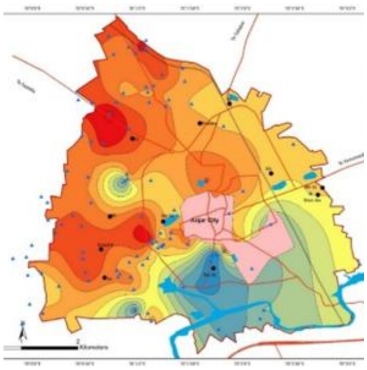


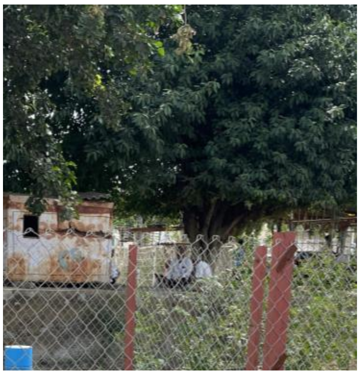

# Geo-hydrological and Aquifer study of Anjar City, Kachchh District

## May 2025

CWAS CENTER FOR WATER AND SANITATION | CRDF CEPT RESEARCH AND DEVELOPMENT FOUNDATION | CEPT UNIVERSITY

# Geo-hydrological and Aquifer study of Anjar City, Kachchh District

**Center for Water and Sanitation**

**CRDF, CEPT University**

**May 2025**

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# Preface

Cities have become more susceptible to water scarcity than ever before. Climate change and resultant uncertain weather patterns are forcing cities to take extreme steps to combat severe water crisis, especially during summer months. Indian cities are no exceptions. Understanding the severity, GoI has launched AMRUT 2.0 (Atal Mission for Rejuvenation and Urban Transformation) which focuses on making cities water-secure and self-sufficient through circular economy of water.

Anjar city is located in the arid region at the Kachchh district, Gujarat. It receives around 430 mm of annual rainfall in comparison to the national average of 1152 mm. Large part of the Kachchh region including Anjar are water stressed with a severe shortage of drinking water in the summer and is characterized as a drought-prone area. This situation has improved significantly since the long distant Narmada canal water has been made available as drinking water. However, change in rainfall pattern in Narmada catchment may result into water scarcity in Anjar, if the local water resources are not managed well.

In this context, CWAS-CRDF- CEPT University in partnership with Arid communities and technologies (ACT) has undertaken a geohydrological study to understand aquifer and watershed of Anjar city, which is a unique and niche study especially for urban areas. The study helped identify potential recharge zones at the city level through preparation of various thematic maps. This integrated approach addresses geological characteristics, watershed delineation, aquifer mapping, groundwater quality assessment, and recommends water resource development strategies.

# Acknowledgements

Understanding the geohydrology and aquifer characteristics of city is fundamental to developing sustainable water management strategies, particularly in water-stressed regions where groundwater serves as a critical resource for municipal supply.

This report is the result of a collaborative effort toward addressing the pressing issue of urban water scarcity, with a focus on Anjar city in the arid Kachchh region of Gujarat. The study, undertaken by CWAS-CRDF, CEPT University in partnership with Arid Communities and Technologies (ACT), aimed to understand the geohydrology of Anjar and identify city-level strategies for water security through an integrated approach. This report serves as a valuable resource for other cities facing similar water challenges and provides a replicable framework for implementing effective water conservation activities and sustainable water management practices in arid and semi-arid urban environments.

We gratefully acknowledge the Anjar municipal council for its unwavering support and active participation throughout the study. Their cooperation was crucial in facilitating data collection and on-ground activities. The findings and recommendations from this study will provide the city government with key insights to develop detailed water management strategy and prioritize infrastructure investments to ensure water security.

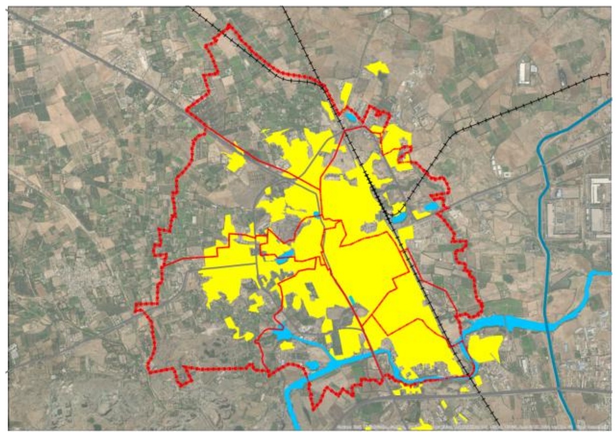
We are thankful to the Dasra team and the Empowerment Foundation for their support for undertaking this study.

**Dr Meera Mehta and Dr Dinesh Mehta**
**Sr. Advisors CWAS**

**Dhruv Bhavsar and Aasim Mansuri**
**Center Heads, CWAS**

# Executive Summary

Cities across India are increasingly vulnerable to water scarcity, with climate change and erratic weather patterns intensifying the crisis—particularly during the summer months. Recognizing this, the Government of India launched AMRUT 2.0 (Atal Mission for Rejuvenation and Urban Transformation) to make cities water-secure and self-sufficient through a circular economy of water.



Anjar, located in the arid Kachchh region of Gujarat, exemplifies these challenges. The city receives only about 430 mm of annual rainfall, far below the national average of 1,152 mm, making it highly water-stressed and prone to droughts. While the Narmada Canal has helped ease drinking water shortages in recent years, its long-term reliability remains uncertain due to fluctuating rainfall in the canal's catchment and the rising demands of a growing urban population.

To address these risks, this study presents the comprehensive geo-hydrological and aquifer assessment for Anjar. It maps aquifers and recharge zones, analyzes groundwater quality and availability, estimates future water balance and proposes integrated strategies for sustainable groundwater and surface water management.

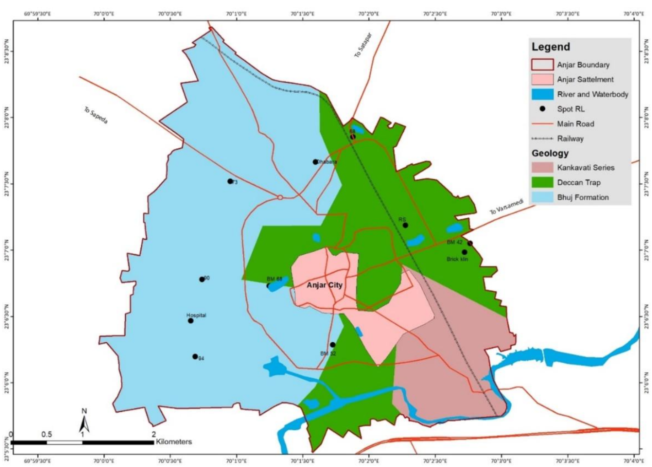
### Terrain Characteristics:

Terrain analysis based on Digital Elevation Model (DEM) and GIS data indicates that nearly 98% of Anjar comprises very gentle to gentle slopes, primarily consisting of flat alluvial plains and undulating pediment zones. The elevation ranges from 31m to 141m above mean sea level. Physiographically, the city can be categorized into four distinct units—hills, rocky pediment plains, alluvial plains and river courses. Drainage analysis shows that Anjar is influenced by two major watersheds: the Sang River basin in the south and a northern micro-watershed system. Urban development has altered natural drainage, small urban micro-watersheds and resulting in increased surface runoff and localized flooding. These terrain characteristics directly influence infiltration, recharge potential, and groundwater movement.

### Geology

Geologically, Anjar forms part of the Kachchh Mainland, characterized by rock formations ranging from the Mesozoic to the Quaternary period. The city's surface geology is dominated by three major formations—Bhuj Sandstone (Cretaceous age), Deccan Trap Basalt (Upper Cretaceous to Paleocene), and Kankavati Sandstone (Tertiary). The western region, underlain by coarse-grained Bhuj Sandstone, serves as a major aquifer zone with good permeability and water-holding capacity. The central basaltic zone acts as a hard, impermeable layer with limited infiltration, while the eastern fine-grained sandstone and clay layers of the Kankavati Series exhibit poor groundwater potential. This geological diversity creates distinct hydrogeological zones that guide groundwater occurrence and recharge initiatives.

## Geohydrology and water quality



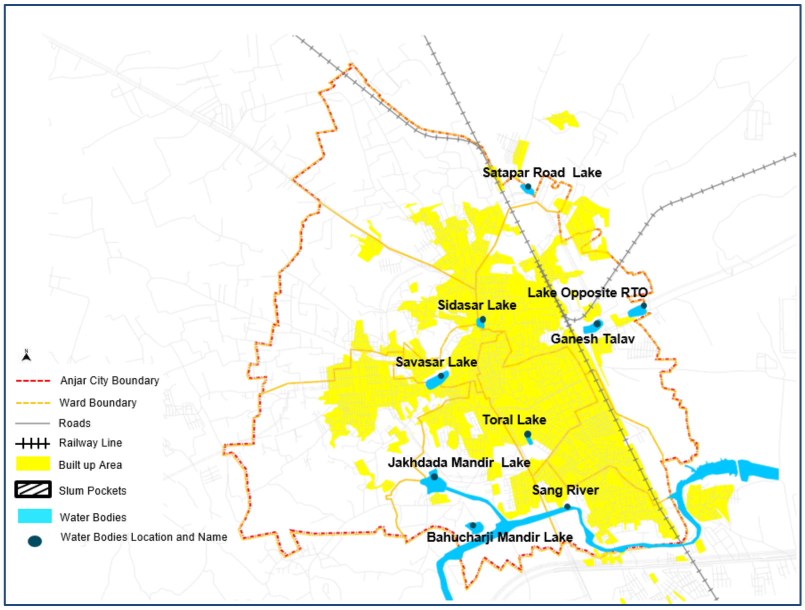

The study reveals that Anjar's groundwater system is complex, with shallow aquifers in sandy and basaltic layers and deeper confined aquifers in sandstone. Shallow aquifers are seasonal, often dry, and prone to contamination, while deeper aquifers, though more reliable, are expensive to access and show signs of depletion. Between 2023 and 2024, groundwater levels declined significantly, necessitating deeper drilling in many areas. Flow patterns also shifted, creating below-sea-level zones that heighten the risk of saltwater intrusion from the coast.

Water quality is a major concern. Many wells record high levels of total dissolved solids (TDS), hardness, chlorides and sulphates, often exceeding permissible drinking water limits. In some locations, TDS levels exceed 2,000 mg/l, rendering groundwater unfit for domestic use. The region's geology and marine influence contribute to naturally saline and hard groundwater. Post-monsoon analysis further showed that instead of diluting salts, rainfall often mobilizes and increases salinity, worsening contamination.

## Water balance

The water balance assessment indicates that by 2051, Anjar's projected demand will reach 14.78 million cubic meters (MCM) annually, while the potential supply is 27.81 MCM—an apparent surplus of nearly 13 MCM. However, this surplus can only be realized if rainfall is effectively harvested and recharged into aquifers. Without proper infrastructure and recharge interventions, water scarcity will persist despite the theoretical availability of resources.

Traditional surface water bodies—Siddhsar, Savasar, Toral Sarovar, Khengarsar, Ganesari, and Khanesari lakes—once played a vital role in recharge and supply. Today, these lakes are encroached, polluted, or silted, greatly reducing their capacity to support groundwater replenishment. Reviving and integrating these traditional systems with modern recharge methods could significantly enhance Anjar's water resilience.




## Water Management Strategies

The study proposes a multi-pronged strategy combining modern initiatives with traditional practices. Recommendations are organized under four key pillars:

**1. Groundwater Recharge**

- Construct artificial recharge wells and pits in suitable aquifer zones and public/residential areas.
- Reuse defunct borewells for cost-effective recharge.

**2. Surface Water Revival**

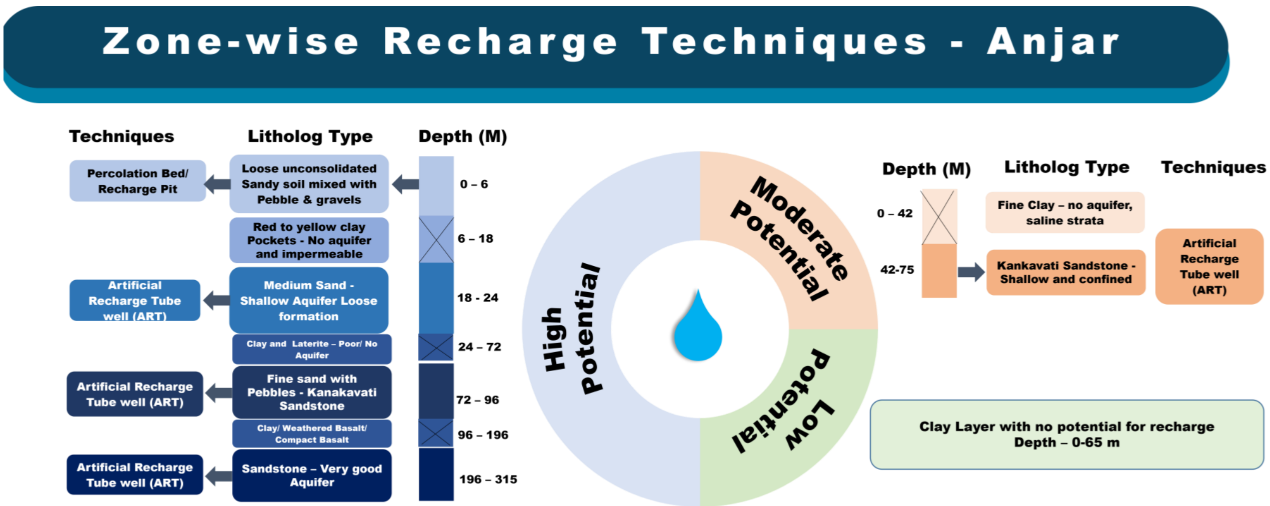
- Renovate and desilt key lakes such as Siddhsar, Savasar, Khengarsar, Toral Sarovar, Ganesari, and Khanesari.
- Restore inflow and outflow channels using **GIS-based catchment mapping**.
- Establish protective buffer zones and divert wastewater away from lakes.
- Engage communities in lake protection and control encroachment and ritual pollution.

**3. Demand Management**

- Regulate borewell drilling, especially in salinity-prone areas.
- Enforce **rooftop rainwater harvesting** in all public and private buildings.
- Promote **reuse and recycling of water** in industries and households to reduce freshwater dependency.

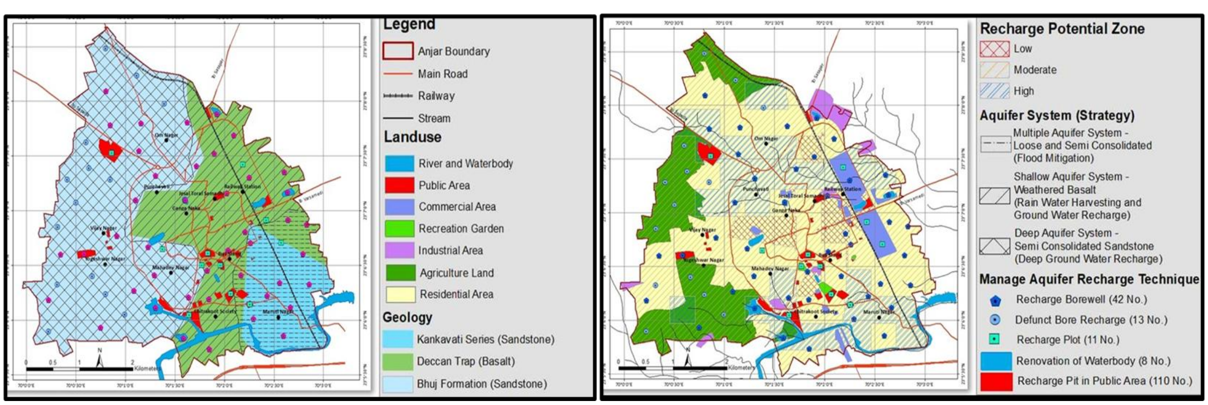
**4. Integrated Citywide Strategy**

- Develop a holistic water management plan integrating groundwater recharge, surface water restoration, reuse and recycling, and supplemental external supply (e.g., Narmada Canal water).
- Align initiatives with **AMRUT 2.0's circular water economy** and water-secure city framework.




## Way Forward

A City-Level water management strategy especially for recharge planning and surface water renovations is essential to address challenges, such as depleting water levels, deteriorating quality and flooding during rainy season. The Anjar city recharge plan aims to implement a variety of methods to recharge depleted aquifers, such as stormwater infiltration, artificial recharge techniques, revival of existing surface water harvesting structures and the optimization of existing infrastructure.




Surface and Groundwater Management Plan of Anjar city

# 1 Introduction

Groundwater represents a critical lifeline in arid and semi-arid regions where unpredictable weather patterns driven by climate change increasingly threaten water security. In these water-stressed environments, aquifer systems not only sustain urban and rural populations but also underpin economic activities including agriculture, industry, and commerce. As highlighted in the Government of India's AMRUT 2.0 initiative, achieving water security through sustainable management practices has become a national priority, emphasizing the need for cities to develop circular water economies. This also aligns with Government of India Jal Sanchay Jal Bhagidari and Catch the Rain program.

The arid town of Anjar in Kachchh exemplifies the complex water management challenges facing rapidly urbanizing areas in water-scarce regions. Substantial urbanization has created a significant imbalance between groundwater extraction and natural recharge capabilities. This is further exacerbated by the region's distinctive geo-hydrological setting characterized by limited rainfall, high evapotranspiration rates, and urban drainage patterns that disrupt natural infiltration processes. Consequently, the aquifer systems supporting Anjar have experienced rapid depletion, threatening both immediate water security and long-term climate resilience for its growing population.

Addressing these interconnected challenges necessitates a paradigm shift in urban water management, moving beyond conventional supply-side approaches to integrated strategies that incorporate geo-hydrological understanding of local aquifer systems. Notably, comprehensive aquifer mapping and geo-hydrological assessment in urban contexts represents a unique and niche area of study. While aquifer studies are common at large watershed region, their application to complex urban environments—with modified landscapes, extensive impervious surfaces, and altered hydrological regimes—offers innovative perspectives for sustainable urban water management. This pioneering approach, as demonstrated by the partnership between CWAS and Arid Communities and Technologies (ACT), provides critical insights into aquifer dynamics that conventional water management strategies often overlook.

Through this specialized geo-hydrological investigation, this study aims to characterize the subsurface water resources of Anjar, identifying potential zones for implementing strategic interventions such as rainwater harvesting, groundwater recharge structures, and urban flood water management systems. The development of thematic maps for potential recharge zones represents a significant advancement in urban water resource planning for arid regions.

This research aligns with the broader water security framework developed by the Center for Water and Sanitation (CWAS), which evaluates water resources based on quantity, quality, accessibility, reliability, and affordability. By integrating scientific aquifer assessment with practical implementation strategies, this study will contribute to developing a robust water security action plan for Anjar, enhancing its capacity to adapt to climate variability while ensuring sustainable water resources for future generations.

## 1.1 Aim and Objectives

The main aim of this project is to conduct a comprehensive geo-hydrological assessment to characterize aquifers in Anjar city. The purpose is to develop a roadmap for effective management of aquifers at the city level. Additionally, the project aims to leverage stormwater for groundwater recharge, thereby reducing or regulating flood hazards in the city.

With this overarching goal in mind, the project focuses on achieving the following specific objectives:

1. **Enhancing Stakeholder Knowledge:** The project aims to enhance the practical and action-oriented knowledge of city stakeholders regarding the scientific management of shallow aquifers. This includes providing them with the necessary understanding and tools to make informed decisions and implement sustainable practices.
2. **Demonstrating Recharge Wells:** One of the key means identified for aquifer management is the use of recharge wells. The project aims to demonstrate the effectiveness of recharge wells as a viable method for managing aquifers. This will involve showcasing their functionality, benefits, and potential impact on groundwater recharge.

In order to achieve the project's overarching aim, several key objectives have been established specifically for the city. These objectives are as follows:

- To understand the geological and tectonic characteristics of the project area.
- To delineate the watershed areas of the cities.
- To delineate aquifers, aquifer boundaries along with recharge discharge areas.
- To understand groundwater quality and water levels status and flow directions
- To delineate recharge potential areas by adopting integrated approach.

- To recommend of water resource development strategies and groundwater recharge potential areas.

By addressing these objectives, the project aims to create a comprehensive framework for managing aquifers in Anjar city. It seeks to empower stakeholders with the knowledge and tools needed to make informed decisions, while also demonstrating the practical implementation of recharge wells. Through these efforts, the project intends to contribute to sustainable groundwater management, utilize stormwater for recharge, and mitigate flood hazards in the city.

## 1.2 Approach and Methodology

An integrated approach has been adopted to develop a groundwater management plan for Anjar city. This approach comprises three key components. Firstly, it involves gathering primary and secondary data from reliable sources, along with conducting fieldwork and surveys. Secondly, community engagement is emphasized, ensuring their involvement in the planning processes. Lastly, the primary and secondary data collected on various aspects are compiled and collated, enabling aquifer mapping and the formulation of aquifer management strategies. Figure 1.1 provides an overview of the adopted approach for preparing the detailed project report.

### 1.2.1 Methodology for Aquifer Mapping

The aquifer mapping process involved comprehensive data collection through fieldwork and secondary sources, capturing primary insights on lithology, topography, land use, and hydrological characteristics. This data was then analyzed using GIS and other geological and hydrogeological techniques, forming the basis for aquifer characterization and zonation. Aquifer zonation considered the physical parameters of geology, lineament fabrics, landform characteristics, and drainage density, which play a crucial role in groundwater occurrence and hydrological processes. Additionally, groundwater quality assessments were conducted, with water samples from wells and bore-wells sent to NABL-accredited laboratories for analysis of pH, electrical conductivity, total dissolved solids (TDS), and other microparameters. Finally, aquifer maps were created using ArcGIS software for effective visualization and mapping of the aquifer system.

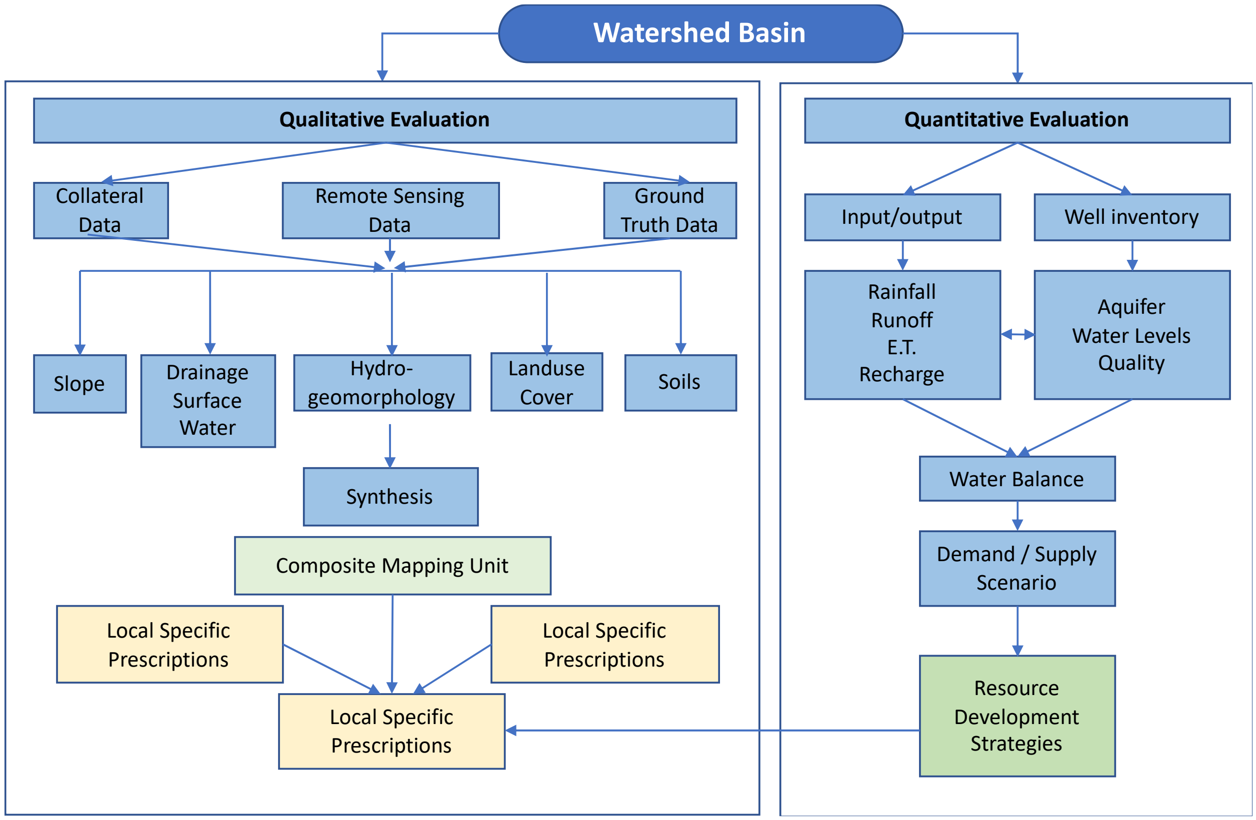



Figure 1.1 Approach Adapted

### 1.2.2 Methodology for Aquifer Recharge Planning

As previously mentioned, one of the key objectives of the present project is to develop an aquifer recharge plan and to demonstrate groundwater recharge methods in an urban context. The planning process has been carried out in two stages: first, to design demonstration projects, and second, to prepare a detailed recharge plan.

For the demonstration component, the methodology adopted is shown in Figure 1.2. The first phase focused on problem identification and assessing the needs of both the Anjar Municipality and the local community. The second phase involved assessment and identification of location-specific actions for groundwater recharge. The third phase concentrated on designing appropriate recharge structures and estimating the budget required for implementation.

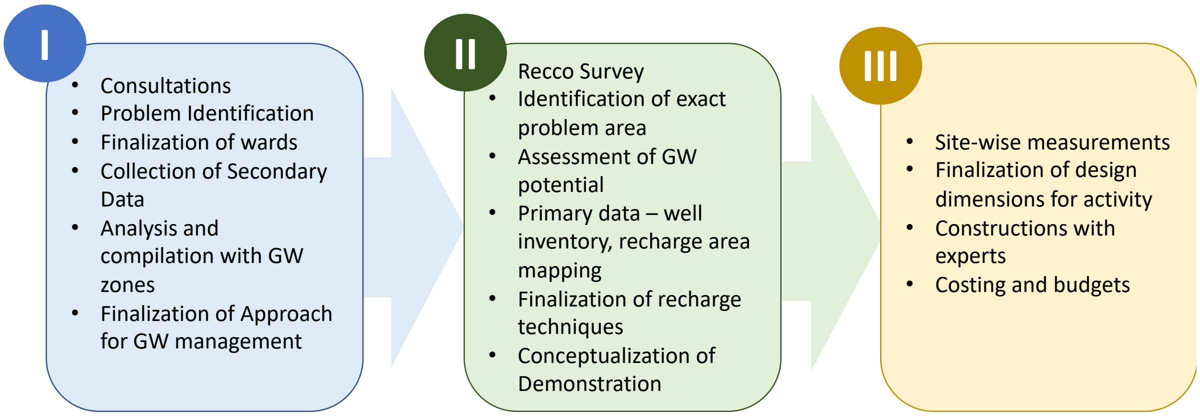



Figure 1.2 Approach for Demonstration Planning

In addition, while prioritization of pilot locations three basic principles has kept in mind viz., (01) development zone of the city; (02) groundwater potential zones; (03) priority by municipality and (04) cost effectiveness and decentralized techniques.

# 2 Anjar City Profile

## 2.1 Location

Anjar is a city of significant historical significance, known for its rich cultural diversity. The town boasts several revered religious temples, including the Jesal-Toral Shrines, which hold great importance in the local heritage. It is located in the Kachchh district of Gujarat, India, approximately 50 km east of the district headquarters, Bhuj, and covers an area of 17.81 square kilometers. The city is geographically positioned between latitudes 23.113424°N and longitudes 70.027744°E. It has an average elevation of 72 meters (240 feet). The elevation of the area in Anjar varies, with the minimum elevation recorded at 31 meters and the maximum elevation at 141 meters. This indicates some variation in the topography of the city, with certain parts being at higher elevations than others. The city is divided into 9 wards, among all, ward no. 01 (2.4 sq.km.), 05 (2.2 sq.km.) and 06 (2.2 sq.km.) are the largest wards while ward no. 08 is the smallest ward has an area of about 1.4 sq.km.

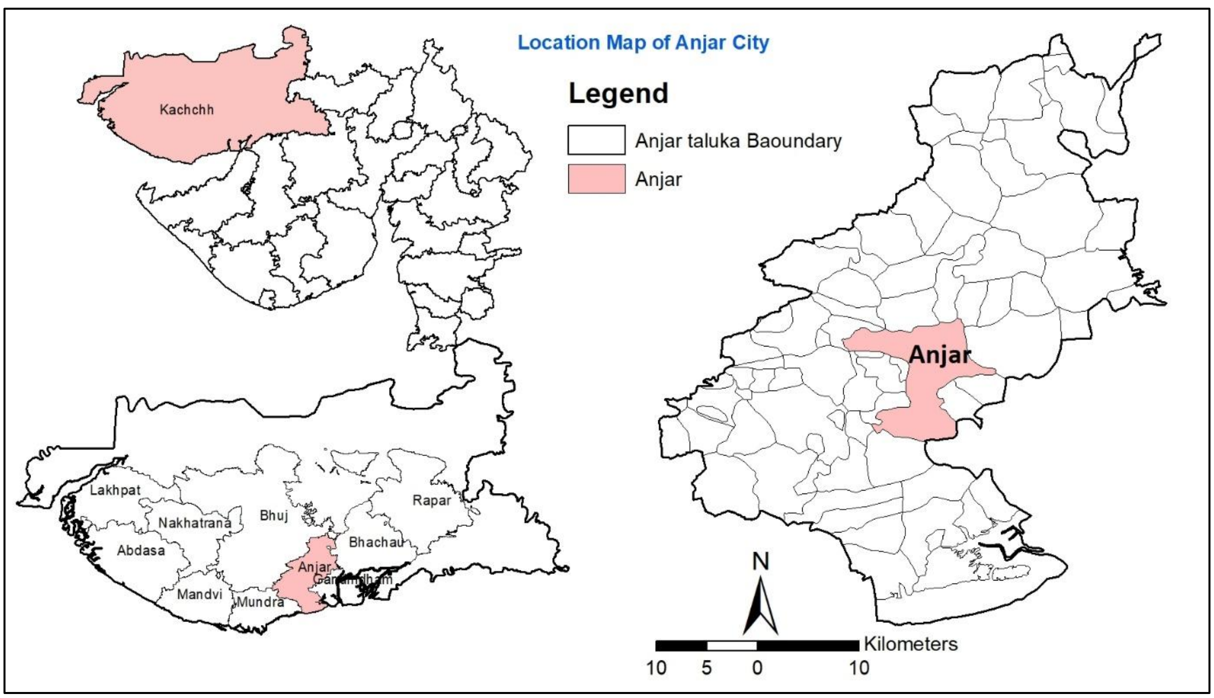



Figure 2.1 Location of Anjar City

## 2.2 Population and Households

According to the 2011 Census, Anjar city had a total urban population of 87,183, of which 45,172 were males and 42,011 were females. Children aged 0–6 years numbered 11,723, accounting for 13.45% of Anjar's total population. The female sex ratio in Anjar was 930, which is higher than the state average of 919. The literacy rate in Anjar was 80.49%, exceeding the state average of 78.03%. Male literacy stood at approximately 86.67%, while female literacy was around 73.84%. In terms of caste demographics, Scheduled Castes (SC) constituted 6.45% and Scheduled Tribes (ST) made up 0.53% of the total population. As of 2023, the estimated population of Anjar Municipality is approximately 113,338.

Table 2.1 Ward Wise Population and Households of Anjar City

| Ward No. | Total Area (Sq. km.) | Population | Households |
|---|---|---|---|
| 1 | 2.4 | 12,280 | 3070 |
| 2 | 1.7 | 13,620 | 3405 |
| 3 | 1.9 | 11,974 | 2993 |
| 4 | 2 | 12,541 | 3135 |
| 5 | 2.2 | 11,740 | 2935 |
| 6 | 2.2 | 12,371 | 3093 |
| 7 | 2.1 | 11,421 | 2855 |
| 8 | 1.4 | 13,689 | 3422 |
| 9 | 2.1 | 13,702 | 3426 |
| **Total** | **18** | **1,13,338** | **28334** |

(Source: Anjar Municipality)

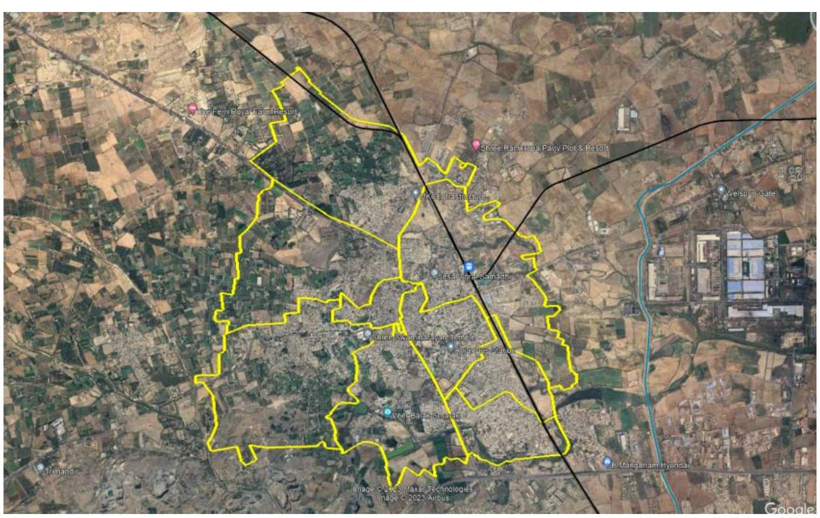


Figure 2.2 Ward Boundaries of Anjar City

## 2.3 Amenities

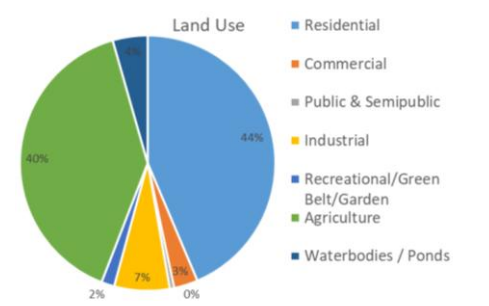
Being one of the main cities in the Kachchh district, Anjar offers a wide range of facilities and infrastructure. In terms of education, the city has numerous government and private schools, colleges, and universities, providing higher education opportunities across various fields, including medical education. Anjar is well-connected by state and national highways, as well as by railways. Air connectivity is available through Kandla Airport, located just 10 kilometers away. In terms of healthcare, the city offers comprehensive services operated by the government, charitable trusts, and private providers—ranging from small dispensaries to multi-specialty hospitals. Banking and financial services are also well-established and easily accessible throughout the city. Additionally, Anjar is located near Gandhidham, a major industrial hub, which enhances its economic and logistical significance.

## 2.4 Land-use

Land-use patterns are a critical aspect to consider in water management. While water resources are often mentioned as a component of land use, they require special attention—particularly regarding the characteristics of their inflow and outflow areas. It has been observed that in most land use planning efforts, inflow and outflow zones are frequently altered, which ultimately impacts the water bodies in a region. In many cases, such water bodies receive inadequate inflow due to blocked or diverted channels, are connected to sources of pollution, or are misused for solid waste disposal. Therefore, during any land use planning or land development process, water bodies must be studied carefully, with emphasis on these influencing factors. Figure 2.3 illustrates the land use and land cover (LULC) analysis of Anjar city. Anjar city land cover has been broadly categorized into three categories viz., (01) Built up area; (02) Open Lands and (03) Water Bodies and water spread areas. Further all three categories representing into 07 different land uses. (Table 2.2)

Table 2.2 Landuse Pattern of Anjar City

| Category | Type of Landuse | Area Ha. |
|---|---|---|
| Built up area | Residential | 1740 |
| | Commercial | 121 |
| | Public & Semi-public | 22 |
| | Industrial | 280 |
| Open Lands | Recreational/Green belt | 65 |
| | Agriculture | 1583 |
| Water Bodies & Ponds | | 176 |



| | | |
|---|---|---|
| **Total** | **3988** | |

## 2.4.1 Built-Up Areas

Built up area category consists of four types of Landuse viz., (01) Residential; (02) Commercial; (03) Public and Semi Public and (04) Industrial. Dominant landuse among this category is residential usage that is about 44 % of total area of City while 80 % of total built up area.

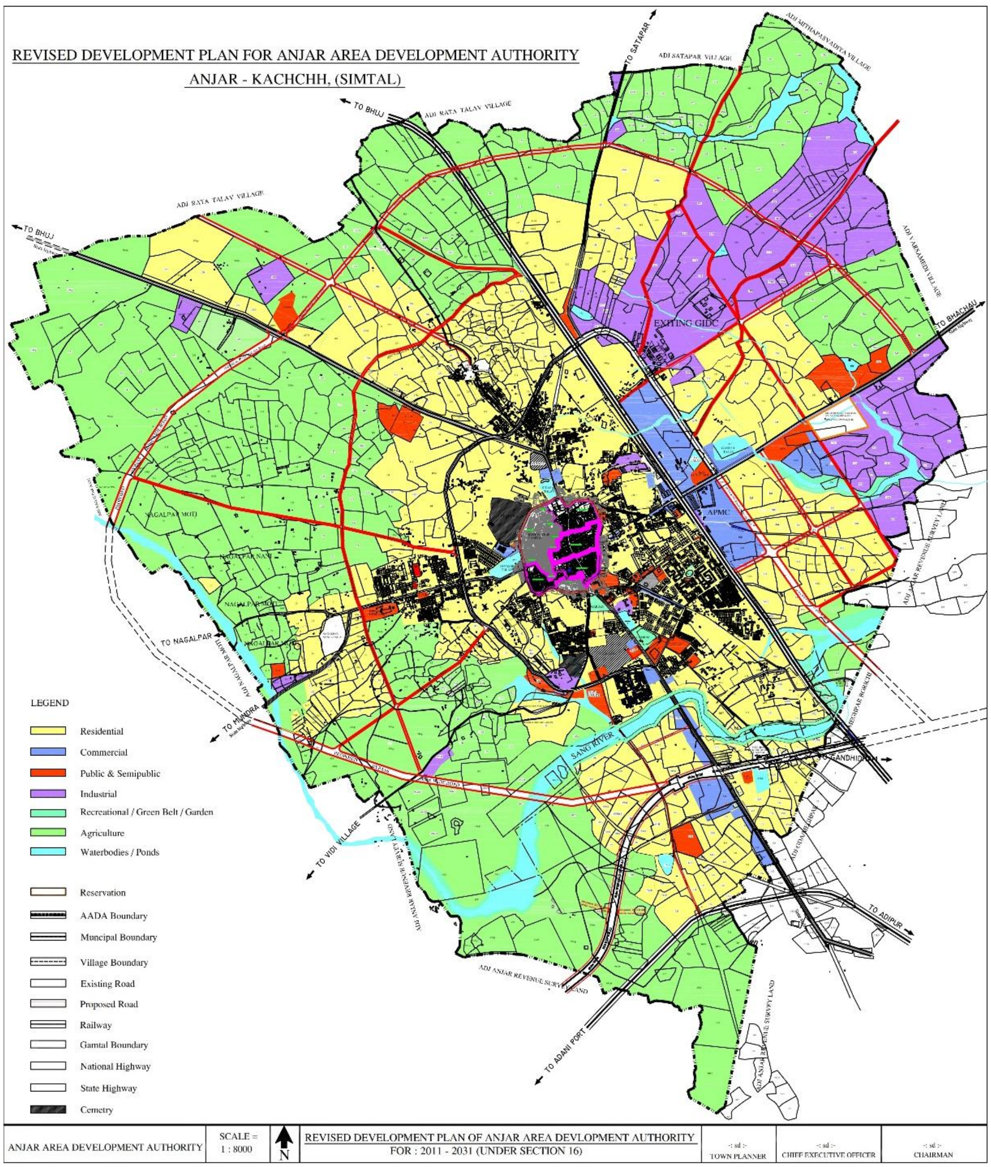



Figure 2.3 Land Use Map of Anjar City

### 2.4.2 Open Lands

Recreational, green belts, garden and agriculture areas are considered as open lands. Almost 41% of the total land area is occupied by this type of landuse. Further agriculture use of land is almost spread over 15.83 sqkm area of city, while 0.65 sqkm area is showing open land in the form of recreational areas.

### 2.4.3 Water Bodies – Water Spread Areas

Water bodies and ponds in the city occupy about 4.5 % of total land. Sang river channel and traditional ponds of the city are major components of this landuse.

## 2.5 Surface Water Resources

Anjar, being one of the historical cities in the Kachchh district, exemplifies the well-known fact that ancient human settlements often developed around surface water resources. It is also evident that, in response to adverse climatic conditions and irregular rainfall, communities in the region historically devised climate-resilient, localized techniques to meet their water needs. Examples from various parts of Kachchh—such as the *virda* and *zeel* in the Banni region, the combination of pond and well in Gardo (western Kachchh), and the Hamirsar Lake in Bhuj—reflect the use of indigenous knowledge and practices for effective water management and self-sufficiency, even during drought periods. These traditional systems demonstrate a clear interconnection between surface water and groundwater, ensuring water availability across seasons and fulfilling critical needs during dry periods. In this context, and considering Anjar's location within the Kachchh district, the city's surface water resources are planned to be studied from the perspective of local, community-based scientific understanding.

Similarly, Anjar city also possesses a traditional water management system that combines surface water structures mainly ponds with groundwater sources such as open wells and stepwells. The major water bodies of Anjar city are illustrated in Figure 2.4. The following section provides a detailed description of each lake in Anjar city, highlighting their historical significance, geological and hydrogeological characteristics, and current status.

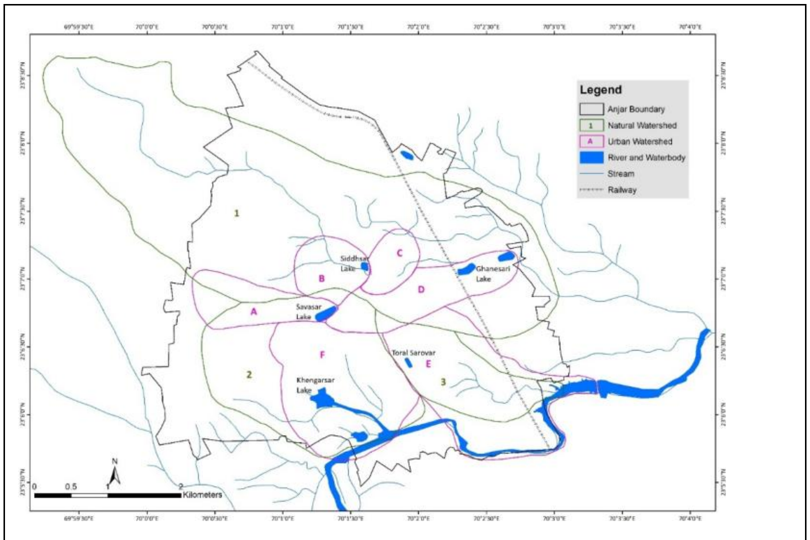


Figure 2.4 Location of Surface Water Bodies of Anjar City

**Siddhasar Lake: (23° 7'5.31"N, 70° 1'36.15"E)**


Siddhasar Lake is a historically significant water body located in the Timba area of Ganga *Naka*, Anjar city. With a history spanning over 400 years, the lake has played an essential role in the local water system and community life. Originally, it covered about 10 acres of land, but due to encroachment and the dumping of waste, its current area has shrunk to roughly 3 acres.

As the waterbody contains ample lotus in it, and seeds of lotus known as ***Pabadi*** in local name, the lake was also known as ***Pabadi Valu Talab***.

**Key Features**

| Historical and Cultural Significance | Geological Formation and Water Extraction | Hydrological Role |
|---|---|---|
| Siddhasar Lake is not just a natural feature but has been a vital source of water for the | The lake was formed in a weathered basaltic zone, which provide it with dual functionality—both as a storage | Siddhasar Lake's overflow is directed to Ghaneshar Lake downstream |

surrounding population, particularly during summer and drought periods. In the past, people relied on two open wells located within the lake's area to provide drinking water during lean periods. These wells were strategically placed so that one remained submerged until the lake dried up entirely, ensuring a continuous water supply.

reservoir and a percolation site. The geology of the region plays a crucial role in the recharge of underground water sources. To facilitate the extraction of this recharged water, A *Jamna Kund* (square step wells) has developed in the Satyanarayan Temple of *Ganga Kund* in *Jund* areas in Anjar city. These stepwells help in harvesting the recharged groundwater, further supporting the community's water needs.

through outflow channels.

This natural overflow helps recharge the shallow aquifers in the region, providing water for the local population.

To monitor lake's overflow a measurement poll has also build in central part of water body.

**Challenge**: Despite its historical significance, Siddhasar Lake faces modern environmental challenges, particularly the ongoing encroachment and waste dumping. These issues have severely reduced the lake's size and water-holding capacity, threatening its ecological and hydrological functions.

Siddhasar Lake serves as a vital link between the past and the present, demonstrating how ancient water management systems once supported both communities and the natural environment. At the same time, it underscores the challenges of preserving such water bodies amid growing urbanization and neglect.

**Savasar Lake: (23° 6'43.98"N, 70° 1'18.87"E)**


Savasar Lake, located near Savasara Naka in Anjar city, is named after Savabhai (Shivjibhai Thakkar), who developed the lake approximately 250 years ago. The lake has a submergence area of around 4 acres. It was once one of the most important lakes in the city due to its perennial water availability, which fulfilled the domestic water needs of nearly half the population in the northern part of Anjar.

**Key Features**

| Historical and Cultural Significance | Geological Formation and Water Extraction | Hydrological Role |
|---|---|---|
| Savasar Lake was originally created by Savabhai and has been an integral part of the local ecosystem. The lake's depth is approximately 7 to 8 feet, and it was historically an important source of water for the surrounding area. Culturally the lake area is surrounded by many religious places and hence people were using lake for praying and for celebrating local festivals. Five years ago, Mavjibhai Sorathia, the president of the municipality, made efforts to preserve the lake by installing iron railings around it. This was intended to protect the lake from encroachments and improve its accessibility. | The lake was formed in a weathered basaltic zone, which provide it with dual functionality—both as a storage reservoir and a percolation site. The geology of the region plays a crucial role in the recharge of underground water sources. There was once a network of 15 wells around the lake, which has now dwindled to just 5. This reduction is likely due to the decrease in groundwater recharge, which has been exacerbated by urbanization and changes in the water flow dynamics. | The outflow of water from the lake used to continue to Siddhasar Lake via a waste weir, but this flow has been interrupted by new constructions. Recently Municipality has created underground pipeline and restored the outflow channels.<br><br>The surrounding area has seen significant changes, particularly with urban development and the construction of roads and buildings. |

**Challenge**: In recent years, the water supply to the lake has come under strain, primarily due to pressure on its original intake systems. Historically, water flowed into the lake through an intake channel from Nangalpur Road, but the volume has significantly decreased over time. To address this, a pipeline has been installed to supply water from the nearby Swaminarayan Temple. While this system is intended to help maintain the lake's ecological balance, the inflow remains insufficient to fully sustain the ecosystem. Another major concern is the lack of effective waste management around the lake. Cattle are frequently fed near the water body, and their waste often ends up contaminating the lake. This adds further stress to the already fragile ecosystem and poses risks to water quality. As such, there is a pressing need for improved waste management strategies to preserve the lake's health and functionality.

**Toral Sarovar: (23° 6'21.93"N, 70° 1'55.65"E)**


Historically, this lake was a *Khadio* (small depression) type water body, estimated to be around 100 years old, and is located in the southeastern part of Anjar. Originally, it had a submergence area of about one acre. In earlier times, the lake was commonly used by local women for washing clothes, often placing shells along the shore—a practice that reflects the lake’s cultural and social significance within the community.

**Key Features**

The lake was later renovated under the **"Nirmal Gujarat"** initiative and the **"Nirmal Anjar-2007"** program by the Anjar Municipality, with a budget of approximately ₹50 lakhs. The project aimed to enhance the lake's condition by increasing its depth and reshaping its boundaries. Additionally, a water flow that previously passed through a nearby burial ground was diverted to the Sang River through the construction of a dedicated channel. However, the outflow channel is no longer operational. Over time, the lake has accumulated garbage and pollution, making it a source of environmental concern.

**Challenge:**

Improper waste management in the surrounding area has significantly contributed to its degradation. Despite past restoration efforts, the environmental condition of the lake continues to deteriorate. Both the inflow and outflow areas are now nearly blocked, preventing proper water circulation. This lack of exchange has led to water stagnation, which further exacerbates pollution and threatens the aquatic ecosystem.

**Khengarsar Lake: (23° 6'21.93"N, 70° 1'55.65"E)**


Khengarsar Lake, built approximately 450 years ago during the reign of ruler Khengarji, is the largest water body in Anjar city. Named in his honor, the lake spans an area of about 30 acres. Strategically, it was developed in grazing lands to provide drinking water for cattle. In 2023, the lake's waste weir was damaged during Cyclone Biporjoy, impacting its water regulation.

**Key Features**

**Historical and Geohydrological Features**

Geologically, the lake is situated on basalt outcrops. Due to the hardness of basalt, the water column in the lake remains shallow, causing it to dry up during the summer season. The catchment area of the lake begins near the village of Vidi, located northwest of Anjar. Historically, a stepwell within the lake allowed *Maldharies* (pastoral communities) to access water during dry periods.

Khengarsar Lake was once perennially sustained by the base flow of nearby rivulets, fed by groundwater discharge. In earlier times, groundwater was available at shallow depths, which maintained a regular inflow into the lake. However, as groundwater levels have gradually declined, the base flow has ceased, leading to significant water shortages.

The village name "Vidi" is believed to be derived from the term *virda*—a small depression dug to extract shallow groundwater—reflecting the traditional water conservation practices of the region. This etymological connection underscores the historical significance of water management and highlights the interdependence between the village and the lake.

**Challenge**: Due to the drying of wells in Vidi, Khengarsar Lake's water supply has been severely affected. Its shallow nature also means that any retained water evaporates quickly, especially during summer, further intensifying the water scarcity. Once a vital resource, the lake now faces mounting challenges from environmental degradation and urbanization pressures. To ensure the lake's sustainability, it is crucial to explore integrated solutions, such as reviving wells in Vidi village, restoring traditional water channels, and incorporating modern water conservation techniques. These measures should be aligned with urban planning efforts to preserve Khengarsar Lake for future generations.

## Ganesari Lake: (23° 7'10.30"N, 70° 2'40.61"E)


**Ganesari Lake**, located on Varsamedi Road, is a historic water body that holds both cultural and environmental significance. Approximately 100 years old, the lake spans an area of about 8 to 10 acres and is often referred to as *Sari* due to its small size and bowl-like shape. Its unique characteristics and historical background make it an important local landmark.

### Key Features

### Historical and Geohydrological Features

Geologically, the lake is situated on basalt outcrops. Due to the hardness of the basalt, the depth of the water column is very shallow, causing the lake to dry up during the summer season. One distinctive feature of Ganesari Lake is the presence of platforms specifically constructed for diving and swimming. The lake is named after its developer, Ganesh. Historically, it was located outside the city, making it relatively undisturbed by community encroachment in earlier times.

**Challenge:** In recent years, several small- to medium-scale industries have emerged around the lake. These units have been removing silt from the lake for land-leveling purposes. Additionally, mining activities in the surrounding area have led to extensive soil excavation, unintentionally increasing the depth of the lake. While this deepening may appear beneficial in terms of water retention, it raises serious concerns about the long-term ecological impacts. Continuous soil extraction threatens to disrupt the lake’s natural structure and ecosystem, necessitating immediate attention and sustainable intervention strategies.

**Khanesari Lake: (23° 7'10.30"N, 70° 2'40.61"E)**

**2012**

2023

Khanesari Lake, named after the local term *Khanetra* (soil excavation), is more than 100 years old and is located between Sorathiya Naka and Devaliya Naka in Anjar city. The lake historically served as a crucial source of domestic water, especially for the population living on the outskirts, primarily slum dwellers. Additionally, farmers from nearby areas regularly de-silted the accumulated silt for agricultural use.

**Challenge:** Due to poor management and unregulated growth of nearby slum settlements, the lake has significantly deteriorated. Its original submergence area of around 2 acres has been reduced to a narrow channel, now primarily carrying untreated sewage. The presence of the slum area near the polluted lake poses serious health risks and negatively affects the well-being of residents. The proximity to contaminated water reduces access to clean water and proper sanitation, thereby impacting the overall quality of life in the area.

# 3 Terrain Characteristics

Terrain characteristics play a fundamental role in understanding the geo-hydrological framework and aquifer systems of any region. The topography, slope, elevation and landforms directly influence groundwater recharge patterns, surface runoff dynamics and overall aquifer geometry and properties. This chapter examines the terrain features of Anjar City to establish their relationship with groundwater movement, storage capacity and potential recharge zones, providing essential insights for sustainable water resource management and planning.

## 3.1 Slope and Elevation Contours

Land slope is an important governing factor that governs the processes of surface run-off and infiltration. Slope and its spatial distribution pattern greatly facilitate in characterization of watershed basins and help in categorization of an area from recharge and / or discharge point of view. In addition, slope in any area also decides landuse pattern.

The slope and slope aspects were studied through DEM image (Fig. 3.1) interpretation using GIS software.

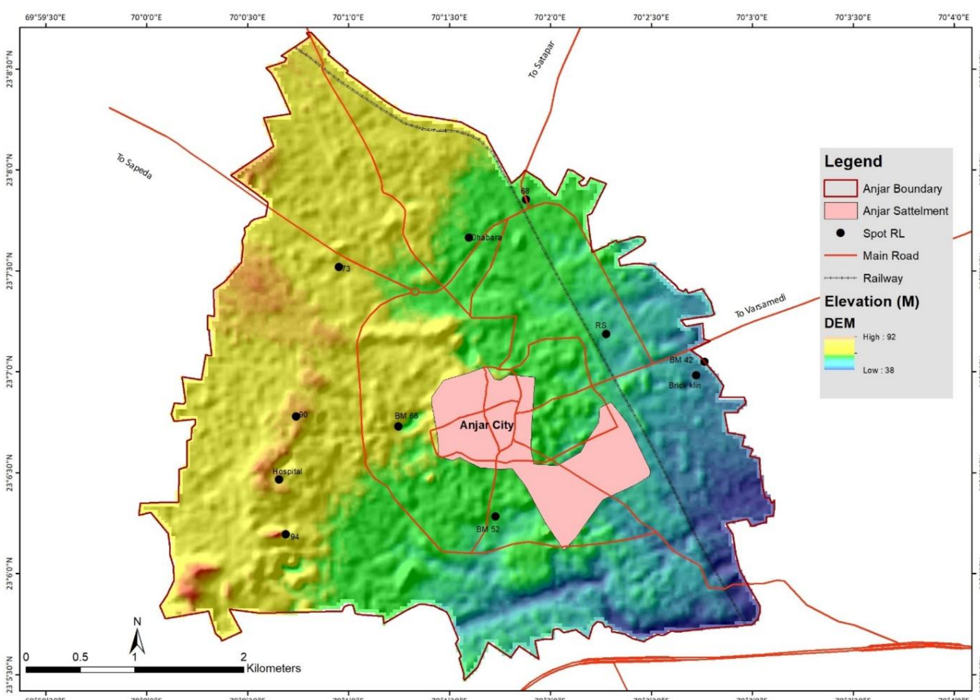



Figure 3.1 Digital Elevation Model Map of Anjar

Figure 3.1, the Digital Elevation Model (DEM) map of Anjar, represents the terrain's elevation using a color gradient where lighter shades indicate higher elevation areas and darker shades represent lower elevations. This visualization allows us to identify the topographic high points in the northwest, west, and southern portions of the city, which reach elevations of up to 92 meters above mean sea level. The gradual shift in colors from light to dark illustrates how the land slopes generally from these high points toward the eastern and southeastern regions.

The Slope Map as given in Fig. 3.2, further categorizes these elevation changes into four distinct slope classes ranging from very gentle (< 2°) to moderately steep (10°-18°). The quantitative and qualitative interpretations of the various slope categories based on Young (1972) and NATMO (1996) are given in Table 3.1. The interpretation of these maps reveals that approximately 98% of Anjar City consists of very gentle to gentle slopes (Class I & II), predominantly comprising flat alluvial plains and undulated pediments. The slope gradually increases up to 5 degrees in pediment and rocky upland zone. The steeper slopes (Class III & IV) appear only as small patches in the western portion, coinciding with the basaltic hills.

Table 3.1 Slope Category wise Computed Area in Anjar City

| Slope | Map Class | Degree | Area Km2 | Geomorphic Characters |
|---|---|---|---|---|
| Very Gentle to Level | I | < 2º | 1376.99 | Even alluvium plains |
| Gentle | II | 2°-5° | 493.5 | Pediments and Rocky uplands |
| Moderate | III | 5°-10° | 37.31 | Ridges |
| Moderately Steep | IV | 10°-18° | 1.04 | Hills |

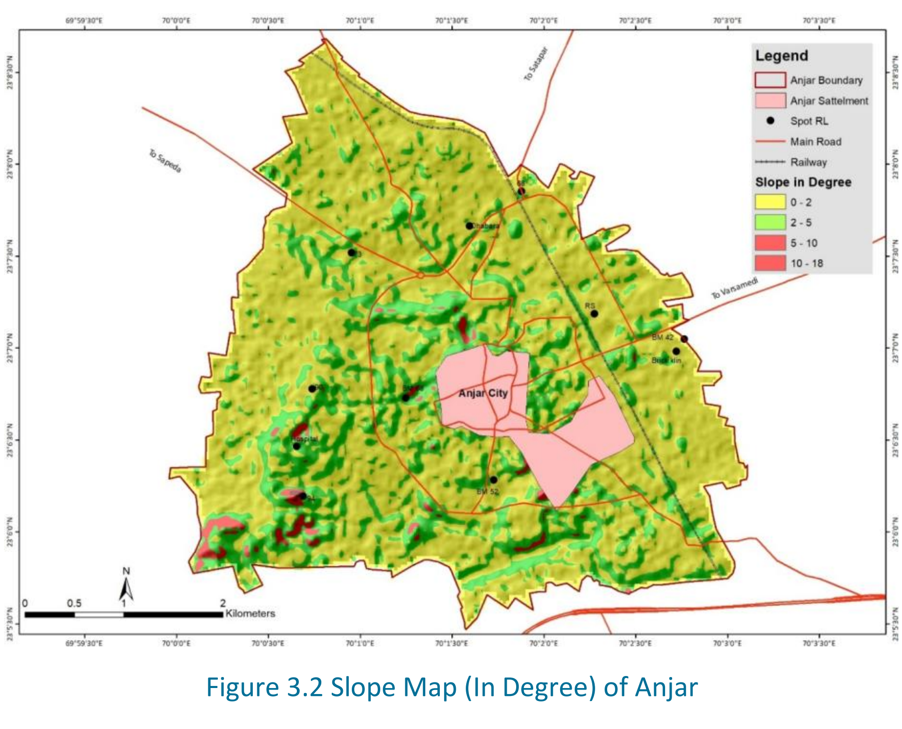



Figure 3.2 Slope Map (In Degree) of Anjar

## 3.2 Physiography and Landform

Terrain features play a fundamental role in the overall distribution and development of water resources in the area. The terrain not only governs recharge and runoff but also strongly influences the socio-economic conditions of local inhabitants. Anjar city is located on the western fringe of Kachchh Mainland, which marks the beginning of coastal plains extending toward the south-western part. The present landscape of Anjar City results from various endogenic and exogenic geological processes that have operated continuously since the Quaternary period. The study area's landscape comprises an array of tectonogenic and geomorphic elements in the form of uplifts and residual depressions. Elevated landforms such as hills and rocky pediment plains contain Mesozoic and Tertiary rocks, while the residual depressions or low-lying regions between the uplifts consist of Quaternary sediments characterized by undulating alluvial plains, slopes of rocky mainland, and clayey flats in coastal areas.

Physiographically, the study area can be categorized from north to south into four units (Fig. 3.3): (1) Hills (> 55 m AMSL); (2) Undulating Pediment Plain (30–55 m AMSL); (3) Alluvial Plain (20–30 m AMSL); and (4) River Courses.

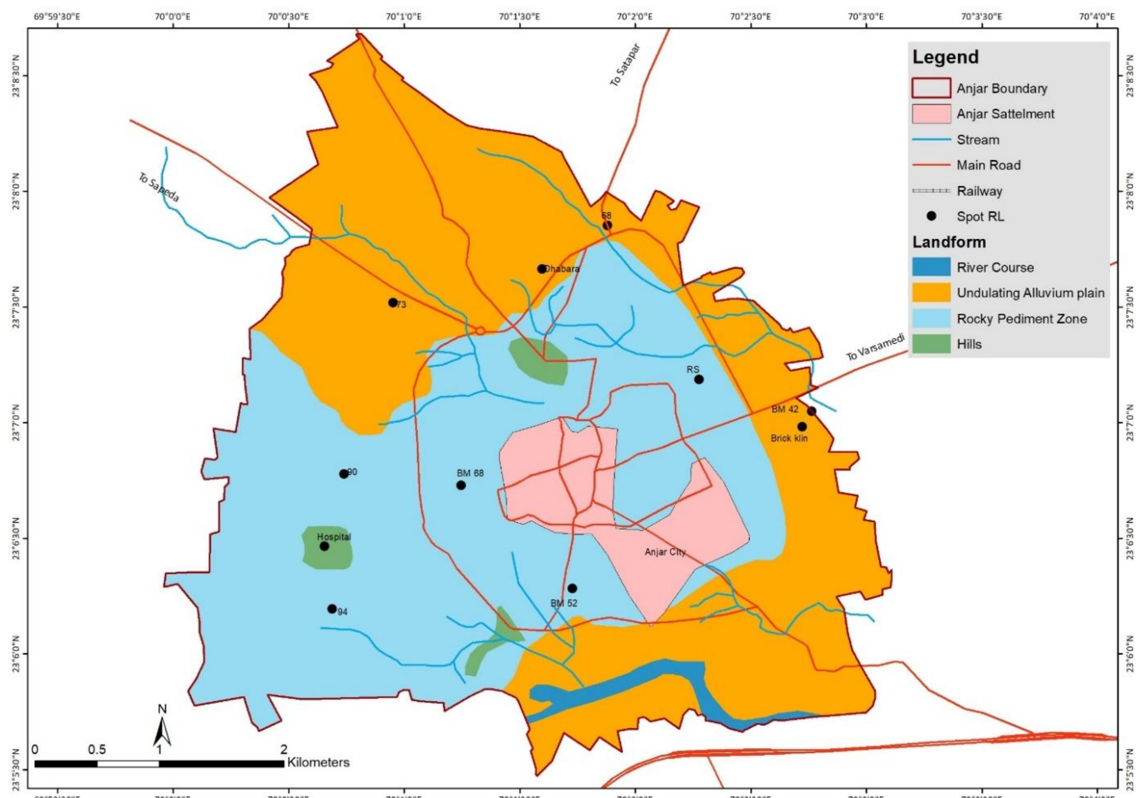



Figure 3.3 Geomorphological Characteristics of Anjar City

**Hills:** hills are located west, north, and south of the old city area. Three small hills exceed 55 m in height, with a maximum elevation of 92 m. All these hills result from basaltic intrusion during Deccan lava flows of the Late Cretaceous to Paleocene period.

**Rocky Pediment Zone:** Regionally, the rocky pediment zone constitutes part of Kachchh Mainland. This landform extends from the southwest to the central part and continues to the eastern boundary of the city. It represents Cretaceous-age sandstone in the western part, while the central and eastern parts represent gently sloping, table-topped undulated areas of Deccan lava flows from the Late Cretaceous to Paleocene period. This unit varies in elevation between 30 to 55 m.

**Undulating Alluvial Plain:** The alluvial plain unit in the city is relatively flat terrain with moderately thick accumulation of river-borne sediments. Its base lies over the Bhuj Formation of the Cretaceous period and Deccan Lava of the Late Cretaceous to Paleocene period. This unit is characteristic of a rich agricultural belt due to better groundwater prospects (Fig. 3.3).

## 3.3 Drainage and Watersheds

Anjar city receives rainwater flow through two major watersheds. As shown in Fig. 3.4, the northern part of Anjar city has a micro watershed that starts from northwestern villages, while the southern watershed is part of the Sang River watershed. It is important to note that although the northern watershed is part of the Sang basin, it originates from areas several kilometers northwest of the city. Almost all rainwater falling in this watershed passes through the city area and merges with the Sang River further downstream in a southeasterly direction, far from the city. In contrast, the southern part of the city occupies only a small portion of the Sang basin (Fig. 3.4).

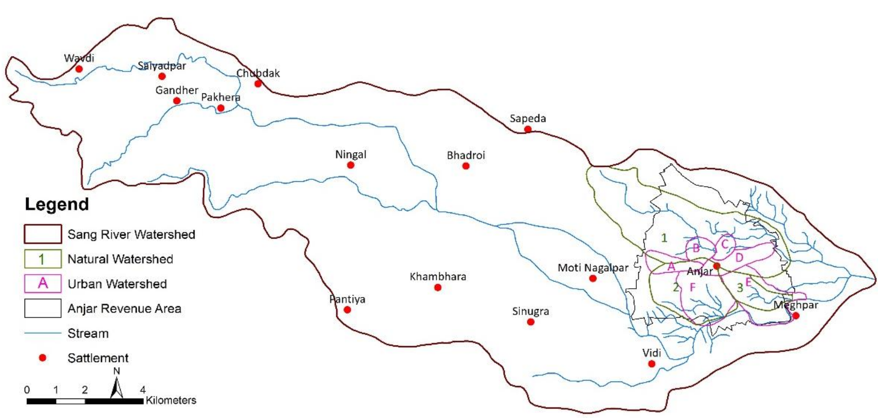



Figure 3.4 Drainage Map of Anjar

Table 3.2 Computed Ares of Regional to Micro Scale Watershed of Anjar City

| Sr. No. | Details | Area (Ha.) |
|---|---|---|
| 1 | Sang Watershed | 17061 |
| 2 | Anjar City Natural Watershed | |
| 2.1 | Watershed No. 1 | 1232 |
| 2.2 | Watershed No. 2 | 439 |
| 2.3 | Watershed No. 3 | 160 |
| **Total** | | **1832** |
| 3 | Anjar Urban Watershed | |
| 3.1 | Watershed No. A | 91 |
| 3.2 | Watershed No. B | 66 |
| 3.3 | Watershed No. C | 43 |
| 3.4 | Watershed No. D | 125 |
| 3.5 | Watershed No. E | 284 |
| 3.6 | Watershed No. F | 251 |
| **Total** | | **860** |

Urban development inevitably influences the landuse pattern of an area, which directly modifies natural drainage, waterways, and inflow areas. Therefore, to understand these alterations, detailed mapping of individual water bodies and their associated inflow areas has been conducted for Anjar city.

Fig. 3.5 shows micro watersheds within Anjar city in relation to natural watersheds. Five micro watersheds have been delineated within the city boundary.

The Sang River watershed covers 17,061 hectares, with the Anjar watershed encompassing approximately 1,832 hectares within Anjar city. While these natural watersheds extend beyond the city limits, urbanization has modified approximately 860 hectares, creating six distinct urban watersheds.

Watersheds E and F still align with the natural watersheds, whereas watersheds A, B, C, and D have been significantly altered due to urban infrastructure. Specifically, watershed A, which previously directed inflow water into Savasar Lake, has shifted its flow into watershed C through a waste weir into the historically developed Siddhsar Lake. Additionally, road construction has redirected water from the upper parts of the watershed into watershed E, leading to increased surface runoff.

As a result, watershed E is now experiencing an overload of surface runoff, contributing to urban flooding in the Ring-road area near the court. This situation highlights the impact of urban development on natural water systems and the importance of sustainable watershed management.

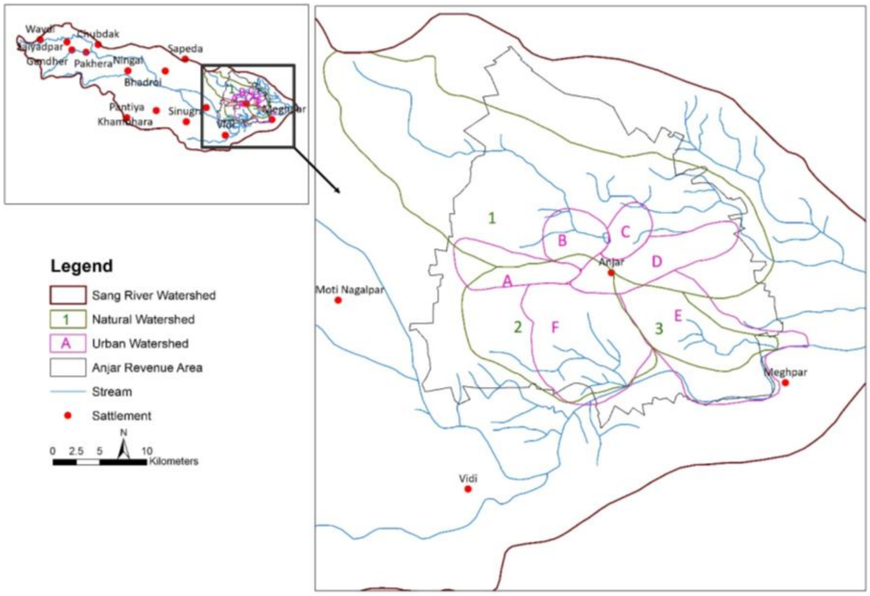



Figure 3.5 Urban Micro Watershed Map of Anjar City

# 4 Geology

## 4.1 Regional Geology

The Kachchh stratigraphy which is represented by a complete sequence of strata ranging from Middle Jurassic to Holocene and its richness in fossil assemblage remained an intrigue issue for earth scientists. A period of non-deposition, followed by diastrophism, erosion and volcanism during the close of the Upper Cretaceous time separates the Mesozoic and Cenozoic rocks of the Kachchh. Igneous activities mostly volcanism, is represented by Deccan Trap lava flows. The Mesozoic system of the region shows sediments ranging in age from Bathonian to Santonian (Biswas, 1970). The Tertiary includes Paleocene to Pliocene sediment sequence and the Quaternary consists of Pleistocene and Holocene sediments. The fault-related uplifts and consequent folding have affected the Mesozoic strata. The Mesozoic rocks are surrounded by strips of gently dipping Tertiary strata forming peripheral plains, which wrap round the Mesozoic structures Biswas (1980, 1982, and 1987). Compilation of regional geology of Kachchh region has been done by researchers by studying in various physiographic divisions such as Kachchh Mainland, Islands, Wagad Uplifts, Banni, Rann and coastal plains. The Anjar city being a part of Kachchh Mainland brief appraisal on overall litho-stratigraphy of the Anjar block is given as under.

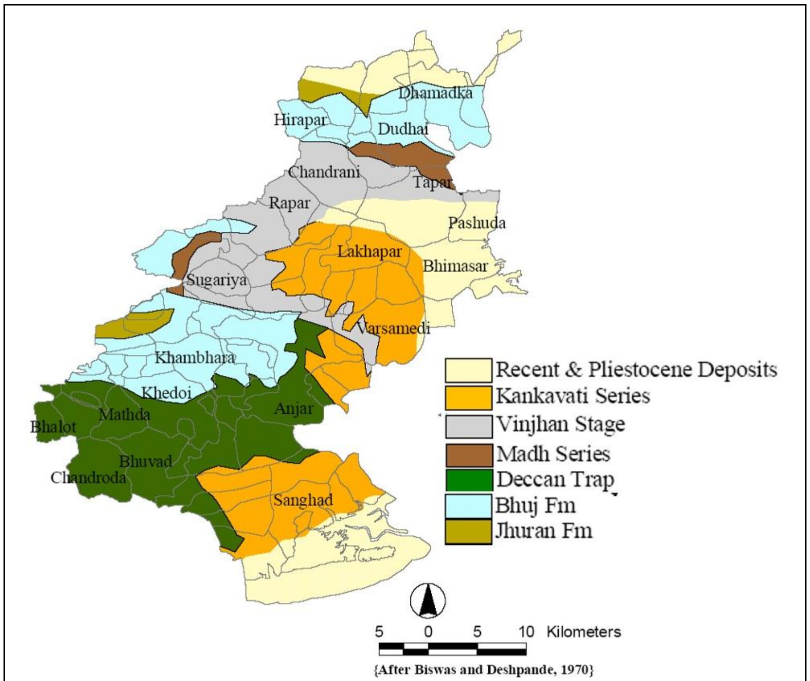


Figure 4.1 Geology of the Anjar Block

**Mesozoic Rocks:** The oldest rocks in the region, called Mesozoic rocks, were formed between the Middle Jurassic and Lower Cretaceous periods. These rocks tell us about ancient environments and are well-preserved in the area around Anjar. The oldest of these rocks can be found northwest of Khambhara village and belong to what geologists call the Jhuran formation. Throughout the region, you can see thick layers of coarse-grained sandstones from the Cretaceous period, with particularly good examples visible in the central, western, and northern parts of the Anjar area.

**Deccan Trap:** One of the most significant geological features in the region is the Deccan Trap, which represents a period of intense volcanic activity. These volcanic rocks are mainly made up of basaltic lava flows that cooled and hardened millions of years ago. In the Anjar area, these volcanic rocks form a distinctive band that runs across the landscape, reaching its maximum width of about 10 kilometers near Anjar town and gradually becoming narrower as it extends westward. The volcanic flows tilt gently toward the south and wrap around the edges of the older Mesozoic rocks.

**Laterites:** Scattered throughout the study area are patches of laterites, which are special types of weathered rock formations. These can be found near villages like Sugariya and Dudhai and are believed to be from the Palaeocene age. These laterites sit between the volcanic basalts and the younger Tertiary rocks, creating layers in the geological sequence.

**Cenozoic - Tertiary Rocks:** Kachchh is considered to be the ‘Type Area’ for the marine Tertiary Rocks of India where a more or less complete sequence has developed. In the study area, the most common Tertiary rocks are sandstones from the Kankavati series and clays from the Vinjhan stage. These younger rocks often extend into the lower areas between the older Mesozoic rocks and volcanic formations. (Biswas, 1965).

Table 4.1 Mesozoic Chrono-stratigraphy of the Kachchh Region

| Period | Time Scale | Rock Unit | Lithology |
|---|---|---|---|
| Recent | Holocene | | Recent Deposits: Alluvium Rann silts and blown sands |
| -=-=-=-=- Unconformity -=-=-=-=- | | | |
| Tertiary | Pliocene | Kankavati Series | Fine grained Sandstone |
| | | Vinjhan Series | Claye |
| | ---------- Disconformity ---------- | | |
| | Paleocene | Madh Series | Laterites |
| -=-=-=-=- Unconformity -=-=-=-=- | | | |
| Middle Mesozoic to Lower Tertiary | Upper Cretaceous to Paleocene | Deccan Trap Formation | Amygdaloidal Basalts, fracture basalts, |

| | | | |
|---|---|---|---|
| Mesozoic | Cretaceous | Bhuj Formation | Upper: Coarser grained felspathic sandstone, pale brown to dirty while, friable, current bedded.<br>Lower: Brown and reddish felspathic sandstone with rhythmic alternations of grey kaolinitic shale, sandy shale and thin hard ironstone bands. |
| | Upper Jurassic | Jhuran Formation | Shale and sandstone with thick calcareous sandstone bands. |

(After Biswas, 1971 and Merh, 1995)

**Quaternary Deposits:** The most recent geological deposits in the area are Quaternary formations, which include modern sediments. These are found in patches along the coastline, in the Rann (salt flats), and in some inland areas. These recent deposits were formed by rivers, wind, and marine processes and include coastal sands, silts, and wind-blown sand dunes. River sediments deposited in coastal plains and valley areas represent the most recent chapter in the region's geological history.

All of these different rock types and formations have been affected by faulting and folding over millions of years, creating the complex but fascinating geological landscape we see in the Kachchh region today. The older Mesozoic rocks form the central highlands, while the younger Tertiary rocks create gentler plains that surround these elevated areas, giving the region its distinctive topography.

## 4.2 Geology of Study area

Surface geology wise Anjar City shows three major rock formations ranging from older to younger. As far as the oldest formation occurrence in Anjar is concerned it is Bhuj Formation's sandstone overlined by Deccan Trap Basalt that shares its boarders with Kankavati Sandstone of Tertiary age. Fig. 4.2 shows surface geological maps of Anjar City while table 4.2 shows litho-stratigraphy sequence of Anjar city.

Table 4.2 Litho-Stratigraphy Sequence of Anjar City

| Period | Time Scale | Rock Unit | Lithology |
|---|---|---|---|
| Tertiary | Pliocene | Kankavati Series | Fine grained Sandstone |
| -=-=-=-=- Unconformity -=-=-=-=- | | | |

| | | | |
|---|---|---|---|
| Middle Mesozoic to Lower Tertiary | Upper Cretaceous to Paleocene | Deccan Trap Formation | Amygdaloidal Basalts, fracture basalts, |
| Mesozoic | Cretaceous | Bhuj Formation | Coarser grained felspathic sandstone, pale brown to dirty while, friable, current bedded |

(After Biswas, 1971)

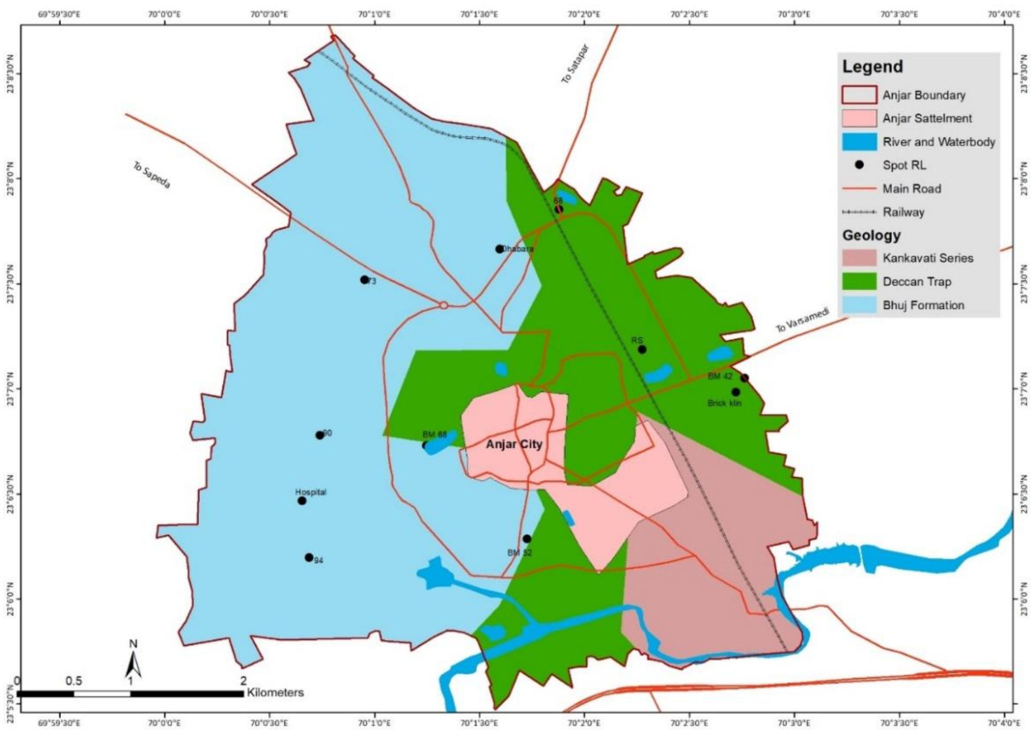



Figure 4.2 Surface Geological Map of Anjar City

The western part of Anjar City is dominated by sandstone, which is the oldest rock formation in the area and belongs to what geologists call the Bhuj Formation. This sandstone is made up of coarse grains and contains a mineral called feldspar, giving it a distinctive pale brown to dirty white color. What makes this sandstone special is that it was formed by ancient rivers, which sorted and arranged the sand grains in a way that created lots of tiny spaces between them. These spaces, called pores, allow water to flow through the rock easily, making it an excellent source of groundwater. The sandstone layer is quite thick, ranging from 200 to 215 meters deep beneath Anjar city. Because this rock formation holds so much water, the western part of the city has become the main agricultural area, with many fruit orchards and farms thriving thanks to the reliable water supply.

The central part of Anjar City has a completely different type of rock called basalt, which is a dark volcanic rock formed during the ancient Deccan Trap period when massive volcanic eruptions covered much of western India. These basalts are hard, consolidated rocks that formed when molten lava cooled and solidified millions of years ago. Over time, weathering and erosion have created varied landscapes in some areas where the basalt has been worn down. Because basalt is such a hard and durable rock, it's valuable for construction and mining, providing economic benefits to the city through quarrying operations. In some places where the basalt has weathered and broken down, especially near rivers and streams, it can hold small amounts of water and serve as a shallow source of groundwater.

Moving toward the eastern part of the city, there's a third major rock formation made up of fine-grained sandstone mixed with clay layers. This formation is much younger than the others and is called the Kankavati Sandstone, dating to the Tertiary period. Unlike the coarse sandstone in the west, this eastern sandstone has much smaller grains and was formed in a different environment - specifically in river deltas where rivers met ancient seas. This layer has poor water storage capacity and restricts groundwater movement due to its small grain size and clay barriers. Eastern formation creates limited groundwater availability and may cause water to flow around rather than through it. This formation doesn't just stop at Anjar but continues westward, extending all the way to the Abadasa area of the district, showing how these ancient river and delta systems once covered a much larger area. This geological difference explains why farming activities are concentrated in the western part of the city where groundwater is more accessible.

The arrangement of these three rock types across Anjar City creates distinct zones with different characteristics. The western area with its coarse-grained sandstone offers excellent groundwater potential and should be prioritized for sustainable groundwater extraction and recharge programs to support continued agricultural activities. The central basaltic zone, while providing limited groundwater storage, could serve as natural barriers and should be utilized for rainwater harvesting and surface water storage due to its hard, impermeable nature. The eastern fine-grained sandstone with clay layers requires alternative water supply strategies such as surface water systems, rainwater collection, and water conservation measures since groundwater availability is severely limited in this zone.

# 5 Geohydrology

## 5.1 Groundwater Occurrence and Distribution

Groundwater availability in any area depends on two main factors: how much water nature provides through rainfall and other sources, and what kind of rocks and soil exist underground to store and move this water. In Anjar city, the underground structure is made up of a mix of soft sedimentary rocks and hard rocks, which creates a complex system where groundwater can be found at different depths ranging from shallow to deep groundwater. To understand groundwater occurrence in Anjar city area detailed well inventory of 93 wells along with lithological measurement of 43 tubewells have been carried out. (Fig. 5.1 Annexure 5.1 & 5.2) In addition to primary measurements, some consultations with borewell driller were held to understand their observations on sub surface geological formation.

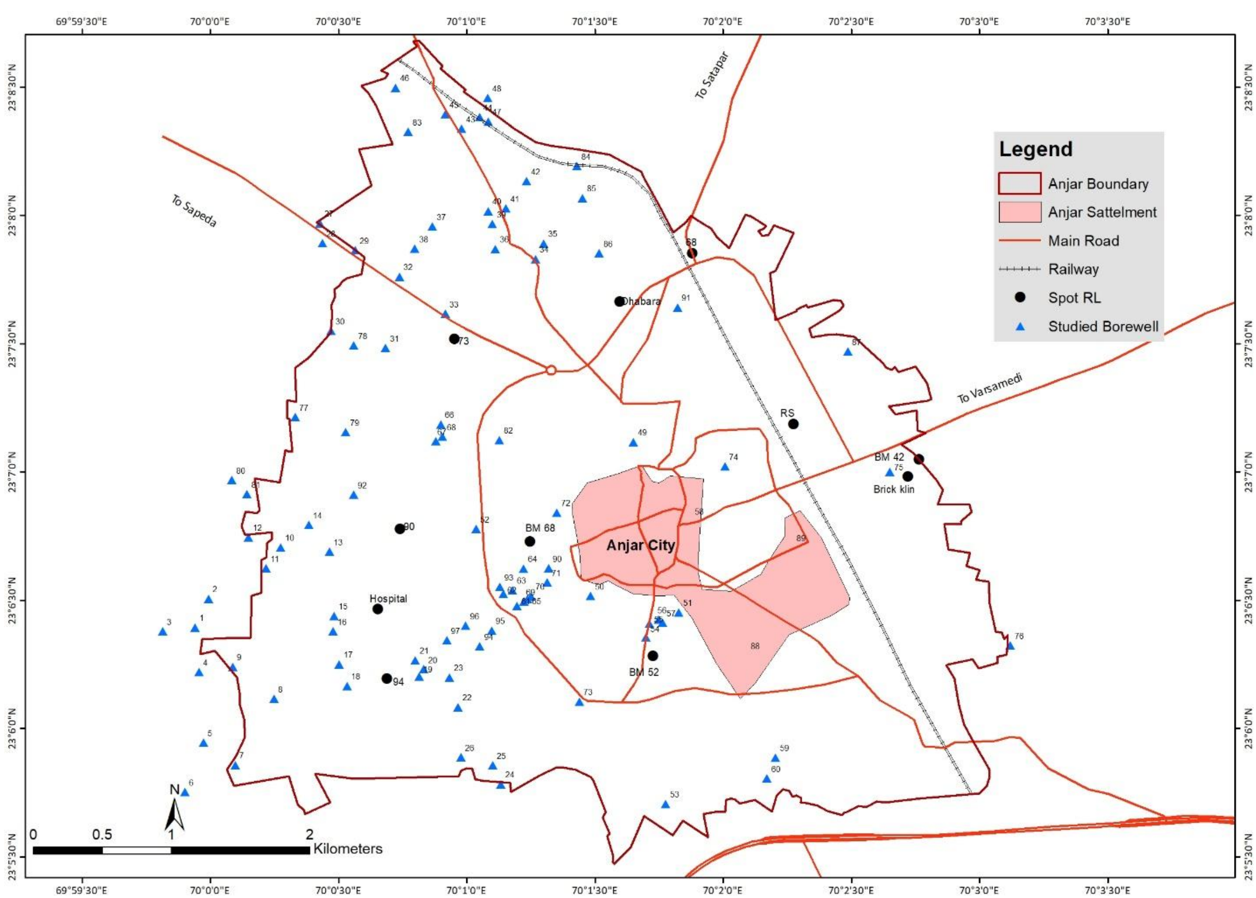



Figure 5.1 Locations of Studied Wells

Further the collected primary data were analyzed on GIS platform and various thematic maps were prepared to appropriately describe geohydrological characteristics. In addition, hydrographs and sub surface cross sections of terrain have also been prepared. By analysing various thematic layers, detailed strategy of groundwater potential zones of city has been defined.

## 5.2 Aquifers

An aquifer is like an underground reservoir - it's a layer of rock or soil that can hold and supply water. Think of it as a natural underground storage tank. In Anjar city, ACT team studied bore hole records from existing wells to understand what lies beneath the ground and how water moves through these underground layers. Bore hole logs gives an excellent opportunity to understand subsurface hydrogeology from the point of view of deriving inferences on (i) Thickness and lateral extent of an aquifer; (ii) Vertical litho-facies changes facilitate in establishing aquifer types and level of hydrostatic pressure. The data have collected from existing borehole logs through well inventory as well as from State Water Resource Departments Viz; GWRDC and GWSSB.

In Anjar city, there are three main types of rock formations that act as aquifers. The first is weathered basalt from the Deccan Trap (ancient volcanic rock that has broken down over time). The second is Kankavati Sandstone, and the third is Bhuj Series Sandstones. Table 5.1 shows aquifer chronology in Anjar city.

Table 5.1 Depth wise Type of Aquifer Occurrence in Anjar City

| Layer Type | Depth M | Thickness (M) | Remark | Type |
|---|---|---|---|---|
| Sandy soil mixed with Pebble & gravels | 0-18 | 18 | Very Good Shallow Aquifer Loose formation | Shallow |
| Medium Sand | 18-24 | 6 | Very Good aquifer Kankavati Sandstone | Shallow |
| Secondary Laterite | 24-30 | 6 | Poor aquifer | Shallow |
| Clay and Laterites | 30-72 | 42 | No Aquifer | Aquiclude |
| Fine sand with Pebbles | 72-96 | 24 | Very Good Aquifer – Kanakavati Sandstone | Deep-Confined |
| Clay | 96-120 | 24 | No Aquifer | Aquiclude |
| Weathered Basalt | 120-136 | 16 | Moderate potential aquifer | Confined |

| | | | | |
|---|---|---|---|---|
| Compact Basalt | 136-196 | 60 | No Potential | Aquifuge |
| Sandstone | 192-315 | > 119 | Very Good Aquifer | Confined |

The underground water system in Anjar has two main levels - shallow and deep aquifers. The shallow aquifers are closer to the surface and include sandy soil mixed with pebbles and gravel (0-18 meters deep), medium sand (18-24 meters), and some laterite rock (24-30 meters). These shallow layers can provide good water supply but are more vulnerable to contamination and seasonal changes.

Below these shallow layers, there are clay layers (30-72 meters and 96-120 meters deep) that act like barriers, preventing water from moving easily between the upper and lower aquifers. Deeper down, there are more water-bearing layers including fine sand with pebbles (72-96 meters), weathered basalt (120-136 meters) and very deep sandstone layers (192-315+ meters) that can provide excellent water supply.

### 5.2.1 Shallow – Unconfined Aquifer Systems

The shallow aquifers in Anjar City are mostly unconfined and often dry. Occasionally, immediately after the monsoon period, some pockets of the city experience periodic availability of groundwater. For example, wells located near temples such as the one near Savsar Lake and the Kund near Ajepar Temple contain groundwater post-monsoon. In most cases, however, this water is either contaminated due to sewage leakage or the infiltration of polluted water during the monsoon. Shallow aquifers are typically found in areas with top sandy soil, the weathered zone of basalt, and exposed Bhuj Series sandstone—particularly in the western part of Anjar City.

### 5.2.2 Deep Aquifer - Confined Aquifer Systems

The deeper aquifer system of Anjar City is characterized by two formations: the Kankavati Sandstone and the Bhuj Series Sandstone. The Kankavati Sandstone, a fine-grained formation, is located above the lateritic layer on the eastern side of the city and represents a shallower confined aquifer. In contrast, the Bhuj Series Sandstone is a medium- to coarse-grained formation found below basalt layers, occurring throughout the city but more prominently exposed in its western part. This formation represents a deeper confined aquifer system. Water levels in these aquifers vary significantly, ranging from 42 to 225 meters deep, depending on the ground elevation across the city. Figure 5.2 shows the subsurface profiles of aquifer conditions in Anjar, illustrating the distribution and depth of these aquifers. This indicates that Anjar City's aquifer systems are complex, with varying geological features and depths that influence water availability across the area.

The underground water system in Anjar city is complex and varies significantly across different areas. The city has both shallow and deep-water sources, but the shallow ones are largely unreliable due to contamination and seasonal drying. The deep aquifers provide the main water supply for the city, but accessing them requires drilling deep wells, which is expensive. The varying depths of water (42-225 meters) mean that some areas of the city have easier access to groundwater than others. This complex underground geology explains why water availability and quality differ from neighbourhood to neighbourhood in Anjar city.

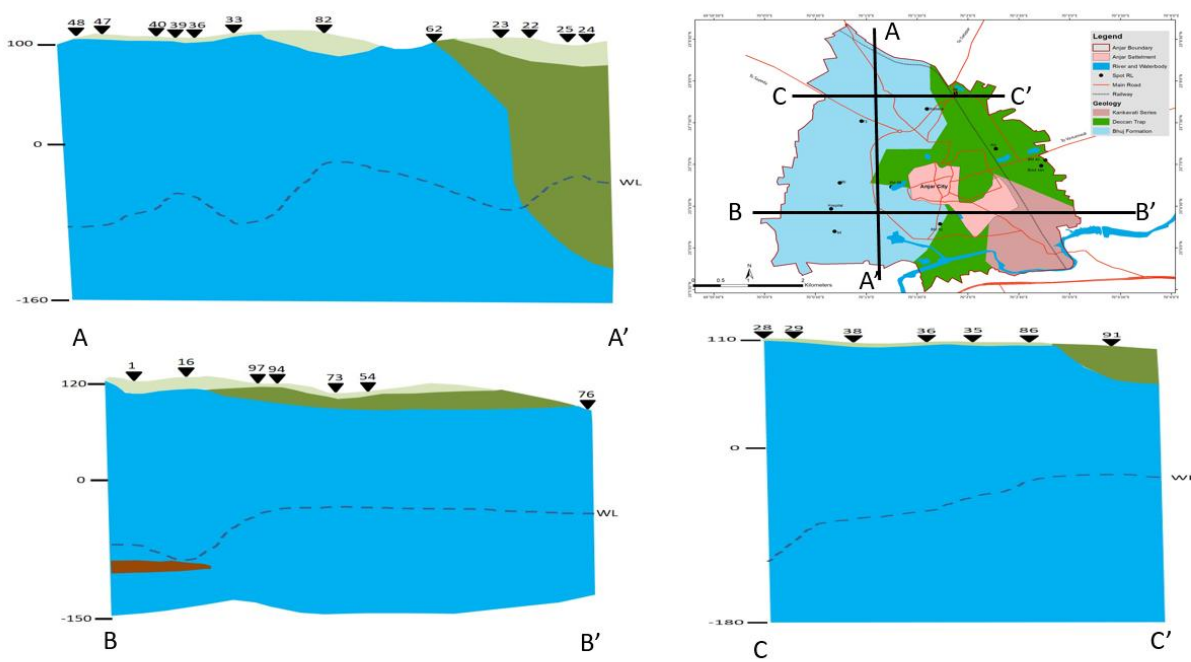



Figure 5.2 North – South (A-A') and East-West (B-B' & C-C') Hydrographs and Geological Profiles Showing Aquifer Characteristics of Anjar City

**Profile A-A' (North to South Cross-Section):** This profile shows what the underground looks like when you cut through the city from north to south, like slicing through a piece of cake. The underground has a very thick layer of sandstone rock (260 meters thick) that acts like a giant underground water storage tank. On top of this sandstone, there's a thin layer of soil (2-5 meters thick) that we see on the surface. As you move toward the north of the city and closer to the coast, the sandstone layer comes into contact with basalt rock (volcanic rock), and this basalt layer gets thicker. The water levels in this deep underground storage system go up and down from north to south, depending on how much water people are pumping out. Interestingly, the water level is highest in the middle part of the city compared to the northern and southern ends. This happens because the shape of the land above ground influences where water collects underground.

**Profile B-B' (East to West Cross-Section - Southern Part):** This profile shows what the underground looks like when you cut through the southern part of the city from east to west. On the surface, you can see mostly basalt rock from the center to the western areas, with only a thin layer of soil covering it. Underground, there's the same sandstone layer that holds water, but the water level varies significantly - it's about 130 meters deep in the western areas and more than 150 meters deep in other parts. The groundwater flows from west to east in this area. This also shows creation of cone of depression may be due to heavy extraction.

**Profile C-C':** The profile falls within the domain i.e., northern part of the city also shows similar geological profile and behavior of groundwater levels.

These underground cross-sections reveal that Anjar city sits on top of a massive underground water reservoir made of sandstone rock. However, the depth to reach this water varies considerably across the city - some areas require drilling much deeper than others. The fact that water levels are dropping and creating cone-shaped depressions around wells suggests that people are pumping out water faster than it can be naturally refilled. The underground water flows in predictable directions (generally from west to east in the southern part), which helps planners understand how the water system works and where new wells might be most effective.

## 5.3 Water Levels

Anjar city has two main types of underground water sources. The first type is called "phreatic" or unconfined water, which is like water sitting in a shallow aquifer that connects directly to the surface. The second type is confined water, which is trapped between layers of rock deep underground, like water stored in a sealed container. Most of the city relies on this deeper, confined water source.

Even though the city has good underground water potential in both shallow and deep layers, it faces serious problems with dropping water levels and deteriorating water quality. This happens because people are pumping out more water than nature can refill, and because the underground water naturally contains salt from ancient sea deposits. The situation is made worse because Anjar shares its underground water with surrounding agricultural areas that also pump large amounts of water for farming and other uses.

To understand water level behavior, an inventory of approximately 97 wells was conducted. Out of these, 16 wells were selected as observation wells and monitored for changes in water level and water quality during different seasons, such as pre- and post-monsoon periods for the years 2023 and 2024 (Table 5.2). The measured water levels were then used to prepare hydrographs and various maps to analyze the status and trends, including:

- **Static Water Level Maps** to understand the depth range of water levels in different seasons
- **Reduced Water Level Maps** to determine groundwater flow directions during various seasons

In addition to this, seasonal water level data was also utilized to estimate groundwater availability and withdrawal rates within the project area.

### 5.3.1 Static Water levels

Study on groundwater level fluctuation constitutes a vital component in geohydrological investigations. Understanding how water levels go up and down is crucial for managing the city's water resources. Water levels tend to fluctuate under varied conditions due to climate-controlled processes (precipitation and evaporation); geological environment (nature, composition and position of aquifers); terrain characteristics (slope, drainage, landforms, landuse pattern) governing infiltration and runoff. However, the most significant factor affecting water levels is how much water people are using. Changes in groundwater levels can be placed under three categories viz., seasonal, short time vectoral and long-term secular (Todd, 1959). In the present context where in the aim is to evaluate study areas' water resources, emphasis has been given to seasonal changes in groundwater levels.

The depth of water levels in any area is a critical parameter for evaluating the groundwater scenario, particularly from the perspective of its occurrence. In the case of Anjar City, a total of 16 observation wells have been monitored across three seasons: the pre-monsoon seasons of 2023 and 2024, and the post-monsoon season of 2023 (Table 5.2). Based on these water level records, iso-static water level maps were prepared for each of these seasons (Figure 5.3). These maps were generated using specific depth contours at 20-meter intervals, developed with the help of GIS software. The groundwater depth across the city was then categorized into eight distinct classes, as presented in Table 5.3.

Table 5.2 Pre and Post Monsoon Water Level Fluctuation in Anjar City (Year 2023 & 2024)

| Well Code | Location | | Owner Name | Water Level (M) | | | |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | 2023 | | | 2024 |
| | | | | Pre Monsoon | Post Monsoon | Change | Pre Monsoon |
| 8 | 70.00417 | 23.10194 | Jyantibhai Sorathiya | 137.2 | 132.0 | 5.2 | 125.0 |
| 14 | 70.00641 | 23.11324 | Naranbhai Valji Kapadiya | 182.9 | 179.7 | 3.2 | 167.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 22 | 70.01611 | 23.10139 | Naran M Sorathiya | 152.4 | 148.0 | 4.4 | 138.0 |
| 35 | 70.02167 | 23.13152 | Jyantibhai Mistri | 152.4 | 147.2 | 5.2 | 137.2 |
| 38 | 70.01329 | 23.13118 | Dilip Daya Sorathiya | 182.9 | 177.7 | 5.2 | 167.7 |
| 45 | 70.01528 | 23.13991 | Jigubhai Sorathiya | 167.7 | 167.2 | 0.5 | 137.2 |
| 49 | 70.0275 | 23.11861 | Sagarsa Water Suppliers | 182.9 | 177.3 | 5.6 | 167.3 |
| 58 | 70.03121 | 23.1135 | Anjar Nagarpalika | 137.2 | -- | -- | 161.6 |
| 59 | 70.03674 | 23.09812 | Shree Radhe Resort | 61.0 | 65.0 | -4.0 | 65.0 |
| 68 | 70.01509 | 23.11896 | Shamajibhia Ahir | 152.4 | 155.6 | -3.2 | 155.6 |
| 73 | 70.02008 | 23.1045 | Anjar ITI | 24.4 | 28.0 | -3.6 | 28.0 |
| 75 | 70.04417 | 23.11667 | Mohanbhai | 122.0 | 121.3 | 0.7 | 121.3 |
| 77 | 70.00552 | 23.12024 | Lalaji Haraji Ahir | 167.7 | 167.7 | 0.0 | 167.7 |
| 85 | 70.02419 | 23.13447 | Jakhavadi | 152.4 | 156.0 | -3.6 | 156.0 |
| 87 | 70.04143 | 23.1245 | Ahir Agro Industries | 122.0 | -- | -- | 82.3 |
| 93 | 70.01882 | 23.10921 | Kanjibhai Valjibhai | 229.0 | 225.0 | 4.0 | 225.0 |

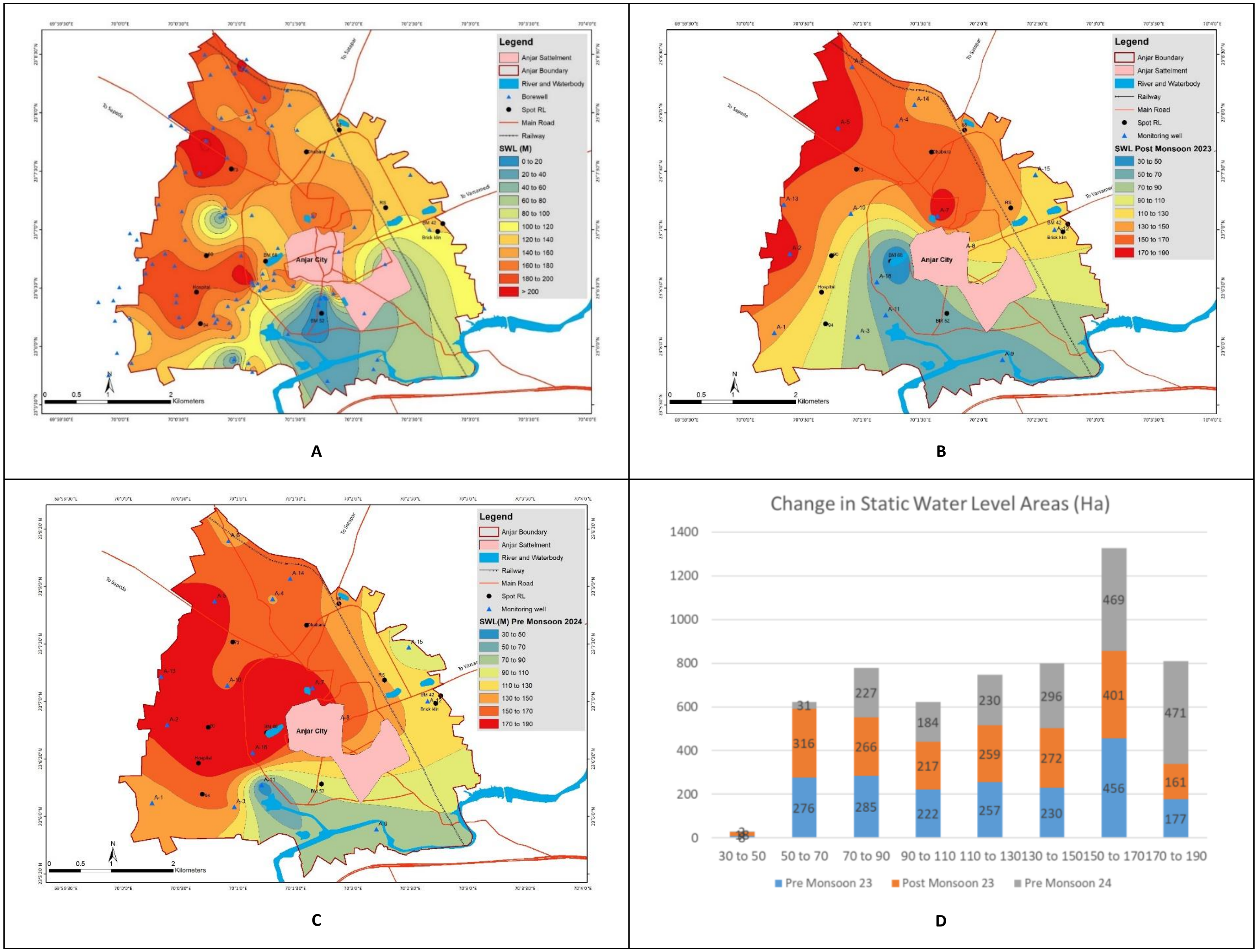



Figure 5.3 Map Showing (A) Pre-Monsoon & (B) Post Monsoon of Year 2023 and (C) Pre-Monsoon of Year 2024 Static Water Levels and (D) Seasonal and Annual Change in Area of Each Depth zone in of Anjar City

During the pre-monsoon season, the depth of static water levels in the city area varies widely, ranging from 20 meters below ground to more than 200 meters. This indicates significant variability in groundwater depth across the city. In the southern and some pockets of the western parts of the city, groundwater occurs at relatively shallow depths. This might be attributed to the proximity of recharge sources such as the Sang River in the south and traditional water bodies in the western part of the city. Shallow groundwater can be more accessible for various uses. Conversely, in the northwest and southwest areas of the city, groundwater levels are very deep, exceeding 200 meters in some places. These areas are primarily characterized by irrigated agriculture, both within the city and in the surrounding rural areas. This heavy agricultural activity might be contributing to the depletion of groundwater in these regions.

Table 5.3 Seasonal Changes in Distribution of Water Level Depth Zones in Anjar City

| Sr. No. | Water Level Depth Category (M) | Area (Ha) | | | | |
|---|---|---|---|---|---|---|
| | | Year 2023 | | Seasonal Change | 2024 | Annual Change |
| | | Pre | Post | | Pre | |
| 1 | 30 to 50 | 8 | 18 | -11 | 3 | 5 |
| 2 | 50 to 70 | 276 | 316 | -40 | 31 | 245 |
| 3 | 70 to 90 | 285 | 266 | 19 | 227 | 58 |
| 4 | 90 to 110 | 222 | 217 | 5 | 184 | 39 |
| 5 | 110 to 130 | 257 | 259 | -2 | 230 | 27 |
| 6 | 130 to 150 | 230 | 272 | -42 | 296 | -66 |
| 7 | 150 to 170 | 456 | 401 | 55 | 469 | -14 |
| 8 | 170 to 190 | 177 | 161 | 16 | 471 | -294 |
| **Total** | | **1911** | **1911** | | **1911** | |

**Key findings from the above analysis:**

**Most water level changes happen in shallow areas:** The biggest changes in water levels occur in areas where water is less than 70 meters deep. This means that shallow water sources are the most affected by seasonal changes and human water use. These shallow areas are like the first layer of an underground water system that responds quickly to rain and water pumping.

**Heavy water use in medium-depth areas:** Areas where water is 50-70 meters deep showed improvement after the monsoon rains in 2023, but then experienced a dramatic decline by 2024. The area in this depth zone dropped from 316 hectares after monsoons to only 31 hectares the following year. This suggests that people are heavily pumping water from these medium-depth sources, using up the water faster than it can be naturally refilled.

**Gradual loss of accessible water:** Areas with water depths of 70-110 meters are gradually shrinking, meaning fewer parts of the city have easily accessible groundwater. This shows that the water table is steadily dropping in these zones.

**Temporary improvement near water bodies:** After monsoons, some areas near Savasar Lake and residential zones in the western part of the city showed rising water levels, creating temporary shallow groundwater zones. However, this improvement is short-lived and doesn't solve the long-term problem.

**Deep water zones are expanding:** The most concerning trend is that areas requiring very deep drilling (more than 130 meters) are constantly growing. This means more and more parts of the city need expensive deep wells to access water. The area requiring drilling deeper than 170-190 meters increased dramatically from 161 hectares to 471 hectares between 2023 and 2024.

**Overall worsening situation:** The general trend shows that water levels are getting deeper throughout the city from 2023 to 2024. This indicates that people are using more groundwater than the monsoon rains can replace. The city is essentially "mining" its underground water reserves faster than nature can refill them.

### 5.3.2 Reduced Water Levels

Another important aspect studied was the "reduced water levels," which shows the height of water compared to average sea level. This is important because Anjar city is located near the coast. In this study, water level data from observation wells were adjusted using ground elevations collected via GPS. These adjusted values, known as Reduced Water Levels (RWL), were then used to create RWL contour maps for the pre- and post-monsoon seasons of 2023 and 2024 (Figure 5.4). These seasonal maps were further analyzed to understand groundwater flow directions and identify recharge and discharge areas during different seasons.

Table 5.4 Seasonal Changes in Distribution of Reduced Water Level Depth Zones in Anjar City

| Sr. No. | Zone WRT AMSL | RWL Zones (M) | Area (Ha) | | |
|---|---|---|---|---|---|
| | | | 2023 | | 2024 |
| | | | Pre-Monsoon | Post-Monsoon | Pre-Monsoon |
| 1 | Above | 50 to 70 | 0 | 3 | 2 |
| 2 | | 30 to 50 | 94 | 153 | 24 |
| 3 | | 10 to 30 | 362 | 319 | 294 |
| 4 | Intermediate | 10 to -10 | 231 | 227 | 268 |
| 5 | Below | -10 to -30 | 232 | 229 | 293 |
| 6 | | -30 to -50 | 285 | 283 | 557 |
| 7 | | -50 to -70 | 562 | 554 | 454 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | | -70 to -90 | 146 | 144 | 19 |
| **Total** | | | **1911** | **1911** | **1911** |

**Key findings from the above analysis:**

**Shifting Flow Patterns**: Underground water flow direction changed from northeast-southwest (2023 pre-monsoon) to west-southeast (2024), indicating major shifts in the aquifer system. Just like the land surface has hills and valleys, the underground water also has high and low areas. During different seasons, these underground "hills" (high water pressure areas) and "valleys" (low water pressure areas) shift around the city. In 2023, there was an underground high area in the northern part, but by 2024, this high area had moved toward the southern part of the city.

**Critical Water Level Decline**: Areas with water above sea level dropped dramatically from 456 hectares (2023) to 320 hectares (2024). This is like losing 136 hectares of good water conditions in just one year.

**Expanding Problem Zones**: Areas below sea level increased from 1,224 to 1,323 hectares, while intermediate zones grew from 231 to 268 hectares, showing overall deterioration. With expanding below-sea-level zones near the coast, saltwater contamination of freshwater sources becomes increasingly likely.

**Over-extraction Evidence**: Cone-shaped depressions around wells indicate water is being pumped faster than natural recharge can replace it. Monsoon recharge cannot keep pace with extraction rates, creating a negative water balance.

This trend suggests that if current water use patterns continue, larger portions of the city will face severe water scarcity. The situation requires immediate intervention through water conservation, better management practices and possibly artificial recharge of groundwater to prevent further deterioration.

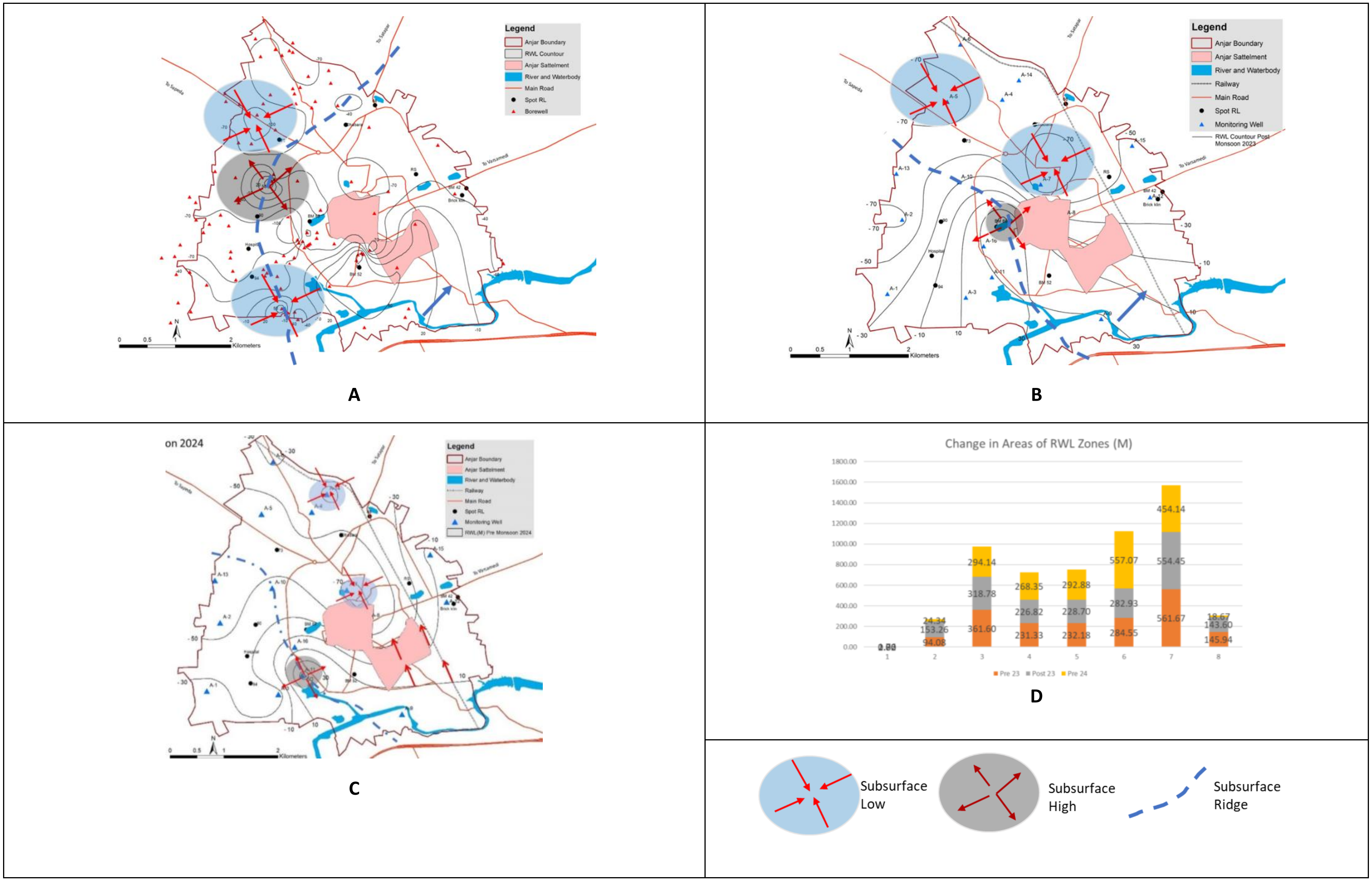



Figure 5.4 Map Showing (A) Pre-Monsoon & (B) Post Monsoon of Year 2023 and (C) Pre-Monsoon of Year 2024 Static Water Levels and (D) Seasonal and Annual Change in Area of Each RWL Zone in of Anjar City

## 5.4 Groundwater Quality

Quality of groundwater is one of the important aspects for water resource development and planning. In Anjar city, the water quality is affected by both natural factors and human activities. Natural factors include the types of rocks and soil the water passes through, which were originally formed under sea conditions and naturally contain salt. Human factors include sewage problems, nearby industries, and too much water being pumped out for farming.

The main objectives of groundwater quality study for Anjar city are to

- Understand the mechanism of chemical interactions of groundwater and sediments
- Quantitative assessment of the various chemical parameters
- To understand changes in groundwater quality due to rainfall
- To assess groundwater quality for its potability as drinking / domestic requirement.

Table 5.5 presents the chemical analysis of domestic water supply tube wells in Anjar city.

Table 5.5 Groundwater Quality of Two Domestic Tube well of Anjar City

| Sr. No. | Characteristics | Value as per IS 10500:2012 | | Analytical Value | |
|---|---|---|---|---|---|
| | | Acceptable Limit (MAX) | Permissible Limit in the absence of Alternate Source (MAX) | Tube Well 22 | Tube Well 23 |
| 1 | Color - Hazen Units | 5 | 15 | Nil | Nil |
| 2 | Odor | Agreeable | Agreeable | Agreeable | Agreeable |
| 3 | Turbidity - NTU | 1 | 5 | 1.48 | 1.52 |
| 4 | Dissolved Solids - mg/l | 500 | 2000 | 2180 | 2780 |
| 5 | Conductivity - µS/cm | ---- | ---- | 3370 | 4310 |
| 6 | pH | 6.5 to 8.5 | No Relaxation | 7.02 | 7.12 |
| 7 | Total Hardness (as $CaCO_3$) mg/l | 200 | 600 | 504 | 596 |
| 8 | Calcium (as $Ca2^+$) mg/l | 75 | 200 | 112 | 122 |
| 9 | Magnesium (as $Mg2^+$) mg/l | 30 | 100 | 54 | 71 |
| 10 | Chloride (as $Cl^-$) mg/l | 250 | 1000 | 796 | 988 |
| 11 | Sulphate (as $SO4^-2$) mg/l | 200 | 400 | 302 | 360 |
| 12 | Nitrate (as $NO3^-$) mg/l | 45 | No Relaxation | 6 | 10 |
| 13 | Fluoride (as $Fl^-$) mg/l | 1 | 1.5 | 0.46 | 0.55 |
| 14 | Alkalinity (as $CaCO_3$) mg/l | 200 | 600 | 424 | 520 |
| Opinion for Potability is given as per Analyzed test parameters only | | | | **UNFIT** | **UNFIT** |

**Source: Anjar Municipality, 2023**

Looking at Table 5.5, both domestic tube wells (22 and 23) in Anjar city are declared "UNFIT" for drinking purposes. The major problems are extremely high Total Dissolved Solids (2180 and 2780 mg/l compared to acceptable limit of 500 mg/l), excessive chloride content (796 and 988 mg/l against 250 mg/l limit), high sulfate levels (302 and 360 mg/l versus 200 mg/l standard), and total hardness exceeding acceptable limits (504 and 596 mg/l against 200 mg/l). While parameters like pH, nitrate, and fluoride are within safe ranges, the water's high mineral content makes it unsuitable for drinking without treatment, indicating serious groundwater quality issues affecting the city's primary water supply sources.

### 5.4.1 Pre-monsoon and Post-monsoon water quality analysis

Water samples were collected from 16 different locations during both pre-monsoon season and post monsoon season in year 2023. Table 5.6 shows groundwater sample results from the pre- and post-monsoon seasons of 2023. Details of various parameters have been discussed below.

### 5.4.2 pH Levels (Acidity/Alkalinity)

pH tells us if water is acidic or alkaline. Most of Anjar's groundwater has pH values above 7, which means it's slightly alkaline. This happens because the water contains carbonates and bicarbonates from the rocks. The pH in Anjar ranges from 6.99 to 7.65 before monsoon and 7.23 to 7.82 after monsoon, which are generally acceptable levels.

### 5.4.3 Total Dissolved Solids (TDS)

The specific conductance of water provides measure of the content of dissolved matter, which is popularly known as Total Dissolved Solids (TDS). It is an important basis for rapid assessment of water quality. By and large groundwater in the Anjar city suffers from higher TDS content. I The water contains much more dissolved solids than it should for drinking. Before monsoon, TDS ranges from 586 to 2,680 mg/l, and after monsoon it gets even worse, ranging from 742 to 4,150 mg/l. For comparison, good drinking water should have less than 500 mg/l of TDS.n the Anjar city TDS varies between 586 mg/l and 2680 mg/l during pre-monsoon season and 742 mg/l to 4150 mg/l during post monsoon.

To develop further understanding on trends and spatial distribution of concentration of TDS iso TDS maps for pre and post monsoon season of year 2023 have been prepared (Fig. 5.5). TDS categories have been decided based on permissible limits suggested as drinking water quality index by Bureau of Indian Standards 10500 revised in 2012. These categories are (01) acceptable limits i.e. less than 500 mg/lit; (02) permissible limits i.e. up to 2000 mg/lit; (03) brackish up to 3000 mg/lit and (04) saline water more than 3000 mg/lit. Category wise change in area from pre monsoon to post monsoon season is given fig. 5.5.

| Sr. No. | Category | TDS mg/Lit | Year 2023 Area (Ha.) | |
|---|---|---|---|---|
| | | | Pre | Post |
| 1 | Acceptable | < 500 | 00 | 219 |
| 2 | Permissible | 500-2000 | 1535 | 967 |
| 3 | Brackish | 2000-3000 | 332 | 399 |
| 4 | Saline | > 3000 | 44 | 326 |
| Total | | | 1911 | 1911 |

Only the northern part of the city has water within acceptable limits, and even that area shrinks after monsoon. The southern part has the worst water quality, with very high salt content.

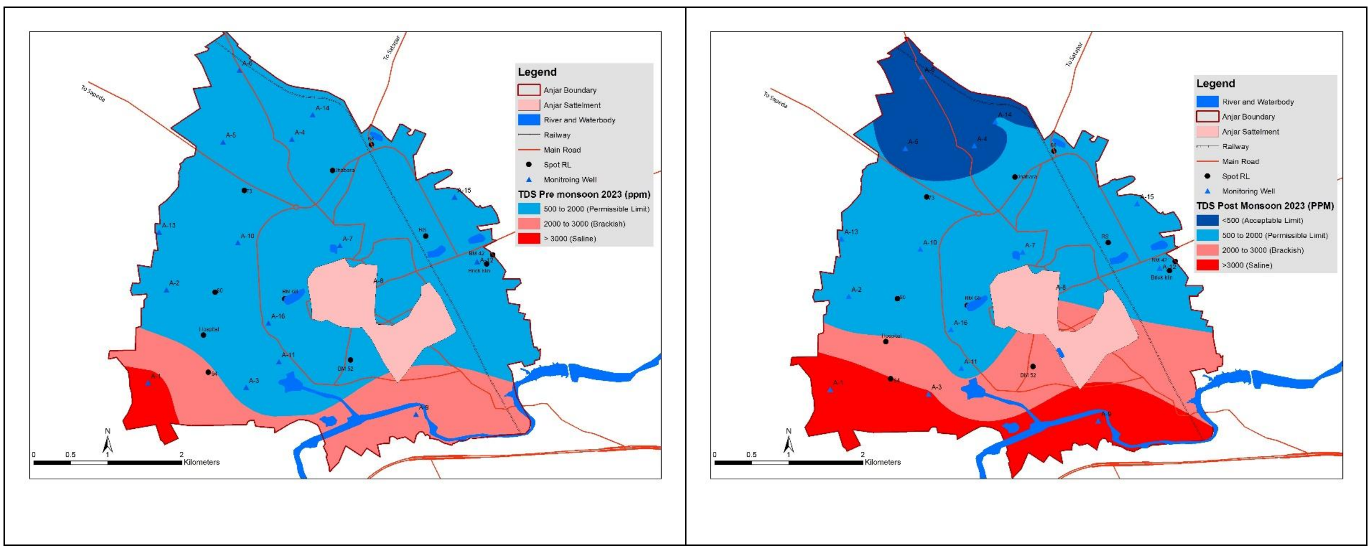



Figure 5.5 Map showing Pre & Post Monsoon TDS Concentrations in Anjar City (Year 2023)

Table 5.6 Groundwater Quality of Two Domestic Tubewells of Anjar City – Pre and Post Monsoon Season Year 2023

| Well Code | Owner name | Pre /post monsoon | Quality parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | pH | TDS | Alkalinity | Hardness | Ca | Mg | Cl | SO4 | NO2 | F |
| A-1 | Jayantibhai Sorathiya | Pre | 7.36 | 3370 | 225 | 1080 | 264 | 102.06 | 1418 | 284.8 | 3.5 | 0.24 |
| | | Post | 7.46 | 4150 | 277.1 | 1330.0 | 325.1 | 125.7 | 1746.2 | 350.7 | 4.3 | 0.35 |
| A-2 | Naranbhai Valibhai Kapadiya | Pre | 7.52 | 852 | 80 | 360 | 96 | 29.16 | 265.88 | 89.6 | 15.8 | 0.4 |
| | | Post | 7.4 | 794 | 74.6 | 335.5 | 467.6 | 142.0 | 1295.1 | 436.4 | 77.0 | 0.4 |
| A-3 | Naranbhai Maghibhai Kapadiya | Pre | 7.33 | 1729 | 220 | 520 | 132 | 46.17 | 584.93 | 226.4 | 8.8 | 0.1 |
| | | Post | 7.8 | 3100 | 394.4 | 932.3 | 316.8 | 110.8 | 1404.0 | 543.4 | 21.1 | 0.2 |
| A-4 | Jayantibhai Mistri | Pre | 7.17 | 654 | 135 | 220 | 64 | 14.58 | 212.7 | 60.5 | 12.5 | 0.8 |
| | | Post | 7.25 | 836 | 172.6 | 281.2 | 406.1 | 92.5 | 1349.7 | 383.9 | 79.3 | 0.72 |
| A-5 | Dilipbhai Dayabhai Sorathiya | Pre | 7.56 | 586 | 160 | 275 | 60 | 18.23 | 159.53 | 74.4 | 18.4 | 0.6 |
| | | Post | 7.8 | 742 | 202.6 | 348.2 | 424.9 | 129.1 | 1129.8 | 526.9 | 130.3 | 0.5 |
| A-6 | Jigneshbhai Sorathiya | Pre | 7.58 | 701 | 150 | 315 | 92 | 20.66 | 194.98 | 81.4 | 16.6 | 0.45 |
| | | Post | 7.75 | 899 | 192.4 | 404.0 | 544.7 | 122.3 | 1154.3 | 481.9 | 98.3 | 0.4 |
| A-7 | Sagarsa Water Suppliers | Pre | 6.99 | 1509 | 155 | 410 | 100 | 38.88 | 602.65 | 165.4 | 7.6 | 0.22 |
| | | Post | 7.2 | 1700 | 174.6 | 461.9 | 275.0 | 106.9 | 1657.4 | 454.9 | 20.9 | 0.25 |
| A-8 | Anjar Nagarpalika Borewell | Pre | 7.66 | 1162 | 160 | 405 | 104 | 35.235 | 407.7 | 124.8 | 18.8 | 0.4 |

| Well Code | Owner name | Pre /post monsoon | Quality parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | pH | TDS | Alkalinity | Hardness | Ca | Mg | Cl | SO4 | NO2 | F |
| | | Post | 7.82 | 1970 | 271.3 | 686.6 | 371.4 | 125.8 | 1456.1 | 445.7 | 67.1 | 0.35 |
| A-9 | Shree Radhe Resort Borewell | Pre | 7.66 | 2680 | 385 | 370 | 76 | 43.74 | 1134.4 | 175.5 | 6.8 | 0.35 |
| | | Post | 7.81 | 3680 | 528.7 | 508.1 | 117.7 | 67.7 | 1756.6 | 271.8 | 10.5 | 0.35 |
| A-10 | Shamjibhai Ahir | Pre | 7.42 | 1055 | 230 | 435 | 116 | 35.24 | 319.05 | 134.9 | 5.7 | 0.5 |
| | | Post | 7.6 | 1460 | 318.3 | 602.0 | 456.3 | 138.6 | 1255.0 | 530.6 | 22.4 | 0.45 |
| A-11 | Behind Nayara Petrolpump | Pre | 7.36 | 1219 | 220 | 550 | 104 | 70.47 | 354.5 | 174.6 | 25.5 | 0.3 |
| | | Post | 7.42 | 1660 | 299.6 | 749.0 | 354.1 | 239.9 | 1206.9 | 594.4 | 86.8 | 0.4 |
| A-12 | Mohanbhai | Pre | 7.23 | 934 | 195 | 310 | 80 | 26.73 | 301.33 | 91.5 | 24.4 | 0.45 |
| | | Post | 7.23 | 1180 | 246.4 | 391.6 | 355.5 | 118.8 | 1338.9 | 406.6 | 108.4 | 0.45 |
| A-13 | Lalji Hirji Ahir | Pre | 7.21 | 910 | 225 | 390 | 98 | 35.24 | 265.88 | 96.6 | 18.4 | 0.25 |
| | | Post | 7.56 | 2070 | 511.8 | 887.1 | 446.9 | 160.7 | 1212.5 | 440.5 | 83.9 | 0.2 |
| A-14 | Jakhavadi | Pre | 7.43 | 1274 | 290 | 510 | 120 | 51.03 | 248.15 | 158.4 | 12.5 | 0.2 |
| | | Post | 7.59 | 1010 | 229.9 | 404.3 | 390.9 | 166.2 | 808.3 | 516.0 | 40.7 | 0.35 |
| A-15 | Ahir Agro Industries | Pre | 7.51 | 712 | 140 | 320 | 78 | 30.38 | 194.98 | 88.6 | 14.4 | 0.65 |
| | | Post | 7.68 | 1040 | 204.5 | 467.4 | 454.6 | 177.1 | 1136.5 | 516.4 | 83.9 | 0.55 |
| A-16 | Kanjibhai Valjibhai | Pre | 7.43 | 1369 | 290 | 480 | 92 | 60.75 | 460.85 | 144.8 | 10.5 | 0.4 |

| Well Code | Owner name | Pre /post monsoon | Quality parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | pH | TDS | Alkalinity | Hardness | Ca | Mg | Cl | SO4 | NO2 | F |
| | | Post | 7.54 | 1750 | 370.7 | 613.6 | 278.9 | 184.2 | 1397.0 | 438.9 | 31.8 | 0.35 |

| | | | | | |
|---|---|---|---|---|---|
| (green) | Within Acceptable Limits | (yellow) | Within Permissible Limits | (red) | Above Permissible Limits |

### 5.4.4 Ionic Content

Cation and Anion in combination with each other gives rise to various chemicals and minerals. To evaluate chemical properties of groundwater in study area author has carried out analysis of important cations viz., Calcium and Magnesium; Anions viz., Sulfate, Chloride, Nitrate and Fluoride.

***Calcium (Ca+2):*** Calcium is naturally found in almost all water because it easily dissolves from rocks and soil. In Anjar, calcium levels range from 60 mg/l in the northern area during dry season to as high as 545 mg/l after monsoon rains. This increase after monsoon shows that rainwater is picking up more calcium as it moves through limestone and other calcium-rich rocks underground.

***Magnesium ($Mg^{+2}$)*****:** Magnesium works together with calcium to make water "hard," which means it doesn't lather well with soap and can leave deposits in pipes and appliances. Magnesium levels in Anjar range from 15-102 mg/l before monsoon and 68-240 mg/l after monsoon. Like calcium, magnesium comes from limestone rocks and increases significantly after rains.

***Sulfate ($SO_4^{-2}$):*** Sulfur levels are naturally high in dry regions like Anjar due to dust in the air and certain types of soil. The sulfate concentration ranges from 61-285 mg/l before monsoon and jumps to 272-594 mg/l after monsoon. High sulfate levels can give water a bitter taste and act as a natural laxative if consumed in large quantities.

***Chloride ($Cl^{--}$):*** **Chloride** is the most problematic mineral in Anjar's water, making it taste salty. This high chloride content (160-1418 mg/l before monsoon, 808-1758 mg/l after monsoon) comes from the area's geological history - the rocks were formed under ancient seas and still contain trapped seawater. Additionally, since Anjar is close to the coast, seawater influence continues to affect the groundwater quality.

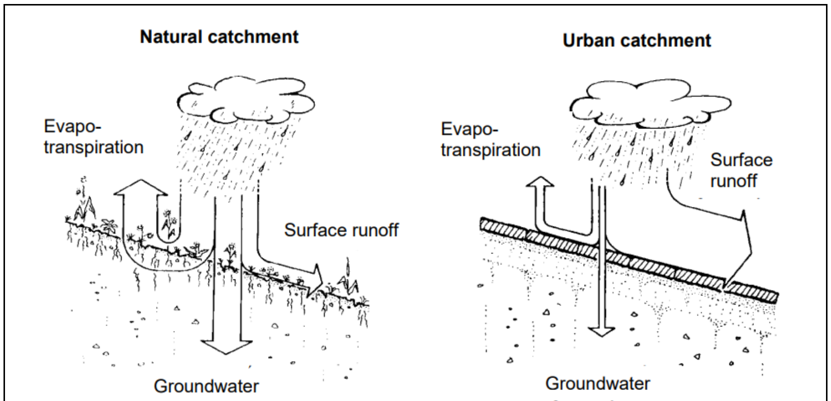
Out of analyzed parameters TDS, hardness, alkalinity chloride and sulphates show variation in concentrations as per permissible limits during pre and post monsoon changes. Fluoride, Nitrate and cations do not show significant change in Groundwater quality.

The main reason for these high mineral contents is Anjar's geological setting - the area's rocks were formed millions of years ago when it was under the sea, so they naturally contain high amounts of salt and other marine minerals. The proximity to the current coastline means seawater continues to mix with groundwater. Surprisingly, all mineral concentrations increase after monsoon rains instead of getting diluted, suggesting that rainwater is dissolving more minerals from rocks as it seeps underground, or that poor drainage is concentrating these minerals. The dominance of chloride over other minerals clearly indicates the marine influence on Anjar's groundwater, making it the primary cause of the city's water quality problems.

# 6 Water Balance analysis of Anjar city

When cities develop and grow, they significantly change how water naturally moves through the environment. In natural areas, when it rains, most water soaks into the ground, some evaporates back into the air, and only a small portion flows away as surface runoff.

**Figure 6.1** illustrates the conceptual differences in the hydrological cycle between a natural catchment and an urban catchment. It clearly shows that, during rainfall, the runoff or stormwater volume is significantly higher than the infiltration or groundwater recharge volume. Therefore, a key objective in estimating the water balance in urban areas is to reduce surface runoff and increase the transfer of rainwater into the groundwater. The urban water cycle is a complex system influenced by many factors. To effectively understand this system, it is necessary to examine each component of the urban water cycle individually—such as runoff, infiltration, groundwater recharge, rainfall, and rainwater harvesting. Thus, a comprehensive approach that considers the entire system holistically is essential.




Source: Sokec, 2018

Figure 6.1 Conceptual Representation of Differences in Hydrological Cycle in Natural and Urban Catchment

To understand Anjar's water situation better, water balance was calculated comparing how much water the city needs versus how much water is available locally. They divided the city into three main areas: residential neighbourhoods, public spaces like parks and government buildings, and industrial zones. Adopted methodology for Anjar city water balance estimation is explained in Fig. 6.2.

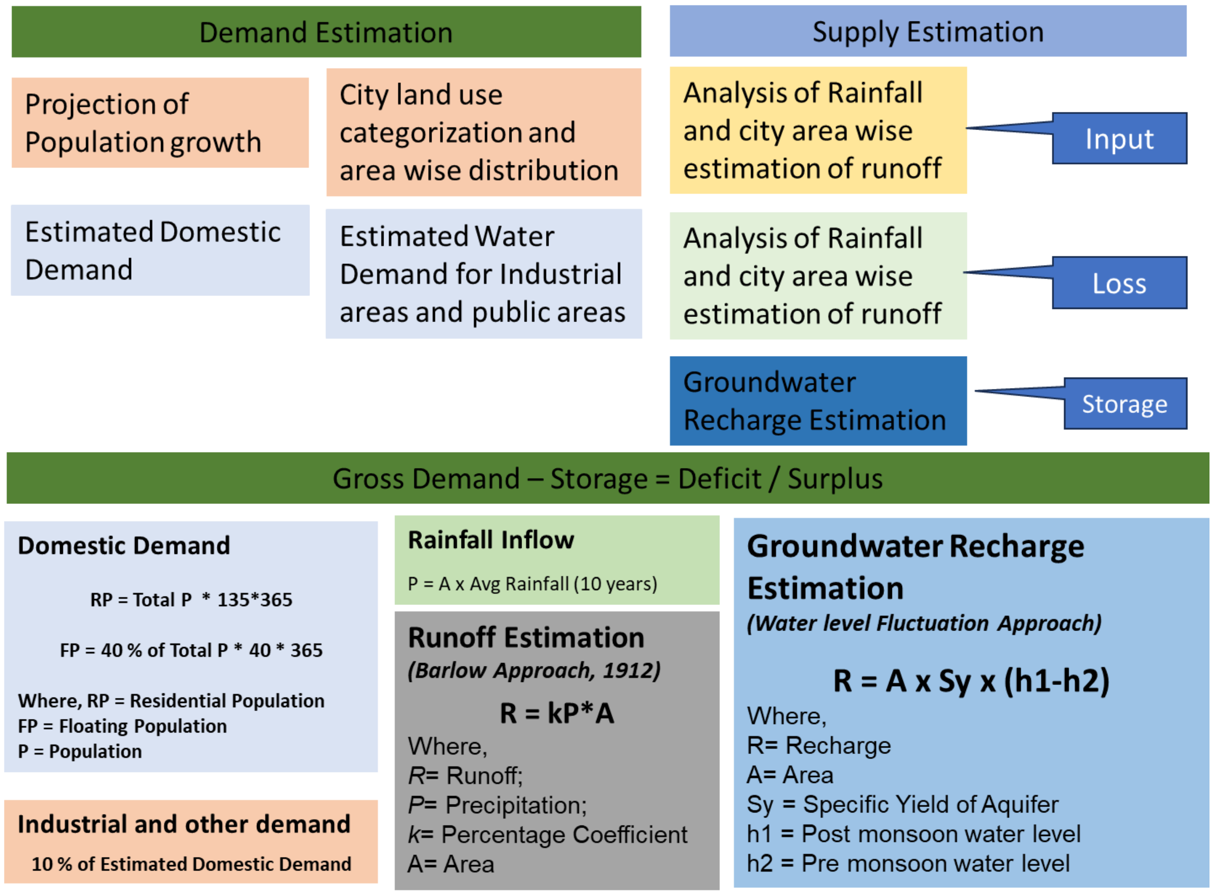



Figure 6.2 Methodology Adopted for Water Balance Estimation of Anjar city

Following steps have followed to estimate water demand:

- **Projected Population**: Population growth projections were analyzed using historical data and trends provided by the municipality.
- **Land Use Analysis**: The city's land use was assessed, focusing on green cover, residential areas, and institutional/industrial zones. This helped identify the areas requiring water for various purposes.
- **Water Demand Calculation**: The per unit water needs for different sectors were sourced from recognized authorities. These standards are essential for ensuring that the estimates are grounded in reliable data.
- **Total Water Demand Estimation**: By multiplying the projected population and the per unit water needs by land use type, the total water demand for Anjar was calculated. This comprehensive approach allows for a more accurate representation of the city's water requirements.

As far as Anjar city is concerned, its current population, according to the latest census data, is 1,19,000, up from 87,183 in 2011. Based on this, a decennial growth rate of 29% has been estimated. Accordingly, the projected population for the year 2051 is 2,43,726 persons (as shown in Table 6.1).

Table 6.1 Project Population for Anjar City up to Year 2051

| Year | Project Population @ 29 % /Decade |
|---|---|
| 2011 | 87,183 |
| 2021 | 1,13,000 |
| 2031 | 1,46,000 |
| 2041 | 1,88,637 |
| 2051 | 2,43,726 |

Source: After https://www.census2011.co.in/data/town/802444-anjar-gujarat.html

**Water balance analysis (Inferences from table 6.2):**

- **Rainfall as a Local Input:** The available volume of rainfall was calculated by multiplying the average annual rainfall with the total area. In the case of Anjar, the average annual rainfall is taken as 802 mm (Table 6.2).
- **Runoff Estimation:** The runoff, considered an outflow parameter, was estimated using Barlow’s approach (1921), which calculates the volume of rainfall that flows out of the city. For Anjar, this was estimated to be 35.47 MCM, assuming that 60% of the total rainwater flows out due to the city’s land use and topography (Table 6.5).
- After accounting for this runoff loss, only 14.19 MCM of rainwater remains within the city boundaries and is potentially available for local use.
- **Local Resource Supply:** The supply from local resources was computed based on the availability from surface water bodies and groundwater storage (Table 6.2).
    - **Surface water storage:** Although there are surface water bodies within the city, their water is not suitable for direct use due to poor water quality. Therefore, they are not considered a direct source for city water supply. However, some of these water bodies contribute to groundwater recharge.
    - **Ground water recharge estimation:** Changes in pre- and post-monsoon water levels from monitoring borewells were used to estimate recharge using the water level fluctuation method. Based on this approach, the groundwater recharge for Anjar after the post-monsoon season of 2023 was estimated at 13.62 MCM.
- **Deficit Analysis**: When comparing the water balance against the city's total estimated demand of 14.78 MCM, the remaining rainwater of 14.19 MCM shows a deficit of 0.59 MCM. This narrow deficit indicates that the city is operating very close to its local water resource limits.

The analysis clearly demonstrates that Anjar's primary water management challenge is not the lack of rainfall but rather the poor capture and retention of the abundant rainwater it receives. The loss of over 21 MCM annually through runoff represents a massive untapped water resource that, if properly managed through recharge structures and surface water retention systems, could easily meet the city's current and future water needs while also helping to restore groundwater levels.

Table 6.2 Water Balance as per Rainfall and Runoff and Groundwater Recharge Estimation for Anjar City

| **Water Balance Against Rainfall vs. Runoff** | | **GW Recharge Estimation** | |
|---|---|---|---|
| **Details** | **Qty** | | |
| Average Annual Rainfall (mm) | 802 | Water level Pre monsoon 2023 (M) | 147.7 |
| Catchment area falls outside the city (a) | 435 | | |
| Catchment area within city (b) | 3988 | Water level Post monsoon- 2023 (M) | 146.3 |
| Catchment area (ha) (a+b) | 4423 | | |
| Total Rainfall MCM | 35.47 | Difference (M) | 1.4 |
| Catchment Type | D | Specific Yield % | 22 |
| Catchment Factor | 0.60 | Total Area (SQKM) | 44.23 |
| **Ruoff (MCM)** | **21.28** | **Total GW recharge MCM** | **13.62** |
| Water Remains in City (MCM) | 14.19 | | |
| Total Demand of City (MCM) | 14.78 | | |
| **Water Balance against Remaining Rainwater (MCM)** | **-0.59** | | |

**Estimated water balance for Anjar City (Inferences from Table 6.3)**

The water balance analysis for Anjar City reveals several important insights about the city's water situation by 2051. On the demand side, the projected population of 243,726 people will require approximately 12.01 million cubic meters (MCM) of water annually for domestic use, calculated at 135 liters per person per day. When adding floating population needs (1.42 MCM) and industrial requirements (1.34 MCM, estimated at 10% of domestic demand), the total gross water demand reaches 14.78 MCM per year.

The supply analysis shows that Anjar has two main local water sources. From rainfall, after accounting for runoff losses, about 14.19 MCM of rainwater remains available within the city boundaries. Additionally, groundwater recharge contributes 13.62 MCM annually, bringing the total available supply to 27.81 MCM. This creates a significant water surplus of 13.04 MCM, meaning the city theoretically has nearly double the water it needs.

Table 6.3 Estimated Water Balance for Anjar City

| Details | | | Water Balance Estimation |
|---|---|---|---|
| **Demand Estimation** | Projected Domestic water for Human (MCM) | Population | 243726 |
| | | Unit Need lit/day | 135 |
| | | Total (MCM) | 12.01 |
| | Floating Population need | | 1.42 |
| | Industrial and other need (10 % of total Domestic need) | | 1.34 |
| | **Gross Demand** | | **14.78** |
| **Supply Estimation** | Rainwater Remains in City | | 14.19 |
| | Existing Groundwater (MCM) | | 13.62 |
| | **Total (MCM)** | | **27.81** |
| **Water Balance** | | | **13.04** |

However, this apparent abundance comes with important caveats. The surplus heavily depends on capturing and utilizing the rainwater that currently remains in the city after runoff. This requires proper infrastructure for rainwater harvesting and groundwater recharge, which may not currently exist at the scale needed. The groundwater recharge figure of 13.62 MCM also assumes sustainable extraction rates that don't exceed natural replenishment.

The analysis reveals that Anjar's water challenge is not about absolute scarcity but about water management and infrastructure. The city receives adequate rainfall, but without proper capture and storage systems, much of this water potential remains unrealized.

# 7 Water Management Strategies

For effective management of water resources in Anjar city, an integrated approach that focuses on four strategies viz., (01) Groundwater Recharge; (02) Surface Water Resource Management; (03) Recycle and Reuse and (04) Manage deficit by external resources should be considered. Since this study focuses on natural water resources, the emphasis is primarily on groundwater recharge strategies and surface water management.

## 7.1 Groundwater recharge strategies

### 7.1.1 Groundwater Potential Zones

Understanding where groundwater exists and how it moves depends on the natural setup of an area. The geology (types of rocks and soil), the presence of cracks and fractures in rocks (called lineaments), the shape of the land, and how water drains from the surface all play important roles in determining whether an area will have good groundwater sources or not. These factors control how much rainwater runs off the surface versus how much seeps into the ground to become groundwater.

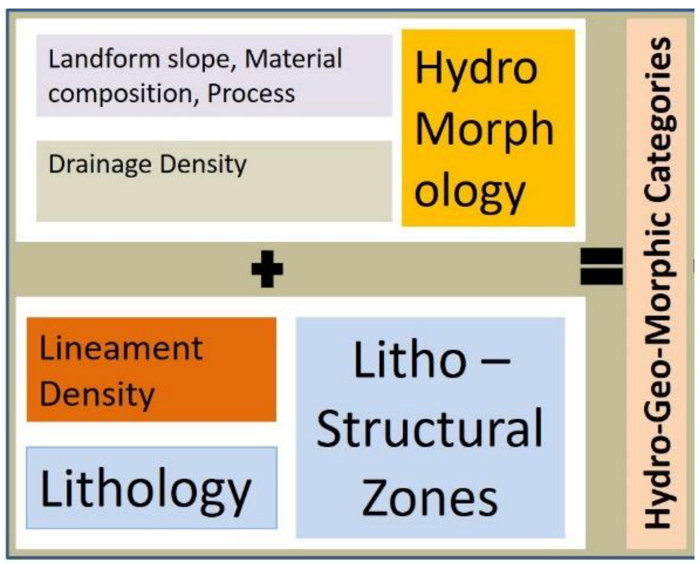



Figure 7.1 Flow Chart Depicting Methodology for Geohydrological Potential Categorization

Keeping this in mind, a groundwater-based categorization of Anjar City has been carried out by considering geology, lineament density, landforms, and drainage density. A three-fold hydro-geo-morphological categorization of the city was developed to define water management strategies using the following methods:

- A rating approach was followed to categorize each thematic layer (Table 7.1)
- Lithology (Loose, semi consolidated and consolidated rocks) and lineaments (Density based on minimum to maximum numbers) were synthesized to prepare hydro-litho-structural category (Fig. 7.2 - A)

- Landform and drainage density were synthesized to prepare Hydro-morphology category (Fig. 7.3 - B)
- The above two categories were synthesized to produce Hydro-geo-morphology categorization or groundwater potential (recharge or runoff) map from (Fig. 7.3) for categorization of groundwater management strategy.

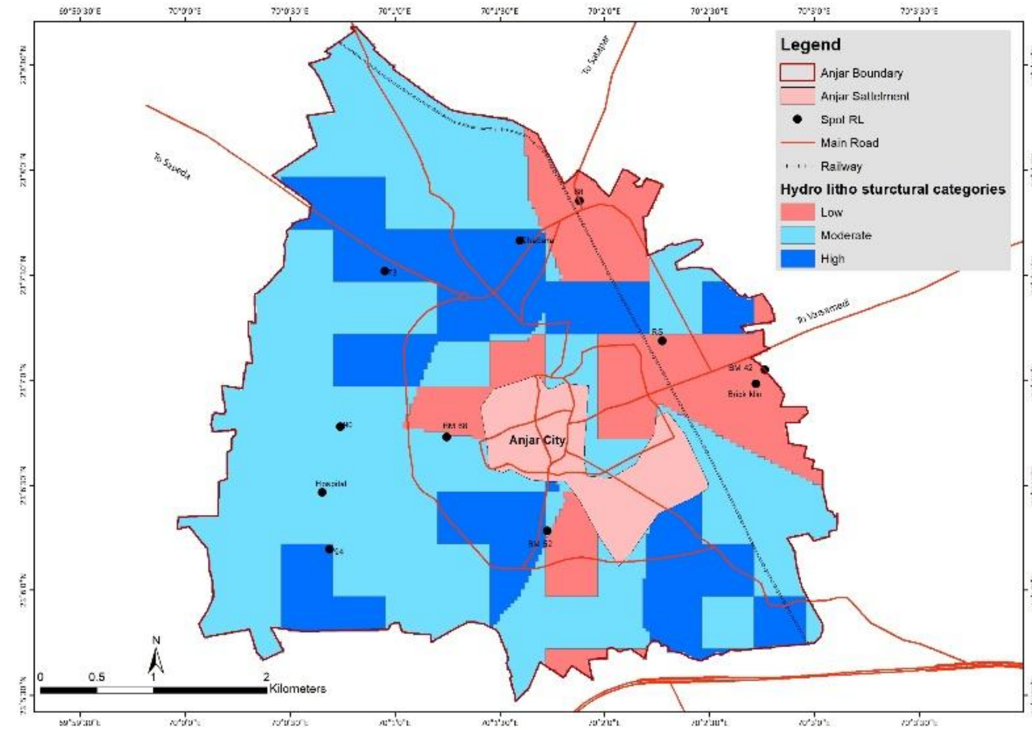
Table 7.1 Rating approach adopted for Categorization of Groundwater Management Strategies

| Category | Rate | Lithological Categorization | Landform Categorization | No of Lineament/grid | Drainage Density |
|---|---|---|---|---|---|
| Low | 1 | Massive Basalt & Amygdaloidal basalt Weathered fractured Basalt | Hills and Plateau | <0 | 1 |
| Moderate | 2 | Sandstone & heavily weathered Amygdaloidal basalt. | Buried Pediment zone | 1-2 | 2-3 |
| High | 3 | Loose unconsolidated sediments | Undulating Alluvium Plains | >2 | > 3 |

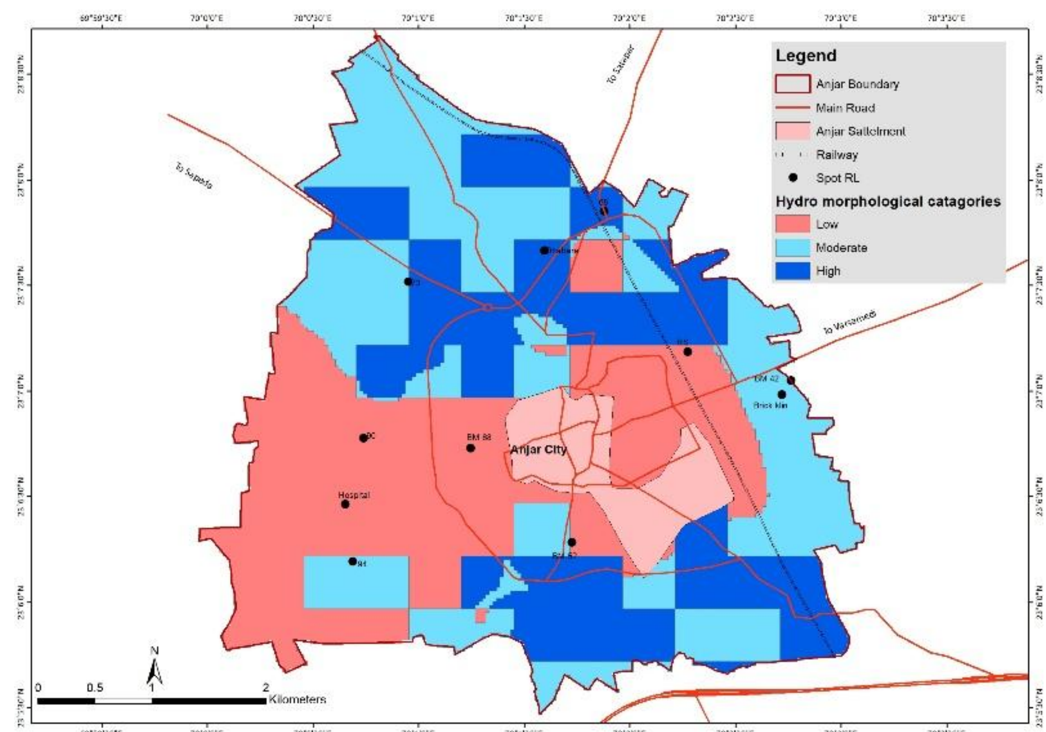
The geology was categorized into three types: loose unconsolidated sediments (like sand and gravel) received the highest rating of 3 because water can easily pass through them; sandstone and heavily weathered rocks got a moderate rating of 2; while massive basalt and hard rocks received the lowest rating of 1 because they don't allow much water to pass through. Similarly, flat alluvial plains were rated highest for landforms, buried pediment zones received moderate ratings, and hills and plateaus got the lowest ratings.

**Key Inferences from Hydro-Litho-Structural and Hydro-Morphological Categorization (Fig 7.2)**

The spatial analysis reveals that Anjar City has distinct zones with varying groundwater potential based on geological and morphological characteristics. The hydro-litho-structural map (combining rock types with lineament density) shows that areas with loose unconsolidated sediments and higher lineament density create the most favorable conditions for groundwater occurrence. Meanwhile, the hydro-morphological map (combining landforms with drainage patterns) indicates that flat alluvial plains with better drainage networks provide superior conditions for water infiltration and groundwater recharge compared to hilly or plateau areas.




**A**




**B**

Figure 7.2 Hydro-Litho-Structural (A) and Hydro-Morphological (B) Categorization of Anjar City

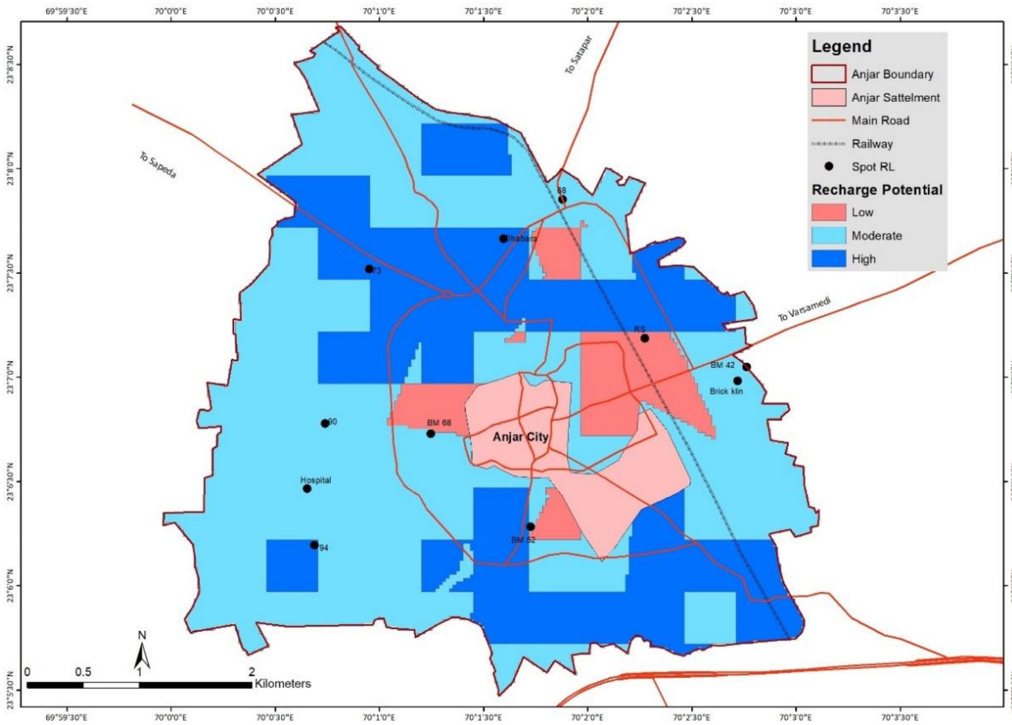



Figure 7.3 Geohydrological Potential Categorization for Management Strategies

**Key Inferences from Geohydrological Potential Categorization (Fig 7.3)**

The final integrated map demonstrates that Anjar City can be divided into three distinct groundwater management zones.

The **good groundwater potential zones** are primarily concentrated in the central and eastern portions of Anjar City. These areas benefit from favorable geological conditions with loose unconsolidated sediments and moderate to high lineament density, combined with suitable landforms like undulating alluvial plains that facilitate better water infiltration. The eastern sections particularly show consistent good potential due to the presence of permeable sandy soils mixed with pebbles and gravels that allow easy groundwater recharge.

The **moderate groundwater potential zones** are distributed across the northern and southwestern sections of the city. These areas typically have weathered basalt formations or sandstone geology with moderate lineament density. The landforms in these zones include buried pediment areas that provide reasonable but not optimal conditions for groundwater occurrence and recharge. This represents transitional areas that need targeted interventions like existing well recharge and campus-level groundwater recharge programs.

The **low potential zones** are predominantly located in the western and some southern parts of Anjar City. These areas are characterized by massive basalt and compact rock formations that create barriers to groundwater movement and recharge. The presence of hills, plateau-like features, and low drainage density in these zones further restricts groundwater potential, making them less suitable for conventional groundwater development. This area requires alternative approaches such as surface water harvesting and creating buffer reserves for periodic groundwater recharge in downstream areas.

This spatial categorization provides a scientific foundation for implementing zone-specific water management strategies rather than applying uniform approaches across the entire city, ensuring more efficient and sustainable groundwater resource management for Anjar City.

### 7.1.2 Groundwater Management Strategies

It is essential to manage and conserve groundwater resources carefully, especially in areas where groundwater levels are deep and agricultural practices heavily rely on it. Sustainable water management practices, such as rainwater harvesting, recharging aquifers, and promoting efficient irrigation techniques, can help mitigate the depletion of groundwater resources and ensure a more reliable water supply in the future. Additionally, monitoring and regulating groundwater use is crucial to maintain a balance between agricultural needs and groundwater sustainability. Considering this, the groundwater management strategies for each potential zone are proposed in table 7.2 while Anjar city specific issues for each category are described in table 7.3.

Table 7.2 Groundwater Management Strategies in Different Groundwater Category for Anjar City

| GW Category | Strategies |
|---|---|
| Good Potential | Develop surface recharge structures and drinking water sources. Construct percolation wells and recharge beds in common plots or public places. |
| Moderate Potential | Recharge existing wells/borewells; implement campus-level groundwater recharge. Treat catchment areas that contribute to waterlogging in low-lying zones. Use injection methods for groundwater recharge. Utilize rooftop water for recharge. |
| Low Potential | Surface Water harvesting and developing buffer reserves to periodically recharge groundwater in downstream areas. Utilize public spaces for water conservation. |

Table 7.3 Groundwater Potential Zone wise Geohydrological Characteristics and Major Issues in Anjar City

| GW Potential Zone | Geohydrological Characteristics | | | | | Major Issue |
|---|---|---|---|---|---|---|
| | Rock type | Depth M | Thickness (M) | Characteristic | Type | |
| Good | Loose unconsolidated Sandy soil mixed with Pebble & gravels | 0-6 | 6 | Very Good Shallow highly porous strata | Aquitard | High percolation limited storage saturates strata. Sewage leakage creates water quality issues |
| | Red to yellow clay Pockets | 6-18 | 12 | No aquifer low and impermeable | Aquiclude | No Percolation, resist recharge and hence water logging at surface |
| | Medium Sand | 18-24 | 66 | Very Good Shallow Aquifer Loose formation | Shallow Semi confined | Groundwater Quality and contamination |
| | Secondary Laterite | 24-30 | 6 | Poor aquifer | Shallow | |
| | Clay and Laterites | 30-72 | 42 | No Aquifer | Aquiclude | No Percolation |
| | Fine sand with Pebbles | 72-96 | 24 | Very Good Aquifer – Kanakavati Sandstone | Deep-Confined | Getting low natural recharge due to overlined impermeable strata and extraction of groundwater deteriorates quality |
| | Clay | 96-120 | 24 | No Aquifer | Aquiclude | No Percolation |
| | Weathered Basalt | 120-136 | 16 | Moderate potential aquifer | Confined | Limited storage |
| | Compact Basalt | 136-196 | 60 | No Potential | Aquifuge | No percolation |
| | Sandstone | 192-315 | > 119 | Very Good Aquifer | Confined | |
| Moderate-1 | Fine clay | 0-42 | 42 | No Aquifer, Saline strata | | Impermeable strata don't allow natural recharge |
| | Kankavati Sandstone | 42-75 | 33 | Very Good aquifer Kankavati Sandstone | Shallow and confined | Exploitation results into quality deterioration and low yield |
| Moderate -2 | Weathered Basalt | 0-15 | 15 | Moderate potential aquifer | Un Confined | Varying thickness at places limit Groundwater storage. Sewage leakage and surface waterbody's water quality influence GW Quality |

| GW Potential Zone | Geohydrological Characteristics | | | | | Major Issue |
|---|---|---|---|---|---|---|
| | Rock type | Depth M | Thickness (M) | Characteristic | Type | |
| | Compact Basalt | 15-68 | 53 | No Potential | Aquifuge | Impermeability doesn't allow recharge |
| Low-1 | Tertiary clay | 0-42 | 42 | No Aquifer | | Impermeability doesn't allow recharge |
| Low-2 | Clay and Laterites | 0-72 | 72 | Poor aquifer | Shallow | Groundwater Quality |
| Low-3 | Compact Basalt | 0-65 | 65 | No Potential | Aquifuge | No percolation |

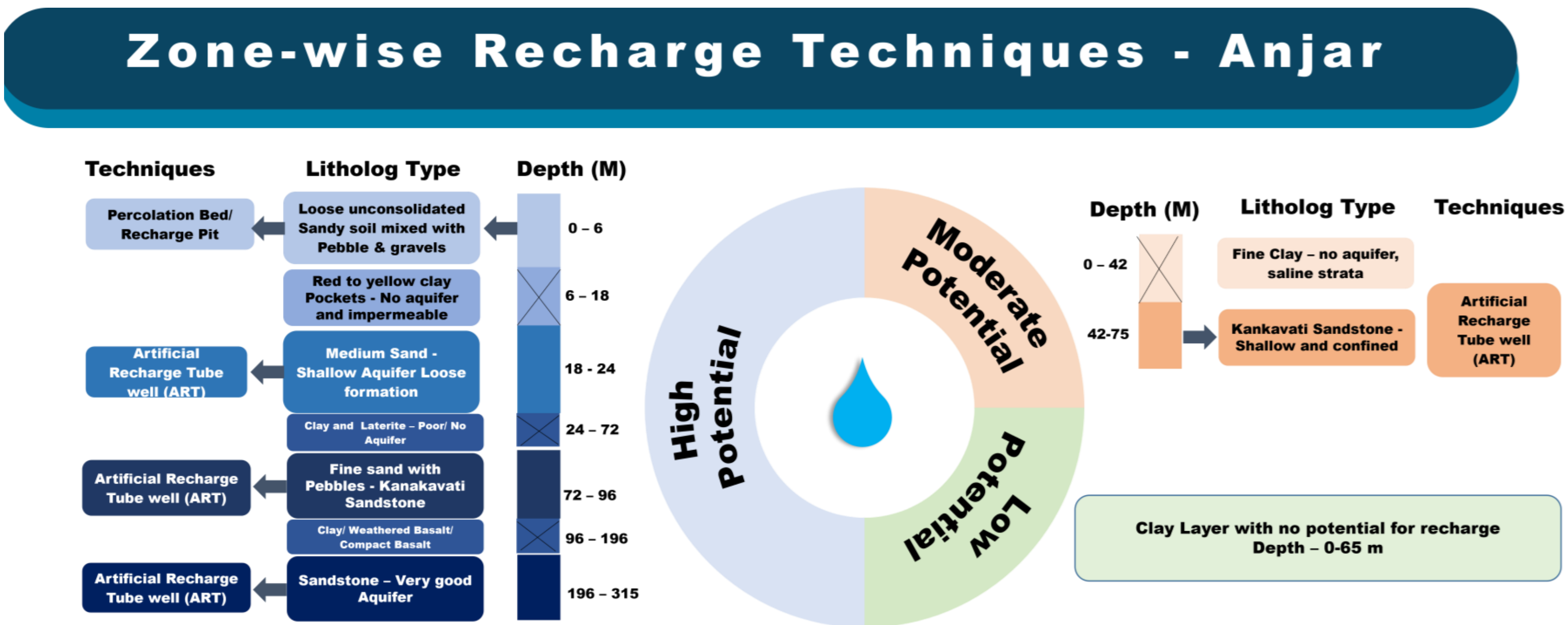
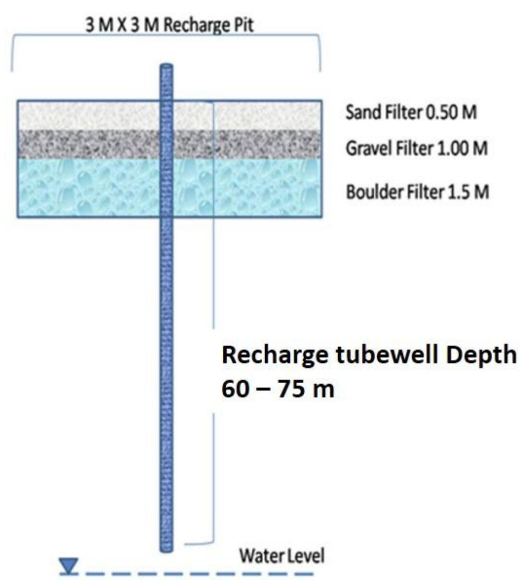



Figure 7.4 Geohydrological Potential Categorization for Management Strategies

### 7.1.3 Groundwater Recharge Techniques

The following are suggested recharge techniques for Anjar City

**Artificial Recharge Tubewell:** This structure is proposed in locations where rainwater frequently accumulates and remains stagnant for a few hours to several days. Figure 6.6 illustrates the design components and precautions required for the implementation of this structure. In Anjar city, several existing water bodies provide suitable sites for implementing this technique to enhance groundwater recharge. Additionally, areas prone to waterlogging within the city have been identified for the installation of these tubewells, along with specific safety measures to ensure the quality of incoming rainwater. This method is particularly suitable for areas with good groundwater potential and can effectively support recharge in the city's multi-aquifer zones.




- **Filter chamber** with graded filter to clean inflowing water
- **Perforated casing pipe**: Installed in the aquifer zone to allow water to percolate into the groundwater table.
- **Blind casing pipe**: Used in zones where no aquifer is present (mainly clay layer) to prevent leakage or contamination.
- **Depth of tubewell** should be slightly above the groundwater level to ensure effective recharge
- **Anjar specific Recommendations**
  - Recommended Depth of tubewell between 60 m to 75 m
  - Filter chamber atleast 3 m dia and 3 m depth
  - Borewell diameter in sedimentary strate preferable 24 inch with RCC casing pipe of 12 inch dia
  - Borewell diameter in area where baslat overlays on sedimentary layer 10 inch dia borewell with PVC casing PVC of 6 inches

| | |
|---|---|
| | • Estimated approximate costing is around 4.5 to 6.25 lakh INR including site specific geological feasibility and casing design. |
| **Precautions and Preventive Measures** | |
| • The catchment area directing runoff to the recharge site must be free from pollution.<br>• Entry of sewage into the structure must be strictly prevented.<br>• If needed, activated charcoal can be used to remove minor impurities from the incoming stormwater. | |

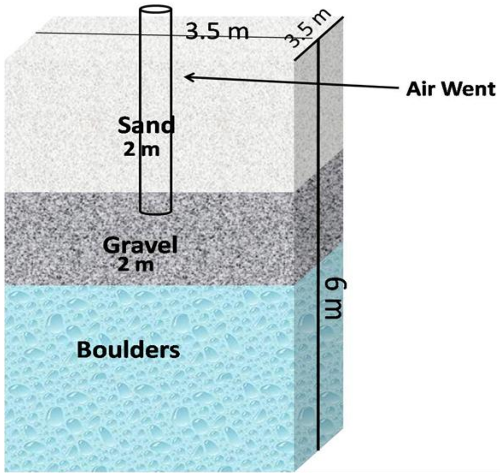
Figure 7.5 Design Components and Precautionary Suggestion for Implementation of Artificial Recharge Tubewell

**Recharge Pits:** Recharge pits are a versatile and cost-effective solution for enhancing groundwater recharge and minimizing surface runoff. These structures are particularly effective in areas where the subsoil strata are permeable, such as sandy, gravelly, or weathered rock formations. In urbanized regions, where surfaces are often covered with concrete and paving, recharge pits play a crucial role by introducing sponginess to the surface, allowing stormwater to infiltrate into the subsurface layers.

Key Benefits:

- Increase the infiltration capacity of soil, allowing more rainwater to percolate into the groundwater system and reducing surface runoff.
- Due to their small size and low construction cost, recharge pits are feasible for widespread adoption in urban and semi-urban settings.
- Can be constructed in various locations, including roadside stormwater drains, building rainwater outlets, and low-lying areas where water tends to accumulate.
- Facilitate the rapid absorption of stormwater, helping to mitigate localized flooding during intense rainfall events.
- Provide partial filtration of sediments and pollutants as water passes through the pit, improving the quality of water that reaches the aquifer.

| | |
|---|---|
| | • Connecting rooftop rainwater outlets to recharge pits helps capture excess stormwater and direct it into the ground, promoting recharge rather than runoff.<br>• Integrating recharge pits into existing stormwater drainage systems improves both recharge potential and runoff management. |



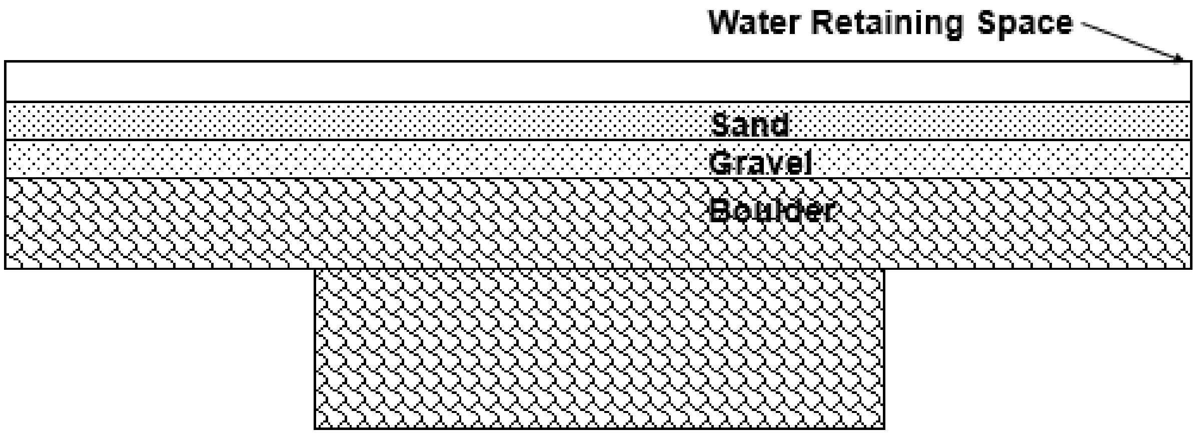

- Constructing recharge pits in natural water accumulation zones enhances infiltration and reduces erosion risks.
- **Anjar specific Recommendations**
  - Recommended Depth: Between 3 to 5 meters
  - Recommended Diameter: Between 2 to 3 meters
  - Estimated Cost: Approximately ₹10,000 to ₹25,000 (INR), including site-specific geological assessments and casing design.

**Preventive Measures and Maintenance**

- Ensure that the underlying subsoil is permeable to maximize recharge effectiveness.
- Conduct regular maintenance to prevent clogging, including debris removal and sediment monitoring.
- Engage local communities in planning and maintenance to build stewardship and ensure long-term sustainability.
- Establish a system to monitor groundwater levels and water quality to evaluate the performance and impact of the recharge pits over time.

Figure 7.6 Design Components and Precautionary Suggestion for Implementation of Filter Well

**Percolation Bed:** Percolation beds are an effective solution for managing stormwater and enhancing groundwater recharge, especially in residential areas, institutional campuses, and community plots. This structure also has similar benefits like recharge pit, but the volume of water percolates by this type of structure is very high. This structure can also be integrated with recharge tubewells in case of common plots of the societies and campuses.




| Key Features and Implementation | Prevention |
| --- | --- |
| • **Site Selection and Design**: Percolation beds should be constructed in areas where water naturally accumulates. The size of the bed must be designed according to the anticipated runoff volume, ensuring sufficient space for effective drainage and infiltration.<br>• **Construction:** A standard percolation bed consists of layered materials—typically gravel and sand—that enhance both water flow and filtration. The top layer may be vegetated to promote evapotranspiration and improve aesthetic appeal.<br>• **Integration:** These beds can be effectively combined with recharge tubewells, particularly in common areas of residential societies or campuses, to maximize groundwater recharge.<br>• **Estimated Cost:** Approximately ₹5.25 to ₹6.25 lakh per unit, including site preparation and integration with tubewells if applicable. | • **Routine Maintenance:** Regular inspections are essential to check for blockages, manage vegetation, and ensure the water is percolating properly. Sediment removal and debris clearing may also be required.<br>• **Community Engagement:** Involving residents, campus staff, or other users in the planning, monitoring, and upkeep of the percolation beds fosters community ownership and raises awareness about sustainable water practices.<br>• **Soil Testing:** Prior to construction, conduct soil tests to verify that the subsoil strata support efficient infiltration.<br>• **Regulatory Compliance:** Ensure that all designs comply with local stormwater management and groundwater recharge regulations.<br>• **Monitoring System:** Implement a monitoring plan to track the effectiveness of the percolation bed and any connected recharge tubewells over time. |

Figure 7.7 Design Components and Precautionary Suggestion for Implementation of Filter Well

**Defunct Well / Bore well Recharge:** There are many wells and borewells in the city area, that are abandoned by communities either due to water scarcity or decline in water quality. It is recommended to use these types of groundwater structures for recharging the aquifer. This method is both cost-effective and highly beneficial, especially when implemented with community involvement. Following are major benefits of this technique.

- Cost-Effective Use of Existing Infrastructure: Utilizing abandoned wells and borewells eliminates the need for constructing entirely new recharge systems, reducing both material and labor costs.
- Community Participation: Engaging local communities in the reuse and maintenance of these wells fosters a sense of ownership and raises awareness of water conservation practices, leading to more sustainable outcomes.
- Rapid Recharge During Rainfall: These structures offer a ready-made channel for rainwater and stormwater to infiltrate the ground, accelerating groundwater recharge, particularly during the monsoon season.
- Potential Water Quality Improvement: Using these wells to divert clean rainwater can help dilute existing contaminants in the aquifer, potentially improving groundwater quality over time. Fig. 6.9 shows recommended design and respective criteria for its planning.

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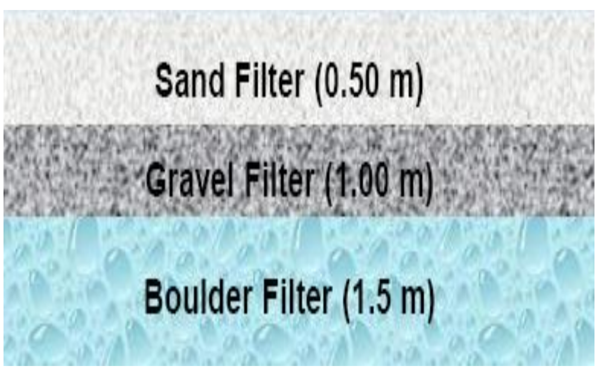
<td>
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<ul>
<li>Before reusing the wells, abandoned well should be cleaned and rehabilitated to prevent any potential contamination of the aquifer. This can include removing debris and ensuring proper sealing of any deteriorated sections</li>
<li>Filter chamber—recommended to be at least 3 meters in diameter and depth—must be installed to ensure that only clean water enters the well. This chamber should include graded filtering materials like sand, gravel, and charcoal.</li>
<li>There is a need of filter chamber and some plumbing work to implement this technique. Use of roof rain water bye end large ensures inflow water quality.</li>
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Figure 7.8 Design Components and Precautionary Suggestion for Implementation of Filter Well

## 7.2 Traditional Water Management and Strategies

Another approach suggested for Anjar city water management is the integration of revival of traditional surface water management practices along with aquifer management. It is described previously that the urbanization of the Anjar city has had significant negative impacts on its water bodies, creating several challenges for traditional water management. Therefore, to develop management plans for these surface water sources, it is important to list out the challenges and constraints ascended due to urbanization. The main constraints that have arisen as a result of the development and growth require attention while developing water management plan.

- **Modification of Natural Catchment Areas**: The natural pathways that used to direct water to these lakes have been altered, causing water to flow in diverted directions. This modification disrupts the natural hydrological cycle and led to inefficient water distribution to the water bodies. As a result, watershed E is now experiencing an overload of surface runoff, contributing to urban flooding in the ring-road area near the court.
- **Encroachment in Water Bodies**: Urban expansion has led to encroachments in areas that were once submerged. This led to reduction of storage capacity of Siddhsar and Khanesari lakes, especially during high water seasons, and led to the loss of important ecosystem services that these lakes once provided.
- **Solid Waste Dumping in Inflow and Outflow Channels and Water Bodies**: Dumping of solid waste in inflow channels and directly into the lakes has deteriorated water quality. These wastes not only contribute to pollution but also block natural water flow, which can degrade aquatic ecosystems and harm aquatic life.
- **Direct Sewage Disposal**: In case of Savasar, Khengarsar and Khanesari lakes, untreated sewage is directly discharged into the lakes, worsening water pollution.
- **Loss of Aesthetic Values**: As urbanization encroaches on natural water bodies and pollution levels rise, the lakes are losing their aesthetic value. The degradation of these natural spaces affects the quality of life for residents and reduces recreational opportunities.
- **Insufficient Water Storage and Shallow Aquifer Recharge**: The reduced size and altered flow patterns of the lakes have also restricted their ability to recharge the shallow aquifers. This limits the amount of groundwater available for use, especially during dry periods, exacerbating water scarcity.

Considering the above constraints, a traditional lake revival approach has been proposed for Anjar city. A water management framework has been developed for each lake to address issues related to its integral components—namely, the catchment area, the lake body, and the outflow or tail channel. (Table 7.4)

Table 7.4 Surface Water Source Management Planning Framework

| Lake | Area | Issue | Proposed Action |
|---|---|---|---|
| Siddhsar lake | Inflow Area | --- | Repair or improve sewage system and establish proper connections |
| | Lake submergence | • Unauthorized Settlements and Constructions<br>• Contamination from untreated sewage and household Waste | • Relocation of unauthorized settlements<br>• Demarcate lake boundaries scientifically by authority for lake submergence and buffer areas |
| | Outflow Channel | Blockages in a lake's downstream area creating serious flooding risks, especially during heavy rains or overflow conditions | Regular cleaning solid waste from tail channel areas |
| Savasar Lake | Inflow Area | Unauthorized settlements and constructions in the catchment Area | • Need to do assessment and demarcation of catchment area using geographic information system (GIS) mapping and field surveys.<br>• Clear all artificial barriers, debris, and obstructions in the natural water channels that feed water into the lake |
| | Lake submergence | Cattle Foddering Near the Lake | Make arrangements for foddering cattle at safe place |
| | Outflow Channel | --- | |
| Toral Sarovar | Inflow Area | Blockage | Establish cleaning mechanisms and maintain cleanliness |

| Lake | Area | Issue | Proposed Action |
|---|---|---|---|
| | Lake submergence | Insufficient filling due to blockage | Address blockage issues to ensure proper water filling |
| | Outflow Channel | Blockage | |
| Khengarsar Lake | Inflow Area | --- | |
| | Lake submergence | Pollution due to various religious rituals | Environmental management, and regular maintenance of the lake; community awareness program |
| | Outflow Channel | Broken Waste Weir | • Repairing the breached earthen bund and cleaning the pond,<br>• Implement strategies for ongoing maintenance involving engineering solutions |
| Khanesari Lake | Inflow Area | Untreated sewage spills | Repair sewage infrastructure |
| | Lake submergence | Reduced area due to encroachment | Relocation of such settlement; Demarcate lake boundaries scientifically by authority for lake submergence and buffer areas |
| | Outflow Channel | --- | |
| Ganesari Lake | Inflow Area | --- | Prevention measures based on lessons learned from other lakes |
| | Lake submergence | --- | |
| | Outflow Channel | --- | |

The management framework emphasizes a systematic approach addressing three key areas - catchment management, lake boundary demarcation with scientific buffer zones, and regular maintenance protocols - indicating that effective lake revival requires integrated solutions combining engineering interventions, community awareness, and strict regulatory enforcement to restore these traditional water bodies to their ecological and hydrological functions.

## 7.3 Overall Citywide Water Management Strategies

A City-Level water management strategy especially for recharge planning and surface water renovations is essential to address challenges, such as depleting water levels, deteriorating quality and flooding during rainy season. The Anjar city recharge plan aims to implement a variety of methods to recharge depleted aquifers, such as stormwater infiltration, artificial recharge techniques, revival of existing surface water harvesting structures and the optimization of existing infrastructure. This plan comprises a recharge potential and problem zone wise appropriate techniques along with its specific dimensions and designs. By integrating these two scales—demonstration projects and city-level strategies—the groundwater management plan for Anjar City aims to ensure the long-term sustainability of groundwater resources while addressing the city's increasing demand for water. The combination of on-the-ground pilot projects and overarching policy planning can help balance the need for urban growth with the protection and conservation of vital water resources. By considering geology, aquifer systems, landuse and flood prone areas integrated strategic action points have prepared for overall city level ground water management plan. Fig. 7.10 shows preferred locations of various surface and groundwater management activities. Whereas table 7.5 shows various considerations for the groundwater recharge planning.

Table 7.5 Aquifer System wise Major Issues and Landuse wise Proposed Actions

| Aquifer system | Location | Geology | Major issues | Landuse | Proposed Action |
|---|---|---|---|---|---|
| Semi consolidated Deep Aquifer system | Western Part of City | Sandstone | Over Exploitation | Residential | Common plot recharge<br>Artificial Recharge tubewell with filter chamber |
| | | | | Agriculture | Defunct borewell Recharge |
| | | | | Public Area | Artificial Recharge Tubewell with filter chamber |
| Weathered consolidated Shallow Aquifer system | Central Part of City | Weathered Basalt | High runoff | Residential | Recharge Pits and Recharge Plots |
| | | | | Public Area | Recharge borewell to connect flood water to deep aquifer system |
| | | | | Water Bodies | Revival of inflow channel, outflow |

| Aquifer system | Location | Geology | Major issues | Landuse | Proposed Action |
|---|---|---|---|---|---|
| | | | | | channel, desilting and maintenance of storage capacity manage pollution |
| Multi aquifer system loose and semi consolidated | Southern Eastern part of the city | Alluvium and fine-grained sandstones | Flooding | Residential | Dense Recharge borewell with different depths according to aquifer layers |
| | | | | Public Area | |
| | | | | Water Bodies | Regulate inflow and outflow in water body and develop connectivity with Sang rivers |

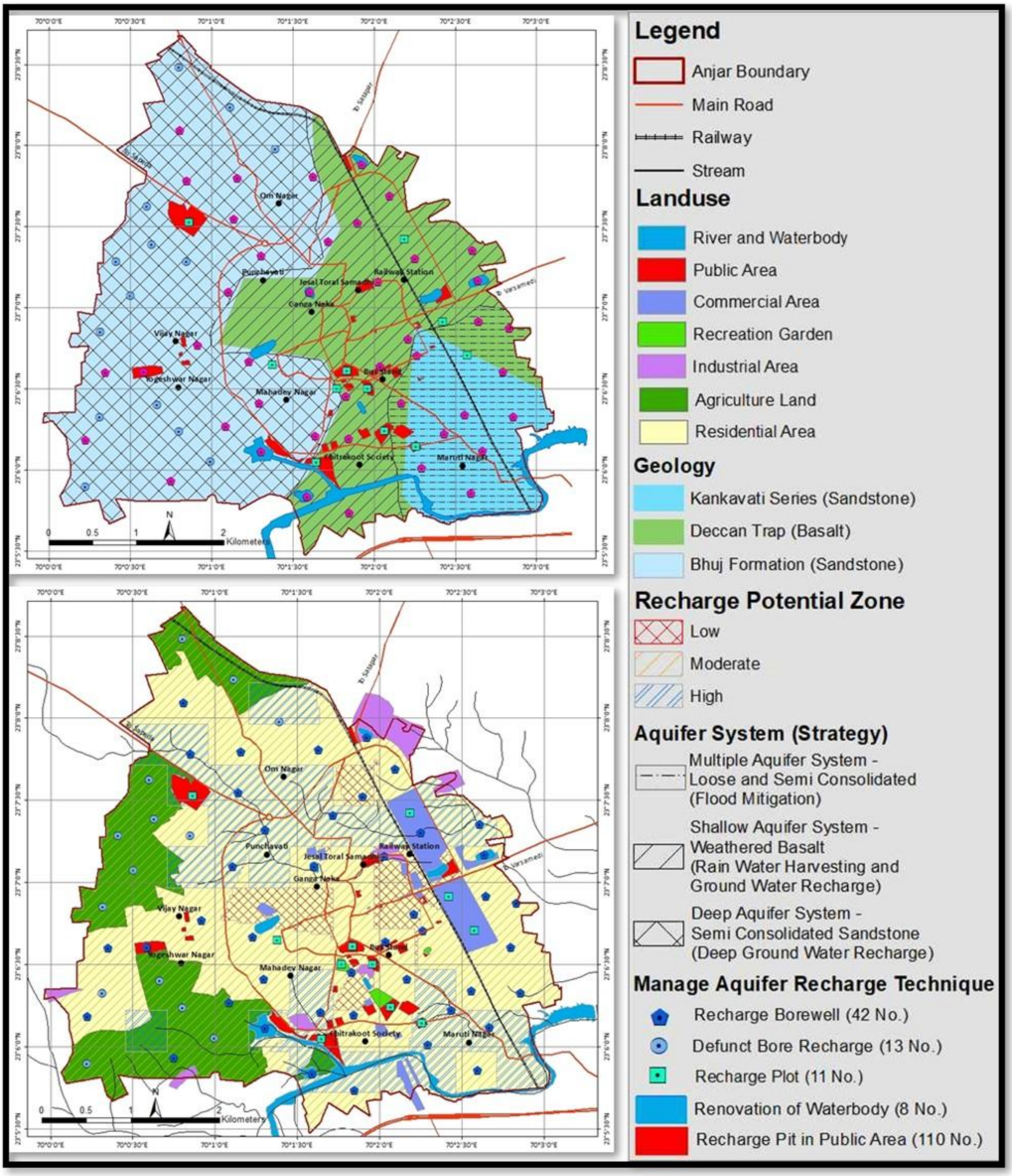


Figure 7.9 Surface and Groundwater Management Plan of Anjar city

**Five main types of initiatives have been proposed** for revival of surface and groundwater resources of Anjar city. For each activity, locations have been selected based on factors such as existing land use, availability of land and/or groundwater sources, and the subsurface geological profile. Additionally, the design dimensions of each structure have been considered and the unit costs have been estimated. As a result, the total investment required for implementing the groundwater and surface water recharge plan across Anjar city has been calculated. According to this **calculation**, about 4.46 crores INR has been estimated to implement water management initiatives in Anjar city (Table 7.6).

Table 7.6 Estimated Investments for water management initiatives across Anjar city

| Sr. No. | Activity | Qty. | Unit | Unit Cost (INR) | Total Cost (INR) |
|---|---|---|---|---|---|
| 1 | Renovation of Waterbody | 8 | No. | 1000000 | 80,00,000 |
| 2 | Recharge Borewell with Filter Chamber | 42 | No. | 600000 | 2,52,00,000 |
| 3 | Defunct Borewell Recharge | 13 | No. | 30000 | 3,90,000 |
| 4 | Recharge Borewell with Recharge Plot | 11 | No. | 800000 | 88,00,000 |
| 5 | Recharge Pit | 110 | No. | 20000 | 22,00,000 |
| **Total Estimated Amount** | | | | | **4,45,90,000** |

# 8 Annexure

## Annexure 8.1 Well Inventory Data

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 1 | 23 | 6 | 23.652 | 69 | 59 | 56.508 | Hiraji Ramji Kapadi | 252 | 183 | 0.3 | SP | 50 | Domestic |
| 2 | 23 | 6 | 30.372 | 69 | 59 | 59.614 | Jayeshbhai Mistry | 213 | 198 | 0.3 | SP | 45 | Irrigation |
| 3 | 23 | 6 | 22.779 | 69 | 59 | 48.912 | Kaushik Gadhvi | 213 | 198 | 0.3 | SP | 50 | Irrigation |
| 4 | 23 | 6 | 13.203 | 69 | 59 | 57.345 | Kalashibhai Gadhavi | 183 | 122 | 0.3 | SP | 35 | Irrigation |
| 5 | 23 | 5 | 56.720 | 69 | 59 | 58.452 | Bharatbhai Mistri | 244 | 99 | 0.3 | SP | 45 | Irrigation |
| 6 | 23 | 5 | 45.146 | 69 | 59 | 54.050 | Gautam Traders | 180 | 137 | 0.3 | SP | 50 | Domestic |
| 7 | 23 | 5 | 51.466 | 70 | 0 | 5.847 | Madhubha Jadeja | 244 | 152 | 0.3 | SP | 45 | Domestic |
| 8 | 23 | 6 | 6.999 | 70 | 0 | 15.000 | Jyantibhai Sorathiya | 183 | 137 | 0.3 | SP | 40 | Domestic |
| 9 | 23 | 6 | 14.457 | 70 | 0 | 5.242 | Dharamashi Vadhamashi | 192 | 137 | 0.3 | SP | 40 | Domestic |
| 10 | 23 | 6 | 42.372 | 70 | 0 | 16.542 | Giradharbhai Jethava | 244 | 183 | 0.3 | SP | 45 | Domestic |
| 11 | 23 | 6 | 37.496 | 70 | 0 | 13.130 | Ishvar Bhai | 259 | 183 | 0.3 | SP | 45 | Domestic |
| 12 | 23 | 6 | 44.755 | 70 | 0 | 8.933 | S.K.Pedwa | 244 | 183 | 0.3 | SP | 50 | Domestic |

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 13 | 23 | 6 | 41.403 | 70 | 0 | 27.889 | Bhavanbhai Vaghamshi | 244 | 183 | 0.3 | SP | 40 | Irrigation |
| 14 | 23 | 6 | 47.657 | 70 | 0 | 23.059 | Naranbhai Valji Kapadiya | 244 | 183 | 0.3 | SP | 45 | Irrigation |
| 15 | 23 | 6 | 26.362 | 70 | 0 | 28.958 | Ramesh Velaji Baldaniya | 198 | 192 | 0.3 | SP | 40 | Irrigation |
| 16 | 23 | 6 | 22.742 | 70 | 0 | 28.733 | Jtantibhai Vaghamashi | 213 | 198 | 0.3 | SP | 40 | Irrigation |
| 17 | 23 | 6 | 15.043 | 70 | 0 | 30.205 | Jivabhai Kapadi | 244 | 198 | 0.3 | SP | 50 | Irrigation |
| 18 | 23 | 6 | 10.000 | 70 | 0 | 32.000 | Premajibhai Sorathiya | 213 | 183 | 0.3 | SP | 40 | Irrigation |
| 19 | 23 | 6 | 12.189 | 70 | 0 | 48.852 | Harilal Viraji Sorathiya | 220 | 168 | 0.3 | SP | 45 | Irrigation |
| 20 | 23 | 6 | 14.000 | 70 | 0 | 50.000 | Ramesh Khera Sorathiya | 229 | 168 | 0.3 | SP | 40 | Irrigation |
| 21 | 23 | 6 | 15.999 | 70 | 0 | 47.999 | Kantilal Ratna Sorathiya | 213 | 159 | 0.3 | SP | 40 | Irrigation |
| 22 | 23 | 6 | 5.000 | 70 | 0 | 57.999 | Naran Sorathiya | 168 | 152 | 0.3 | SP | 50 | Irrigation |
| 23 | 23 | 6 | 11.999 | 70 | 0 | 56.000 | Shamaji Shivaji Chotara | 274 | 168 | 0.3 | SP | 45 | Irrigation |
| 24 | 23 | 5 | 47.000 | 70 | 1 | 8.000 | Sanjaybhai Sorathiya | 213 | 146 | 0.3 | SP | 50 | Irrigation |
| 25 | 23 | 5 | 51.399 | 70 | 1 | 6.056 | Dayaram Hiraji Sorathiya | 213 | 137 | 0.3 | SP | 40 | Irrigation |
| 26 | 23 | 5 | 53.322 | 70 | 0 | 58.65 | Prabhubhai Sorathiya | 30 | 18 | | EM | | Irrigation |
| 27 | 23 | 7 | 58.162 | 70 | 0 | 25.728 | Kedarnath Bag | 274 | 213 | 0.3 | SP | 50 | Domestic |
| 28 | 23 | 7 | 53.499 | 70 | 0 | 26.223 | Nimendra Bhai Patel | 274 | 229 | 0.3 | SP | 50 | Domestic |

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 29 | 23 | 7 | 51.878 | 70 | 0 | 33.945 | Ganesh Bag Nursery | 244 | 192 | 0.3 | SP | 50 | Domestic |
| 30 | 23 | 7 | 33.004 | 70 | 0 | 28.332 | Vishrambhai Adiya | 229 | 168 | 0.3 | SP | 40 | Domestic |
| 31 | 23 | 7 | 28.999 | 70 | 0 | 41.000 | Ganesh Farm | 305 | 213 | 0.3 | SP | 50 | Domestic |
| 32 | 23 | 7 | 45.666 | 70 | 0 | 44.252 | Koteshwar Farm House | 274 | 229 | 0.3 | SP | 45 | Domestic |
| 33 | 23 | 7 | 36.999 | 70 | 0 | 55.000 | Kailash Bag | 259 | 198 | 0.3 | SP | 40 | Domestic |
| 34 | 23 | 7 | 49.832 | 70 | 1 | 16.076 | Vijay Karasan Ahir | 195 | 168 | 0.3 | SP | 40 | Irrigation |
| 35 | 23 | 7 | 53.467 | 70 | 1 | 17.994 | Jyantibhai Mistri | 213 | 152 | 0.3 | SP | 45 | Irrigation |
| 36 | 23 | 7 | 52.140 | 70 | 1 | 6.737 | Keshvaji Manaji Mistri | 259 | 168 | 0.3 | SP | 50 | Irrigation |
| 37 | 23 | 7 | 57.399 | 70 | 0 | 51.950 | Narasinh Naran Sorathiya | 229 | 152 | 0.3 | SP | 40 | Irrigation |
| 38 | 23 | 7 | 52.242 | 70 | 0 | 47.835 | Dilip Daya Sorathiya | 244 | 183 | 0.3 | SP | 40 | Irrigation |
| 39 | 23 | 7 | 58.000 | 70 | 1 | 5.999 | Karasan Khima Sorathiya | 183 | 152 | 0.3 | SP | 40 | Irrigation |
| 40 | 23 | 8 | 0.999 | 70 | 1 | 5.000 | Devajibhai Sorathiya | 213 | 168 | 0.3 | SP | 45 | Irrigation |
| 41 | 23 | 8 | 1.627 | 70 | 1 | 9.230 | Kanaji Govind Vaghamashi | 198 | 168 | 0.3 | SP | 40 | Irrigation |
| 42 | 23 | 8 | 8.000 | 70 | 1 | 14.000 | Lalaji Ruda Vaghamashi | 244 | 192 | 0.3 | SP | 45 | Irrigation |
| 43 | 23 | 8 | 20.275 | 70 | 0 | 58.782 | Dhanajibhai Sorathiya | 229 | 183 | 0.3 | SP | 40 | Irrigation |
| 44 | 23 | 8 | 22.999 | 70 | 1 | 3 | Jitubhai Sorathita | 244 | 223 | 0.3 | SP | 45 | Irrigation |

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 45 | 23 | 8 | 23.691 | 70 | 0 | 54.993 | Jigubhai Sorathiya | 183 | 168 | 0.3 | SP | 40 | Irrigation |
| 46 | 23 | 8 | 29.878 | 70 | 0 | 43.387 | Navinbhai Sorathiya | 244 | 183 | 0.3 | SP | 40 | Irrigation |
| 47 | 23 | 8 | 21.999 | 70 | 1 | 5.000 | Jitendrabhai Sorathiya | 229 | 183 | 0.3 | SP | 45 | Irrigation |
| 48 | 23 | 8 | 27.473 | 70 | 1 | 4.957 | Naranbhai Sorathiya | 213 | 195 | 0.3 | SP | 45 | Irrigation |
| 49 | 23 | 7 | 6.999 | 70 | 1 | 39 | Sagarsa Water Suppliers | 183 | 183 | 0.3 | SP | 45 | Domestic |
| 50 | 23 | 6 | 30.999 | 70 | 1 | 28.999 | Nileshbhai Sorathiya | 183 | 168 | 0.3 | SP | 35 | Domestic |
| 51 | 23 | 6 | 27.179 | 70 | 1 | 49.639 | Anjar Municipality Bore | 244 | 183 | 0.3 | SP | 40 | Domestic |
| 52 | 23 | 6 | 46.707 | 70 | 1 | 2.192 | Kamalivadi Bore | 213 | 195 | 0.3 | SP | 45 | Domestic |
| 53 | 23 | 5 | 42.381 | 70 | 1 | 46.576 | DAV Publick School | 101 | 37 | 0.3 | SP | 25 | Domestic |
| 54 | 23 | 6 | 21.322 | 70 | 1 | 41.973 | Bhadreshwa Temple | 18 | 5 | 0.3 | SP | 20 | Domestic |
| 55 | 23 | 6 | 24.577 | 70 | 1 | 42.823 | Girish Bhai Seth | 6 | 3 | 0 | EM | | Irrigation |
| 56 | 23 | 6 | 25.493 | 70 | 1 | 44.901 | Girish Bhai Seth | 18 | 3 | 0.3 | SP | | Irrigation |
| 57 | 23 | 6 | 24.751 | 70 | 1 | 45.791 | Girishbhai Seth | 21 | 4 | 0.3 | SP | | Irrigation |
| 58 | 23 | 6 | 48.588 | 70 | 1 | 52.346 | Anjar Muni. | 213 | 137 | 0.3 | SP | 45 | Domestic |
| 59 | 23 | 5 | 53.242 | 70 | 2 | 12.246 | Shree Radhe Resort | 198 | 61 | 0.3 | SP | 40 | Domestic |
| 60 | 23 | 5 | 48.321 | 70 | 2 | 10.233 | Kishorbhai Patel | 213 | 46 | 0.3 | SP | 50 | Irrigation |

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 61 | 23 | 6 | 28.699 | 70 | 1 | 11.78 | Devajibhai Vaghamashi | 168 | 107 | 0.3 | SP | 35 | Irrigation |
| 62 | 23 | 6 | 31.460 | 70 | 1 | 8.540 | DhanajiMalsattar | 229 | 152 | 0.3 | SP | 45 | Irrigation |
| 63 | 23 | 6 | 32.378 | 70 | 1 | 10.689 | PravinbhaiBambhaniya | 157 | 137 | 0.3 | SP | 40 | Irrigation |
| 64 | 23 | 6 | 37.446 | 70 | 1 | 13.278 | Kakarvadi | 183 | 122 | 0.3 | SP | 40 | Domestic |
| 65 | 23 | 6 | 30.301 | 70 | 1 | 14.271 | Dhanajibhai Sorathiya | 183 | 137 | 0.3 | SP | 45 | Domestic |
| 66 | 23 | 7 | 11.168 | 70 | 0 | 53.924 | Shamajibhai Ahir | 183 | 152 | 0.3 | SP | 50 | Irrigation |
| 67 | 23 | 7 | 7.212 | 70 | 0 | 52.779 | Shamajibhai Ahir | 46 | 15 | 0.3 | SP | | Irrigation |
| 68 | 23 | 7 | 8.252 | 70 | 0 | 54.33 | Shamajibhia Ahir | 183 | 152 | 0.3 | SP | 45 | Irrigation |
| 69 | 23 | 6 | 29.736 | 70 | 1 | 13.472 | Mandavadi Borewell | 183 | 174 | 0.3 | SP | 50 | Domestic |
| 70 | 23 | 6 | 30.934 | 70 | 1 | 15.042 | Manjibhai Ahir | 244 | 152 | 0.3 | SP | 50 | Domestic |
| 71 | 23 | 6 | 34.189 | 70 | 1 | 18.876 | Lalji Naran Ahir | 168 | 137 | 0.3 | SP | 25 | Irrigation |
| 72 | 23 | 6 | 50.500 | 70 | 1 | 21.075 | Anjar Muni. | 229 | 122 | 0.3 | SP | 40 | Irrigation |
| 73 | 23 | 6 | 6.330 | 70 | 1 | 26.351 | Anjar Iti | 107 | 24 | 0.3 | SP | 25 | Domestic |
| 74 | 23 | 7 | 1.313 | 70 | 2 | 0.394 | Brijesh Sorathiya | 183 | 159 | 0.3 | SP | 40 | Domestic |
| 75 | 23 | 7 | 0.000 | 70 | 2 | 39.000 | Mohanbhai | 168 | 122 | 0.3 | SP | 40 | Domestic |
| 76 | 23 | 6 | 19.469 | 70 | 3 | 7.200 | Vijay Bhai Ahir | 198 | 122 | 0.3 | SP | 45 | Domestic |

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 77 | 23 | 7 | 12.871 | 70 | 0 | 19.879 | Lalaji Haraji Ahir | 213 | 168 | 0.3 | SP | 50 | Domestic |
| 78 | 23 | 7 | 29.614 | 70 | 0 | 33.573 | Shree Lakshmi Farm | 244 | 183 | 0.3 | SP | 50 | Domestic |
| 79 | 23 | 7 | 9.329 | 70 | 0 | 31.709 | Vishnubhai Sorathiya | 213 | 168 | 0.3 | SP | 40 | Domestic |
| 80 | 23 | 6 | 58.107 | 70 | 0 | 5.076 | Samajibhai Hirani | 244 | 168 | 0.3 | SP | 40 | Domestic |
| 81 | 23 | 6 | 54.849 | 70 | 0 | 8.64 | Ravaji Mavaji Patel | 259 | 152 | 0.3 | SP | 45 | Domestic |
| 82 | 23 | 7 | 7.470 | 70 | 1 | 7.700 | Yadavraj Ahir | 168 | 122 | 0.3 | SP | 40 | Domestic |
| 83 | 23 | 8 | 19.579 | 70 | 0 | 46.35 | Pinjara Mansuri Farm | 229 | 168 | 0.3 | SP | 50 | Domestic |
| 84 | 23 | 8 | 11.529 | 70 | 1 | 25.809 | Shambhubhai Ahir | 213 | 155 | 0.3 | SP | 40 | Domestic |
| 85 | 23 | 8 | 4.099 | 70 | 1 | 27.099 | Jakhavadi | 244 | 152 | 0.3 | SP | 40 | Domestic |
| 86 | 23 | 7 | 51.15 | 70 | 1 | 31.010 | Dashrath Bhai Ahir | 229 | 137 | 0.3 | SP | 35 | Domestic |
| 87 | 23 | 7 | 28.189 | 70 | 2 | 29.159 | Ahir Agro Industries | 183 | 122 | 0.3 | SP | 40 | Domestic |
| 88 | 23 | 6 | 17.070 | 70 | 2 | 5.470 | ABV Eng. Med. School | 107 | 46 | 0.3 | SP | 25 | Domestic |
| 89 | 23 | 6 | 42.289 | 70 | 2 | 16.109 | City Fire Dept. | 101 | 52 | 0.3 | SP | 25 | Domestic |
| 92 | 23 | 6 | 54.71 | 70 | 0 | 33.53 | Kanjibhai Nathabhai | 298 | 168 | 0.32 | SP | 40 | IRRIGATION |
| 93 | 23 | 6 | 33.14 | 70 | 1 | 7.74 | Kanjibhai Valjibhai | 244 | 229 | 0.3 | SP | 40 | IRRIGATION |
| 94 | 23 | 6 | 19.23 | 70 | 1 | 3.09 | Harilal Mulajibhai | 137 | 125 | 0.32 | SP | | IRRIGATION |

| Sl. No. | Latitude | | | Longitude | | | Owner | Borewell Details | | | Lift. Device | | Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | M | S | D | M | S | | Depth (M) | WL (M) | Dia | Type | Hp | |
| 95 | 23 | 6 | 22.95 | 70 | 1 | 5.82 | Danabhai Sejabhai | 189 | 143 | 0.3 | SP | 35 | IRRIGATION |
| 96 | 23 | 6 | 24.09 | 70 | 0 | 59.75 | Khimajibhai Dhanjibhai | 228 | 168 | 0.3 | SP | 40 | IRRIGATION |
| 97 | 23 | 6 | 20.65 | 70 | 0 | 55.35 | Khimjibhai Jethabhai | 175 | 137 | 0.3 | SP | 35 | Irrigation |

## Annexure 8.2 Well Litholog Data

| Well Code | Layer – 1 | | | Layer –2 | | | Layer 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) |
| 1 | Top Soil | 2 | 2 | Sandstone | 252 | 250 | | | |
| 2 | Top Soil | 1 | 1 | Black Soil | 213 | 212 | | | |
| 3 | Top Soil | 2 | 2 | Black Soil | 213 | 211 | | | |
| 4 | Top Soil | 2 | 2 | Sandstone | 183 | 181 | Black Clay | >183 | |
| 5 | Top Soil | 2 | 2 | Sandstone | 244 | 241 | Black Clay | >244 | |
| 6 | Top Soil | 1 | 1 | Sandstone | 180 | 179 | Black Clay | >180 | |
| 7 | Top Soil | 0.3 | 0.3 | Sandstone | 244 | 243.7 | | | |
| 8 | Top Soil | 2 | 2 | Sandstone | 122 | 120 | Black Clay | 182 | 62 |
| 9 | Red Soil | 15 | 15 | Sandstone | 192 | 177 | Basalt | >192 | |
| 10 | Top Soil | 1 | 1 | Sandstone | 213 | 212 | Black Clay | 242 | 30 |
| 11 | Top Soil | 1 | 1 | Sandstone | 259 | 259 | Black Clay | | |
| 12 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 243.7 | | | |
| 13 | Top Soil | 2 | 2 | Sandstone | 213 | 212 | Black Clay | 244 | 29 |
| 14 | Top Soil | 1 | 1 | Sandstone | >1 | 243 | | | |
| 15 | Top Soil | 2 | 2 | Sandstone | 198 | 197 | | | |
| 16 | Top Soil | 1 | 1 | Sandstone | 244 | 243 | Black Clay | | |
| 17 | Top Soil | 1 | 1 | Sandstone | 242 | 243 | | | |
| 18 | Top Soil | 1 | 1 | Sandstone | 213 | 212 | | | |
| 19 | W B | 9 | 9 | Sandstone | 219 | 210 | | | |
| 20 | W B | 9 | 9 | Sandstone | 229 | | Black Clay | >229 | |
| 21 | W B | 9 | 9 | Sandstone | 229 | 220 | | | |
| 22 | Top Soil | 18 | 18 | Basalt | 168 | 150 | | | |
| 23 | W B | 9 | 9 | Basalt | 61 | 52 | Sandstone | 213 | 152 |
| 24 | Basalt | 213 | 0 | | | | | | |
| 25 | Basalt | 213 | 0 | | | | | | |
| 26 | Basalt | 30 | 0 | | | | | | |
| 27 | Top Soil | 2 | 2 | Sandstone | 274 | 272 | | | |

| Well Code | Layer – 1 | | | Layer –2 | | | Layer 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) |
| 28 | Top Soil | 1 | 1 | Sandstone | 274 | 273 | | | |
| 29 | Top Soil | 2 | 2 | Sandstone | 242 | 242 | | | |
| 30 | Top Soil | 1 | 1 | Sandstone | 228 | 227 | | | |
| 31 | Top Soil | 2 | 2 | Sandstone | 305 | 303 | | | |
| 32 | Top Soil | 2 | 2 | Sandstone | 274 | 272 | | | |
| 33 | Top Soil | 1 | 1 | Sandstone | 258 | 257 | | | |
| 34 | Top Soil | 1 | 1 | Sandstone | 195 | 194 | Clay (Matti) | >195 | |
| 35 | Top Soil | 2 | 2 | Sandstone | 213 | 212 | Clay (Matti) | >213 | |
| 36 | Top Soil | 1 | 1 | Sandstone | 259 | 258 | | | |
| 37 | Top Soil | 1 | 1 | Sandstone | 229 | 228 | | | |
| 38 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 243.7 | | | |
| 39 | Top Soil | 1 | 1 | Sandstone | 183 | 182 | | | |
| 40 | Top Soil | 2 | 2 | Sandstone | 213 | 211 | | | |
| 41 | Top Soil | 1 | 1 | Sandstone | 198 | 197 | | | |
| 42 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 243.7 | | | |
| 43 | Top Soil | 1 | 1 | Sandstone | 229 | 228 | | | |
| 44 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 243.7 | | | |
| 45 | Top Soil | 1 | 1 | Sandstone | 183 | 182 | | | |
| 46 | Top Soil | 2 | 2 | Sandstone | 244 | 242 | | | |
| 47 | Top Soil | 1 | 1 | Sandstone | 229 | 228 | | | |
| 48 | Top Soil | 1 | 1 | Sandstone | 213 | 212 | | | |
| 49 | Top Soil | 2 | 2 | Sandstone | 183 | 181 | | | |
| 50 | Top Soil | 1 | 1 | Sandstone | 183 | 182 | | | |
| 51 | Top Soil | 0.3 | 0.3 | Sandstone | >1 | 243 | | | |
| 52 | Top Soil | 1 | 1 | Sandstone | 213 | 212 | | | |
| 53 | CLAY | 30 | 30 | Basalt | 97 | 67 | Sandstone | 101 | 4 |
| 54 | W B | 5 | 5 | Basalt | >5 | 13 | | | |
| 55 | W B | 6 | 6 | Basalt | >6 | | | | |
| 56 | W B | 5 | 5 | Basalt | 18 | 13 | | | |

| Well Code | Layer – 1 | | | Layer –2 | | | Layer 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) |
| 57 | W B | 5 | 5 | Basalt | 21 | 16 | | | |
| 58 | W B | 21 | 21 | Sandstone | 213 | 192 | | | |
| 59 | CLAY | 9 | 9 | Basalt | 198 | 189 | | | |
| 60 | CLAY | 6 | 6 | Basalt | 213 | 207 | Sandstone | >213 | |
| 61 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 167.3 | | | |
| 62 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 228.7 | | | |
| 63 | Top Soil | 1 | 1 | Sandstone | 157 | 156 | | | |
| 64 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 182.7 | | | |
| 65 | Top Soil | 1 | 1 | Sandstone | 183 | 182 | | | |
| 66 | W B | 24 | 24 | Sandstone | 183 | 159 | | | |
| 67 | Top Soil | 0.3 | 0.3 | Sandstone | >1 | 45 | | | |
| 68 | W B | 9 | 9 | Sandstone | 183 | 174 | | | |
| 69 | Top Soil | 1 | 1 | Sandstone | 183 | 182 | | | |
| 70 | Top Soil | 1 | 1 | Sandstone | 244 | 243 | | | |
| 71 | Top Soil | 1 | 1 | Sandstone | 168 | 167 | | | |
| 72 | Basalt | 61 | 61 | Sandstone | 228 | 168 | | | |
| 73 | W B | 6 | 6 | Sandstone | 107 | 101 | | | |
| 74 | W B | 24 | 24 | Sandstone | 183 | 159 | | | |
| 75 | Top Soil | 1 | 1 | Sandstone | >1 | 167 | | | |
| 76 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 197.7 | | | |
| 77 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 212.7 | | | |
| 78 | Top Soil | 1 | 1 | Sandstone | >1 | 243 | | | |
| 79 | Top Soil | 2 | 2 | Sandstone | 214 | 212 | Black Clay | >213 | |
| 80 | Top Soil | 0.3 | 0.3 | Sandstone | 244 | 244 | Black Clay | >244 | |
| 81 | Top Soil | 1 | 1 | Sandstone | 259 | 258 | | | |
| 82 | W B | 21 | 21 | Sandstone | 168 | 147 | | | |
| 83 | Top Soil | 1 | 1 | Sandstone | >1 | 228 | | | |
| 84 | Top Soil | 1 | 1 | Sandstone | >1 | 212 | | | |
| 85 | Top Soil | 2 | 2 | Sandstone | 244 | 242 | | | |

| Well Code | Layer – 1 | | | Layer –2 | | | Layer 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) | Type | Depth(m) | Thickness(M) |
| 86 | Top Soil | 0.3 | 0.3 | Sandstone | >0.3 | 228.7 | | | |
| 87 | Top Soil | 1 | 1 | Sandstone | >1 | 182 | | | |
| 88 | W B | 9 | 9 | Basalt | 107 | 98 | | | |
| 89 | W B | 9 | 9 | Basalt | 100 | 91 | | | |
| 90 | Top Soil | 1 | 1 | Sandstone | 229 | 228 | | | |
| 91 | W B | 30 | 30 | Sandstone | 183 | 153 | | | |
| 92 | W B | 3 | 3 | Sandstone | 186 | 183 | Sandstone | 91 | |
| 93 | Top Soil | 1 | 1 | Sandstone | 168 | 167 | | | |
| 94 | Top Soil | 3 | 3 | Sandstone | 137 | 134 | | | |
| 95 | Top Soil | 2 | 2 | Sandstone | 106 | 104 | Clay | 137 | 31 |
| 96 | Sandstone | 91 | 91 | Clay | 106 | 16 | Sandstone | 182 | 77 |
| 97 | Basalt | 18 | 18 | Sandstone | 175 | 157 | | | |

## Annexure 8.3 Rainfall Records of Anjar City

| Rainfall | Anjar (mm) |
|---|---|
| 2015 | 899 |
| 2016 | 325 |
| 2017 | 614 |
| 2018 | 231 |
| 2019 | 760 |
| 2020 | 1426 |
| 2021 | 867 |
| 2022 | 919 |
| 2023 | 1134 |
| 2024 | 844 |
| Average | 802 |

Source: GSDMA, 2015 to 2014

## Annexure 8.4 Pre and Post Monsoon Ground Water Levels (Year 2023)

| Well Code | Location | | Owner Name | Water Level (M) | | |
|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Pre Monsoon | Post Monsoon | Change |
| 8 | 70.00417 | 23.10194 | Jyantibhai Sorathiya | 137.2 | 132.0 | 5.2 |
| 14 | 70.00641 | 23.11324 | Naranbhai Valji Kapadiya | 182.9 | 179.7 | 3.2 |
| 22 | 70.01611 | 23.10139 | Naran Mghajibhia Sorathiya | 152.4 | 148.0 | 4.4 |
| 35 | 70.02167 | 23.13152 | Jyantibhai Mistri | 152.4 | 147.2 | 5.2 |
| 38 | 70.01329 | 23.13118 | Dilip Daya Sorathiya | 182.9 | 177.7 | 5.2 |
| 45 | 70.01528 | 23.13991 | Jigubhai Sorathiya | 167.7 | 167.2 | 0.5 |
| 49 | 70.0275 | 23.11861 | Sagarsa Water Suppliers | 182.9 | 177.3 | 5.6 |
| 58 | 70.03121 | 23.1135 | Anjar Nagarpalika Borewell | 137.2 | -- | -- |
| 59 | 70.03674 | 23.09812 | Shree Radhe Resort Borewell | 61.0 | 65.0 | -4.0 |
| 68 | 70.01509 | 23.11896 | Shamajibhia Ahir | 152.4 | 155.6 | -3.2 |
| 73 | 70.02008 | 23.1045 | Anjar ITI | 24.4 | 28.0 | -3.6 |
| 75 | 70.04417 | 23.11667 | Mohanbhai | 122.0 | 121.3 | 0.7 |
| 77 | 70.00552 | 23.12024 | Lalaji Haraji Ahir | 167.7 | 167.7 | 0.0 |
| 85 | 70.02419 | 23.13447 | Jakhavadi | 152.4 | 156.0 | -3.6 |
| 87 | 70.04143 | 23.1245 | Ahir Agro Industries | 122.0 | -- | -- |
| 93 | 70.01882 | 23.10921 | Kanjibhai Valjibhai | 229.0 | 225.0 | 4.0 |
| **Average Rise in Water Levels** | | | | | | **1.7** |

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