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From Scarcity To Sustainability: A Study On Reviving Quetta's Aquifer Through Rainwater Harvesting

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ABSTRACT
Growing water demands of the world's population are leading to the depletion of groundwater resources. Increasing Urbanization is changing the natural recharge patterns of aquifers. High abstraction rates of groundwater are adding more pressure on the already stressed aquifer system of Quetta. Depleting water levels are giving rise to water scarcity and land subsidence issues in the city. For centuries rainwater harvesting and managed aquifer recharge has been practiced in semi-arid and arid areas of the world to conserve water resources. This research evaluated the suitability of MAR implementation to both control and preserve further exploitation of the aquifer. Relevant maps were digitalized to create raster layers of data to develop an understanding of hydrologic and geologic conditions. Estimations reveal that a considerable amount of rainwater can be harvested from different impervious surfaces in the city. Rainwater combined with pre-treated wastewater can reduce the recharge deficit; however, the high abstraction rates need to be controlled to achieve a sustainable equilibrium which can last for seeable future.

KEYWORDS: Managed Aquifer Recharge (MAR), Groundwater Depletion, Quetta City, Urban Water Scarcity, Water Resource Management.

INTRODUCTION

The planet water resources to be used effectively and sustainably means the world population will get their water requirements met with good water quality. Nevertheless, the water scarcity and water quality deterioration are critical issues that present challenging situations in attaining adequate amount of good quality of water to satisfy human, environmental, social and economic demands to sustain the sustainable growth of nations (UNESCO, 2015). Water scarcity refers to either an inadequate supply or lack of supply caused by physical shortage of water or lack of supply caused by lack of access facilities brought by failure of institutions. Scientists state that about one-third of major earth aquifers are being used unsustainably, and this amounts to life-sustaining water supplies and ecosystems being threatened due to a lack of sustainable use (Buis & Wilson, 2015).

Almost 40 percent of world population is currently experiencing water shortage. The world is experiencing global tension and stress in water and land resources through population growth, rise in per-capita cost of food and food-energy demand. With dependency on non-renewable resources are forcing depletion of these resources (Bhatti & Iftakhar, 2023). The resultant reduction of the crop yield can result in malnutrition particularly in the third world countries. Other resources on which there is also depletion are ground water resources, reservoirs and lakes, in most areas, though all the above impacts are highly dependent upon context based conditions (Pfister et al., 2011).

The subsurface water plays a very important role in the development of 'critical infrastructure elements of cities like provision of water supply, sanitation, drainage and disposal of industrial effluents and waste management. Subsurface is a major recipient of pollution that is induced by industrial effluents either through their deposits or through treatment ponds or through infiltration by surface waterways. Groundwater, pore pressure and quality may alter significantly, and this can seriously affect urban infrastructure and life at a greater scale (Foster, 2001). Regions with concentrated and heavy groundwater abstraction exceeding the average rates of local recharge, groundwater levels may continue to drop over the decades, giving rise to an expensive and inefficient cycle of well deepening or even untimely investment losses due to well abandonment (Foster, 2001).

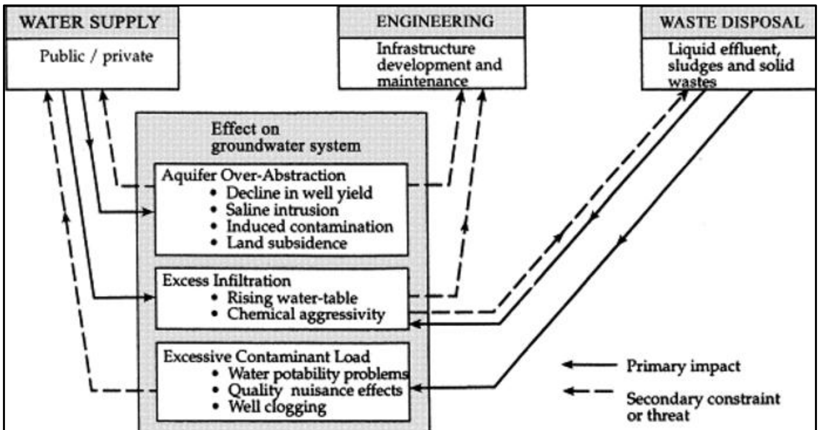


Figure 1: Interaction between urban services through the underlying groundwater system. (Foster, 2001)

Quetta is the capital city of Balochistan province in Pakistan that is situated at Quetta Valley elevated 1680 meters above the sea level. The total area of alluvium in the valley is 792 km² which is a part of the watershed area of 1756 km². The valley is bifurcated into two basins namely the Quetta valley and Dasht plain in two basins namely the Quetta valley and Dasht plain in the north and south respectively (Alam & Ahmad, 2014). The valley consists of three landforms, that is, the valley floor occupies the mid part of the valley. The second topography is the piedmont region which is a territory between the valley plain and the mountains. It recharges the groundwater since it has large hydraulic conductivity. The third land form is the high mountains having steep slopes and this form includes Zarghoon, takatu, Daghari, Chiltan and Murdar mountains. The location of Quetta valley is in the southern basin watershed called the QuettaPishin sub basin that is within Northeast Pishin Lora Basin (NEPL). According to (Kakar et al., 2016), full-service payment is the type of payment that is not affiliated to any particular network.

Results on the depletion of the water table of Quetta in the period between 1987 and 2010 were provided, using 55 observation wells, and they showed a downward trend level 1.5 m/year in the north west and south of Quetta (Khan et al., 2013). Kakar et al (2016) have computed the average water decline rate between 2010 -2015, it was revealed that the average decline rate on the eastern part is 1.5-5.0m/yr and 0.5-1.5 m/yr on the western side. The dark red stands for the distribution of the decline rate of approximately 5-15/yr and the yellow color stands for the distribution of the decline rate of 0.5-1.5m. The green depicts the areas in which the groundwater table is on the increase. Subsidence rate of land also was calculated and this revealed that land in Quetta city is subsiding by 30 mm on sides to 120 mm annually in the middle.

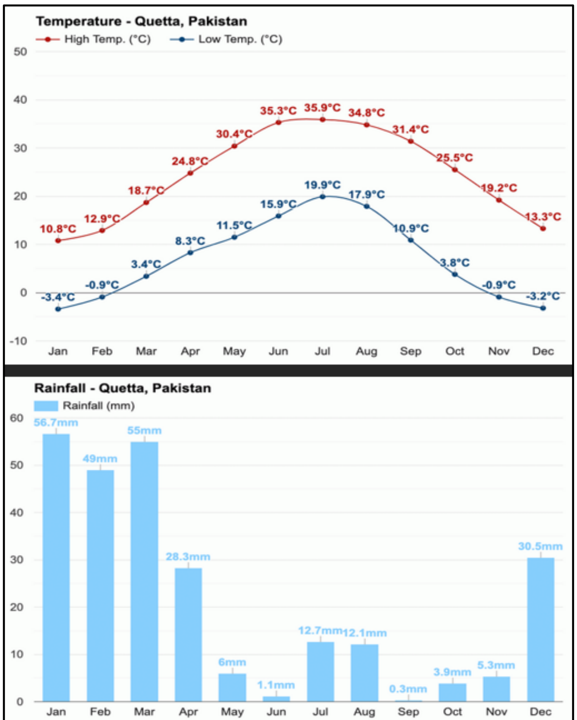


Figure 2: Average monthly temperature and rainfall (source: weather-atlas.com)

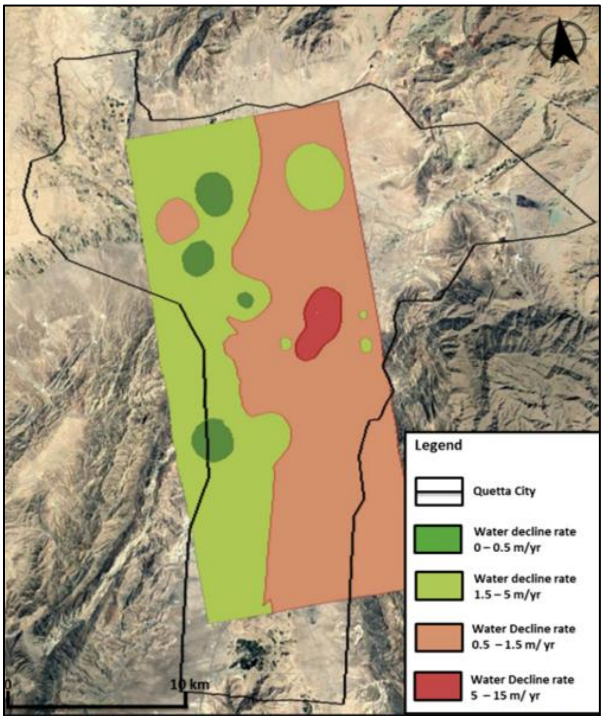


Figure 3: Water decline map. Redrawn from (Kakar et al., 2016)

The main source of water in Quetta for domestic, agricultural and industrial use is groundwater. Ghani et al., 2019 calculated the groundwater recharge deficit for the period of 20 years (1995-2014) and reported that the average recharge for the study period was 37.04 Mm3 while the average abstraction was 84.20 Mm3 revealing an annual deficit of 47.11 Mm3. The maximum deficit of 2.95 MGD was reported for the year 2012 with an annual rainfall of 93.3 mm and the minimum deficit was 0.586 MGD for the year 2011 with annual rainfall of 458 mm. This study also revealed that the difference between the annual recharge and abstraction is increasing with passing time. Two scenarios were also modeled to predict future forecasts, in scenario 1 it was assumed that the abstraction rate remains the same as of year 2014 and in scenario 2 it was assumed that the abstraction rate will increase by 5580 m3 which is the difference between the abstraction rates of years 2013 and 2014. 20% of the average rainfall over 20 years was used as the recharge of the groundwater. (fig 4) presents the results of both scenarios.

PROBLEM STATEMENT

Increasing population is leading to an increase in water abstraction rates in Quetta, fluctuations in precipitation and low recharge rates are causing high decline rates in the water table as a result the land is subsidizing in Quetta valley. Quetta cannot continue to rely completely on its aquifers for the growing water demands. The current problems call for urgent attention and a long-term sustainable solution to reverse the impacts caused by these issues.

Hence the research objective set forth mainly included the following:

The objective of this research was to develop an understanding of Hydrological and geological conditions of Quetta. Evaluate how beneficial would be the implementation of MAR techniques in terms of controlling the groundwater depletion in Quetta.

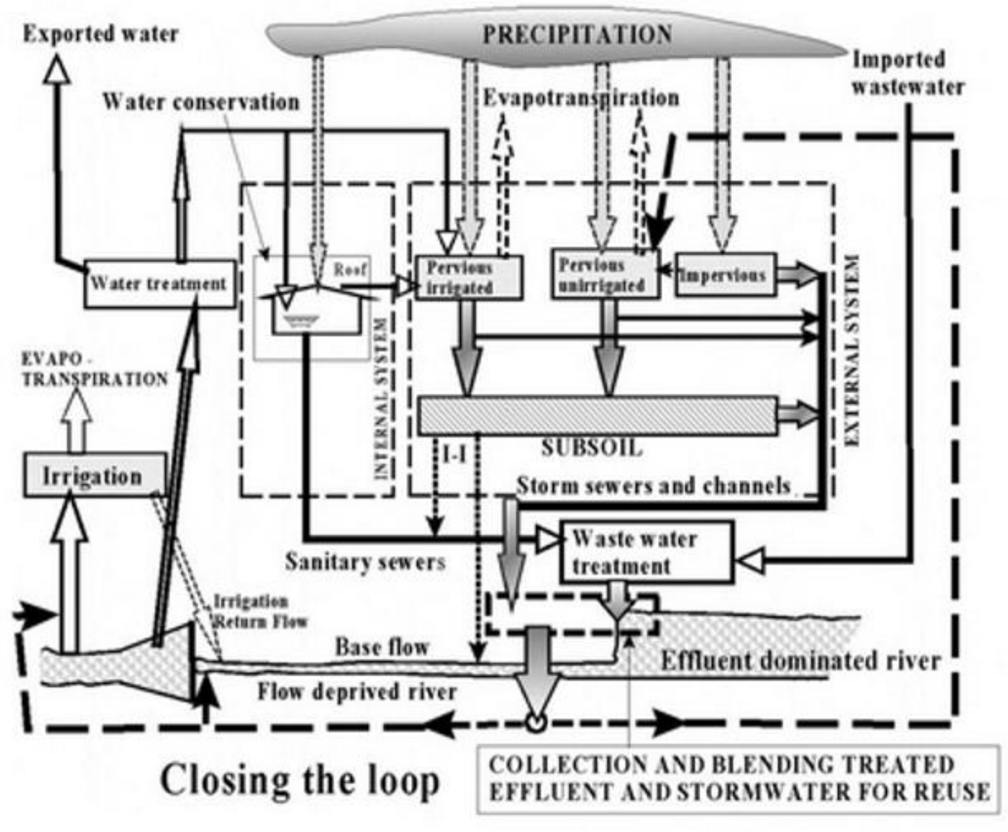


Figure 5: Recycle and reuse of wastewater and urban runoff closes the loop in total hydrological cycle in urban areas (Novotny & Brown, 2007)

The successes and failures in efforts to control pollution has led to the emergence of a new paradigm of urban water resources and drainage known as the fifth paradigm – Towards Hydrological and ecological sustainability of future cities. This paradigm pledges adequate amounts of clean water for all positive uses adopting a holistic approach to the urban watershed, unlike the previous paradigms with functional focus on drinking water, sewage and stormwater as separate components. The evolution of the fifth paradigm is based on the concept of total hydrologic water and mass balance inwhich all the components of water supply, stormwater and wastewater are managed in a close loop (Novotny & Brown, 2007).

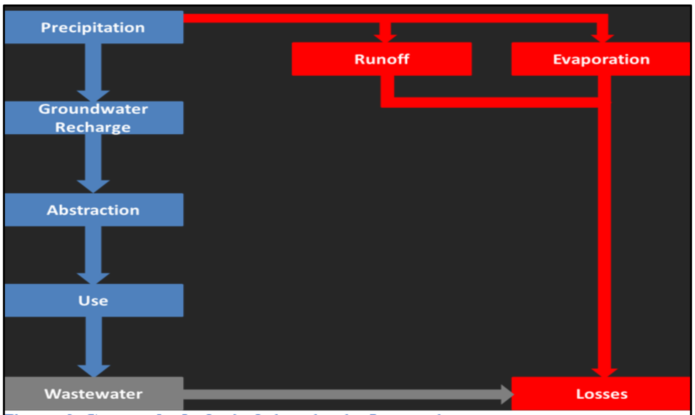


Figure 6: Current hydrological situation in Quetta city

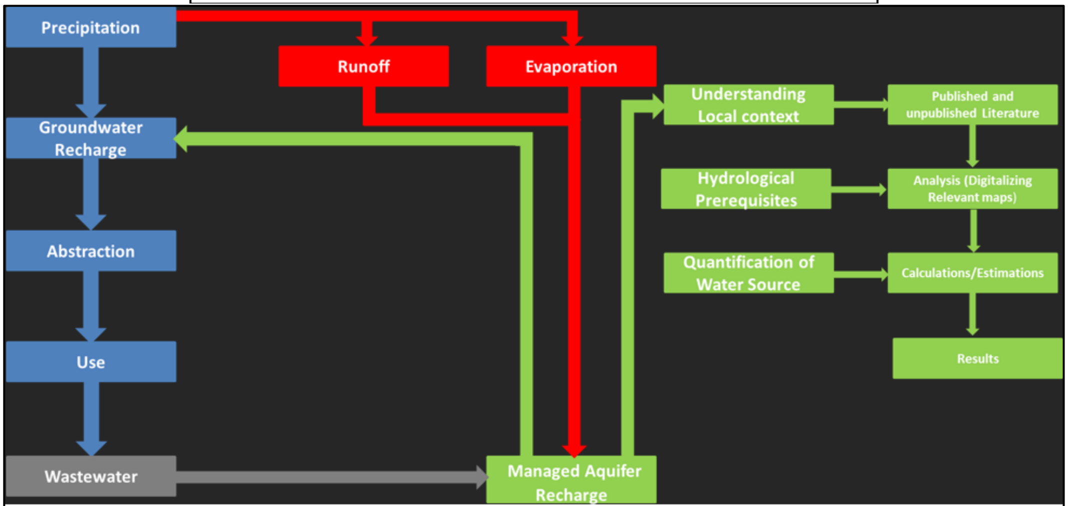


Figure 7: Research methodology

This research will follow the concept of closing the loop in Quetta city, where opportunities of recharging groundwater will be explored through MAR technologies using rainwater as source and wastewater as secondary recharge source depending on underground water quality in Quetta city.

REVIEW OF LITERATURE

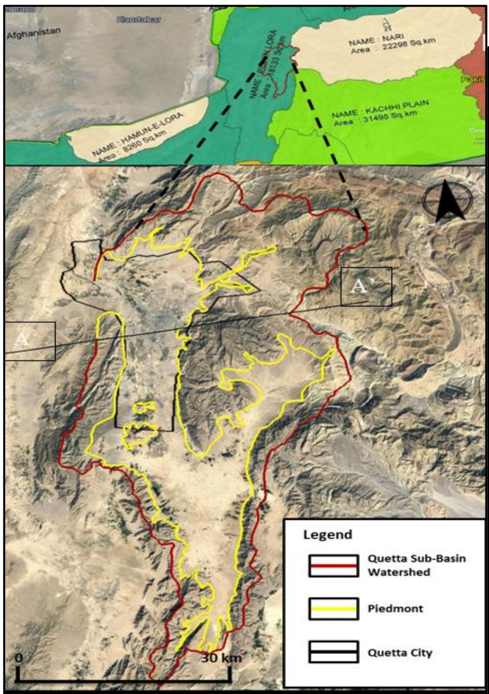


Figure 9: Location map of Quetta sub basin and Quetta city. (Redrawn from (Alam & Ahmad, 2014))

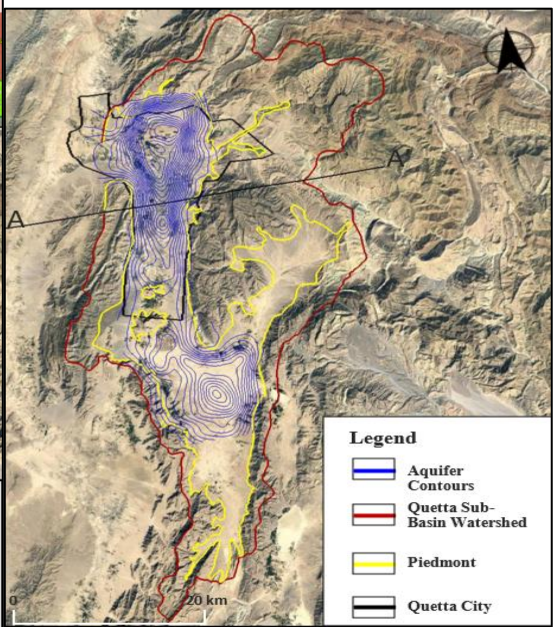


Figure 10: Quetta sub-basin aquifer contours (Redrawn from (Alam & Ahmad, 2014))

The aquifer system of Quetta is divided into four zones. Alluvial fan is the upper-most zone with high porosity and high permeability due to coarse-grained sediments. The groundwater is mainly recharged from this zone because of high hydraulic conductivity. Water depletion in the valley has led to the drying of this zone. The alluvium is the second zone with intermediate porosity and permeability and is composed of sand, gravel and clay. The third zone has very low hydraulic conductivity due to the presence of silt and clay particles and is called Boston Formation. Chilton Limestone is the fourth zone of the Quetta valley aquifer, mainly composed of limestone. The primary porosity of this zone is very low; however, fractures are developed because of high tectonic activity making the secondary porosity very high (Kakar et al., 2016).

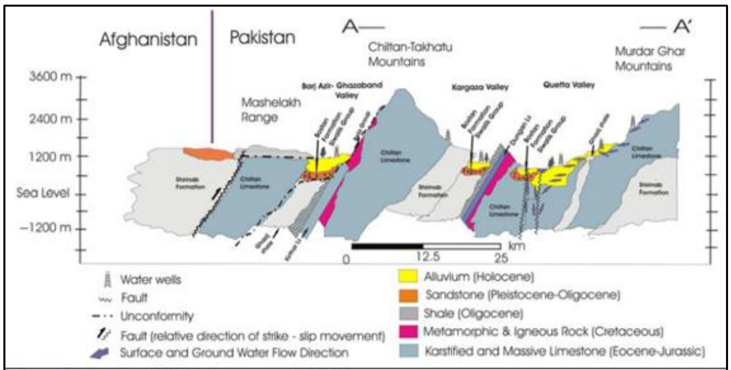


Figure 12: Section AA' (Sagintayev et al., 2012)

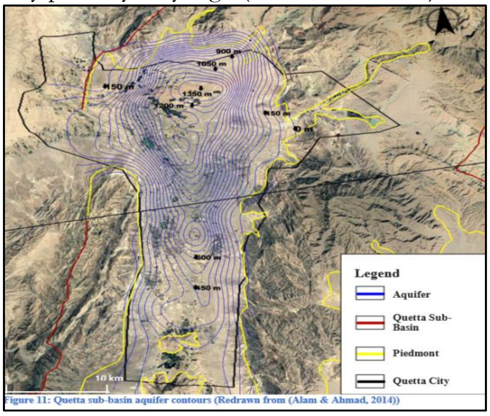


Figure 11: Quetta sub-basin aquifer contours (Redrawn from (Alam & Ahmad, 2014))

The unconsolidated alluvial aquifer and the bedrock are connected to each other hydraulically. The depth of the limestone bedrock varies within the valley; on the northern end, the depth is about 1500 meters and 1058 meters on the southern end (Alam & Ahmad, 2014).

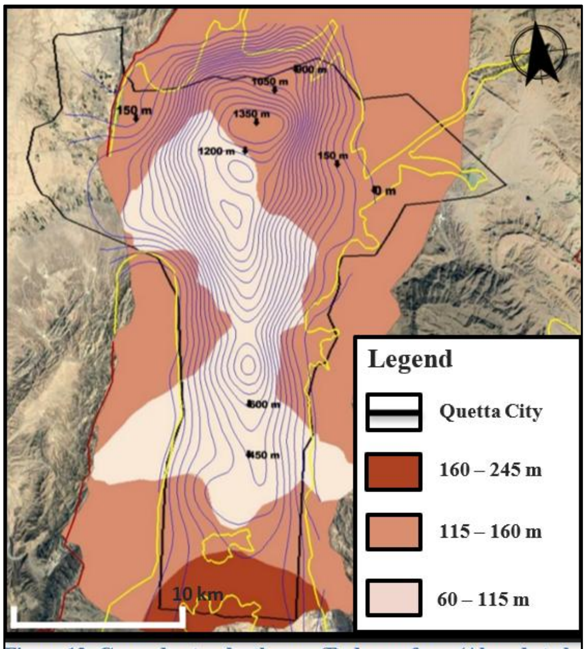


Figure 13: Groundwater depth map (Redrawn from (Ahmed et al., 2019))

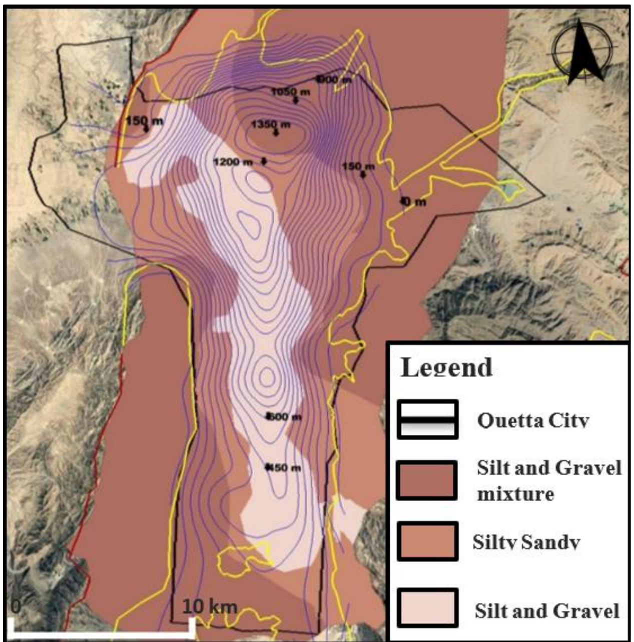


Figure 14: Soil Media Map (Redrawn from (Ahmed et al., 2019))

The groundwater depth map shows the groundwater levels in and around Quetta valley. It can be seen from the map that the groundwater levels range from 60 to 245 meters. The dark brown color on the southern end represents groundwater levels from 160 – 245 meters. Light brown color displays water levels ranging from 115 – 160 meters. The white color shows water levels from 60 – 115 meters in the middle. Soil is the uppermost surface layer up to 2 meters that plays a vital role in the infiltration process and transportation of contaminants (Lathamani et al., 2015). The soil of Quetta valley is composed of alluvial materials such as Silty sandy clay, gravel and their mixtures (Ahmed et al., 2019). The soil media map displays the locations of these alluvial materials in the Quetta valley.

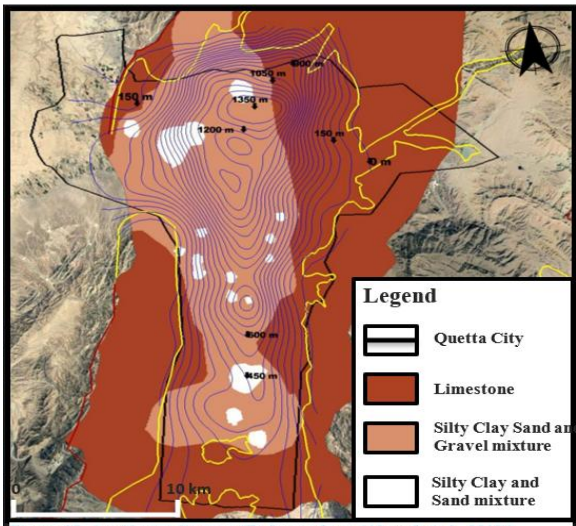


Figure 15: Aquifer media map (Redrawn from (Ahmed et al., 2019))

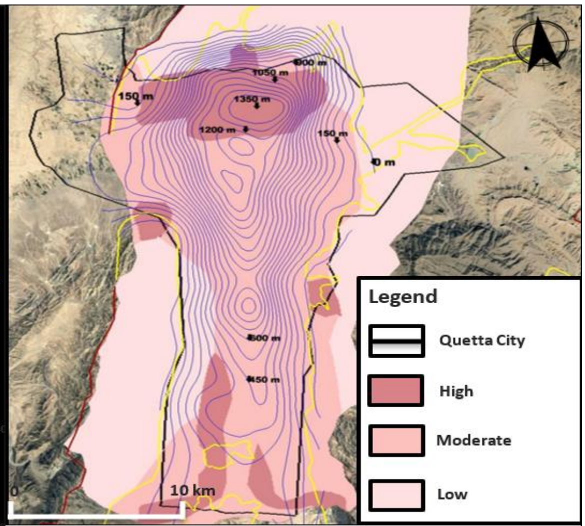


Figure 16: Net recharge map (Redrawn from Ahmed et al., 2019))

The alluvium sediments (clay, silt, sand, gravel) and sediments rocks (limestone and shale) make up the aquifer media of Quetta valley (Ahmed et al., 2019). The Aquifer media map of Quetta valley shows the composition of aquifer media. The net recharge map displays the recharge potential in different areas in the Quetta valley. The variance of colors from dark to light shows the recharge potential from high to low recharge.

The groundwater recharge process is categorized as a gravity-driven infiltration recharge measure of the precipitation through surfaces (original ground) and riverbeds. In contrast, the artificial recharge measures are mainly through the recharge devices in the form of infiltration wells and ponds. Gravitate recharge is quantitatively less expected because of low rainfall intensity with precipitation in the range of 144 mm per annum in Balochistan. River runoff does not generally contribute to subsurface groundwater recharge due to its short duration; moreover, severe surface erosion caused by floods devastates the groundwater conservation conditions in the drainage areas. Several storage dams and artificial recharge facilities have therefore been constructed to accelerate groundwater recharge in the province. 4 out of the 166-delay action/small storage dams built in the Pashin-Lora basin are in Quetta District (Government of Balochistan, 2017).

Since the early 2000s, urbanization and urban sprawl has been occurring in Quetta city (Iftakhar et al., 2023). Severe challenges in terms of housing, traffic congestion, water and sanitation problems, and solid waste management, etc., have been presented due to unplanned, unregulated and accelerated urbanization. The situation will further aggravate if not appropriately managed. The built-up area of Quetta city increased from 105.14 km2 (1999) to 160.17 km2 and 205.03 km2 in the years 2009 and 2019, respectively, depicting a total increase of 45.45 % over 20 years (Bazai & Panezai, 2020).

According to Mahar & Attia (2018) a survey it is seen that most of the houses in Quetta are built with reinforce cement concrete (65%) with other using brick masonry (31%) and sundried brick (5%) and only 25 percent of them were designed by architects over the past 10-15 years. The Roof coverings are R.C.C slabs (79%) and others are burnt brick tiles, C GI sheets or thatch. Water scarcity exists despite high rates of water connections, and the residents utilize the services of the private water tankers and tube wells, which more than doubled between 1995 (880) and 2014 (1,630) (Ghani et al., 2019). The wastewater drainage is mainly done on the basis of the public sewers and other ancillary channels like septic tanks, soak pits and seasonal mountain fed channels called locally named Nala or Lora. Wastewater is usually utilized in irrigation because of the shortage of freshwater, but later on the state started cracking down on the use of wastewater in the fields because it causes health problems. Through these efforts, shortage of alternative water supply has continued to perpetuate the use of wastewater. Water and Sanitation Authority (WASA) had intended to build three sewage plant treatment plants but one of the plants was built and is not yet functional because of funding implications whereas the other two were shelved and subsequently abandoned. Another strategy relates to the construction of another plant BHK 15 km away that will supply agricultural water (Jehan, 2020).

Managed Aquifer Recharge (MAR) involves the deliberate replenishment of aquifers to recover water or achieve environmental benefits, supplementing natural recharge processes such as rainfall infiltration and stream seepage (Dillon et al., 2009). MAR methods range from unintentional recharge, like pipe leaks or vegetation clearing, to unmanaged disposal of water, and fully managed approaches such as injection wells and infiltration basins. Water sources for MAR include stormwater, reclaimed water, rainwater, and even desalinated seawater, with treated water reused for drinking, agriculture, industry, or ecosystem support (Gale, 2005). While MAR alone cannot solve over-extraction, it is a valuable groundwater management tool when combined with measures to control abstraction. It helps prevent saltwater intrusion, improve water quality, and reduce evaporation losses. Despite its cost-effectiveness and historical use in arid regions, MAR's broader implementation is limited by gaps in hydro geological knowledge. Its success depends not just on technical but also social and economic factors, and it holds significant potential in supporting sustainable water supply goals, including the UN Millennium Goals.

All MAR systems are mostly composed of seven elements. However, depending on the aquifer type for storage, MAR system could appear different.(Huber et al., 2015) The seven common elements of MAR projects are listed below.

1.Capture zone

2.Pre-treatment

3.Recharge
4.Sub-surface storage
5.Recovery
6.Post-treatment
7.End-use

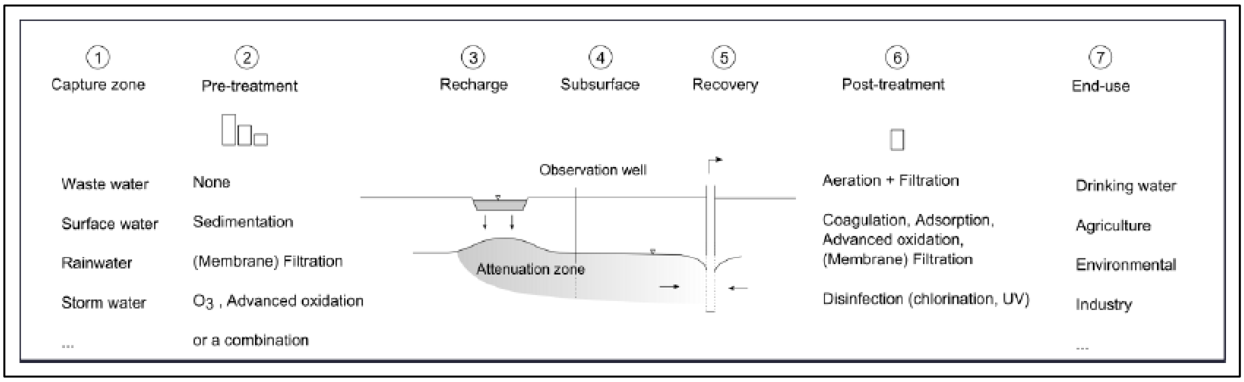


Figure 17 MAR components

Pre-treatment primarily is applied in MAR systems; (Sharma et al., 2015; Dillon et al., 2008; Asano & Cotruvo, 2004):
• Remove critical contaminants (bulk organics, nutrients and organic pollutants) from water, which are fully removed by MAR systems.
• Remove contaminants that may cause clogging to enhance efficiency.
• Ensure long-term functionality.
• Meet local water quality requirements for artificial recharge and use of reclaimed water.
• Meet future water quality requirements.
• Ensure existing use of aquifer beyond the recharge zone.

MAR systems can have pre-treatment, post-treatment or both depending on the determining parameters (Sharma et al., 2015). Treatment may not be necessary when water having low turbidity from a lake or river is diverted to augment groundwater supplies (Dillon et al., 2009). Sedimentation, filtration and sand disinfection are common pre-treatment methods for MAR systems. The basic and low-cost measures used for reducing TSS and turbidity are primary sedimentation. Pre-treatment filters with additional layers of absorbents can be used for the removal of heavy metals and other contaminants from the source water. Pre-screening, skimming, dissolved air flotation, activated sludge, biofilter and wetlands are some of the later pre-treatment processes (Huber et al., 2015).

For specific flow conditions, water quality and flow rate engineered treatment processes are designed. Obstructions in operating processes can be caused by high variability in water quality. Thus, to achieve a uniform water quality for smooth and efficient operation several pre-treatments may be necessary (Dillon et al., 2008).

SITE ANALYSIS & DATA COMPILATION

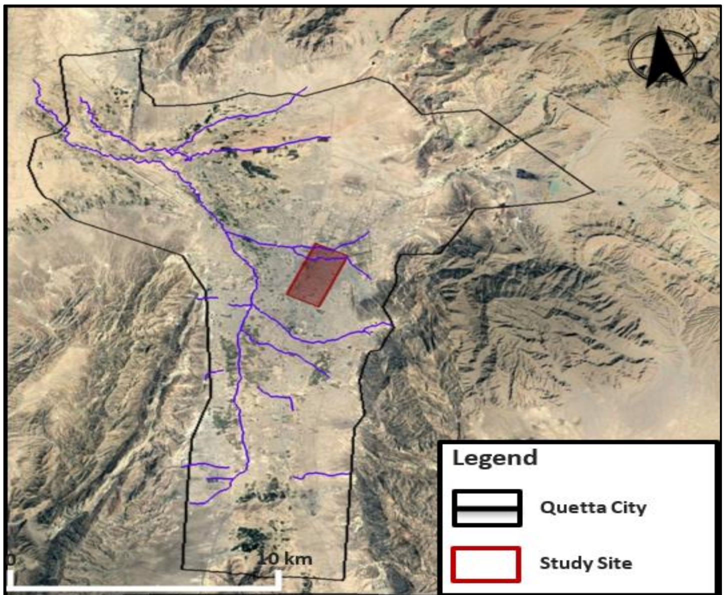


Figure 32: Study site location map

A study site with an area of 5km2 was selected in downtown Quetta city to calculate the percentage of Rooftop area and roads in the selected area using Google Earth Pro software. The selected area represents the whole city on a smaller scale, containing areas with both high and low building densities. The study site was divided into eight zones for the reason of smooth workability. The results of this analysis are presented below

Table 1: Study site details

Study Site	
Total Area	5416366 m²
Rooftop Area	2415597.6 m² (44.59%)
Road Area	1041543.36 m² (19.22%)

The percentage of rooftops and roads in the study area comes to be 44.59% and 19.22%. These percentages have been generalized for the whole city to estimate the amount of rainwater that could be harvested annually from all the rooftops and road surfaces in the city. Using the percentage of roofing materials provided by (Mahar & Attia, 2018),the share of rooftops made of concrete, burnt

Brick tile and CGI have been estimated. Rooftops made from Thatch/palm/bamboo, Asbestos and Reinforced brick concrete have been neglected in the estimation.

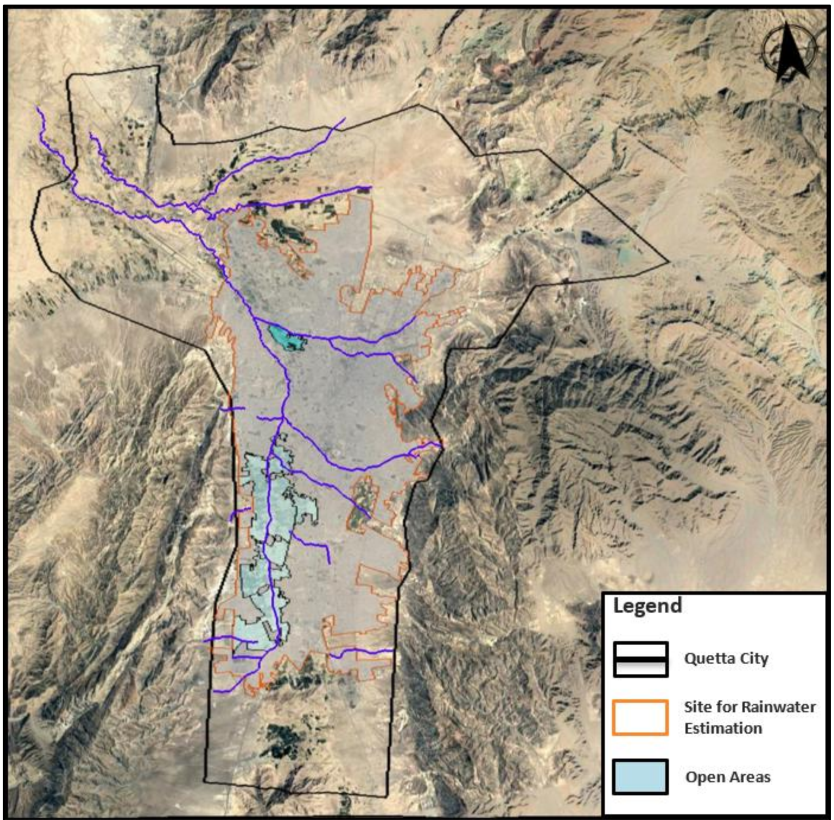


Figure 33: Selected site for rainwater estimation

Table 2: Areas of different surfaces

Total Area	139891543 m²
Total Rooftop Area	51002904 m²
Concrete Rooftops	40292294.16 m²
Burnt Brick Tile Rooftops	6630377.52 m²
CGI Sheets	1530087.12 m²
Road Area	21956407.1 m²

The calculations show that a total of 15.66 Mm³ of rainwater can be harvested from all the rooftops and road surfaces. The table presents the results of the estimation of runoff volume for the above-mentioned rooftops and road surfaces.

Table 3: Runoff estimations from selected surfaces

Surface	**Area**	**Runoff coefficient**	**Rainwater volume per year (m³)**
Concrete Rooftops	40292294.16	0.9	9461033.592

Burnt brick tile	6630377.52	0.75	1297399.121
CGI sheets	1530087.12	0.8	4582741.291
Roads	21956407.1	0.8	319359.7837
Total			15660533.79/ 15.66 Mm³

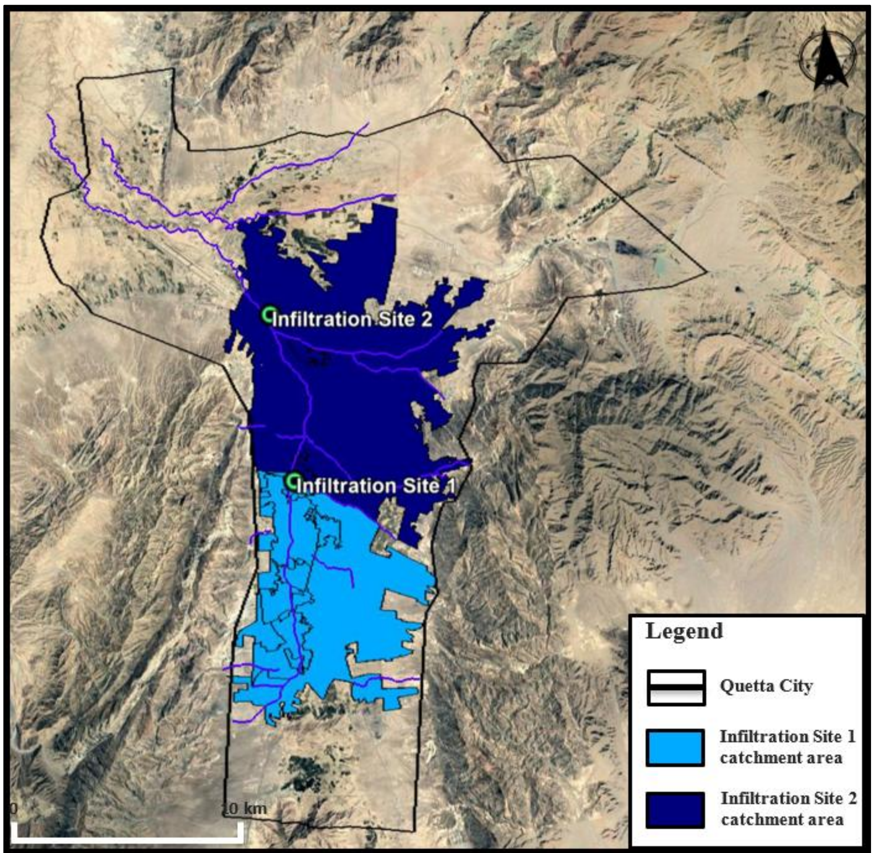


Figure 34: Location of infiltration sites

The idea is to convey collected rainwater to the injection sites by using the already existing water channels. 6% of the residents use these water channels to drain wastewater (Mahar & Attia, 2018).

Table 4: Hydrogeological conditions at infiltration sites. Extended from (Huber et al., 2015)

Parameter	Criteria	Suitability assessment	Infiltration Site 1	Infiltration Site 2
Aquifer confinement	Confined	Well injection only. Protection by impermeable layer from surface. contamination Storage capacity depends on aquifer transmissivity and water quality.		
	Unconfined	Surface spreading viable No protective cover from surface contamination Storage capacity depends on depth-to-water table and effective porosity	Y Y	Y Y
Target aquifer permeability kf (m/s)	$< 10^{-6}$	Very low, limited suitability	Alluvium 1 X 10^{-5}	Alluvium 1 X 10^{-5}
	$10^{-6} - 10^{-5}$	Low, limited suitable		
	$10^{-5} - 10^{-4}$	Medium, suitable		
	$10^{-4} - 10^{-3}$	High, suitable		
	$>10^{-3}$	Very high, suitable		

Saturated thickness in target aquifer (m)	<10	Thin, high potential recovery rate	515 – 560m	710 – 765m
	10-50	Medium, medium potential recovery rates		
	>50	Thick, low potential recovery rate		
Depth-to-water or thickness of unsaturated zone (m)	<10	Limited potential storage potential	115 – 160m	60 – 115m
	10-30	Good potential storage potential		
	>30	High potential storage potential, groundwater mounding can be neglected		
Aquifer pore type and consolidation	Porous	Most suitable	Porous	Porous
	Porous/ Fractured	suitable (limited)		
	Fractured	suitable (limited), in consolidated aquifers simpler well completion and easier to prevent well clogging		
	Fractured/Karstified	suitable (limited)		
	Karstified	suitable (limited)		
The salinity of native groundwater	Fresh (TDS <1000 mg/l)	Fresh aquifers are suitable for aquifer recharge.	Y	Y
	Brackish/saline (TDS >1000 mg/l)	Mixing with native saline groundwater must be minimised (e.g. injection of buffer volume) Saline groundwater causes buoyancy effects (density driven drift in lateral direction)		

Infiltration site 1: 6.185 Mm^3
Infiltration site 2: 9.474 Mm^3
Additionally, three potential options have been identified to increase the quantity of collected rainwater that can be treated and used for aquifer recharge. Interventions at these identified sites present the possibility for treatment and injection recharge at proximity to the storage or to be connected to the existing water channels to direct water flow to the treatment/injection sites.

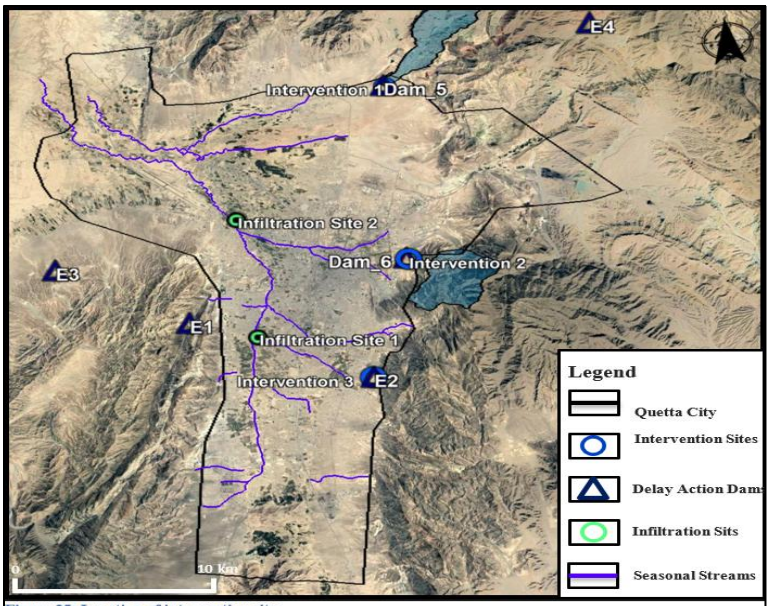


Figure 35: Location of intervention sites

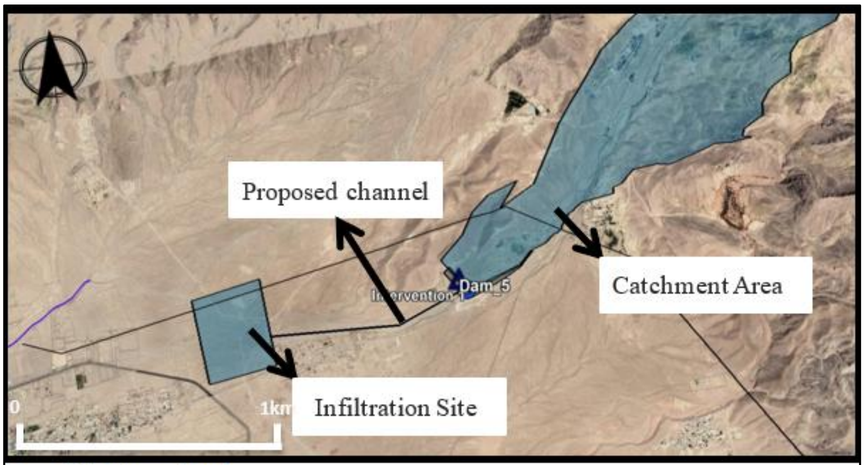
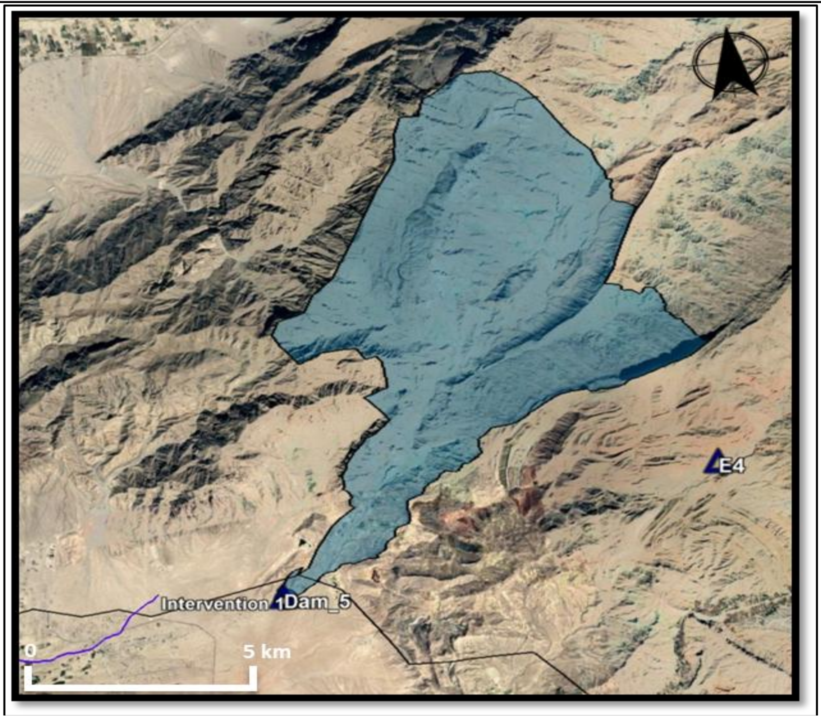


Figure 36: Intervention 1



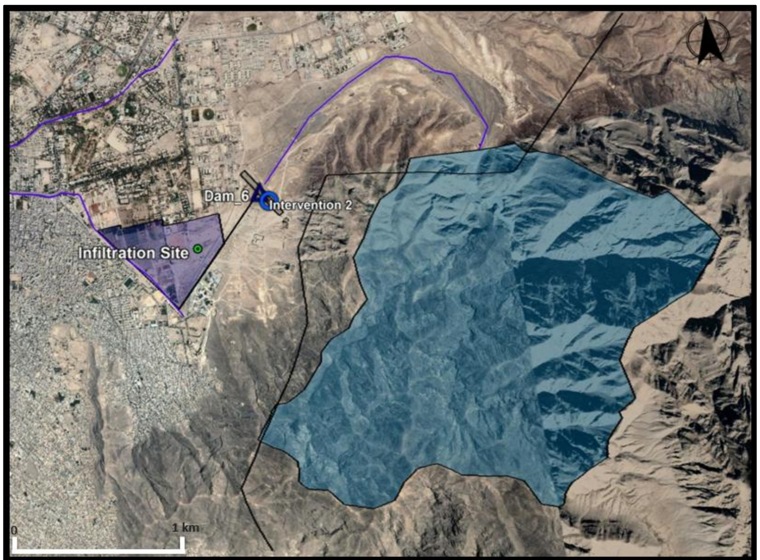


Figure 37: Intervention 2

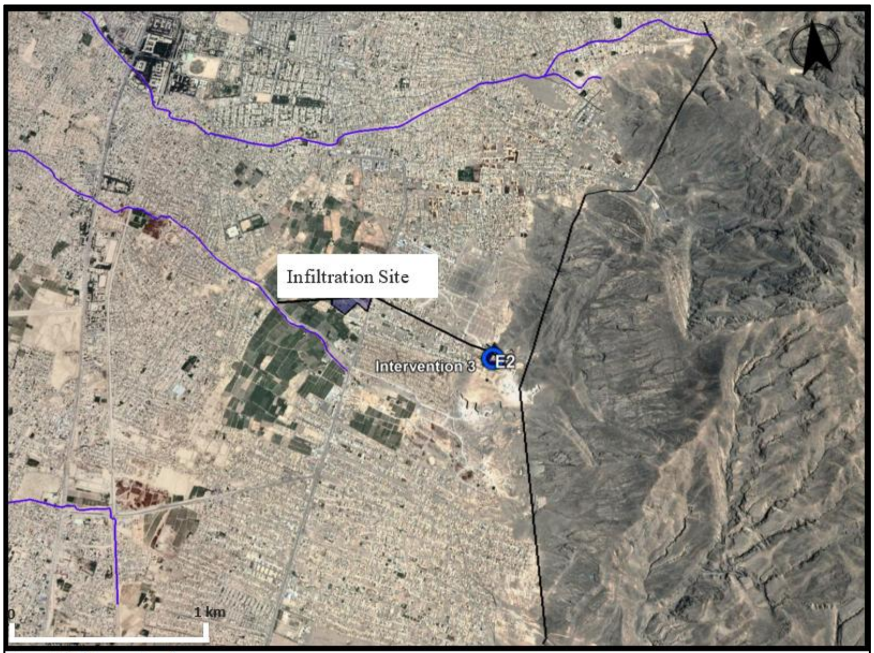


Figure 38: Intervention 3

Table 5: Runoff estimation at intervention sites

	Intervention site	Catchment area	Rainwater volume (M^3)	Treatment/Injection close to site	Connection to existing water channel
Option 1	Dam-5	56564527	5903074.382/ 5.9 Mm^3	Y	N
Option 2	Dam-6	9971994	1040677.294/ 1.04 Mm^3	Y	Y
Option 3	E2- Hangi Dam	2900000	302644/ 0.3 Mm^3	Y	Y

Table 6: Hydrogeological conditions at intervention sites. Extended from (Huber et al., 2015)

Parameter	Criteria	Intervention Site 1	Intervention Site 2	Intervention Site3
Aquifer confinement	Confined			
	Unconfined	Y	Y	Y
Target aquifer permeability kf (m/s)	< 10^{-6}			
	10^{-6} – 10^{-5}	Alluvium 1 X 10^{-5}	Alluvium 1 X 10^{-5}	Alluvium 1 X 10^{-5}
	10^{-5} – 10^{-4}			
	10^{-4} – 10^{-3}			
Saturated thickness in target aquifer (m)	>10^{-3}			
	<10			
	10-50	515 – 560m	260 – 315m	710 – 765m
	>50			
Depth-to-water or thickness of unsaturated zone (m)	<10			
	10-30			
	>30	115 – 160m	60 – 115m	60 – 115m
	Porous	Y	Y	Y

Aquifer pore type and consolidation	Porous/ Fractured			
	Fractured			
	Fractured/Karstified			
	Karstified			
Uniformity of hydraulic properties	Homogenous (e.g. variance of K ≤ 0.5 log10)			
	Heterogeneous (e.g. variance of K ≥ 0.5 log10)			
Redox state of native groundwater	Aerobic			
	Sub-oxic			
Salinity of native groundwater	Fresh (TDS <1000 mg/l)	Y	Y	Y
	Brackish/saline (TDS >1000 mg/l)			
Hydraulic gradient	Gentle (<0.1%)			
	Moderate to steep (> 0.1 %)			
Topographic slope (not relevant for injection methods)	Gentle (< 5%)	0 – 6%	0 – 6%	0 – 6%
	Moderate to steep (> 5%)			

RESULTS

Estimations reveal that a total of 22.905 MCM of rainwater can be collected, treated and infiltrated. 15.66 MCM of which comes from the rooftops and road surfaces and 7.245 MCM comes from the interventions at specific sites mentioned above. A recharge factor of 20% (5.796 MCM) was taken out from this volume; as mentioned previously, 20% of the annual precipitation is the actual recharge amount that reaches the aquifer of Quetta city. The remaining amount (17.109 MCM) was added to the water budget; as it can be seen from the figure, the deficit will still be higher than 40 MCM and will continue to rise if the abstraction continues according to the modelled scenario.

Wastewater production of Quetta was estimated for the years 2020-2040 by using projected population data and per capita per day water consumption which is 59 litres (Mahar & Attia, 2018). 41.8% of this consumption per day ends up as wastewater (Zakaria, 2005).

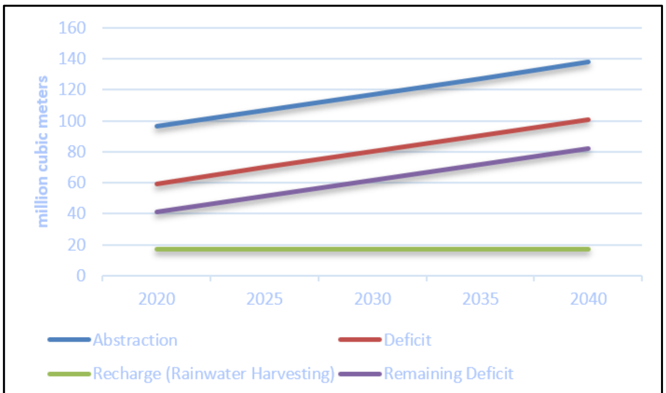


Figure 39: Remaining deficit estimation

Table 7: Wastewater estimation

Year	Projected population	Per capita water consumption/day	Water consumption MCM	Wastewater MCM
2020	1099546	59	23.67	9.7
2025	1253108	59	26.98	11.06
2030	1419937	59	12.53	12.53

2035	1607476	59	14.19	14.19
2040	1804791	59	15.93	15.93

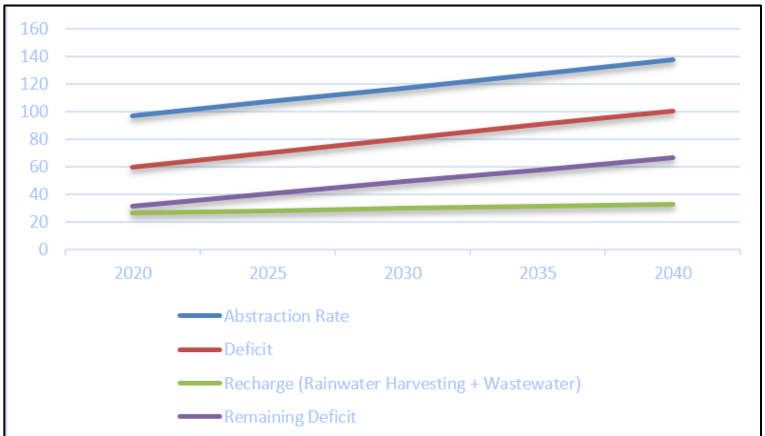


Figure 40: Results after added wastewater

The graph shows the results of added wastewater to the system. The deficit would decrease over the years but the quantity of water added as recharge is still not enough to meet the estimated deficit. However, it is important to note that estimated wastewater production by 2040 is only 18.1% of the original abstraction of 84.2 MCM in 2014(Ghani et al., 2019). A question that arises in light of these results is why water is being abstracted at such a high rate. A possible answer to this question could be that the per capita per day water consumption for Quetta mentioned in literature is too low; in reality, it could be much higher, or the high abstraction of water is attributed to the agriculture sector.

CONCLUSIONS & RECOMMENDATIONS

The world's major aquifers are depleting at an exponential rate. In regions with concentrated and heavy groundwater abstraction exceeding the average rates of local recharge, groundwater levels may continue to drop over the decades, giving rise to an expensive and inefficient cycle of well deepening or even untimely investment losses due to well abandonment.

The case of Quetta is no different; water levels are declining at an alarming rate in different parts of the city. Increasing population combined with the high number of refugees migrating from Afghanistan due to civil war, subsidy on electricity for the farmers, agriculture, illegal tube well drilling, violation of tube well spacing regulations and fluctuations in the precipitation along with the drought period are the reasons for high abstractions of groundwater.

The implementation of MAR technology can be useful in mitigating the effects of unsustainable withdrawals of groundwater by storing water from several sources like stormwater, reclaimed water, mains water, rainwater, desalinated seawater or even groundwater from other aquifers. The recovered water could be used for drinking water supplies, industrial applications, irrigation, toilet flushing and sustaining ecosystems with pre-treatment before the recharge and sometimes post-treatment on recovery.

Successful implementation of MAR techniques will bear fruitful results in terms of reducing the deficit by increasing the recharge quantity. This can be achieved by harvesting rainwater from the impervious surfaces in the city and pre-treated wastewater. However, as the literature suggests, MAR itself is not the solution for issues arising from unsustainable abstractions of groundwater. It is part of a larger framework that includes managing the groundwater resources sustainably. A framework needs to be developed for Quetta city to ensure sustainable management of water resources for future use.

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