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Assessing the Land Use/Land Cover and Climatic Changes Impacts on Static Groundwater Level: A Study of Quetta, Pakistan

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ABSTRACT

Various natural and anthropogenic factors are affecting recharge processes in urban areas due to intense urban expansion; land-use/landcover change (LULC) and climate considerably influence the ecosystem functions. In Quetta, a terrible transformation of LULC has occurred due to an increase in human population and rapid urbanization over the past years. According to the Pakistan Bureau of Statistics, the population growth from 252,577 in 1972 to 2,275,699 in 2017 shows an abrupt rise which, in turn, has affected the aquifer recharge capability, vegetation, and precipitation at Quetta. This study focuses on the influence of population growth and LULC on groundwater table level by employing multi-temporal, multispectral satellite data during the selected years, i.e. 2014, 2017, and 2020. The results of land classification showed that barren land has shown a considerable decrease whereas the urban area has increased over time from 152.4 km^2 in 2014 to 195.5 km^2 in 2017 to 283.3 km^2 in 2020. In contrast, surface-water area coverage has increased since 2014 because of the construction of a few dams around the valley. The rapid urbanization stressed limited hydrology resources. This limitedness needs to be addressed to conserve/sustain the resources through educating the local community, awareness regarding water use and climate change, and supporting artificial recharge of the aquifers.

Keywords: Climate changes, Urbanization, Geographic information system (GIS), Landcover changes, Watershed

INTRODUCTION

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The land use land cover (LULC) map has a major role in agricultural and water resources planning and management and in resources monitoring programs at local and national levels (Adham et al., 2018). Earth's surface or LULC change analysis is vital for understanding the relationship between natural phenomena of the environment and anthropogenic activities. LULC in a watershed can influence water quality as well as water supply (Rawat & Kumar, 2015). Geographical information system (GIS) is an important technology for the study of LULC and has been used widely to examine and assess large-scale land use changes (Khair et al., 2019). Land classification through GIS is a faster and more cost-effective method than traditional methods. With the advent of GIS, land use mapping provides a very effective and inclusive method for improving the selection of areas designed for agricultural, urban, and/or industrial areas of a region (Rawat et al., 2013).

In a watershed area urbanization, LCLU changes, and deforestation continuously affect the water availability as well as the nature and extent of surface water interactions thus affecting watershed ecosystems. Safer water conservation strategies can be made with an appropriate understanding of the spatial and temporal changes that take place in a watershed over time and the interaction of the hydrological components of a watershed with each other (Ashraf, 2013).

Some studies have shown that climate changes have substantial impacts on watershed hydrology (Earman, 2011). Some research has also indicated that even a slight variation in precipitation amount can significantly impact themean annual discharge. An urban watershed might experience severe weather incidents whether floods or droughts, with increased global warming and climate change (Zhang & Chang, 2013). Still, the hydrologic impacts of the alterations in climate and land use, particularly urbanization, may operate in cycles, and it is often hard to detect which factor will have a more dominant effect (Tomer & Schilling, 2009). A study concluded that climatic variables, such as precipitation and air temperature, might directly influence watershed hydrology although land use and land cover (LULC) can also have substantial impacts (Legesse et al., 2003). Another researcher also concluded that climate change has a significant relationship with peak discharge. Sultana and Hasan concluded in their research that the influence of climate sensitivity in a region could impact socioeconomic, demographic migration, and general community health (Sultana and Hasan, 2024). This change detection analysis requires utilizing multi-temporal and GIS tools to quantitatively examine the effects of an occurrence in the past and, thus, helps determining the changes associated with land cover and land use properties concerning the multi-temporal datasets (Butt et al., 2015).

Numerous research has been performed globally relating to the change analysis of watersheds through different methods, and these studies are important for developing efficient watershed management strategies (Bashir & Ahmad, 2017). Watershed management is immensely important because it's not just a hydrological unit (Singh et al., 2014), but it also has socio-ecological importance, which shows an essential role in determining economic, food, and social security and provision of life support services to residents (Wani & Garg, 2009). Understanding the aquifer's characteristics is extremely important to explore the water potential and groundwater development program for specific areas (Oluwatoyin, & Olatunji, 2022).

The study area is chosen for LULC change detection since it has been subjected to rapid urbanization, increased and unplanned human settlements, soil erosion, overgrazing, deforestation, lack of any cooperative communal structure, and overcrowding over the past 10 years. The rapid urban development that took placein Quetta has led to environmental challenges (Khan et al., 2013).

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Hence, the main objective of this study is to apply GIS applications to determine the extent of changes that occurred in Quetta land use and watersheds over time in which future climate changes and urbanization can cause drastic consequences for water supply and demand. However, the objectives included (i) identification and delineation of different LULC categories and patterns of land use change in the watershed of the years 2014, 2017, and 2020 (ii) to examine the changes in the watershed (iii) to predict the hydrologic impact of land cover changes on groundwater table.

METHODOLOGY

Study Area

Quetta is a district of Balochistan, Pakistan, located in the northwest, on the border with Kandahar Province, Afghanistan. Area-wise Quetta is the 4th smallest district of Balochistan and has an area of 2,741(2653) km^2. It is situated at about 30° 10′N to 30° 25′ N and 66° 42′ E to 67° 18′ E, at an elevation level of 1,680 m above the sea level (Ahmad et al., 2020). Quetta district climate is considered as sub-tropical continental highland, that is, hot summers and extreme winters (Mahar et al., 2018).

Hydrology and Geology

Quetta is located on the border of the two Provinces of Balochistan (Pakistan) and Kandahar (Afghanistan). It is part of the Pishin Lora regional basin which is a landlocked watershed. Two aquifers have been identified: an unconsolidated alluvial aquifer and a bedrock aquifer. The main aquifer is an alluvial aquifer that consists of gravel, sand, and silt deposits. This aquifer is recharged from infiltration of precipitation, runoff, and inflow from the bedrock aquifer in the foothill areas. Water supply is largely dependent on groundwater, mainly derived from this alluvial aquifer. The bedrock aquifer consists of the limestone of the Shirinab and Chiltan formations and conglomerates of the Urak Formation. This aquifer is recharged in the surrounding mountain areas where these formations are exposed (Khan et al., 2013).

Balochistan is comprised of thirteen major river basins, and the flow of these rivers is characterized by spring runoff and occasional flash floods. Of the total water available per annum in Balochistan which is 27.73 billion m^3, 96% is contributed by surface water, and only about 4 percent is contributed by groundwater. The largest source of water, contributing 57% to the total available water, is floodwater. However, due to mountainous and variable terrain, the floodwater typically comes in the form of flash floods, and unfortunately, only 23% of this water resource is utilized. Indus Basin Irrigation System (IBIS) contributes around 39% to the total available water resource and is exploited by 60% in only 5% area of the province in the Kachhi Plain basin towards the east of Balochistan. The rest of the province benefits largely from the groundwater due to the absence of any other perennial source of water (Bhatti et al., 2008).

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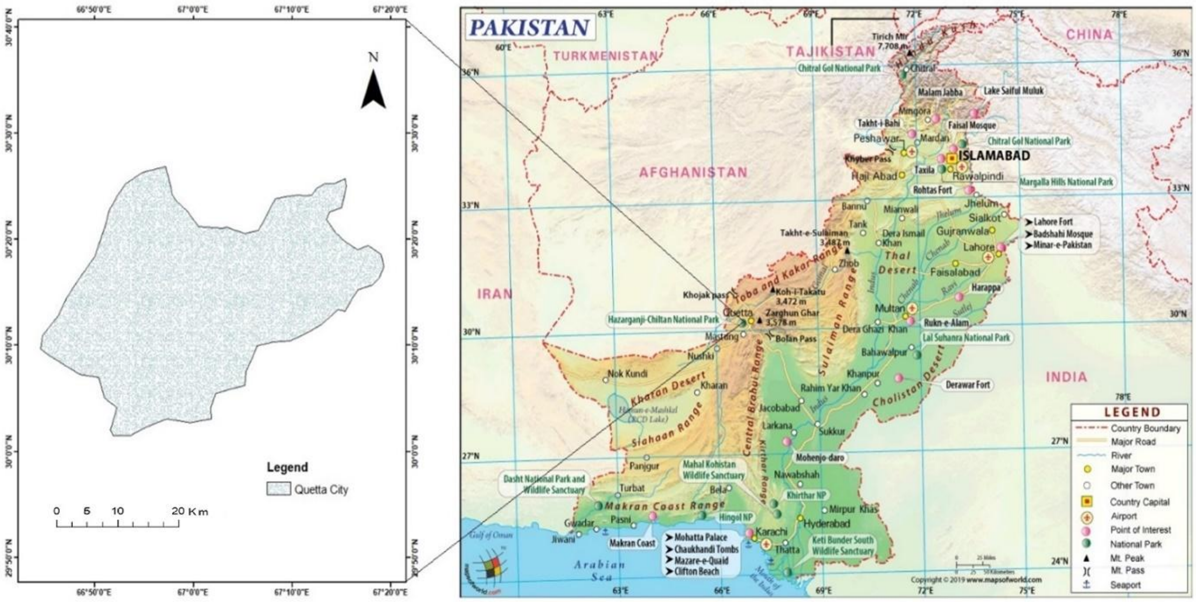

Figure 1. Location map of the study area

Temperature

Temperature data of the past years helps to analyze the temperature variation over time and helps to conclude future predictions. the temperature rise results from several factors. The only source for urban and rural water supply schemes for Quetta is the aquifers. Temperature varies in the valley, i.e., semi-arid climate with great deviations from summer to winter temperatures. The temperature usually rises to 38°C in summers and drops to 4°C to 6°C on average in winters (Durrani et al., 2018).

Precipitation

Quetta Valley does not have sustained rainfall in the monsoon season. From December till February, snow falls, and it very rarely occurs in March. The imbalance between precipitation and temperature is very important to note. The evaporation is usually higher than precipitation, and, thus, the sustainability and level of the groundwater table cannot be maintained. The highest rainfall of 113 mm was recorded on December 17, 2000 and the highest monthly rainfall of 232.4 mm was documented in March 1982 (Durrani et al., 2018).

Population

According to a census, the population of Quetta District in 1975 was reported to be 252,577. The population rapidly expanded in the late 1970s and 1980s because of migrations from a neighboring country, Afghanistan, due to wars. So, by 1981, the population had almost doubled and raised to 383,403. The population continued to increase at a constant rate, and according to 1998 census data, the population recorded was 773,936. In recent years, because of severe droughts in the surrounding areas of Quetta City, an increased migration from rural areas to Quetta occurred. In the recent census of 2017, the population of Quetta District increased to 2,275,699.

Table 1 Population census of Quetta city over the years

Name	Status	Population Census (1972)	Population Census (1981)	Population Census (1998)	Population Census (2017)
Quetta	District	252,577	383,403	773,936	2,275,699

Source**:** Pakistan Burau of Statistics

Data collection

This research is dependent on secondary data. To prepare the base maps for analysis purposes, satellite images have been downloaded from USGS Earth Explorer, and the study period is selected from the year 2014 to 2020 on an interval of 3 years. The second imagery source was Landsat 8 (05/05/2014), Landsat 8 (04/29/2017), and Landsat 8 (04/17/2020) satellites with 30 m resolution, from which we used the full set of spectral bands (USGS). We chose available cloud-free images from 2014, 2017, and 2020. The imagery georeferenced was 30 m to ensure proper alignment.

Data Pre-processing

In this stage, collected satellite images are processed through geo-referencing. At first, they are transformed into the World Transverse Mercator (WTM) map projection system, with datum WGS1984 (GCS) or UTM.

Land Classification

Among the two supervised and unsupervised classifications (Roy and Saha, 2016), the supervised classification method has been used in this study. In a supervised classification, an image is classified using polygons that represent separate sample areas of the different land use types to be classified. Four specific classes are taken for the classification: Urban Area, vegetation, Barren land, and Water body. The designation and covering features of each class are shown in Table 2.

Digital Elevation Model (DEM)

Water resources planning tools and hydrologic simulation models usually use hydrographic datasets, most significantly, stream network polylines, and watershed boundaries, which can be made from gridded (raster) digital elevation models (DEMs), using well-established terrain analysis techniques (Yang et al., 2014). The 30 m resolution SRTM DEM was downloaded from USGS Earth Explorer and was processed for the extraction of flow direction, flow accumulation, stream network generation, and finally the delineation of the watershed and sub-basins.

Table 2 Details of the land cover types

LAND USE	DESCRIPTION
Urban area	Commercial, residential, industrial, transportation, roads, housing schemes and other urban populations
Vegetation	Forest, vegetative lands, scrubs, and others crop fields
Barren land	Uncovered soils, sand fill, landfill sites

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Water body	Permanent open water, dams, lakes, and reservoirs

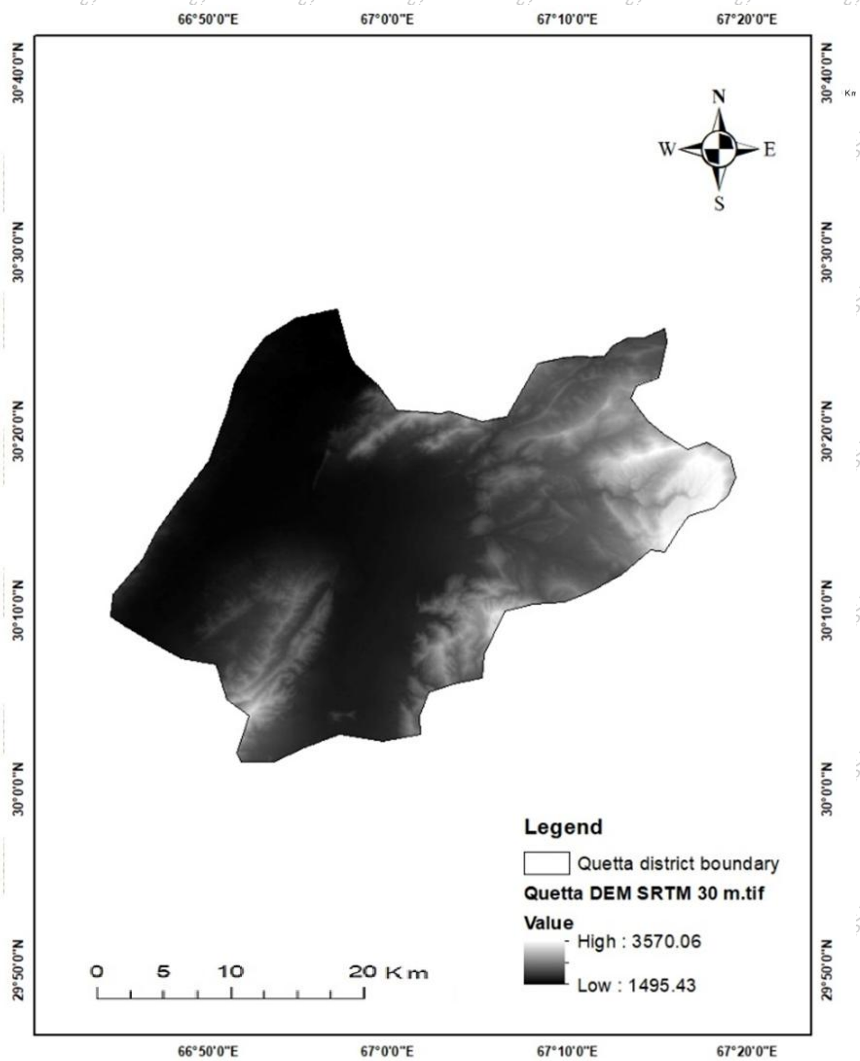

Figure 2 DEM with 30m resolution of the Study Area

RESULTS AND DISCUSSIONS

Land classification

From the analysis of the geometry calculation on ArcGIS, it can be seen in Table 3 that urbanization is increasing at an alarming rate in Quetta District. The area covered by urbanization was 152.4 km^2 in 2014. It increased to 195.5 km^2, and further, it has increased to 283.3 km^2 in 2020. Vegetation seems to be lesser in 2017 as compared to 2014, but it has grown in 2020, covering an area of 242.5 km^2. According to a housing survey (Mahar et al., 2017), most of the houses were constructed during the last 40 years as shown in Fig 2. A major issue across the world faced by many countries is rapid urbanization. Pakistan is among the countries which are facing urbanization at the rate of 3% annually, reported at the fastest rate in South Asia. Urban expansion in Pakistan may be due to the natural increase in human population, or it might be due to external and internal migration of the people to metropolitan cities. The United Nations Population Division estimated that, by 2025, approximately half the country's population might be living in cities in comparison to one-third of the population at present. More recently, people of Pakistan's tribal areas and refugees from Afghanistan have triggered enormous pressure on urban areas, particularly, Peshawar, Quetta, and Karachi. At the same time, many Pakistanis, particularly farmers and fishermen affected by rural water shortages and natural disasters including flooding and earthquakes, are moving to cities to seek better livelihoods (Jabeen et al., 2017). According to the results, the land cover with vegetation increased from 153.8 to 242.5 km2 over the last 10 years.

Table 3. Land use classification of the selected years

Year		**2014**	**2017**	**2020**
Sr. #	**Class name**	**Area (km^2)**	**Area (km^2)**	**Area (km^2)**
1	Barren land	1098.6	1134.3	878.5
2	Urban area	152.4	195.5	283.3
3	Vegetation	153.8	75.15	242.5
4	Water bodies	0.7406	0.4825	1.1498
Total Area		1405.5	1405.5	1405.5

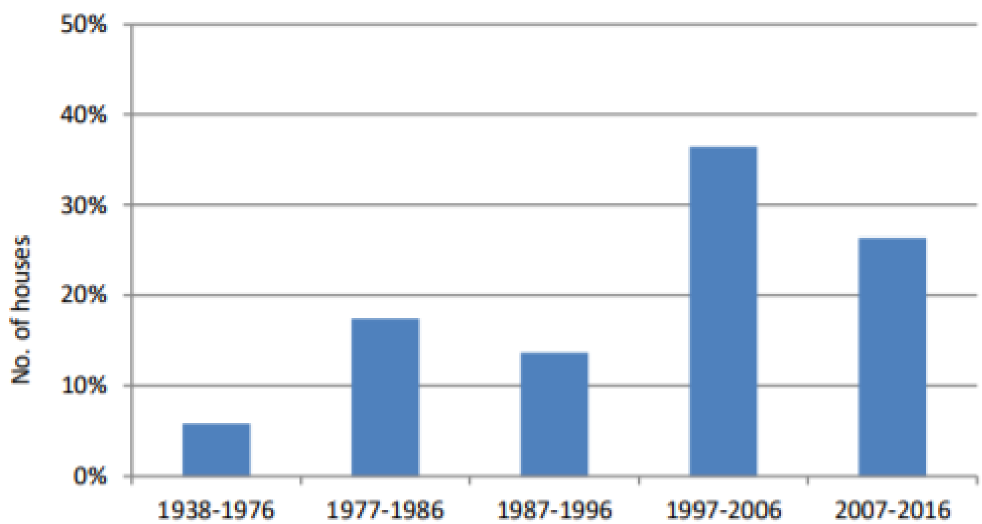

Figure 3. Rate of Construction in Quetta City (Mahar et al., 2017)

This proves a direct relationship between increased agriculture and water resource depletion. However, the major influence for these effects seems to be a rapid increase in population, which is creating a gap between water supply and demand. Deforestation in the mountain regions in 2017 may be contributing to the decrease in precipitation and rise in temperature. Water bodies covered an area of 0.7406 km^2 in 2014. It decreased to 0.4825 km^2 in 2017 due to droughts and lack of rainfall. In 2020, as a result of dam construction, the surface water body area increased to 1.1498 km^2. LULC can directly or indirectly impact infiltration, evapotranspiration, and surface runoff generation of water. LULC map was prepared (Fig. 4) from the satellite imagery of Landsat-8 OLI through a supervised classification technique (Samanta et al., 2018).

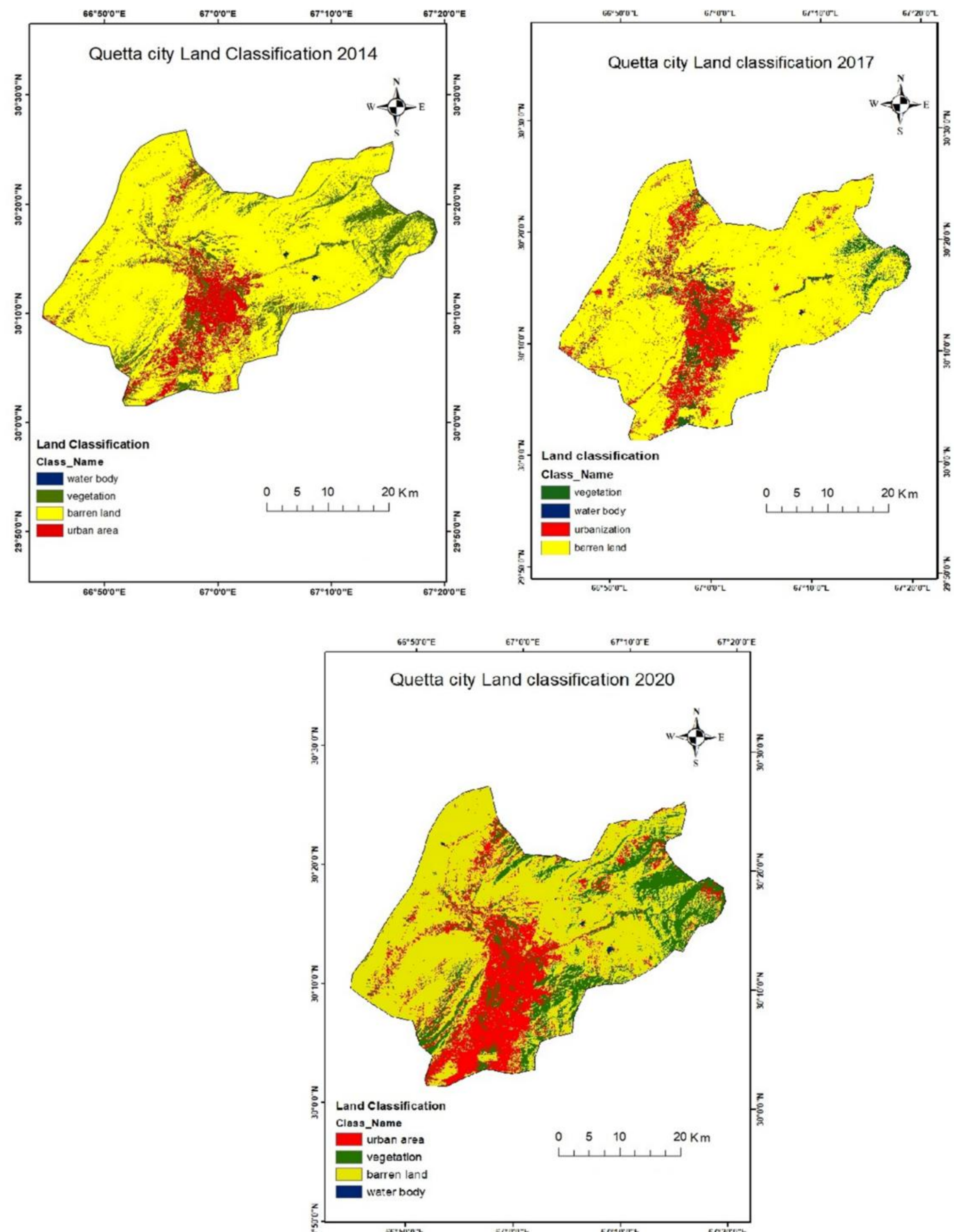

Figure 4. Land use classification comparison of different years

Climatology

According to data obtained from the weather stations installed by the meteorological department in Quetta. Figure 5 shows the annual rate of average temperature and precipitation in 2019. The highest average temperature has been recorded in July, i.e., 28.5 °C, whereas the lowest temperature recorded was in January, i.e., 4.6 °C. The highest average precipitation was recorded in March, i.e., 55.9 mm whereas the lowest average precipitation was recorded in September, i.e., 2.3 mm. The total precipitation in 2017 was 370.81 mm. In the highland Balochistan Province, rainfall decreases with altitude and each zone has differing climatic conditions, water availability, and cropping systems (Khair et al., 2015).

According to Durrani on July 10, 1998, the highest temperature recorded in Quetta was 42 °C. On January 8, 1970, the lowest temperature recorded was -18.3 °C. The summer season continues from May till September with an average temperature of 24-26 °C. The autumn duration is basically from September-November with a temperature range of 12-18 °C. The winter ranges from October to March with temperature variation of 4-5 °C. Spring ranges from April to May with an average temperature of 15 °C (Durrani et al., 2018).

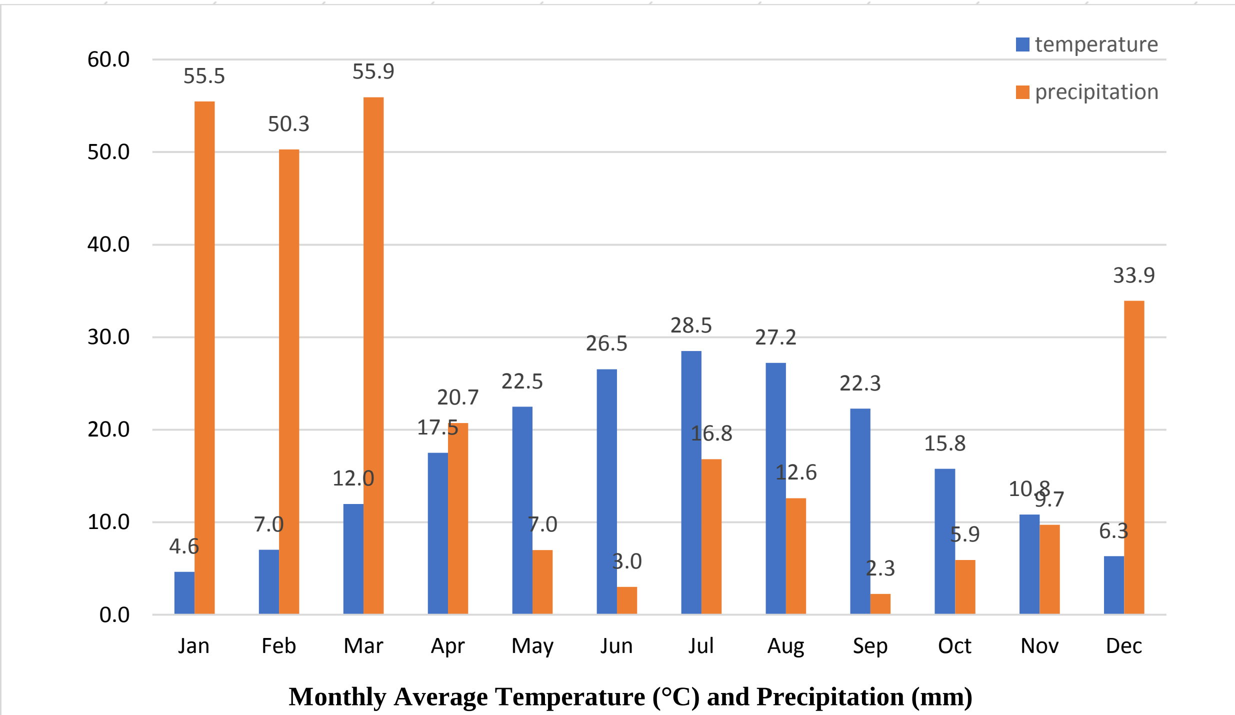

Figure 5. Summary of one-year temperature and precipitation

Watershed Model

Figure 6 shows the DEM of Quetta District on which the stream orders are also indicated with dark blue and light blue color lines. The colored parts on the map show the catchment areas. The blue lines show the path of the water streams that flow from the mountainous region in different directions in each catchment. The steeper slopes result in a low contact period with the land surface and reduce infiltration and groundwater recharge (Rukundo & Dogan, 2019), so the water running down the hilly terrain to the valley does not get enough time to get infiltrate.

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These streams, when reaching the ground surface and favorable soil quality, infiltrate into the groundwater aquifers

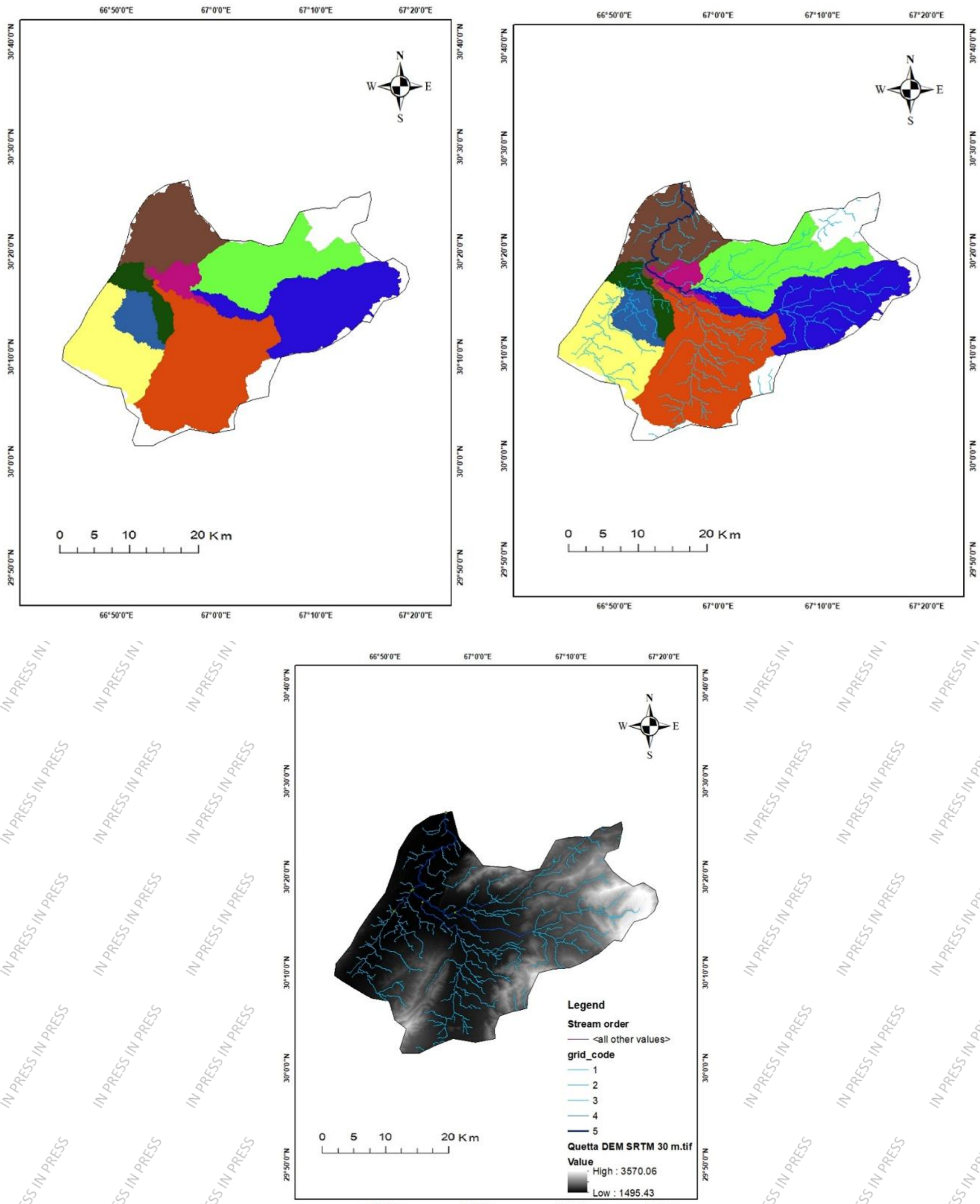

Figure 6. Watershed models of study area

slowly and gradually recharging the aquifers, but this recharge can be hindered when the recharge zones are covered with the construction and settlements. It is very necessary to identify the recharge zones of a city or any region so that the related departments or governments can avoid the coverage of recharge zones by the settlements either by construction parks or forests. Quetta City has led to unmanageable abstraction and use of groundwater causing deterioration in groundwater quantity and quality (Ahmed et al., 2019). Some researchers employed the inverse interpolation technique (IDW) in GIS environments of various parameters to develop spatial distribution maps of water quality in Iraq (Al-Hadithi et al., 2019).

For each parameter, these parameters were used to calculate water quality index values which were also reassigned to the GIS environment to generate the IWQI maps.

Groundwater level

Groundwater table data was obtained from the Irrigation Department and Water and Sanitation Authority (WASA) of the year 2019. The number of observational tube wells under study was 72. The average groundwater level is indicated on the diagram in Fig. 7. The map is divided based on grid lines, and the average water table is denoted on the diagram. However, climate alterations over time, such as an increase in average temperature and a decrease in average precipitation have caused the groundwater table to decline. But the most important problem arising is the rapid urbanization and increased population growth of Quetta. Being the largest business and educational center, migration to Quetta City has increased drastically (Ghani et al., 2019). The population density affects the groundwater resources due to overexploitation and wastewater infiltration in other urban units in Pakistan such as Lahore (Muhammad et al., 2016).

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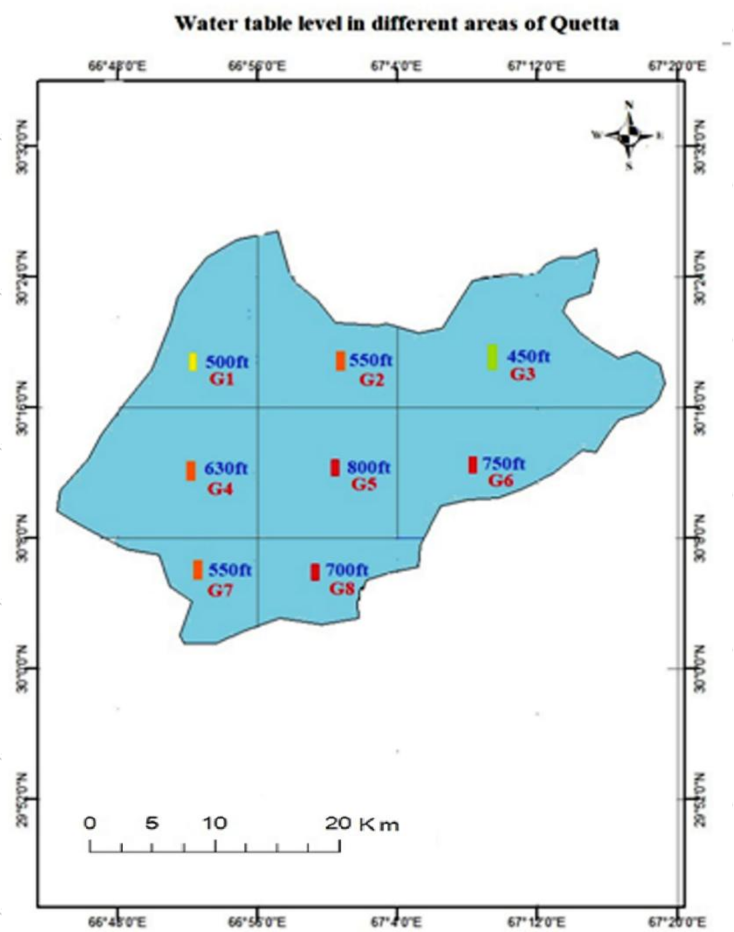

Figure 7. Map indicating groundwater levels in different regions of study area

According to the data presented, the deepest groundwater level is found in the main city labeled as G5, which is 800ft, and as the urban population expands downwards, the water level is 700ft in G8, which is mainly due to the over-exploitation of groundwater reservoirs over the past few years (Kakar et al., 2020). G3 is the mountainous region of Hannah Urak where the water table is at the lowest 400ft. Dams, such as Hannah Jheel, Spin Karez, and Wali Tangi, are also constructed in this region which has water almost all year round, contributing to the maintenance of groundwater table. Although regions G1, G2, and G3 are mountainous, regions of the valley still contain a human population that depends on groundwater for drinking purposes. The water table has not yet exceeded 500ft on average, below the ground in this region. In terms of recharge, extraction, and urbanization, the aquifers of Quetta need insight research studies to evaluate the behavior of the aquifer to future stresses and to find a future strategy for operating the system.

Groundwater is an essential local and regional natural resource worldwide and is often in high demand. As groundwater is a common resource, it is frequently overused, resulting in the decline of water tables and water resource security reduction over time. Major factors, causing groundwater over-exploitation in Balochistan, are increased rate of irrigated fruits and vegetable cultivation, drought, mass installation of tube-wells, inefficient irrigation practices, lack of efficient government policies and subsidies that promote groundwater development, and lack of effective groundwater governance (Khair et al., 2019). More than 72% of the rural population in Balochistan depends on dug wells and streams for drinking water (Akhtar et al., 2021).

The Quetta District population has increased from 0.26 million in 1975 to 1.452 million in 2014 at a growth rate of 3 percent, and an increase in urbanization rate is 4.2%. Urbanization's impact on groundwater is one of the key factors that need to be studied in Quetta City. A study was conducted to explore urban growth through satellite images that are classified and processed to quantify the LU/LC changes, which highlight an increase in urbanization in the central region of the Quetta Valley (Dawood et al., 2021). Water streams and Channels indicated in Fig 6 through the watershed model show the flow of water towards the middle of the valley, and if it is not infiltered into the ground, it flows down the valley. Although drought and climate change do have an impact on groundwater availability due to the intense extraction of groundwater through tube-wells as a result of increased population and drinking water demand in the city, the groundwater table is the deepest in city region G5 (Ghani et al., 2019). Tam also concluded in their study that extensive groundwater abstraction as a result of rapid urban population growth was the major cause of groundwater table decline in the city, whereas the change in land use practice, resulting from increased urbanization and decreased agricultural activity and natural land only causes a slight decrease of groundwater recharge (Tam & Nga, 2018). The land cover changes have created water-related issues, such as the water balance, evapotranspiration, groundwater recharge, and water erosion due to forest reduction in the Quiscab River subbasin (Gonzalez-Celada et al., 2021).

In fig.7, the study area is divided according to the gridlines regions as G1, G2, G3, G4, G5, G6, G7, and G8. The recharge of groundwater is also not supported in G5 region due to the overconstructed areas and unplanned settlements as shown in Fig. 4. This site is suitable for the recharge of groundwater aquifers as all the water streams are moving down the mountainous region into G5 region, but due to the rise in urban land and construction, i.e., from 152.4 km^2 in 2014 to 283.3 km^2 in 2020, the infiltration of the water is not possible (Wakode et al., 2018), and the water moves out of the valley through G8 region.

Vegetation was abruptly reduced from 158.3 km^2 in 2014 to 75.15 km^2 in 2017 due to less rainfall and droughts, but it increased gradually to 242.5 km^2 in 2020. Droughts have occurred in Balochistan province, for many years with destructive impacts. The lack of proper monitoring and mitigation measures for droughts in this area increases the vulnerability of the province's agriculture and economy to more destructive impacts (Naz et al., 2020).

RECOMMENDATIONS

- Quetta is a small valley surrounded by numerous mountain ranges, being the provincial headquarters of Balochistan, the population pressure has always been higher due to numerous facilities so there is an imperative need for good urban planning.
- There is a need for extensive research to identify recharge zones, and the government should clear out those areas for parks to support the groundwater recharge, delay actions dams should be constructed to increase the recharge.
- The concerned departments should work on the promotion of artificial recharge of groundwater because, in the rainy season, a lot of water flows out of the valley.

CONCLUSIONS

This study concluded that unplanned construction is creating a lot of environmental problems, as a result of land classification, uncontrolled and increased urbanization is detected around the valley which is also reducing the recharge opportunity, especially in city areas i.e., G5 and G8. The flow of population in this area is higher due to the plain topography and so the demand for fresh drinking water is also higher. The excessive construction of tube wells to overcome the drinking water demand of the human population is deteriorating groundwater levels.

Due to several droughts over the past years, the vegetative land, reduced to a very small number in 2017, i.e., 75.15 km^2 but has increased gradually again to 242.5 km^2 in 2020, mainly because of regular precipitation in rainy seasons and snowfall. Since the water supply of the valley utterly depends on groundwater and the economy of Balochistan largely depends on agriculture, the conclusions from this study support the suggestion that water resources management strategies are based on rainwater smart irrigation techniques or tools.

The study area particularly has two vegetation types which are seasonal and orchard vegetation. In seasonal vegetation areas, the whole land is usually not cultivated by the farmers due to the scarcity of irrigation water and associated tubewell maintenance or pumping costs. Consequently, most of the area remains unsown or barren. Likewise, where orchard vegetation is occurring, the plantation of trees is carried out in grids with several meters distance between plants, therefore the proportion of actual vegetation to the total area is fairly low, and the presence of significant bare soil surface could contribute to the detection of barren land during land classification.

According to the rainfall fluctuating patterns in the Balochistan Province, water reuse or recycling techniques need to be adopted at the local level. The strenuous decline of the groundwater table means that the urbanization or LULC and impermeabilization of the soil have largely affected the natural recharge process, and most of the precipitation is either converted into runoff or lost through evapotranspiration. Overall, this study indicates that the urbanization process has altered the natural hydrological cycle.

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