area was prepared by the Hunting Survey Corporation (Jones, 1961). Shah (1975) studied structure of the Quetta valley and revealed that the Chiltan, Murdar and Takatu peaks represent the major anticlinal folds of the Quetta Synclinorium. Afzal et al. (2010), Afzal et al. (2011), Allemann (1979), Babar et al. (2018) and Muhammad et al. (2018) provided further details of the biostratigraphy of the rock succession of the Quetta area, specifically of the Murree Brewery section. Maldonado et al. (1993) reported a summary of the stratigraphy and structural elements of the Quetta-Muslimbagh-Sibi Region. Kassi et al. (2009) studied the contrasting Late Cretaceous-Palaeocene lithostratigraphy across the Bibai Thrust, western Sulaiman Fold-Thrust Belt, including lithostratigraphy of the Quetta and surrounding area, and their significance in deciphering the early collisional history of the NW Indian Plate Margin. These studies reveal that very thick succession of the shallow marine Jurassic limestone (Shirinab Formation and Chiltan Limestone) is disconformably overlain by the widespread pelagic succession of the Parh Group. Naseer et al. (2019) and Kasi et al. (2021) analyzed the lithostratigraphy and facies associations of the Quaternary Succession of Hanna-Spin Karez Area, Quetta District, and proposed new lithostratigraphic units of formations rank; and collectively named them as the Spin Karez Group.

Asian Development Bank (2000) carried out detailed groundwater investigation studies of the Quetta Sub-basin under the "Quetta Water Supply and Environment Improvement Project". The report shows a considerable water deficit (-36.5 million m^3), i.e. total annual recharge of 61.15 million m^3 and the total annual discharge of 97.65 million m^3. Ahmad et al. (2006) carried out a comprehensive study on the "Balochistan's Water-Sector Issues and Opportunities", on behalf of the joint mission of the World Bank and Asian Development Bank. Sagintayev et al. (2012) used the remote-sensing techniques for the hydrologic modeling of the watersheds and groundwater depletion of the Pishin Lora Basin. They concluded that excessive number of tube wells was the major cause of groundwater depletion and that the alluvial aquifer in Kuchlak area exhausted within three decades due to intensive extraction of groundwater from more than 300 agricultural tube wells. Steenbergen et al. (2015) and Techno-Consult (2018) worked on the groundwater depletion in Balochistan and concluded that the main reasons for groundwater depletion in the sub-basins are the massive subsidies of the electricity tariffs for agriculture tube wells and absence of the water pricing and regulatory enforcement. The massive increase in population, due to the migration of rural communities to the urban areas, drought and jobs in industries worsened the situation. Aftab et al. (2018) revealed that 11 river basins, out of 18, in the Balochistan Plateau showed steady depletion of the groundwater levels during the last three decades due to indefensible long-term groundwater extraction. The cumulative decline of water-table ranged from 2 to 3 meters/year. The most significant decrease of 60 meters in the last 12 years has been recorded in some parts of the Quetta Valley.

In the Quetta and surrounding areas sedimentary successions of Lower Jurassic through Holocene age are exposed, which include the Lower Jurassic Shirinab Formation, Upper Jurassic Chiltan Limestone, Cretaceous Parh Group, Fort Munro and Pab formations, Palaeocene Dungan Limestone and Early Eocene Ghazij Formation (Allemann, 1979; Kassi et al., 1999; Kassi et al., 2009; Kassi et al., 2000). The same stratigraphic succession extends northeastwards in the Hanna-Urak, Sor Range, Kach-Ziarat of the western Sulaiman Fold-Thrust Belt, and southwards in the Bolan Pass and Mastung areas of the northern Kirthar Fold-Thrust Belt. Also towards the northeast (Hanna, Urak, Sor Range, Zarghun Trough and Kach-Ziarat areas) younger sedimentary successions, i.e. the Late Eocene Kirthar Formation, Miocene through Pleistocene Urak Group and Pleistocene Spin Karez Group are exposed (Durrani, 1997; Kassi et al., 1999; Kassi et al., 2009; Kassi et al., 2000; Naseer et al., 2019). Towards the northwest thick succession of the Pleistocene Bostan Formation is exposed (Jones, 1961).

Sedimentary successions of the Quetta and surrounding areas, having varying competency, reacts differently to the compressional forces. The Jurassic Chiltan Limestone, being very thick-bedded, and comparatively hard, is influenced by broad and open types of folds and brittle deformation i.e., flexures and fractures. The other rock types are comparatively thin-bedded and softer, therefore, display plastic type of deformation, such as tight asymmetrical folds. The Eocene Ghazij Formation, however, is the most incompetent and soft succession, which mostly ends-up in formation of broad valleys (e.g. Quetta Valley) and also acts as decolama for major thrusts of the region; e.g. in the Murrey-Brewery area the Ghazij Formation acts as decolama for the Murry-Brewery Thrust (Allemann, 1979; Kassi et al., 1999; Kassi et al., 2009).

The hydrological aspects of the Quetta area have both structural and stratigraphic controls. The Quetta valley is situated in the upper-most part of the Kirthar Fold-Thrust Belt, which mostly comprises hog-backed anticlinal features having dip-ward slopes on either side. To the north and west, the thrusts dominate and generally have steep faulted scarps, which developed as a result of interaction of various major thrusts. Folds have been cut by tear faults and/or their limbs truncated by reverse faults or high-angle thrusts (Jadoon et al., 1992; Jadoon et al., 1993; Jones, 1961; Kazmi, 1955; Kazmi & Hamza, 1979). The belt also contains several large NW-to NNW-trending strike-slip faults along the eastern and western margins, respectively.

The valleys make wide synclinal basins, which mostly comprise softer/incompetent rocks and generally contain parallel or concentric, low, homoclinal ridges, hogbacks and cuestas. Foothills of the valleys are generally covered with gravel fans that form distinct piedmont zones, which generally comprise four to five series of fan terraces. They are followed by sub-piedmont zones characterized by finer sediments (sand and silt) and gentler slope. Central parts of the valleys are plain areas, which are either flood plains entrenched by streams or flat playas filled with silt and clay. The Zarghoon, Quetta and the Pishin basins are good examples of such types of structures (Kazmi & Jan, 1997).

The Quetta and Pishin basins have been strongly influenced by the Quetta Transverse Zone, which is generally composed of EW-trending mountain ranges of the Sulaiman Fold-Thrust Belt and Sibi-Zarghun Trough, which mostly comprises ridges of Miocene-Pleistocene Molasse-type sediments that attain thickness of over 7 km (Bender & Raza, 1995; Durrani et al., 1997; Durrani, 1997; Kazmi & Jan, 1997; Sarwar, 1979). The Chiltan and Takatu faults located at the southeastern base of the Chiltan and Takatu ranges, west and north of the Quetta valley, may be regarded as active on the basis of seismological data; a ground rupture appeared along this fault during the 1935 Quetta-earthquake. There is a wide gap area between the Chiltan and Takatoo ranges near the Baleli and Quetta International Airport, which is filled with alluvium. The two faults are probably interconnected in this gap area. After the 1935 Quetta-earthquake a linear fracture developed through the alluvium of this gap area, which had NE-SW trend and could be traced for a distance of over one mile. Moreover, a number of hypocenters are aligned with the Chiltan Range, located southwest of the Quetta valley, which are probably associated with this fault. Most of these hypocenters cluster near the northern end of the meizoseismal zone (i.e., the area of maximum damage) of the 1935 Quetta-earthquake. Most of the current seismicity on the Quetta Fault occurs near the northern end of the 1935 rupture; only four of the epicenters correlate with the central portion of the fault (Armbruster, 1980).

Kazmi et al. (2005) identified two types of aquifers in Quetta valley: i) unconsolidated alluvial aquifer and ii) bedrock aquifer. The alluvial fan aquifer is the main, and widely used, aquifer comprising both the proximal fan (gravel-dominant) deposits in the peripheral parts of the valleys and distal fan (sand and silt-dominant) deposits in the central part of the valley. This aquifer is recharged by direct precipitation as well as indirectly from the infiltration of precipitation, runoff and inflow from the bedrock aquifer in the foothill areas. The bedrock aquifer comprises very thick limestone succession of the Shirinab Formation and Chiltan Limestone, and conglomerates and sandstones of Urak and Spin Karez groups (Kazmi et al., 2005; Naseer et al., 2019). The alluvial aquifer is also recharged from inflows of the surrounding mountain areas where these formations are exposed. The unconsolidated alluvial aquifer and the bedrock aquifer are hydraulically connected to each other (Halcrow & Cameos, 2008; Kazmi et al., 2005).

The so-called “hard-rock” or “bedrock” aquifer of the Quetta Sub-basin has been strongly influenced by the thrusts and tear faults of the surrounding mountain belts (Kazmi et al., 2005). The faults have caused shear, imbrication and network of fracture zones, fault breccia and, ultimately, turning into karstic features, which have provided conditions favorable to develop secondary porosity and permeability and developing into good aquifers. The Jurassic Shirinab Formation and Chiltan Limestone, mostly comprising thick and massive limestone succession, are considered to be good reservoirs, as they possess secondary porosity and permeability. Especially, the Chiltan Limestone contains high secondary porosity and permeability in the form of cracks, fractures and karstic features. Most of the tube wells in the “hard-rock” aquifer(s) are hosted in the Jurassic Chiltan Limestone; therefore, we hereby re-name it, more appropriately, as the “Limestone aquifer”.

The Cretaceous Parh Limestone and Fort Munro Formation are also fractured, having secondary porosity and permeability. The Upper Cretaceous Pab Sandstone is also porous and permeable; hence, it may be a good reservoir rock, however, it has not been developed in the Quetta Sub-basin and surrounding area. The Paleocene-Early Eocene Dungan Formation, comprising hard and compact limestone, is also fractured, may be having secondary porosity and permeability, and can be a good reservoir rock too. The Eocene Ghazij Formation is shale-dominant, and mostly impermeable, hence, not a good reservoir rock. However, sporadic sandstone and conglomerate horizons of the Ghazij Formation are also porous and permeable. Limestone-dominant succession of the Spin Tangai Formation is also highly fractured and possesses secondary porosity and permeability (Sagintayev et al., 2011).The Uzhda Pusha Sandstone is mostly, Shin Matai Formation is partially and Urak Conglomerate is very highly porous and permeable. The Hanna Lake Conglomerate, Spin Karez Conglomerate of the Spin Karez Group (Naseer et al., 2019), are highly porous and permeable. It is envisaged that they contain ample quantity of groundwater, both in the form of confined and unconfined aquifers.

This paper aims to present an estimate of the decline of static water level of the Quetta Sub-basin for one water year, i.e., from April 2019 through March 2020, by direct measurements of the static water level of the forty (40) tube wells, installed in the Alluvial and Limestone aquifers, by the Quetta Water and Sanitation Authority (Q-WASA). The research work is important to address the issues of existing water crises in the Quetta Sub-basin, future planning and better management of the groundwater resources by the policy makers and researchers. The study also highlights the severity and alarming effects of the decline of static water level of the Quetta Sub-basin.

2. METHODS

2.1 Study design

Our research used quantitative approach. The quantitative work includes the values of static water level of both the tube wells installed in the Limestone as well as Alluvial aquifer of the Quetta Sub-basin; measured each month from April 2019 through March 2020. The qualitative approach includes plotting of tube wells on map, through ArcGIS software, Version 10.3.1, of all the 40 monitored tube wells installed in the Zarghoon and Chiltan Towns of Q-WASA, as well as estimation of decline of the static water level using the well-level data method (Qablawi, 2016).

2.2 Setting

This study was conducted in Quetta sub-basin. The Quetta Water Supply and Sanitation Authority (Q-WASA) subdivided the Quetta sub-basin into two towns and nine sub-divisions to manage its water supply schemes (Figure 2). The two towns were named as the Zarghoon Town and Chiltan Town, covering a total area of about 274.35 km^2, which were further subdivided into 4 and 5 sub-divisions, respectively (Figure 2; Table 1 and Table 2).

2.3 Instrumentation

The geographic coordinates of all 40 monitored tube wells of Q-WASA were obtained by GARMIN GPS, Model No. GPS map 62 and their locations were plotted on the watershed map of the Quetta Valley (Figure 2). The static water levels of all 40 tube wells were taken by Sonic Water Level Meter and Manual Water Level Meter Model-102.Watershed map of the Quetta Sub-basin was prepared, which shows locations of all the 40 monitored tube wells of the Q-WASA, with the help of Arc Geographic Information System (AGIS), Version 10.3.1 (Figure 2). The data of the static water levels of the monitored tube wells was prepared using the Excel Sheet.

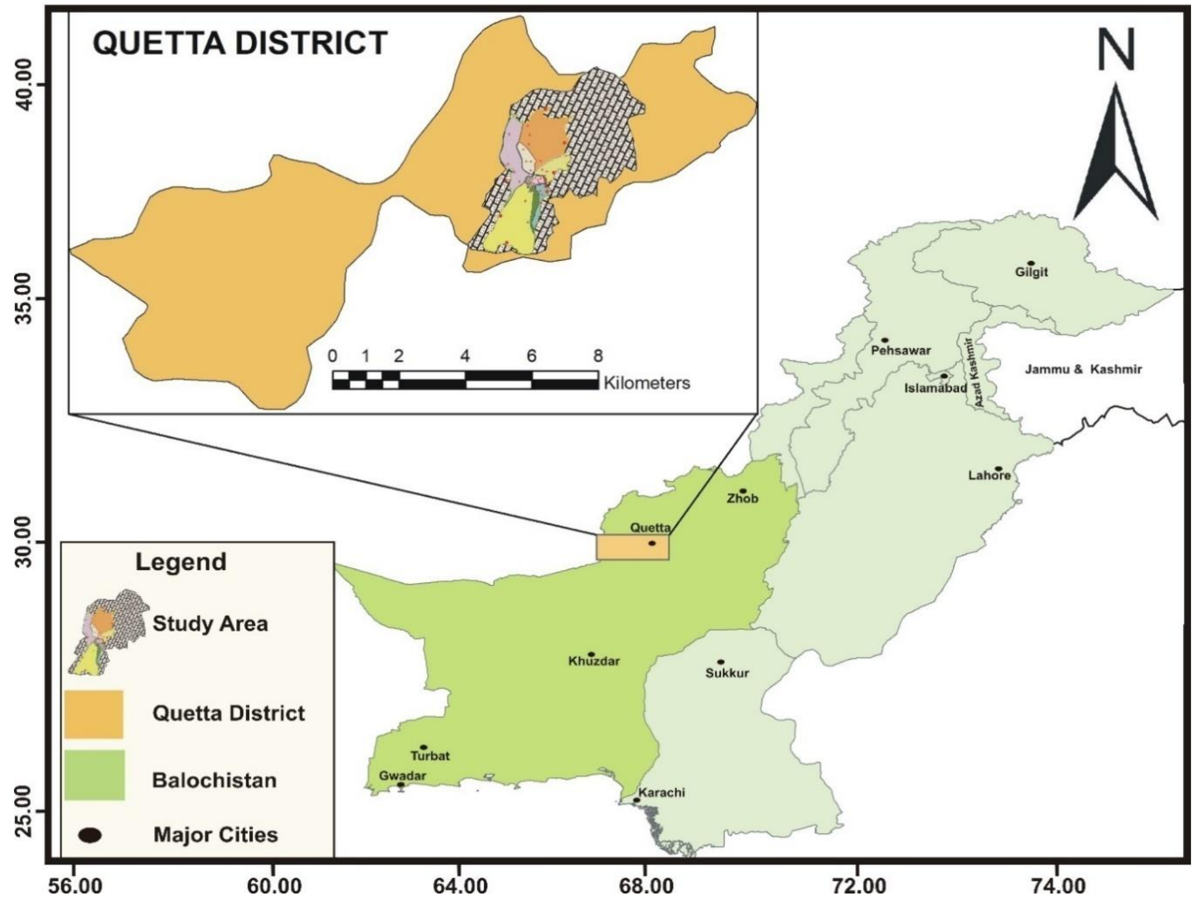

Figure 1. Locational map of Balochistan, Pakistan including Quetta District and the study area

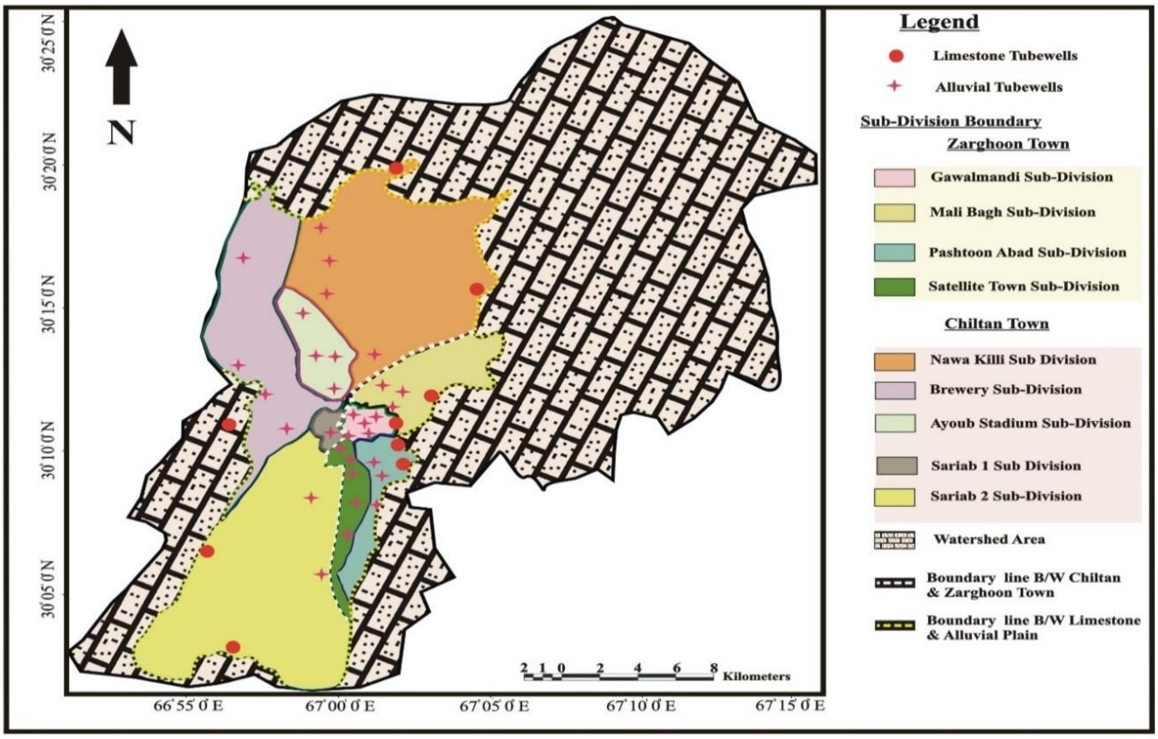

Figure 2. Watershed map of the Quetta sub-basin showing the towns, sub-divisions and locations of the forty (40) monitored tube wells of the Q-WASA.

2.4 Measurements

In order to measure the static water level of both the Limestone and Alluvial aquifers, the tube wells selected for monitoring were brought to rest for 10 hours, from midnight (12:00 am) up to 10:00 am. Such a rest period to the selected tube wells brought them to the static water levels, which were measured first by using Sonic Water Level Meter, and later, by Manual Water Level Meter Model-102, to obtain the calibrated and accurate values of the static water level. Extra care was also taken into consideration that other government or private tube wells were not operating in the vicinity of 1000 m near the monitored tube wells.

2.5 Sampling

Out of the 430 tube wells of the Q-WASA, installed in 274.35 km2, 40 tube wells were randomly selected from different parts of the Quetta Sub-basin for monitoring for a period of one year; i.e., from April 2019 to March 2020 (Fig.2). Among them, 9 tube wells were selected from the Limestone aquifer (Table 1) and 31 tube wells from the Alluvial aquifer (Table 2). The data was collected, recorded and estimated through direct field observations and calculations.

2.6 Data analysis methods

The groundwater inventory and monitoring were conducted to collect primary data through direct measurements of static water levels. The total surface area (i.e., 603 km^2) of the Quetta Sub-basin was estimated through the Arc GIS software, version 10.3.1. Out of the total surface area, the surface area of the Limestone Aquifer comprises 328.35 km^2 and that of the Alluvial aquifer comprises 274.35 km^2. Values of static water level on ground were measured in feet and later on converted into meters through "Microsoft Office-13 (Excel Sheet)". Tables of the static water levels values of both the Limestone and Alluvial aquifers were prepared using Excel Sheet of the Microsoft Office-13.

3. RESULTS

3.1 Estimation of the decline of static water level

For the estimation of the decline (or rise) in the static water levels, of both the Limestone and Alluvial aquifers, the well-level data method of Qablawi (2016) was used, which is basically specified for the estimation of the groundwater recharge. This method is considered as the most accurate method for the estimation of the recharge, as well as the decline or rise of static water levels, of an aquifer for one water year, because it measures the groundwater recharge based on the difference in water levels at the beginning and at the end of the water year. According to USGS, a "Water Year" is defined as the 12 month period starting from October 1st for any given year through September 30th of the following year (Qablawi, 2016). However, this period specified by Qablawi (2016) applies only on the Western America and, infact, does not apply on every region, as different regions across the globe have variable geographical, climatological and seasonal conditions. Therefore, on the basis of the climatology, geography and seasonal patterns, a water year, firstly, is calculated on the basis of lowest (minimum) to lowest (minimum) static water level in a 12 months period and, secondly, on the basis of maximum precipitation to maximum precipitation within one year period. On the basis of lowest-to-lowest static water level data, we consider the "Water Year" of the Quetta Sub-basin to be starting from April 1st to March 30th of each year (Figure 3). In the following section, we discuss the formula, according to which we have estimated the decline (or rise) of the static water level for one year.

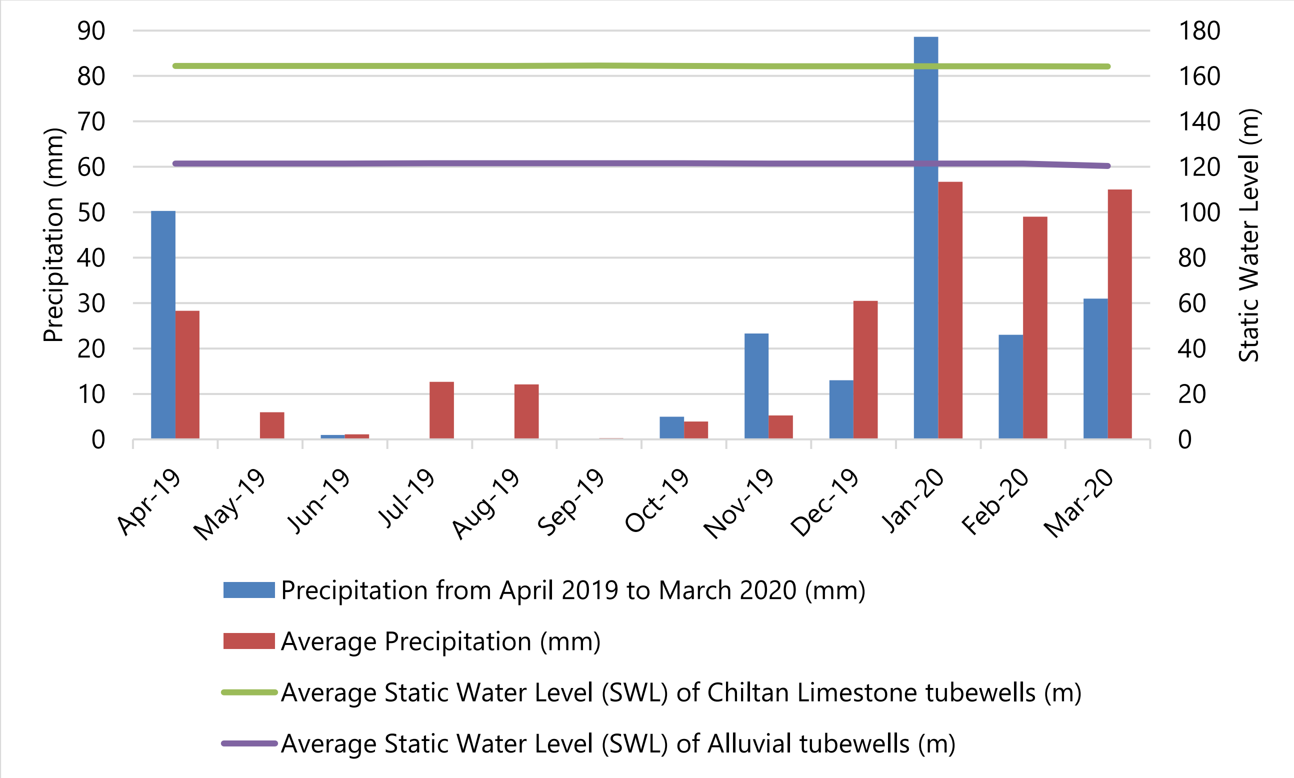

Figure 3. Graphical Correlation between precipitations, average static water level of the limestone and alluvial tube wells from April 2019 to March 2020.

3.1.1 The well-level data method

The well-level data method is considered as the most accurate method for the estimation of recharge and decline (or rise) of static water level of an area for one year (Qablawi, 2016), because this method measures the groundwater recharge based on the difference in static water level at the beginning and at the end of the water year, which in Quetta sub-basin is considered to be from April through March, with consideration of the soil porosity (Qablawi, 2016).

As per this procedure, the decline (or rise) in static water level may be estimated, using the following equation:

$$R = (WL_2 - WL_1)\, P$$

Where,

R = Estimated Recharge,

WL_2 = Water level at the beginning of water-year in meters,

WL_1 = Water level at the end of the water year in meters and

P = Adjusting for porosity [0.2] (Ward & Trimble, 2003).

3.1.2 Decline of static water level of the Limestone aquifer

Details of the static water levels of the forty (40) monitored tube wells; nine (09) in the Limestone aquifer and thirty-one (31) in the alluvial aquifer, town and sub-division-wise, are given in Table 1 and Table 2, respectively. The annual average static water level of the nine (09) tube wells of the Limestone aquifer at the beginning of water-year (i.e., April 2019; as WL_2) is estimated as 164.41 m; whereas at the end of the water-year (i.e., March 2020; as WL_1) is estimated as 164.21 m (Table 3). Subtracting values of WL_1 from WL_2, the total decline in the static water level of Limestone aquifer may be estimated as:

Annual average static water level at the beginning of water year (WL_2) = 164.41 m

Annual average static water level at the end of water year (WL_1) = 164.21 m

Therefore, decline of the annual average static water level = WL2 – WL_1

= 164.41 m – 164.21 m

= 0.2 m

Table 1. Data of the static water levels, monitored from April 2019 through March 2020 of 09 tube wells of the Limestone aquifer

#	Tube well Name& Location	Rock Type	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
			Static Water Level (Below Ground Level in meters)											
Zargoon Town														
Gwal Mandi Sub Division														
1	Kansi Qabristan Haji Umar	Ch.L.	75.4	75.4	75.5	75.6	75.4	76.3	74.3	74.4	74.4	74.4	74.2	74.2
Pashtoon Abad Sub Division														
2	Mehmood Mina Malik	Ch.L.	187.8	187.8	187.8	187.9	187.9	187.9	187.8	187.7	187.7	187.6	187.6	187.5
3	Usmanabad 2 Pashtoon Abad	Ch.L.	216.3	216.3	216.3	216.4	216.4	216.3	216.3	216.2	216.1	216.0	216.0	215.9
Mali Bagh Sub Division														
4	Marriabad WASA	Ch.L.	136.3	136.4	136.5	136.5	136.6	136.7	136.6	136.5	136.5	136.5	136.3	136.3
Chiltan Town														
Brewery Sub Division														
5	Karkhasa-3	Ch.L.	79.9	79.8	79.8	79.8	79.9	79.9	79.8	79.8	79.8	79.7	79.7	79.6
Nawa Killi Sub Division														
6	Dara Manda *RTU 38 Solar	Ch.L.	163.7	163.8	163.8	163.8	163.9	163.8	163.8	163.8	163.8	163.8	163.7	163.6
7	Dara Manda North-5 Kach Road	Ch.L.	163.5	163.5	163.5	163.5	163.5	163.6	163.6	163.5	163.5	163.5	163.5	163.4
Sariab 2 Sub Division														
8	Mian Ghundi Dawood Shahwani	Ch.L.	278.8	278.8	278.8	278.9	279.0	279.1	279.2	279.3	279.3	279.4	279.3	279.2
9	South-2 Hazar Ganji	Ch.L.	178.2	178.3	178.3	178.4	178.4	178.4	178.4	178.3	178.3	178.3	178.2	178.2

Source: Primary Data, 2019-2020

Abbreviations: *Ch.L.= Chiltan Limestone; RTU: Remote Telemetry Unit

3.1.3 Decline of static water level of the Alluvial aquifer

The annual average static water level of thirty-one (31) tube wells of the Alluvial aquifer at the beginning of water-year (i.e., April 2019; as WL_2) is estimated as 121.43 m, whereas, at the end of water-year (i.e., March 2020; as WL_1) is estimated as 120.44 m (Table 4). Subtracting the values of WL_1 from WL_2, the total decline in the annual average static water level of Alluvial aquifer may be estimated as:

Annual average static water level at the beginning of water year (WL_2) = 121.43 m

Annual average static water level at the end of water year (WL_1) = 120.44 m

Therefore, decline of the annual average static water level= WL2 – WL_1

= 121.43 m – 120.44 m

= 0.99 m

Table 2: Data of the static water levels, monitored from April 2019 through March 2020, of the 31 tube wells of the Alluvial aquifer of the Q-WASA

#	Name & Location of Tube Wells	Rock Type	Static Water Level (in meters)											
			Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
	Zargoon Town													
	Gwalmandi Sub Division													
1	Tareen Road Gawal Mandi Police Station	Allu.	129.7	129.8	129.8	129.9	129.9	129.8	129.9	129.6	129.3	129.2	129.2	128.0
2	Akhter Muhammad Road	Allu.	133.5	133.7	133.8	133.9	134.0	133.9	133.7	133.6	133.5	133.4	133.3	132.3
3	Abdullah Pall Street	Allu.	89.3	89.4	89.5	89.5	90.9	90.7	90.6	90.6	90.5	90.4	90.4	89.4
4	Ismail Colony Gali-2	Allu.	130.1	130.2	130.3	130.4	130.4	130.3	130.2	129.9	129.9	129.8	129.7	128.7
5	Patail Road	Alllu.	160.1	160.2	160.2	160.2	160.2	160.1	160.1	160.0	160.0	159.9	159.9	158.2
	Pashtoon Abad Sub Division													
6	Afghania Road Pashtoon Town	Allu.	135.5	135.6	135.6	135.7	135.8	135.7	135.6	135.6	135.5	135.5	135.5	134.1
7	Baqi Masjid Kakaran RTU 60	Allu.	154.3	154.4	154.5	154.5	154.5	154.4	154.4	154.4	154.4	154.3	154.3	153.2
8	Muslim Ithad Colony	Allu.	167.3	167.9	167.9	168.0	168.1	168.0	167.9	168.0	168.0	167.9	167.8	167.7
	Mali Bagh Sub Division													
9	Basti Panchayat	Allu.	87.9	88.0	88.1	88.1	88.1	88.1	88.0	88.0	88.0	88.0	87.9	86.9
10	Circuit House	Allu.	94.5	94.6	94.7	94.7	94.8	94.7	94.7	94.7	94.7	94.6	94.6	93.6
11	Saeedabad Alamdar Road	Allu.	111.5	111.6	111.7	111.7	111.8	111.8	111.8	111.7	111.7	111.7	111.7	111.7
	Satellite Town Sub Division													
12	Urban Planning Office	Allu.	96.9	96.9	96.9	97.0	97.0	97.1	97.0	97.0	97.0	96.9	96.7	96.8
13	Gol Masjid	Allu.	142.6	142.7	142.7	142.8	142.9	142.9	142.8	142.8	142.8	142.7	142.7	141.7
14	Satellite Town Block-5	Allu.	136.5	136.6	136.7	136.7	136.7	136.7	136.7	136.7	136.7	136.6	136.6	134.1
15	Khilji Colony	Allu.	147.0	147.0	147.0	147.1	147.1	147.1	147.1	147.1	147.0	147.0	147.0	145.4
16	Zahir Barech	Allu.	84.6	84.7	84.8	84.8	84.8	84.9	84.8	84.8	84.7	84.7	84.6	83.6
	Chiltan Town													
	Ayub Stadium Sub Division													
17	Pir Muhammad Road	Allu.	95.5	95.6	95.6	95.7	95.7	95.8	95.7	95.7	95.6	95.6	95.6	94.6
18	Killi Ismail-1	Allu.	99.0	99.1	99.1	99.2	99.2	99.2	99.2	99.2	99.1	99.1	99.1	98.1
19	Killi Shaboo	Allu.	91.1	91.1	91.2	91.2	91.3	91.3	91.3	91.3	91.3	91.2	91.3	91.1
20	*GOR Colony	Allu.	112.8	112.9	112.9	112.9	113.0	113.0	113.0	112.9	112.9	112.8	112.8	110.8
	Brewery Sub Division													
21	Ali Abad Hazara Town	Allu.	125.6	125.7	125.7	125.8	125.8	125.8	125.7	125.6	125.6	125.6	125.6	124.25
22	WASA Store Western Bypass	Allu.	140.3	140.4	140.5	140.5	140.5	140.5	140.4	140.4	140.4	140.4	140.3	139.3
23	Railway Forman Colony	Allu.	95.6	95.6	95.7	95.7	95.8	95.8	95.9	95.9	95.8	95.8	95.7	95.7
24	Kakar Town Akbarabad Pashtoon Bagh	Allu.	146.3	146.4	146.4	146.4	146.5	146.5	146.5	146.5	146.4	146.4	146.4	145.4
	Nawa Killi Sub Division													
25	Qilla Saidan Airport Road	Allu.	140.6	140.6	140.7	140.7	140.7	140.7	140.7	140.7	140.6	140.6	140.6	139.6
26	North– 3	Allu.	139.3	139.4	139.5	139.5	139.5	139.5	139.5	139.5	139.4	139.3	139.3	138.3
27	North– 2	Allu.	163.2	163.2	163.3	163.3	163.3	163.4	163.3	163.3	163.2	163.2	163.2	162.1
28	Killi Samaly	Allu	149.4	149.5	149.5	149.5	149.6	149.6	149.6	149.6	149.5	149.5	149.5	148.4
	Sariab 1 Sub Division													
29	Shah Zaman Road	Allu.	72.9	73.0	73.0	73.1	73.1	73.1	73.1	73.0	73.0	73.0	72.9	71.9
	Sariab 2 Sub Division													
30	Ferozabad Akakhail Colony	Allu.	98.6	98.7	98.8	98.8	98.8	98.9	98.9	98.8	98.8	98.8	98.8	97.8
31	Haq Bahoo Sariab	Allu.	92.7	92.7	92.7	92.8	92.8	92.9	92.9	92.9	92.9	92.9	92.9	91.4

Source: Primary Data, 2019-20

Abbreviations: Allu. =Alluvial; GOR=Government Officer Residence; RTU=Remote Telemetry Unit

4. DISCUSSION

Population of the Quetta valley rapidly increased, due to several socio-political reasons, and now reached to over 3.0 million, resulting in rapid urbanization and settlements of the population on the piedmont and recharge zones of the Quetta Valley. The heavy population is now burden on the two (Alluvial and

Limestone) aquifers of the Quetta Sub-basin, leading to rapidly increasing rate of discharge, as well as, decline of the static water level at an alarming rate. The agriculture in the valley has increased specifically in the northern and southern parts of Quetta valley and groundwater being the only source of irrigation (Kakar et al., 2016). Illegal private drillers have been drilling tube wells to extract precious groundwater resource without any authorization from the government. An estimated number of 1561 public and private tube wells have been installed, among which 1340 were installed in the Alluvial aquifer and 221 in the Limestone aquifer of the Quetta Sub-basin. These tube wells are supplying groundwater at unprecedented rate due to lack of check-and-balance by the concerned authorities. Accordingly, emphasis has been mostly on the development of resources and less attention has been given to the planning and management of the available groundwater resources, resulting in very high rate of discharge of groundwater from the Quetta Sub-basin.

Conversely, the gradually decreasing rate of precipitation, as indicated by the record of Meteorological Department, indicate fluctuations and a severe drought during the period of 1998-2004 (Kakar et al., 2016) when reservoirs of the Spin Karez and Hanna Lake, situated northeast of the Quetta valley, dried-up and caused very high rate of decline of the static water level of aquifers.

Results of geodesy work of the Quetta valley illustrates that the subsidence is at a very high rate in the central part of the valley, which mostly comprise unconsolidated silt and mud (Kakar et al., 2016). They observed that average subsidence ranges from 81 to 120 mm/y during the period 2006-2016, showing an increase with time. Subsidence at the flanks of the valley is at a lesser rate than in the central parts of the basin, which may be because the peripheral zone comprises less proportion of unconsolidated material (silt and mud) as compared to the central part. Khan et al. (2013) and Ahmad (2007) observed very high rate of water decline (1-1.5 meter/year) based on their observations at several places in the Quetta valley during the period of 1987-2010, whereas, during 2010-2015 they claim it to have reached at an alarming rate of 1.5-5.0 meter/year.

The change in pattern of the water table in Quetta Sub-basin, from 1980 onward, largely follow the pattern of water discharge from the reservoir, droughts and other geo-hydrological stresses (Planning & Monitoring Wing, 2011). The analysis carried out by the (Planning & Monitoring Wing, 2011) indicates that decline of the water table in the Quetta sub-basin is a phenomenon in the hydrogeological regime indicating an average decline rate of up to 3.4 meters/year. The rate of groundwater extraction increased

Table 3. Annual average static water level of the 09 tube wells of the Limestone aquifer

S.#	Name of tube well and location of the Limestone Aquifer	GPS Coordinates		*SWL) at the beginning of water year (April 2019, WL_2) (in meter)	SWL at the end of water year (March 2020, WL_1) (in meter)
		Northings	Eastings		
1	Kansi Qabrastan Haji Umar *RTU	30° 10' 57.1"	67° 01'32 .7"	75.4	74.2
2	Mehmood Mina Malik	30° 09' 17.3"	67° 01' 29.2"	187.7	187.5
3	Usmanabad 2 Pashtoon Abad	30° 09' 44.0"	67° 01' 41.3"	216.3	215.9
4	Marriabad WASA	30° 10' 49.4"	67° 02' 14.3"	136.3	136.3
5	Karkhasa-3	30° 11' 05.3"	66° 56' 28.5"	79.9	79.6
6	Daramanda -1 Dara Manda RTU 38 Solar	30° 19' 50.7"	67° 01' 54.5"	163.7	163.6
7	Daramanda North North-5 Kach Road	30° 15' 48.3"	67° 04' 51.3"	163.5	163.4
8	Mian Ghundi Dawood Shahwani	30° 02' 47.3"	66° 56' 21.0"	278.8	279.2
9	South-2, Hazar Ganji	30° 06' 06.2"	66° 56' 23.3"	178.2	178.2
	Annual Average SWL			**164.4**	**164.2**

Source: Primary Data 2019-2020

Abbreviations: WL_2= Water Level at the beginning of Water year, *WL_1=Water Level at the beginning of Water year, *SWL: Static Water Level, *RTU: Remote Telemetry Unit

Table 4 Data of the Tube wells of the alluvial aquifer, their GPS Coordinates, annual average static water levels

S #	Tube well Name & Location of the Alluvial Aquifer	GPS Coordinates		Static Water level at the beginning of water year (April 2019, WL_2) (meter)	Static Water Level at the end of water year (March 2020, WL_1) (meter)
		North	East		
1	Tareen Road, Gawal Mandi Police Station	30° 10' 50.3"	67° 00' 51.4"	129.7	128.0
2	Akhter Muhammad Road	30° 10' 48.7"	67° 00' 21.8"	133.5	132.3
3	Abdullah Pall Street	30° 11' 20.0"	67° 00' 13.3"	89.3	89.4
4	Ismail Colony, Gali-2	30° 10' 35.5"	67° 00' 49.2"	130.1	128.7
5	Patail Road	30° 11' 19.5"	67° 00' 40.1"	160.1	158.2
6	Afghania Road, Pashtoon Town	30° 05' 31.9"	66° 59' 53.7"	135.6	134.1
7	Baqi Masjid Kakaran, RTU 60	30° 10' 00.2"	67° 01' 03.2"	154.3	153.2
8	Muslim Ithad Colony	30° 09' 09.3"	67° 01' 08.1"	167.3	167.7
9	Basti Panchayat	30° 11' 35.3"	67° 01' 11.8"	87.9	86.9
10	Circuit House	30° 11' 57.0"	67° 00' 30.5"	94.5	93.6
11	Saeedabad Airport Road	30° 11' 10.5"	67° 01' 46.9"	111.5	111.7
12	Urban Planning Office	30° 10' 18.9"	66° 59' 57.7"	96.9	96.8
13	Gol Masjid	30° 10' 02.8"	67° 00' 26.0"	142.6	141.7
14	Stateline Town, Block-5	30° 09' 28.9"	67° 00' 10.7"	136.5	134.1
15	Khilji Colony	30° 08' 26.1"	66° 59' 52.8"	147.0	145.4
16	Zahir Barech	30° 08' 29.4"	66° 59' 03.7"	84.6	83.6
17	Pir Muhammad Road	30° 12' 20.9"	66° 59' 50.7"	95.5	94.6
18	Killi Ismail-1	30° 12' 57.9"	66° 59' 59.5"	99.0	98.1
19	Killi Shaboo	30° 13' 43.2"	66° 59' 16.6"	91.1	91.1
20	Government Officer Residence (GOR) Colony	30° 13' 16.8"	66° 59' 58.1"	112.8	110.8
21	Ali Abad, Hazara Town	30° 10' 54.9"	66° 75' 31.3"	125.6	124.3
22	WASA Store Western Bypass	30° 12' 12.1"	66° 57' 28.1"	140.3	139.3
23	Railway Forman Colony	30° 11' 26.4"	66° 59' 50.7"	95.6	95.7
24	Kakar Town Akbarabad, Pushtun Bagh	30° 11' 57.3"	66° 57' 51.6"	146.3	145.4
25	Qilla Saidan Alamdar Road	30° 14' 41.3"	66° 59' 06.7"	140.6	139.6
26	North – 3	30° 17' 04.6"	66° 56' 51.8"	139.3	138.3
27	North – 2	30° 17' 28.3"	66° 57' 27.6"	163.2	162.1
28	Killi Samaly	30° 19' 28.0"	66° 56' 09.9"	149.4	148.4
29	Shah Zaman Road	30° 11' 02.0"	66° 59' 35.7"	72.9	71.9
30	Ferozabad, Akakhail Colony	30° 10' 22.5"	66° 58' 51.4"	98.6	97.8
31	Haq Bahoo Sariab	30° 07' 20.2"	66° 58' 37.1"	92.7	91.4
		Annual Average SWL		121.4	120.4

Source: Primary Data, 2019-2020

Abbreviations: $*WL_2$: Water Level at the Beginning of Water Year, $*WL_1$: Water Level at the end of Water Year

rapidly, along with the number of wells, in the last two decades. The uncontrolled, and prolonged, groundwater extraction severely affected the water levels, as groundwater withdrawals are exceeding the recharge (Planning & Monitoring Wing, 2011). The groundwater is being extracted beyond the sustainable limits; therefore, the recharge to the aquifer system cannot keep pace with the discharge from it. Particularly, the water is being extracted brutally under the shadow of an inherent incentive of subsidy on agriculture tube wells, which accordingly allows farmers to unlimited exploitation of groundwater without keeping in views the depressed condition of the sub-surface reservoir of the sub-basin.

The gradually reducing natural vegetation cover and uncontrolled urbanization has shrunk the water retention capacity of the watershed area, and allowed rapid runoff from the Quetta Sub-basin (Planning & Monitoring Wing, 2011).

The static water level decline from April 2019 through March 2020 is estimated as 0.2 m in limestone aquifer and 0.99 m in Alluvial aquifer. In the past 12 years, the cumulative decline of water table has been recorded 60 meters in parts of Quetta Sub-basin (Aftab et al., 2018). Hence the current decline is neither stated as drastic nor as dramatic rather estimated as a comparatively lower decline than that of the past 12 years. This is more possibly due to the high rate of rainfall and snowfall (precipitation) during 2019-2020. Yet, due to indefensible long- term groundwater extraction, a decline of 0.2 and 0.99 m is being estimated in Limestone and Alluvial aquifers respectively.

Through current monitoring, it is being estimated that the average static water level of the Limestone aquifer and the Alluvial aquifer is found on 164 meters and 121 meters respectively. On the other side, through many drilling departments such as Irrigation and Power Department and Public Health Engineering Department, it has been observed that water bearing strata in Limestone aquifer and Alluvial aquifer is up to 300 meters and 266 meters respectively. Hence, we have a thickness of 134 meters water bearing strata left in Limestone aquifer and 145 meters left in Alluvial aquifer. It is difficult to say how long these aquifers will take to be depleted (a study recommended to be carried out on this subject) but if there continues a high rate of discharge extraction, low precipitation rates, more increase in the already over-population, dense and quick urbanization and pavement and settlement of population on piedmont recharge zones of the Quetta sub-basin, it is predicted that both these aquifers will get dried soon.

Monitoring of the static water level was carried for the purpose of study of fluctuations in the "static water level". Out of 430 tube wells of the Q-WASA, forty (40) tube wells were randomly selected from both the Limestone and Alluvial aquifers and caution was taken during the measurement of the static water level giving a rest period of 10 hours in order to accurately measure the static water levels of both the aquifers. Extra care was taken so that other government or private tube wells were not operating in the vicinity of 1000 m near the monitored tube wells. The term "Static Water Level" refers to the rest position of the water level of an aquifer in contrast to the "Dynamic Water Level", which refers to the water level in an operating position. Both these terms come under the umbrella of the "Water Table"; however, measurements of the "Static Water Level" are considered accurate for estimation of the decline (or rise) of the aquifers, therefore, we have preferably used the term "Static Water Level" in this research work.

According to USGS a "Water Year" is defined as the 12 month period starting from October 1st for any given year through September 30th of the following year (Qablawi, 2016); however, this period, does not apply to every geographic region of the world, as different regions have variable geographical, climatological and seasonal conditions. Therefore, on the basis of the climatology, geography and seasonal patterns of the Quetta sub-basin we consider the "Water Year" of the area to be starting from April 1st to March 30th of each year.

5. CONCLUSION

We concluded that there is a decline of the static water level in Quetta sub-basin, both in the Limestone and Alluvial aquifers, during the water year 2019-2020. The total decline of the static water level during the water year 2019-2020 in the Limestone aquifer was estimated as 0.2 m, whereas, in the Alluvial aquifer was estimated as 0.99 m. Decline of the static water level in the Quetta Sub-basin is at an alarming rate, therefore, drastic measures must be taken in order to properly manage the ground-water recharge and cope with the acute situation of water shortages in Quetta city.

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