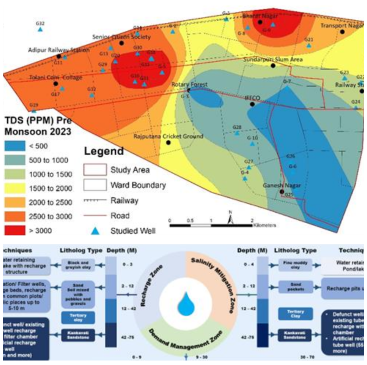

Geo-hydrological and Aquifer study of Gandhidham City, Kachchh District

CWAS CENTER FOR WATER AND SANITATION

CRDF CEPT RESEARCH AND DEVELOPMENT FOUNDATION

CEPT UNIVERSITY

Geo-hydrological and Aquifer study of Gandhidham City, Kachchh District

Center for Water and Sanitation

CRDF, CEPT University

June 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.

Gandhidham 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 Gandhidham 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 Gandhidham, 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 Gandhidham 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 Gandhidham 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 Gandhidham 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 Gandhidham municipal Corporation 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.

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Sr. Advisors CWAS

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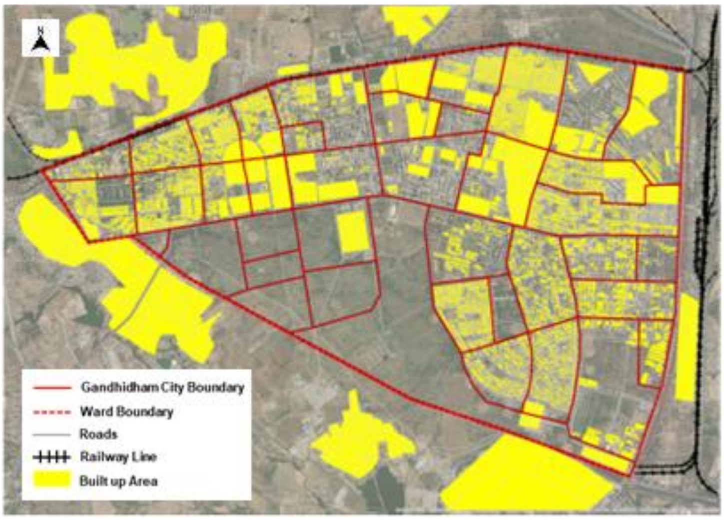
Center Heads, CWAS

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.



Gandhidham, located in Gujarat's arid Kachchh district, exemplifies these challenges. It receives only about 430–530 mm of rainfall annually—less than half the national average of 1,152mm 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. With surface water availability limited and rainfall both low and erratic, the city depends heavily on groundwater. In the context of climate change, water security in such regions is under growing threat, making the need for sustainable water management even more urgent.

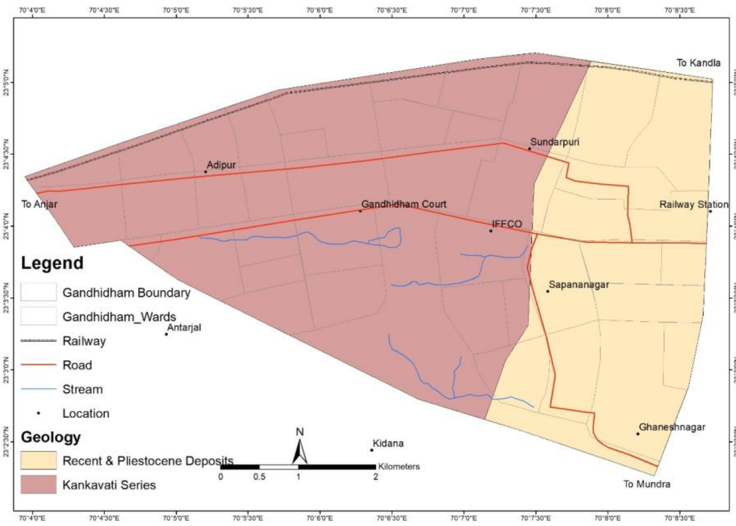
To address these risks, this study presents the comprehensive geo-hydrological and aquifer assessment for Gandhidham. It maps aquifers and recharge zones, analyzes groundwater quality and availability, estimates future water balance and proposes integrated strategies for sustainable groundwater and surface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

Terrain Characteristics:

The terrain characteristics play a crucial role in shaping its geo-hydrological framework and groundwater behaviour. The city exhibits a predominantly flat topography with slopes of less than 2°, resulting in limited surface runoff and moderate groundwater recharge potential. Physiographically, Gandhidham lies within the coastal plain division, comprising two main landform units—clayey alluvial plains and coastal mudflats. The clayey alluvial plains, resting on older Bhuj and Deccan formations, feature fertile soils and favourable aquifer conditions, supporting agriculture and groundwater storage. In contrast, the mudflats along the western fringe consist of marine sediments that have been altered by human development, restricting natural tidal movements. Due to the city's flat terrain, well-defined drainage systems are absent; instead, small, shallow rivulets—often termed "lost rivers"—appear and vanish within the plains. The drainage generally flows east to west, influenced by local slopes and human infrastructure, forming three minor watersheds within the urban area.

Geology:

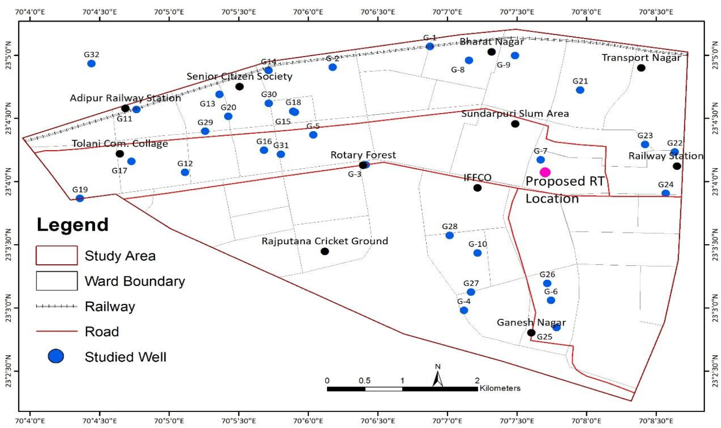
The geology reflects the broader geological framework of the Kachchh region, which showcases a complete stratigraphic sequence from the Middle Jurassic to the Holocene period. The region's geological evolution has been shaped by tectonic movements, erosion, and volcanic activity—particularly the Deccan Trap eruptions during the Upper Cretaceous. Within the Gandhidham area, two main rock formations are evident: The **Tertiary Kankavati Series**, comprising fine-grained sandstone found mainly in the central and western parts, and the **Recent Holocene deposits**, including alluvium, Rann silts, and blown sands dominating the eastern side. These unconsolidated Quaternary and Holocene sediments, composed of coastal sands, silts, and aeolian dunes, form the uppermost layer, influencing groundwater storage and movement.



Overall, Gandhidham's geological composition—marked by Tertiary sandstone overlain by younger alluvial deposits—plays a vital role in determining its aquifer characteristics and groundwater potential.

Geohydrological and Water Quality

The geohydrological characteristics are shaped by its semi-consolidated sedimentary formations and coastal geomorphology. Groundwater occurs in both shallow unconfined and deep confined aquifers, primarily within sandy clay layers and the Kankavati Sandstone formation. Shallow aquifers are mainly found in sandy soils and are unconfined, making them prone to salinity and contamination, especially from sewage and surface runoff during the monsoon. The deeper Kankavati Sandstone aquifer, beginning around 36–40 meters below ground, serves as a significant groundwater source, although its deeper sections often exhibit higher salinity due to marine influence.



An inventory of 16 wells and borehole logs confirmed these trends and highlighted the pressures on the city's aquifers. While they hold significant potential, the continued degradation of water quality and over-extraction underscore the need for systematic monitoring and sustainable management practices to preserve groundwater as a reliable resource.

Groundwater levels across the city remain mostly within 20 meters of the surface, showing seasonal fluctuations influenced by rainfall recharge and over-extraction. GIS-based mapping and hydrographs indicate a general improvement in water levels post-monsoon, particularly in the northeastern zones, but highlight persistent risks of seawater intrusion in low-lying coastal areas.

Groundwater quality is governed by its geological setting and coastal proximity. Water quality data from 10 sampling sites revealed that pH values remain within permissible limits (7.3–7.9), indicating slightly alkaline conditions. However, **Total Dissolved Solids (TDS)** and **chloride levels** are often elevated, especially in the western and northern regions, reflecting saline intrusion and mineral dissolution. Seasonal variation shows slight improvement in water quality post-monsoon due to dilution from rainfall. Other parameters like calcium, magnesium, hardness, and alkalinity are generally within acceptable limits, while sulphate and nitrate levels fluctuate depending on land use and recharge conditions. Overall, while groundwater remains usable in parts of Gandhidham, increasing salinity and coastal intrusion pose serious long-term challenges to water quality sustainability.

Water Balance

The **water balance analysis** highlights the growing stress between water availability and demand under rapid urbanization. The study compares rainfall-derived supply and groundwater storage against the city's rising domestic, industrial, and institutional water requirements. Gandhidham receives an average annual rainfall of **534 mm**, generating about **14.6 MCM** of rainwater annually, of which approximately **60% (8.76 MCM)** flows out as surface runoff due to limited infiltration. The remaining **5.84 MCM** stays within the city, contributing to **groundwater recharge of 9.62 MCM**. However, the total **water demand**, projected based on population growth (expected to reach **7.4 lakh by 2050**), stands at **44.96 MCM**—including domestic, industrial, and floating population needs. In contrast, the **total available water supply** from rainfall retention and groundwater amounts to only **15.46 MCM**, resulting in a **deficit of about 29.5 MCM**. This imbalance underscores the urgent need for enhanced recharge measures, stormwater harvesting and efficient demand management to ensure Gandhidham's long-term water sustainability.

Water Management Strategies

The city is divided into three groundwater management zones based on geological and hydrological characteristics to ensure sustainable water use.

1. **Recharge Zone:**

    - Focus on areas with high infiltration potential.
    - Implement **stormwater harvesting systems** and **artificial recharge wells**.
    - Promote **permeable surfaces** to enhance natural groundwater recharge.

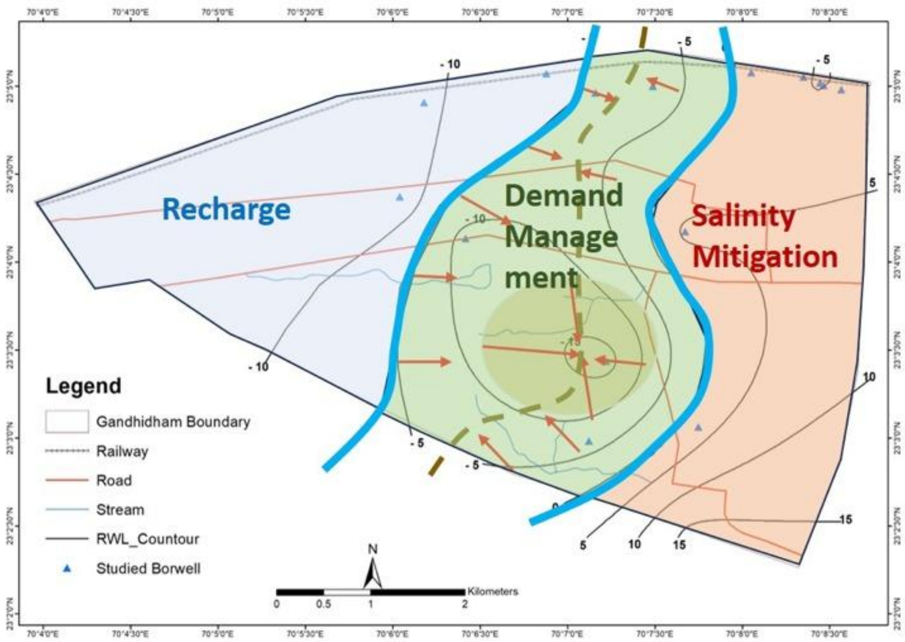
2. **Demand Management Zone:**

    - Target regions with **high groundwater extraction** and **deteriorating quality**.

- Enforce **regulations on water withdrawal** and promote **efficient water use**.
- Encourage **reuse, recycling**, and adoption of **water-saving technologies**.

3. **Salinity Mitigation Zone:**

- Concentrate on **coastal and low-lying areas** affected by seawater intrusion.
- Implement **controlled extraction** to prevent further salinity ingress.
- Develop **buffer recharge systems** to create a hydraulic barrier against saline water.



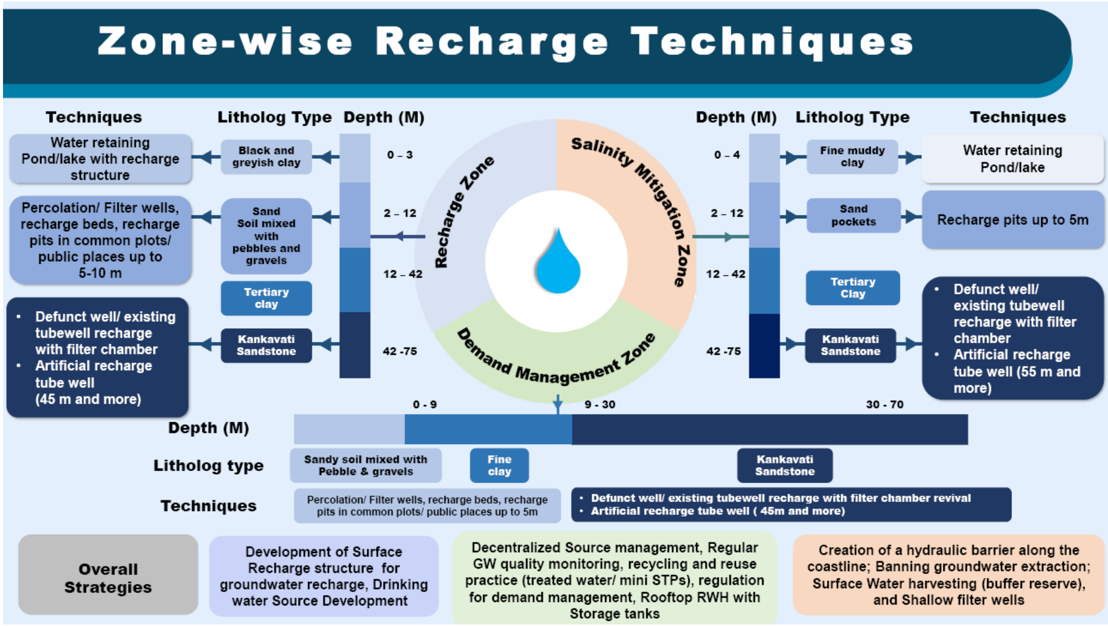
Integrated Outcome:

- These zone-specific strategies together aim to build a **resilient, adaptive water management framework** that balances groundwater demand with sustainable supply.

Way Forward

To secure Gandhidham's groundwater resources, the study proposes a comprehensive set of strategies anchored by a City-Level Groundwater Recharge Plan. This plan emphasizes stormwater harvesting, construction of artificial recharge structures, and integration of recharge systems into existing urban infrastructure. These interventions not only help combat falling water tables and salinity but also mitigate urban flooding during monsoons. By aligning recharge projects with the natural infiltration capacity and lithological conditions of each management zone, the plan seeks to ensure long-term water sustainability, improve aquifer health, and secure a reliable water supply for current and future needs.

Alongside recharge measures, demand-side actions are critical. These include regulating borewell extraction, particularly in salinity-prone areas, and promoting efficient water use in industries and households through reuse, recycling, and metering. Municipal by-laws should mandate rainwater harvesting for all new buildings and industrial units to reduce dependence on external sources.



Incorporating nature-based solutions—such as urban green spaces, permeable surfaces, and wetlands—can further support infiltration and aquifer recharge. Regularly updating the aquifer database and refining management zones based on changing hydrological conditions will help maintain the effectiveness of strategies in the face of climate variability and urban growth. By embedding water-sensitive approaches into all new development projects and consistently implementing these measures, Gandhidham can transform from a water-stressed city into a resilient, climate-adaptive, and water-secure urban hub.

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 city of Gandhidham 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 Gandhidham have experienced rapid depletion and salinity ingression due to its proximity to coastline, 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 Gandhidham, 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 Gandhidham, 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 Gandhidham 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 and mitigating urban flooding. 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 the water balance of the project city.
- 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 Gandhidham 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 Gandhidham 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.

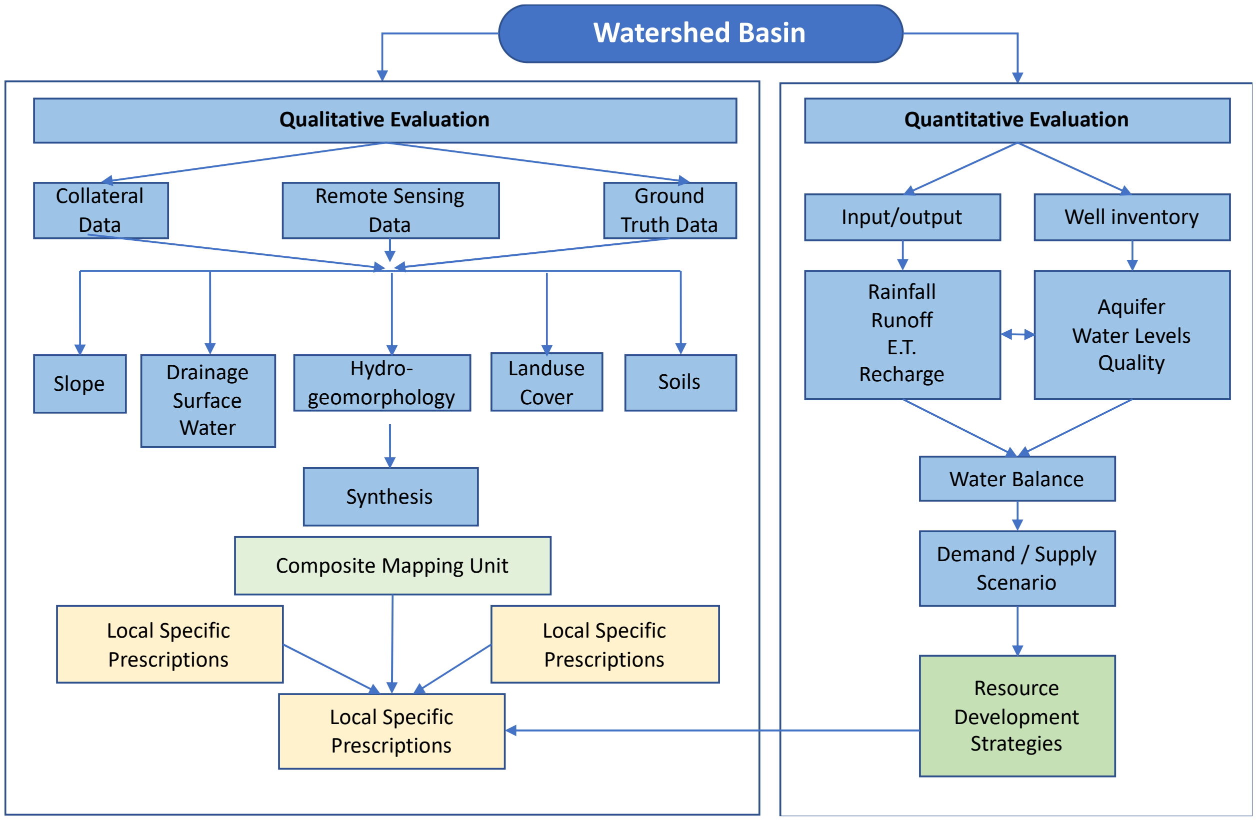


Figure 1.1 Approach Adapted

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 Gandhidham Municipal Corporation 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.

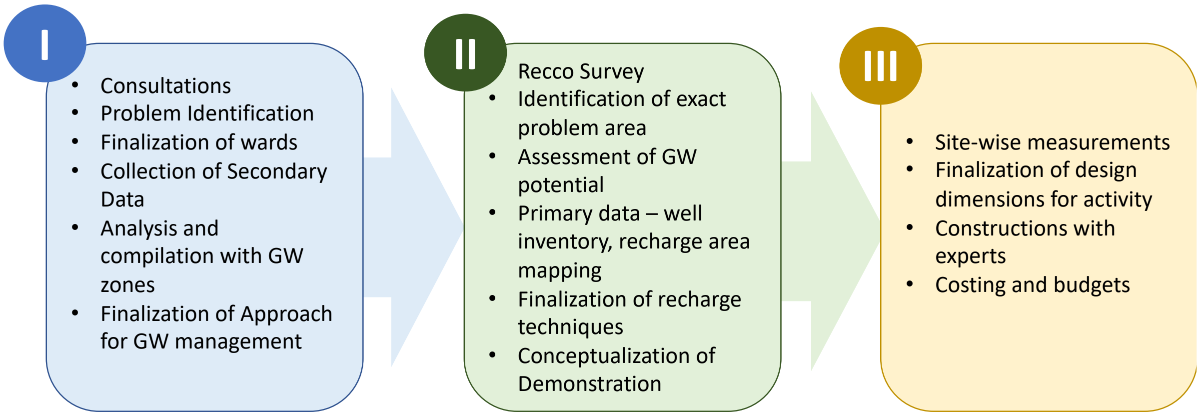


Figure 1.2 Approach for Demonstration Planning

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 Gandhidham City Profile

2.1 Location

Gandhidham is a prominent business hub located in the Kachchh district of Gujarat, India. It is a relatively newly developed and well-planned city, established post-Independence, particularly after the 1962 war, to provide settlement for Sindhi refugees who migrated from Sindh, Pakistan.

Situated approximately 55 Km east of the district headquarters, Bhuj, Gandhidham spans an area of 27.34 square Km. Geographically, the city lies between latitudes 23°04’57.53” N to 23°05’00.61” N and longitudes 70°03’57.53” E to 70°08’44.90” E in the north, and between 23°04’50.05” N to 23°02’17.51” N and 70°04’18.19” E to 70°08’17.92” E in the south. The city's elevation ranges from 8 to 14 meters above mean sea level (AMSL), indicating slight variations in topography across different areas.

Gandhidham is administratively divided into nine wards. Among these, Ward No. 01 (2.4 sq. km.), Ward No. 05 (2.2 sq. km.), and Ward No. 06 (2.2 sq. km.) are the largest in terms of area, while Ward No. 08 is the smallest, covering approximately 1.4 square Km.

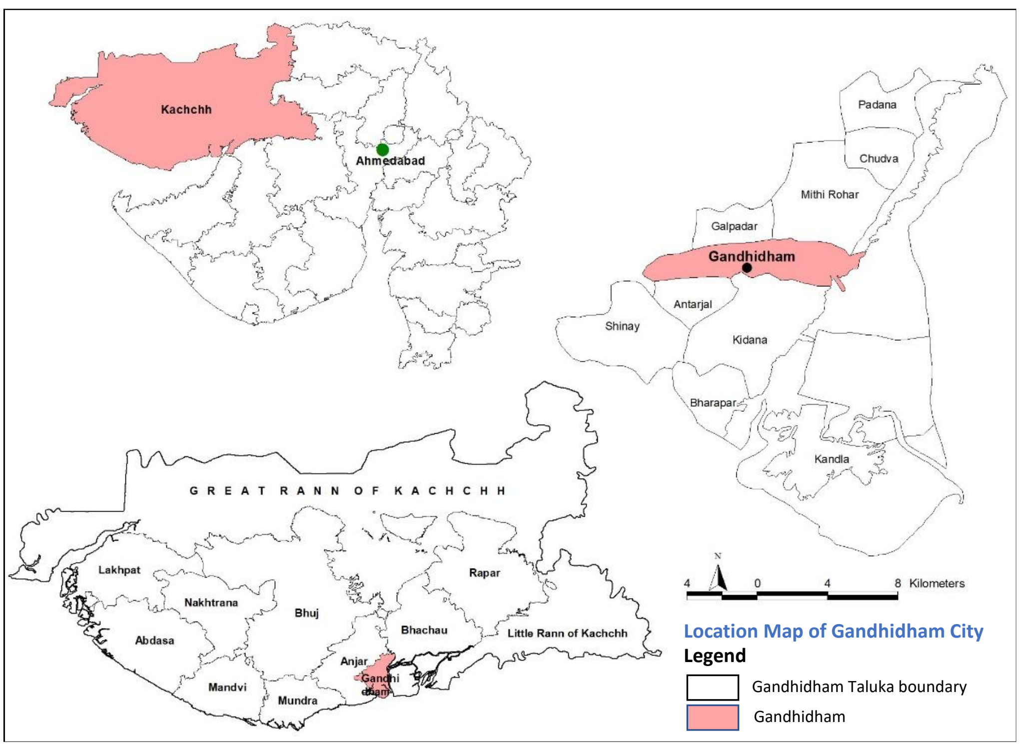


Figure 2.1 Location of Gandhidham City

2.2 Population and Households

According to the 2011 Census, Gandhidham city has a total urban population of 2,47,995, comprising 1,31,484 males and 1,16,508 females. The Female Sex Ratio in the city stands at 886 females per 1,000 males, which is lower than the state average of 919.

The ward-wise distribution of population is presented in Table 2.1. Among all the wards, Ward No. 14 and Ward No. 13 have the highest populations.

Table 2.1 Ward Wise Population and Households of Gandhidham City

Ward No.	Population	Households
1	18631	3971
2	11270	2562
3	29644	9718
4	11641	2376
5	13969	2943
6	20505	4501
7	11364	2413
8	10839	2342
9	20928	4359
10	20111	4311
11	14555	3423
12	18313	3961
13	21575	4918
14	24647	5767
Total	**247992**	**116508**

(Source: Gandhidham Municipal Corporation)

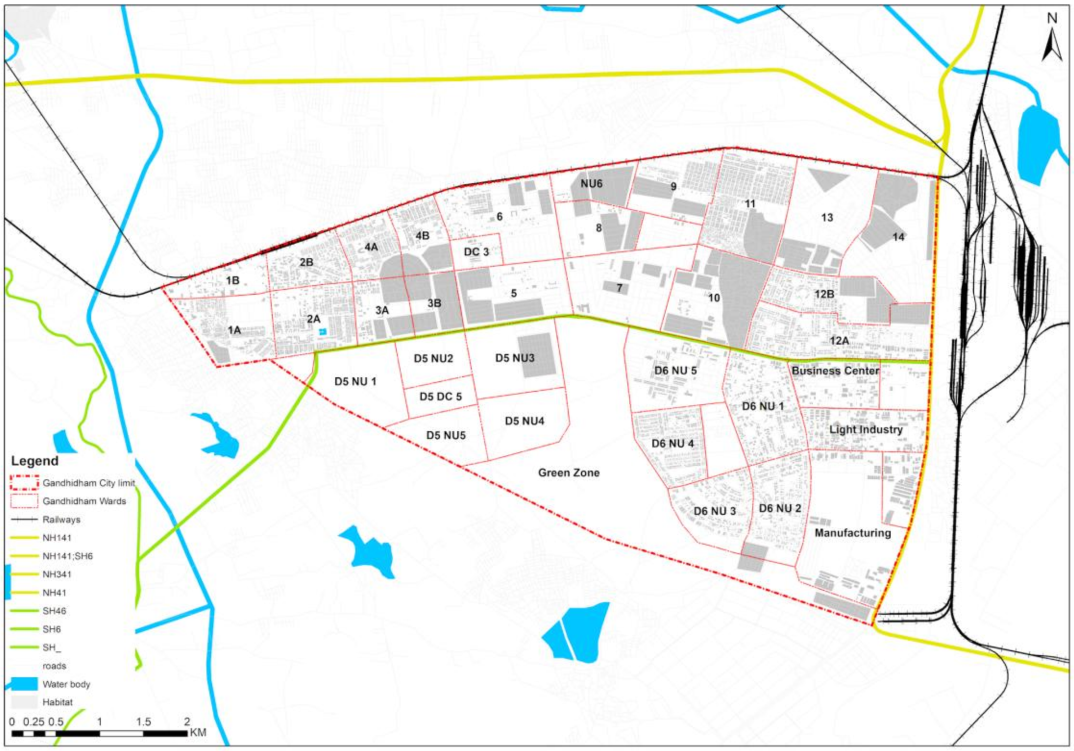


Figure 2.2 Ward Boundaries of Gandhidham City

2.3 Amenities

As one of the major cities in the Kachchh district, Gandhidham offers a comprehensive range of facilities and infrastructure. In terms of education, the city is home to numerous government and private schools, colleges, and universities, catering to all levels of higher education, including medical studies. In terms of healthcare, Gandhidham provides a wide spectrum of medical services. These include government-run health centers, charitable trust hospitals, and private healthcare providers ranging from small dispensaries to large multi-specialty hospitals. The city is also well-served by a variety of banking and financial institutions, ensuring easy access to financial services. Furthermore, Gandhidham is located near a major industrial hub, contributing to its economic importance in the region.

Gandhidham is well connected by state and national highways, as well as by railways, offering convenient travel to major cities across the country. Additionally, the city has air connectivity through Kandla Airport, located just 10 Km away. Rail connectivity is another strength of the city, with direct rail links to several major cities across India. Moreover, Gandhidham benefits from its proximity to Kandla Port—one of the oldest and most significant ports in the country—located about 20 Km away. This port plays a crucial role in both national and international transportation and trade.

2.4 Land-use

Land-use patterns play a crucial role in effective water management. Although water resources are often listed as one of the land-use categories, they require special attention—particularly with respect to the characteristics of their inflow and outflow areas. It has been observed that land-use planning frequently alters these inflow and outflow zones, ultimately impacting the water bodies within a region.

In many cases, such water bodies receive inadequate inflow due to disrupted or diverted channels, are exposed to pollution sources, or are misused for solid waste disposal. As a result, when planning land use or undertaking land development projects, it is essential to consider these factors and study water bodies carefully, ensuring that their ecological and hydrological functions are preserved. Figure 2.3 illustrates the land use and land cover analysis of Gandhidham city.

Almost entire Gandhidham city landcover can characterizes as built-up area. Future this build up area can sub divided into (01) Residential; (02) Commercial; (03) Public and Semi Public and (04) Industrial. Table 2.2 shows sub category wise distribution of land use.

Table 2.2 Landuse Pattern of Gandhidham City

Category	Type of Landuse	Area Sqkm.
Built up area	Residential	20.10
	Commercial	4.70
	Public and Semi Public	0.46
	Industrial	2.08
Open Lands	Recreational/Green belt	
	Agriculture	
Water Bodies & Ponds		

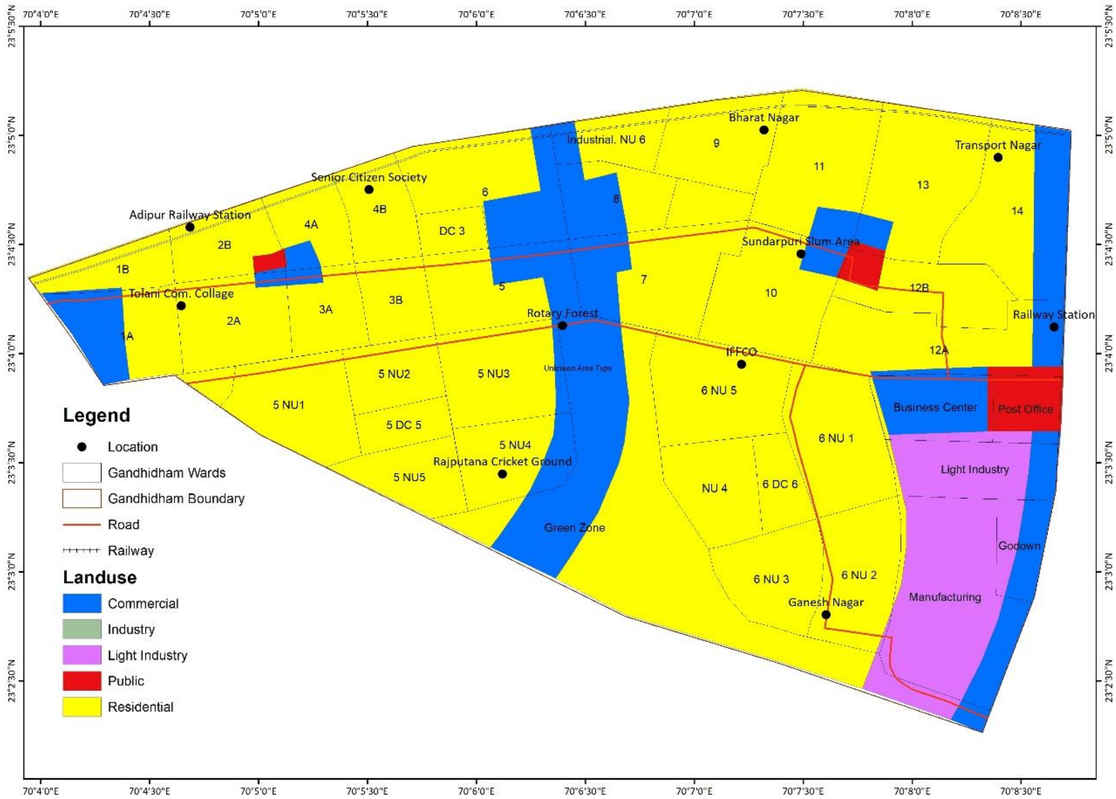


Figure 2.3 Land Use Map of Gandhidham City

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 Gandhidham 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 a critical factor influencing surface runoff and infiltration processes. The slope and its spatial distribution play a key role in characterizing watershed basins and assist in identifying areas as either recharge or discharge zones. Additionally, slope conditions significantly influence land-use patterns. In this study, slope and slope aspects were analyzed using DEM (Digital Elevation Model) interpretation through GIS software. The analysis revealed that the entire Gandhidham city area has a slope of less than 2°.

3.2 Physiography and Landform

Terrain features play a fundamental role in the distribution and development of water resources within a region. Terrain not only influences recharge and runoff patterns but also significantly affects the socio-economic conditions of the local population. Gandhidham city is situated within the coastal plain physiographic division in the southwestern part of the region. The current landscape of Gandhidham is primarily shaped by exogenic geological processes that have been active since the Quaternary period.

The city's landforms are predominantly composed of Quaternary sediments, characterized mainly by clayey alluvial plains that gradually transition into mudflats near the coastline. Physiographically, the study area can be divided into two main units from east to west (as shown in Fig. 3.1): Predominantly clayey alluvium and Mudflats in the western region

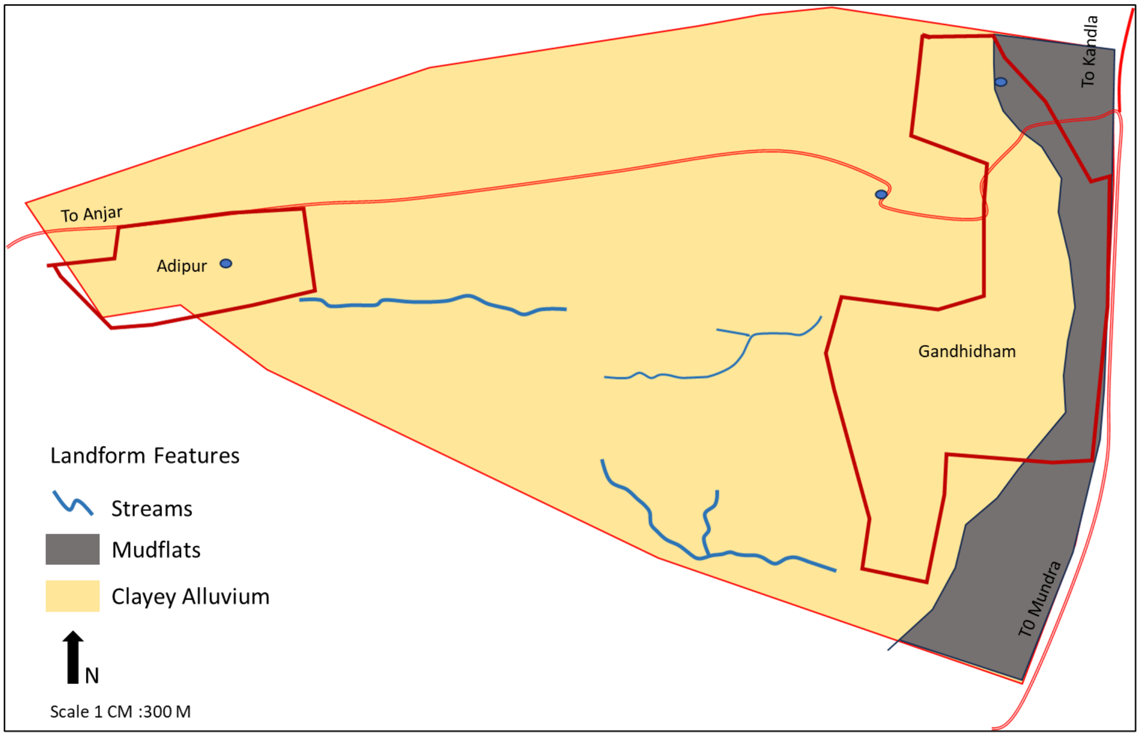


Figure 3.1 Geomorphological Characteristics of Gandhidham City

Clayey Alluvial Plains: The clayey alluvial plain is the dominant terrain unit in the city, characterized by relatively flat topography and a moderately thick accumulation of river-borne sediments. These deposits rest upon the Bhuj Formation of the Cretaceous period and the Deccan Lava of the Late Cretaceous to Paleocene period. This unit is notable for its fertile soils and favourable groundwater conditions, making it a productive agricultural zone (see Fig. 3.1).

Mudflats: The mudflats form a narrow strip along the western fringe of the city, consisting of dried marine sediments deposited during episodes of marine transgression. These areas border the alluvial plains and represent a sensitive coastal feature. However, recent development activities—such as the construction of roads and other infrastructure—have significantly restricted the natural tidal movement of seawater into this region.

3.3 Drainage and Watersheds

Due to the very flat terrain and gentle slopes, well-defined drainage systems have not developed in the Gandhidham region. However, a few small and shallow rivulets can still be traced, mainly resulting from local slope variations. These rivulets are classified as "lost rivers" because they originate and disappear within the plains, without reaching a larger water body.

Figure 3.2 shows the micro-watershed map of Gandhidham city. Three minor watersheds can be identified within the city area. All drainage flows generally from east to west but tends to disappear in the central part of the city, likely due to manmade obstructions such as roads and other infrastructure.

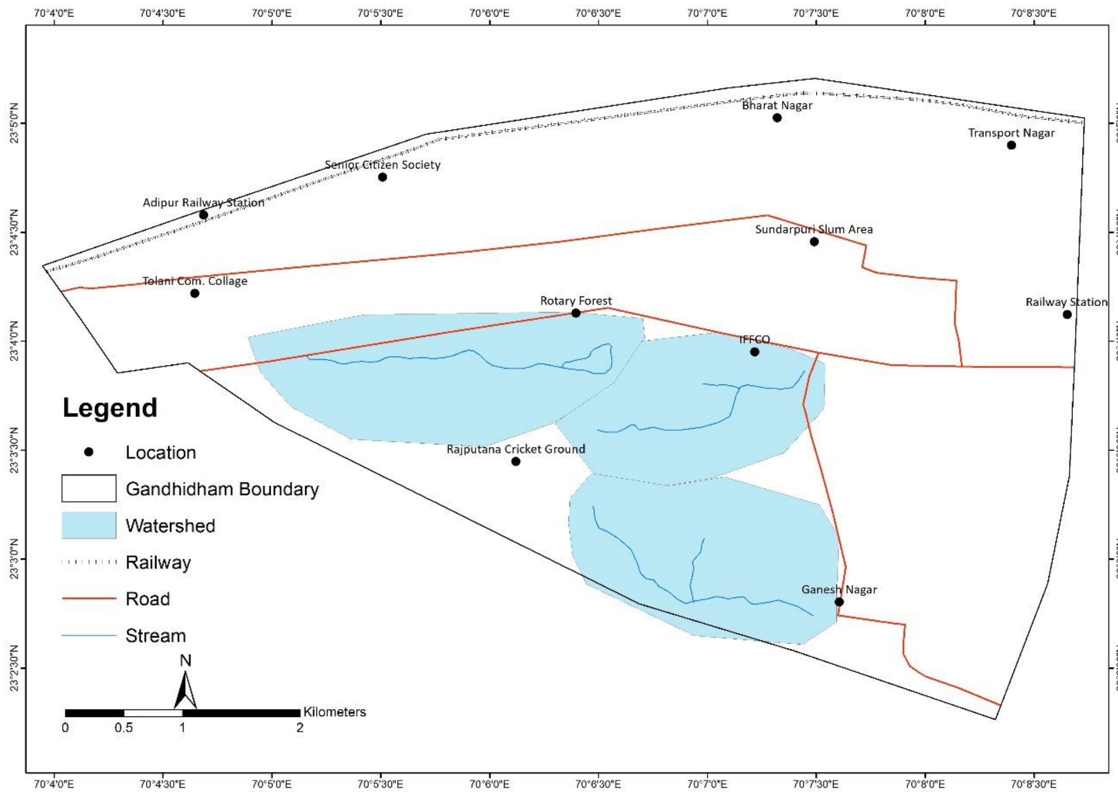


Figure 3.2 Drainage Map of Gandhidham

4 Geology

4.1 Regional Geology

The stratigraphy of the Kachchh region is notable for its complete sequence of rock layers ranging from the Middle Jurassic to the Holocene period, and for its rich fossil record, which has long intrigued earth scientists. A gap in deposition, followed by tectonic activity, erosion, and volcanic events at the end of the Upper Cretaceous period, separates the Mesozoic and Cenozoic rock formations in Kachchh. Volcanic activity during this time is represented by the Deccan Trap lava flows.

The Mesozoic rocks in the region include sedimentary layers dating from the Bathonian to Santonian ages (Biswas, 1970). Overlying these are the Cenozoic formations: the Tertiary rocks range from the Paleocene to Pliocene periods, while the Quaternary deposits include sediments from the Pleistocene and Holocene. Tectonic forces have uplifted and folded the Mesozoic layers, while surrounding them are gently sloping Tertiary rocks that form peripheral plains around the older formations (Biswas, 1980, 1982, 1987).

Researchers have compiled the regional geology of Kachchh by studying various physiographic divisions such as the Kachchh Mainland, Islands, Wagad Uplift, Banni, the Rann, and the coastal plains. However, since the current study is limited to Gandhidham city, the geological discussion is focused on the Gandhidham block area. Located within the coastal plains, Gandhidham mostly features geological formations from the Tertiary and recent periods.

Cenozoic – Tertiary Rocks: Kachchh is recognized as the "type area" for India's marine Tertiary rocks, which display a nearly complete stratigraphic sequence. Within the study area, the most prominent outcrops are the sandstones of the Kankavati Series and the clays of the Vinjhan Stage. Tongue-like extensions of Tertiary rocks are also seen cutting through the lower regions of the Mesozoic and Deccan Trap formations (Biswas, 1965).

Table 4.1 Mesozoic Chrono-stratigraphy of the Gandhidham Blocks area

Period	Time Scale	Rock Unit	Lithology
Recent	Holocene		Recent Deposits: Alluvium Rann silts and blown sands
-=-=-=-=- Unconformity -=-=-=-=-			
Tertiary	Pliocene	Kankavati Series	Fine grained Sandstone

(After Biswas, 1971 and Merh, 1995)

Quaternary Deposits: Exposures of Quaternary deposits are patchy and characterized by fluvio-marine and aeolian accumulation all along the coastline, Rann and in some inland areas. These include coastal marine sand and silt and aeolian miliolite dunal accumulations within the highlands. Sediments deposited in the form of alluvium in coastal plains and along the valley portions of localized rivers are recognized as Holocene deposits in the study region. By and large all these deposits are characterized as unconsolidated formations. Unconsolidated Sediments.

4.2 Geology of Study area

Surface geology wise Gandhidham City shows two main rock formations ranging from older to younger. The oldest formation exposed near city area is Kankavati sandstone majority of this sandstone occupies central and western part of the city that borders it with alluvium in eastern part of the city. Fig. 4.2 shows surface geological map of Gandhidham City while table 4.2 shows litho-stratigraphy sequence of Gandhidham city.

Table 4.2 Litho-Stratigraphy Sequence of Gandhidham City

Period	Time Scale	Rock Unit	Lithology
Recent	Holocene		Recent Deposits: Alluvium Rann silts and blown sands
Tertiary	Pliocene	Kankavati Series	Fine grained Sandstone

(After Biswas, 1971)

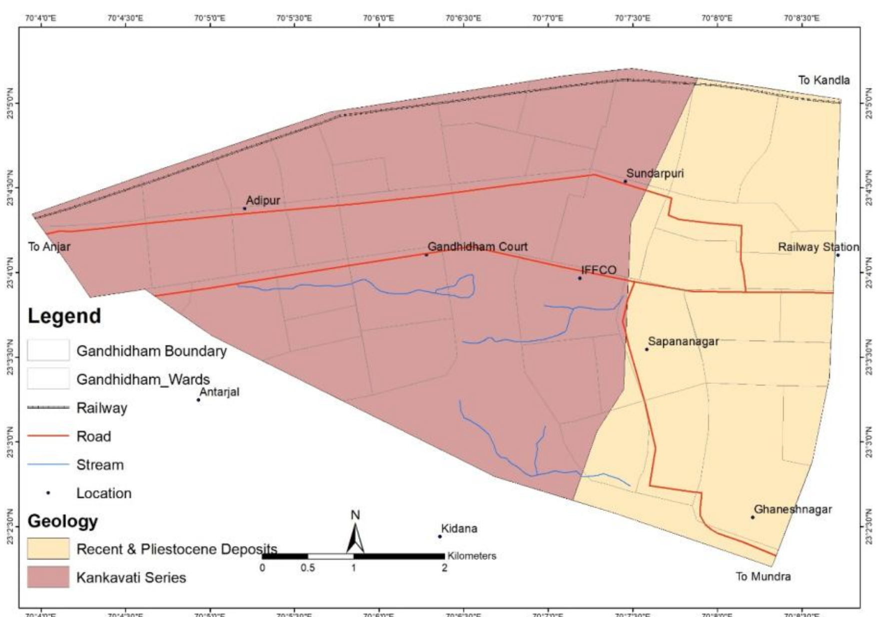


Figure 4.1 Surface Geological Map of Gandhidham City

5 Geohydrology

5.1 Groundwater Occurrence and Distribution

The occurrence of groundwater depends on several factors related to a region's hydro-meteorological and hydro-geological conditions. Hydro-meteorological parameters, such as rainfall and climate, determine the amount of water input, while hydro-geological factors influence groundwater movement, storage, and quality.

As previously mentioned, the geological setting of Gandhidham city is largely influenced by semi-consolidated sedimentary rocks and various geomorphic units. As a result, groundwater availability varies depending on the lithological sequence, with sources ranging from shallow to deep aquifers.

To study groundwater occurrence in the Gandhidham area, a detailed inventory of 16 wells was conducted, including lithological data from all surveyed tubewells (refer to Fig. 5.1 and Tables 5.1 & 5.2). Additionally, discussions with drillers were held to gain practical insights into subsurface geological conditions based on their field experience.

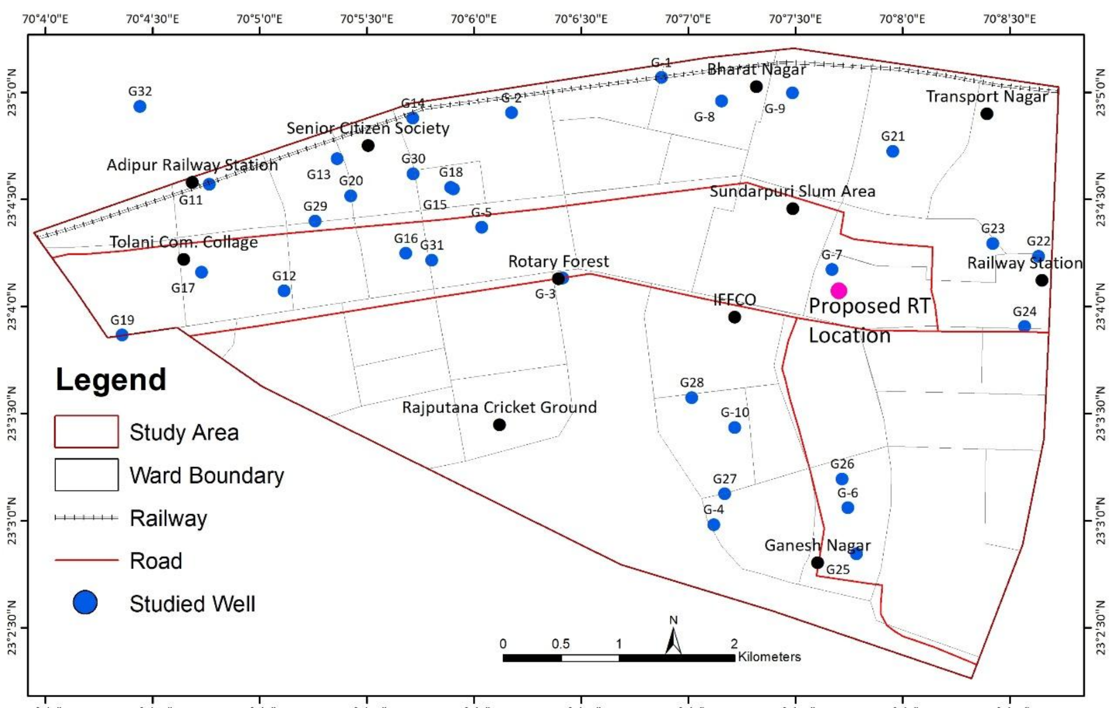


Figure 5.1 Locations of Studied Wells

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 adopting synthesizing of various thematic layer approach groundwater potential zones of city has been defined to frame strategies for water management for respective potential zone for the city. Following is a description of the various geohydrological characteristics of the city.

Table 5.1 Studied Well Information

Code	Owner	Static Water Level (Depth) (M)			Reduced Water Levels		
		Year 2023		Year 2024	Year 2023		Year 2024
		Pre	Post	Pre	Pre	Post	Pre
G-1	Odhavram Vastu Bhandar	16.2	8.2	15.6	10.8	18.8	11.4
G-2	Darsh Water Supply	16.8	8.45	17.4	13.2	21.6	12.6
G-3	Rotary Forest	19.8	19.9	20.3	5.2	5.1	4.7
G-4	Sector 7	16.8	17.35	17.2	1.2	0.6	0.8
G-5	Shivam Water Supply	16.5	17.1	17.0	11.5	10.9	11.0
G-6	Ganesh Nagar Society	12.2	14.2	12.8	4.8	2.8	4.2
G-7	Shaktinagar	12.8	14.1	13.5	9.2	7.9	8.5
G-8	Chavda Mineral Water	17.1	14.3	16.5	8.9	11.7	9.5
G-9	Maheshwari Nagar	18.3	17.2	18.6	7.7	8.8	7.4
G-10	Shisanjal Beverages	19.8	17.8	20.1	2.2	4.2	1.9
G11	Near Railway Station	14.6	14.7	15.4	21.4	21.3	20.6
G12	Sindh Varsha	15.2	15.35	15.8	20.8	20.7	20.2
G13	Mukeshbhai Mali	15.9	16.05	16.4	17.1	17.0	16.6
G14	Zulelal Enterprise	14.9	14.9	15.4	15.1	15.1	14.6
G15	Ashapura Water supply	14.6	23.8	15.1	15.4	6.2	14.9
G16	Opp. St. Xaviers School	8.5	11.2	8.9	23.5	20.8	23.1
G18	DR. Rohitbhai	--	5.3	13.7	--	26.7	18.28
G19	Ramjan Bhai Sangar	--	13.7	15.2	--	23.3	21.76
G20	Sachin Ahir	--	12.2	16.8	--	20.8	16.23
G21	Din Dayal Port colony garden	--	13.7	7.6	--	7.3	13.38
G22	Mohamad Arif Vora	--	6.10	6.1	--	10.9	10.90
G23	Karimbhai	--	4.57	--	--	13.4	--
G24	Hotal Aarti international	--	12.19	9.1	--	4.8	7.85
G25	Karmsi Devji Dheda	--	6.1	12.2	--	10.9	4.80
G26	Om Manishbhai Maru	--	9.1	13.7	--	7.9	3.28
G27	Babubhai Kutan	--	10.6	10.7	--	8.4	8.33
G28	Pratabhbhai Khinival	--	12.1	15.2	--	10.9	7.76
G29	Shamjibhai Ahir	--	10.6	13.7	--	24.4	21.28
G30	Nikhilbhai Gyanchand	--	12.1	15.2	--	15.9	12.76
G31	Ro Water	--	13.7	16.8	--	19.3	16.23
G32	Akbar Harun Kumbhar	--	15.24	--	--	20.8	--

5.2 Aquifers

Borehole logs provide valuable insights into subsurface hydrogeology, helping to determine (i) the thickness and lateral extent of aquifers, and (ii) vertical litho-facies changes that indicate aquifer types and hydrostatic pressure levels. Data for this study were collected from well inventories and borehole logs provided by the State Water Resource Departments, including GWRDC and GWSSB. Using this lithological data, a subsurface hydrogeological profile was developed (see Fig. 5.2). The main aquifers identified in Gandhidham city are shallow sandy clay layers and the Kankavati Sandstone. Table 5.3 presents the aquifer sequence in the study area.

Table 5.2 Depth wise Type of Aquifer Occurrence in Gandhidham City

Layer Type	Depth (M)	Thickness (M)	Remark	Type
Black and grayish clay	0-3	3	Clay	Shallow
Sandy soil mixed with Pebble & gravels	2-12	9	Very Good Shallow Aquifer Loose formation	
Fine clay	12-42	30	No Aquifer	Shallow
Kankavati Sandstone	42-75	33	Very Good aquifer Kankavati Sandstone	Shallow and confined
Clay mud	30-72	42	No Aquifer	Aquiclude

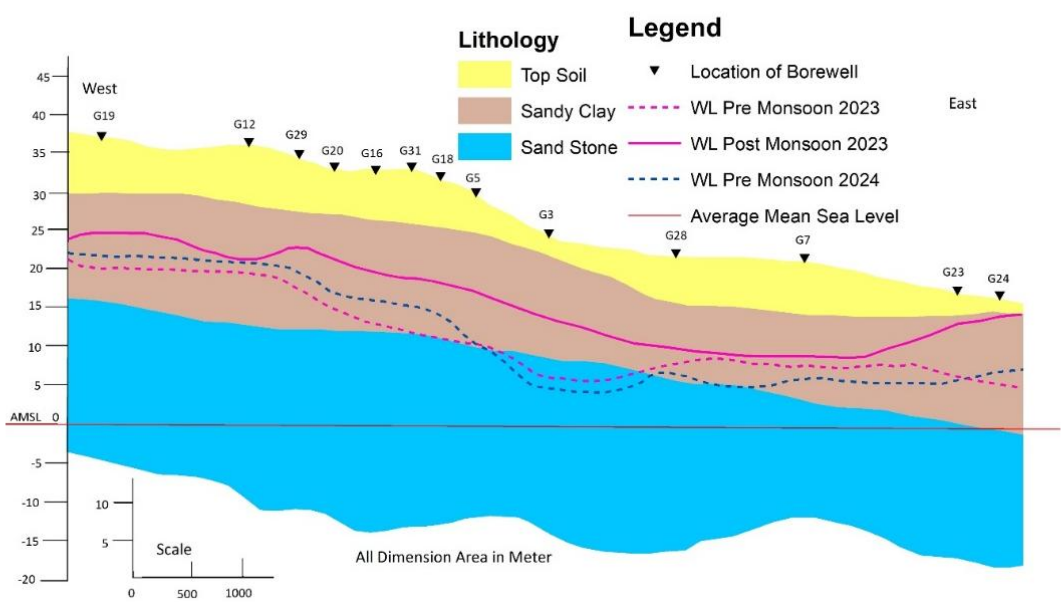


Figure 5.2 Relationship Between Subsurface Litholog and Seasonal Water Levels of in Gandhidham City

5.2.1 Shallow – Unconfined Aquifer Systems

These aquifers are mostly unconfined and contain saline groundwater. Right after the monsoon, water quality is moderately good but gradually becomes more saline by the pre-monsoon period. Additionally, these aquifers are prone to contamination from sewage leaks and infiltration of polluted water during the monsoon. Such shallow aquifers are mainly found in the sandy soils of the western part of Gandhidham city.

5.2.2 Deep Aquifer - Confined Aquifer Systems

The deeper aquifer systems in Gandhidham City are mainly composed of thin, fine-grained Kankavati Sandstone. This formation lies beneath clay layers, starting at a depth of around 36 meters, and can reach up to 40 meters in thickness in some areas. Groundwater quality within this sandstone varies with depth—while the upper portions may have usable water, deeper sections often contain highly saline water, making it unsuitable for most purposes.

5.3 Water Levels

Gandhidham 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.

A large part of the study area has well-developed confined aquifers, which serve as the main source of groundwater. Although the unconsolidated sediments in the city have good potential for storing groundwater, they often face water quality issues due to seawater intrusion and the natural salinity from nearby marine formations. Additionally, since the area is part of a shared aquifer system, groundwater levels and quality are heavily affected by excessive extraction for agriculture, as well as domestic and industrial use.

To understand groundwater level behavior, 31 wells were surveyed, and water level measurements were taken during the pre- and post-monsoon seasons for the years 2023 and 2024 (Table 5.1). This data was used to create hydrographs and maps showing groundwater status and trends, including:

Static Water Level Maps – to show the depth of water levels during different seasons

Reduced Water Level Maps – to identify groundwater **flow directions** across seasons

Additionally, this seasonal water level data was used to estimate groundwater availability and assess withdrawal rates within the project area.

5.3.1 Static Water levels

Studying groundwater level fluctuations is a crucial part of geohydrological investigations. These fluctuations are influenced by a range of factors, including climatic conditions (such as precipitation and evaporation), geological settings (type, composition, and position of aquifers), and terrain features (like slope, drainage, landforms, and land use), all of which affect how water infiltrates and runs off the land. Additionally, groundwater usage patterns are important indicators of how sustainably the resource is being managed.

According to Todd (1959), groundwater level changes can be categorized into three types:

- **Seasonal changes**
- **Short-term (vectoral) changes**
- **Long-term (secular) changes**

For this study, the focus is on seasonal changes in groundwater levels to evaluate the water resource status in the study area.

Understanding the depth of water levels is essential to assess groundwater occurrence and availability. To support this, static water level maps, hydrographs, and geological profiles were developed. Iso-static water level maps were prepared using GIS software for the pre- and post-monsoon seasons of 2023 and the pre-monsoon season of 2024, with depth contours created at five-meter intervals.

The city's groundwater depth was then classified into four depth zones:

- 0–5 m
- 5–10 m
- 10–15 m
- 15–20 m

Based on these maps, zone-wise area calculations were carried out for each season, as shown in Table 5.3. To analyze seasonal and annual changes, the area covered by each depth zone was compared across the 2023 pre- and post-monsoon seasons, as well as between the 2023 and 2024 pre-monsoon seasons.

The results, including increases or decreases in the extent of each depth category, are presented in Table 5.3 and illustrated in Figure 5.3.

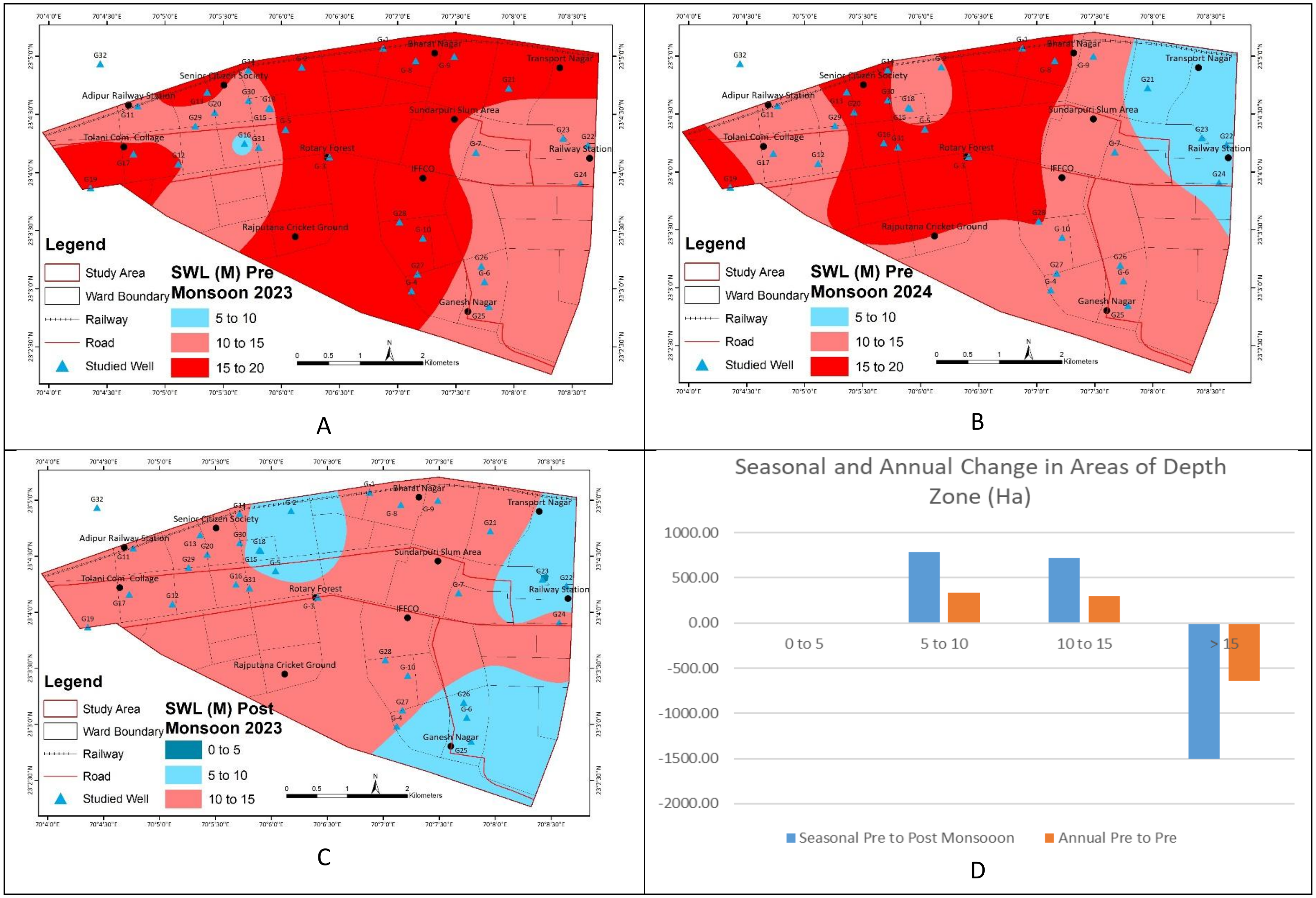


Figure 5.3 Map Showing (A) Pre-Monsoon & (B) Post Monsoon of Year 2023 and (C) Pre-Monsoon of Year 2024 Static Water Levels and (D) Seasonal and Annual Change in Area of Each Depth zone in of Gandhidham City

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

Depth Zone	Area in SQKM				
	Year 2023		Seasonal Change	Year 2024	Annual Change
	Pre	Post		Pre	
0 – 5 M	0	1.14	1.14	0	0
5 – 10 M	7.47	791.70	784.23	345.54	338.10
10 – 15 M	1227.36	1945.74	718.38	1526.93	299.57
15 – 20 M	1503.75	0.00	-1503.75	866.12	-637.60
Total	2738.58	2738.58		2738.58	

The Iso-Static Water Level (ISO-SWL) maps show that groundwater depth throughout the city remains less than 20 meters in all seasons. Based on the comparison of mapped areas and calculated data, the following conclusions can be drawn regarding water level changes in the city.

Key findings from the above analysis:

Groundwater Depth Overview: Groundwater levels across the entire city are found at depths of less than 20 meters.

Seasonal Changes in Groundwater Levels:

- During the post-monsoon season of 2023, about 1.14 hectares of area showed a rise in water levels, reaching depths of less than 5 meters.
- Two depth zones, 5–10 m and 10–15 m, showed an increase in area coverage by 784 hectares and 718 hectares, respectively.
- The Iso-Static Water Level (ISO-SWL) map for the post-monsoon season of 2023 (Fig. 5.3 D) indicates that the water level rise occurred mainly in the north, northeast, and southeast parts of the city.

Persistence and Annual Changes

- The northeastern part of the city experienced a prolonged effect of rising water levels, remaining evident even during the pre-monsoon season of 2024 (Fig. 5.3 C).
- Annually, the area within the 15–20 m depth zone has reduced by 637 hectares, indicating a significant rise in groundwater levels compared to 2023.
- The northeast part of the city shows shallower water levels during the pre-monsoon season of 2024 compared to the same period in 2023.

5.3.2 Reduced Water Levels

Groundwater levels fluctuate with the seasons, directly reflecting changes in groundwater storage. A rise in water level indicates an increase in storage, while a fall shows depletion. Studying the spatial distribution of water levels is an important part of geohydrological investigations. Just like topography and geological features control the spread of aquifers, groundwater behavior—such as flow direction and gradient—can be understood through spatial analysis.

Water level data from observation wells were adjusted using GPS-based ground elevation measurements at each well. These adjusted values, called Reduced Water Levels (RWL), were then used to create RWL contour maps for the pre- and post-monsoon seasons of 2023 and 2024 (Fig. 5.4).

These seasonal maps were further analyzed to determine groundwater flow directions, helping to identify recharge and discharge areas in different seasons. Additionally, the area covered by different RWL zones was calculated. Since reduced water levels indicate the height of the water table relative to mean sea level, this analysis helps check if groundwater levels drop below sea level—a concern for Gandhidham city due to its coastal location. Table 5.5 presents the RWL zones and their respective areas for each season.

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

Sr. No.	RWL Zones (M)	Area (Ha)		
		2023		2024
		Pre- Monsoon	Post- Monsoon	Pre- Monsoon
1	0 to 5	463.87	0.60	218.09
2	5 to 10	1433.52	877.93	690.09
3	10 to 15	263.34	771.61	1110.70
4	15 to 20	244.06	530.25	453.67
5	20 to 30	333.79	558.19	266.03
Total		**2738.58**	**2738.58**	**2738.58**

Key findings from the above analysis:

Seasonal Groundwater Flow Patterns

- During the pre-monsoon season of 2023, groundwater flow was observed primarily from the west to south direction.
- In contrast, the pre-monsoon season of 2024 showed a bifurcated flow pattern, with water moving from the central part of the city towards both the southeast and northeast directions.

- In the post-monsoon season, overall groundwater flow was directed eastward, with a minor subsurface low observed in the eastern part of the city. A valley-like condition also developed in the northeast, where groundwater flowed towards the central part of the 10 m RWL contour.

Subsurface Low Conditions

- Reduced Water Level (RWL) maps indicate subsurface low zones occurring in different parts of the city across seasons:
    - In the post-monsoon season of 2023, a low zone developed in the central-eastern part of the city.
    - During the pre-monsoon season of 2023, another low zone was observed in the northeastern part.

Potential Risk of Seawater Intrusion

- Table 5.4 shows that an area of approximately 470 hectares in 2023 and 218 hectares in 2024 falls within the 0–5 m RWL zone during pre-monsoon seasons.
- This is a critical indicator, suggesting that continued or increased groundwater withdrawal could potentially lead to seawater intrusion, especially given Gandhidham's proximity to the coast.

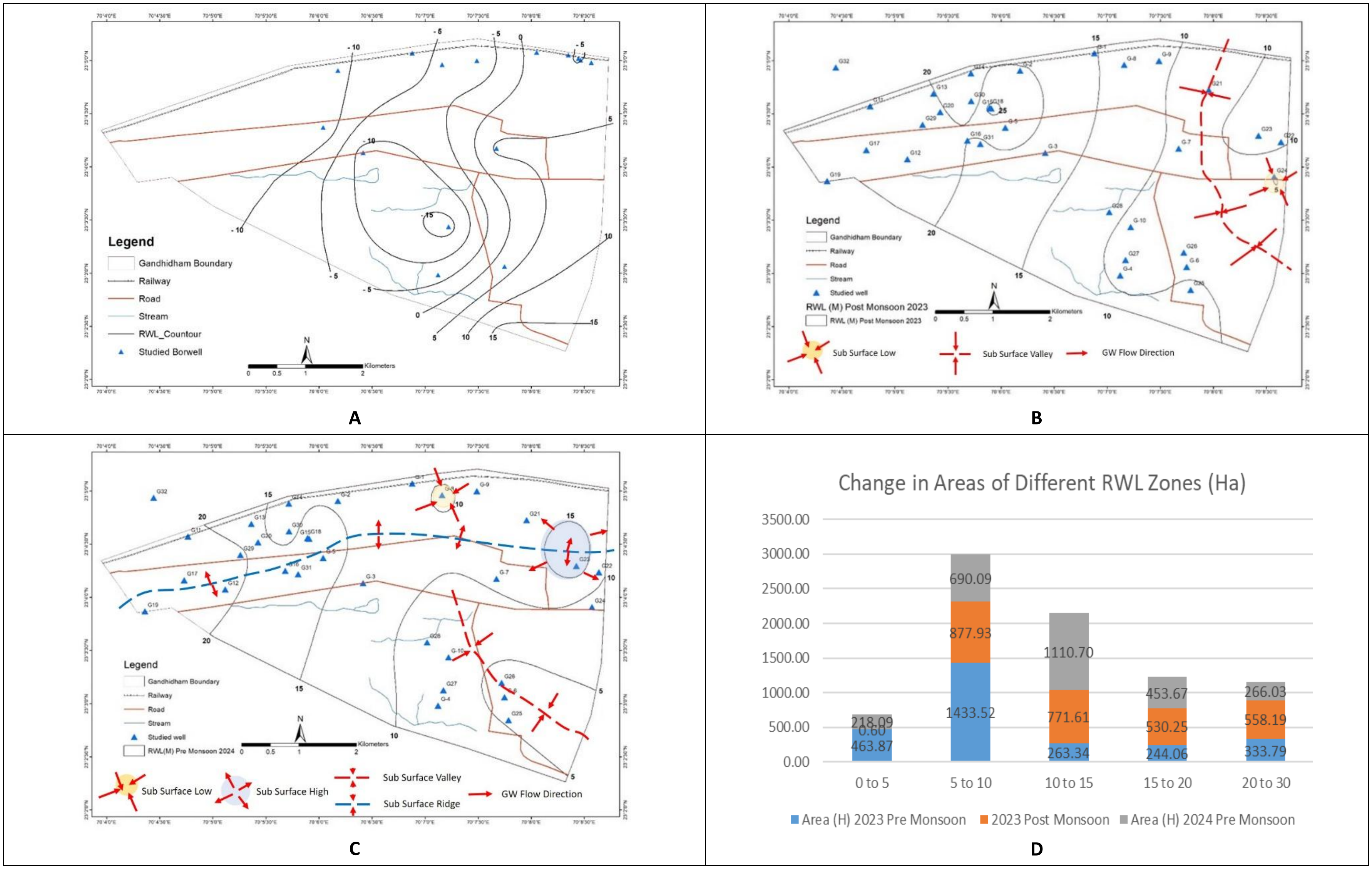


Figure 5.4 Map Showing (A) Pre-Monsoon & (B) Post Monsoon of Year 2023 and (C) Pre-Monsoon of Year 2024 Static Water Levels and (D) Seasonal and Annual Change in Area of Each RWL Zone in of Gandhidham City

5.3.3 Seasonal and Annual Groundwater Level Changes

Seasonal and annual changes in groundwater levels were analyzed by comparing the rise and fall of water levels in observation wells. To estimate seasonal changes, static water level data from the pre-monsoon season was compared with that of the post-monsoon season in 2023, and a rise-and-fall map was created (Fig. 5.5). Based on these changes, the city was divided into four categories: **Depleting areas** — water levels falling by more than 2 meters; **Balanced or marginally rising areas** — water levels rising up to 2 meters; **Moderately rising areas** — water levels rising between 2 to 4 meters and **Highly rising areas** — water levels rising by more than 4 meters. Table 5.5 presents the distribution of the city's area according to these categories.

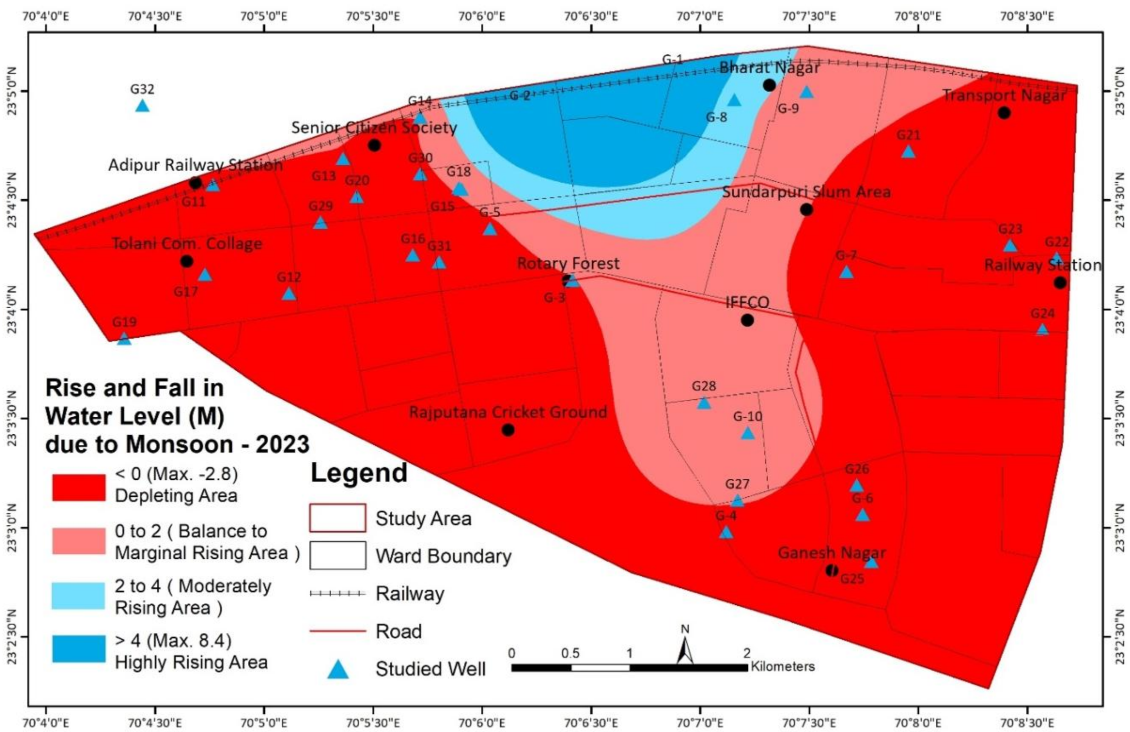


Figure 5.5 Map Showing Rise and Fall in Groundwater Levels in From Pre to Post Monsoon Season in Different Part of Gandhidham City, Year 2024

Table 5.5 Distribution of City Area in Respective Groundwater Change Category

Sl.	Category	Change in Water Level (M)	Area (Ha)
1	Depleting areas	< 0	1899.03
2	Balanced or marginal rising areas	0 to 2	559.22
3	Moderately rising areas	2 to 4	125.35
4	Highly rising areas	> 4	154.98
Total			**2738.58**

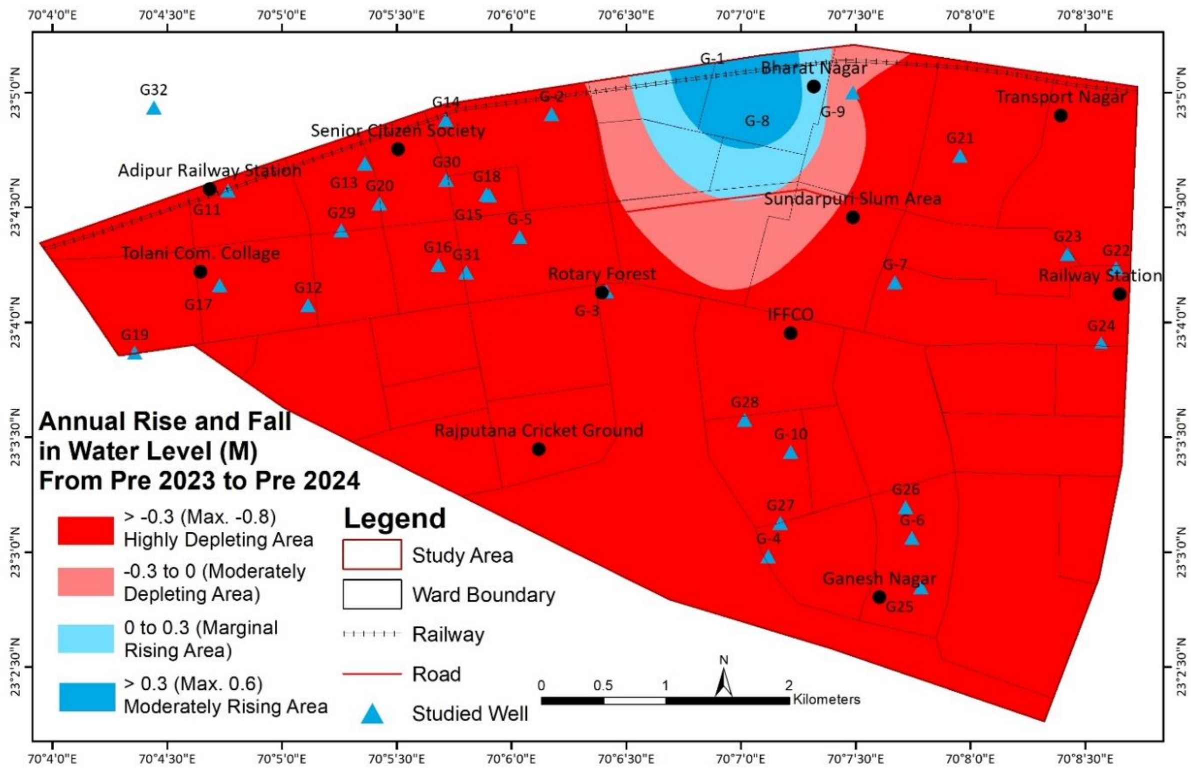


Figure 5.6 Map Showing Rise and Fall in Groundwater Levels in From Pre to Pre Monsoon Seasons of years 2023 and 2024 in Different Part of Gandhidham City

5.4 Groundwater Quality

The chemical composition of groundwater results from various reactions and processes acting on it—from condensation in the atmosphere to its discharge at the surface, either as surface or subsurface flow. Natural water chemistry is influenced by soluble minerals released from weathered and decomposed rocks. Generally, groundwater contains higher concentrations of dissolved constituents compared to surface water, due to its prolonged contact and interaction with subsurface materials (Davis & DeWeist, 1967). Therefore, groundwater quality is a critical factor in water resource development and planning.

In the case of Gandhidham city, groundwater quality is influenced not only by the local rock formations but also significantly by its location in a coastal plain. Naturally, heavy rainfall on the clayey strata often causes waterlogging, while excessive groundwater extraction leads to seawater intrusion into the aquifers. Besides these natural factors, several human activities also impact groundwater quality, including improper management of sewage and stormwater, poor solid waste disposal, and discharge of polluted water from industrial areas.

The main objectives of groundwater quality study for Gandhidham 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.

A total of 10 water samples were collected from different locations and analyzed to determine the chemical concentrations in groundwater. The same locations were sampled again during the post-monsoon season to assess changes caused by rainfall. To evaluate groundwater quality, key hydrochemical parameters such as pH, TDS, alkalinity, and hardness were measured. Additionally, ionic concentrations of calcium, magnesium, nitrate, sulphate, chloride, and fluoride were analyzed.

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

Parameter		pH	TDS (mg/l)	Alkalinity (As CaCO3) (mg/L)	hardness (As CaCO3) (mg/L)	Calcium (mg/l)	Magnesium (mg/l)	Chloride (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)
Code	**Permissible**	**6.5**	**500**	**200**	**200**	**75**	**50**	**250**	**200**	**45**	**1**
	Maximum	**8.5**	**2000**	**600**	**600**	**200**	**150**	**1000**	**400**	**Not Relaxation**	**1.5**
G-1	**Pre**	7.59	1560	295	360	68	46.17	532	171.4	5.8	0.35
	Post	7.65	2050	265	324	56	22	1676	0	6.8	0.25
G-2	**Pre**	7.4	2090	450	680	134	83.84	654	214.8	18.5	0.1
	Post	7.6	750	135	590	48	26	2080	0	12.3	0.1
G-3	**Pre**	7.74	312	95	120	44	2.43	89	34.2	5.8	0.1
	Post	7.35	280	85	95	26	14	927	518	6.3	0.1
G-4	**Pre**	7.43	1476	360	490	96	60.75	425.4	168.1	20.5	0.25
	Post	7.49	1750	320	365	63	42	2013	0	15.3	0.25
G-5	**Pre**	7.4	3870	680	610	92	92.34	1524	314.8	5.5	0.1
	Post	7.98	3530	570	590	17	13	710	59	3.2	0.1
G-6	**Pre**	7.8	314	90	160	40	14.58	85.5	32.1	5.8	0.1
	Post	7.68	1470	120	190	24	13	568	627	6.2	0.1
G-7	**Pre**	7.6	462	107.5	210	60	14.58	141.8	35.2	20.5	0.4
	Post	7.81	454	105	215	22	4	838	382	19.5	0.25
G-8	**Pre**	7.3	2790	510	440	84	55.89	1081	277.4	12.4	0.3
	Post	7.89	2640	495	425	27	18	941	321	11.2	0.25
G-9	**Pre**	7.64	3780	625	520	80	77.76	1595	304.6	15.7	0.4
	Post	7.94	950	415	390	21	45	1420	20	12.7	0.4
G-10	**Pre**	7.53	666	135	280	80	19.44	230.43	56.4	15	0.5
	Post	7.68	1860	165	340	31	30	689	125	11	0.5

Table 5.6 presents the groundwater analysis results for Gandhidham city during the pre- and post-monsoon seasons of 2023, while Table 5.7 provides a statistical overview of the percentile changes of these parameters compared to permissible limits. Detailed discussions on each parameter follow below.

5.4.1 Hydrogen Ion Concentration (pH)

pH is a measure of the solvent power of water. The pH value of water represents the overall balance of a series of equilibria existing in solution (Hem, 1991). The pH of natural water is largely controlled by chemical reactions and equilibria among the ions in solution. The most important type of reaction affecting pH in natural water is hydrolysis, which is due to predominance of carbonate and bicarbonate salts. In natural waters the hydrolysis due to carbonate and bicarbonate salts predominates in most instances, due to this pH value tends to rise above 7 (Ageno and Valla, 1911). In study area almost all water samples show pH value more than 7 thereby, indicating predominance of hydrolysis reaction due to the presence of carbonates and bicarbonates. The pH value of groundwater in study area in different catchments ranges from 7.3 to 7.8 during pre-monsoon season while 7.35 to 7.98 during post monsoon season.

5.4.2 Total Dissolved Solids (TDS)

Specific conductance measures the amount of dissolved solids in water, commonly referred to as Total Dissolved Solids (TDS), and is a key indicator for quickly assessing water quality. Generally, groundwater in Gandhidham city has high TDS levels. During the pre-monsoon season, TDS ranges from 312 mg/l to 3,870 mg/l, while in the post-monsoon season, it varies between 280 mg/l and 3,530 mg/l.

To better understand the trends and spatial distribution of TDS, iso-TDS maps for the pre- and post-monsoon seasons were prepared (Fig. 5.7). The western and northern parts of the city exhibit higher TDS concentrations during the pre-monsoon season, while during the post-monsoon period, increased TDS is observed in the northeastern and southwestern areas. This rise in TDS may be attributed to the sedimentary formations of marine origin in the groundwater recharge zones.

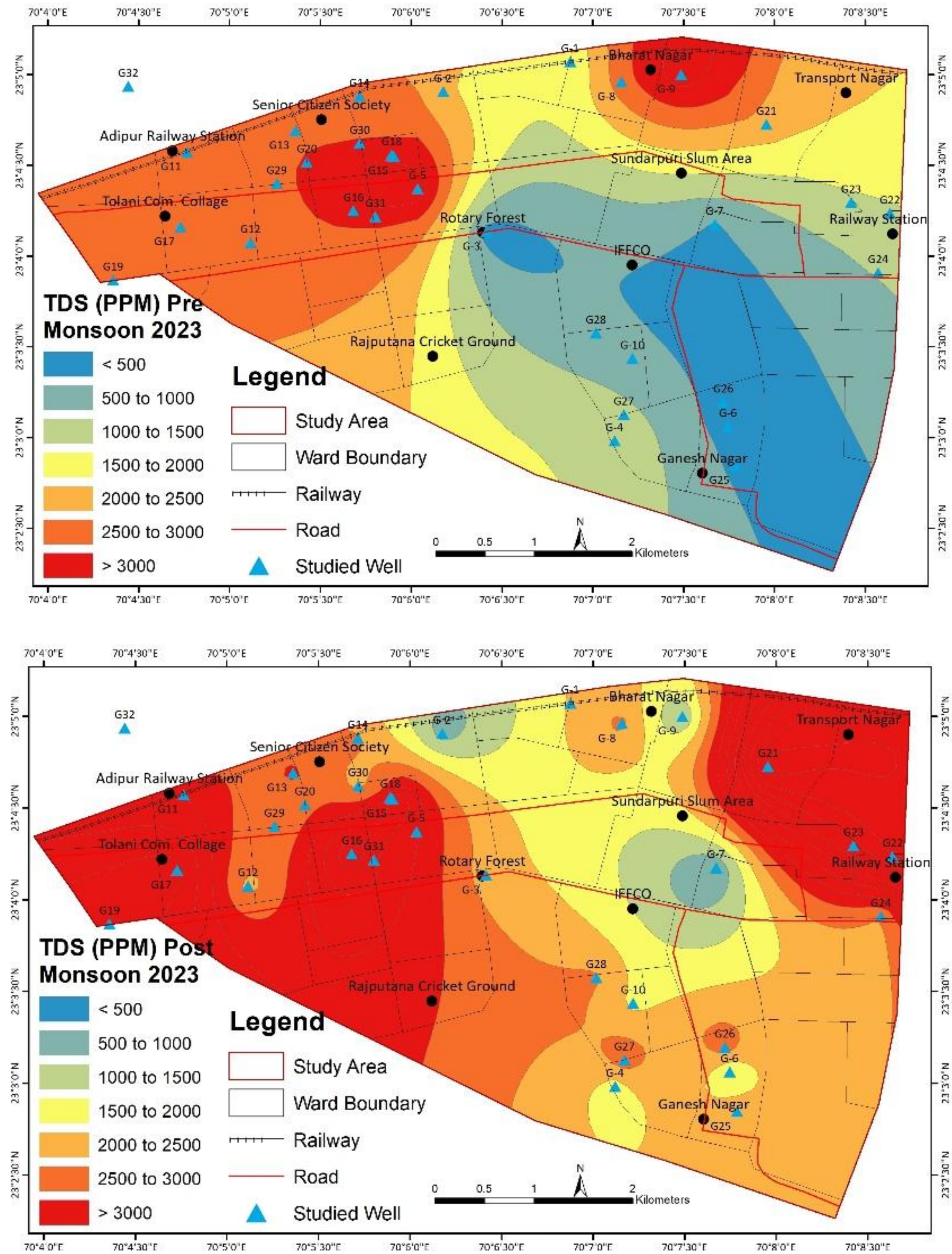


Figure 5.7 Map showing Pre & Post Monsoon TDS Concentrations in Gandhidham City (Year 2023)

5.4.3 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 Gandhidham, the lowest calcium concentration of 40 mg/l was recorded in observation well G6 in the Ganeshnagar area during the pre-monsoon season, while the highest concentration of 134 mg/l was observed in well G2. During the post-monsoon season, calcium levels ranged between 17 mg/l and 63 mg/l.

***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 Gandhidham ranges from 2 mg/l to 92 mg/l before monsoon and 45 mg/l to 225 mg/l after monsoon.

Sulfate (SO_4^{-2}): Sulfur in water mainly occurs as sulfate (SO_4). High sulfate levels are common in arid and semi-arid regions, where rainfall often carries sulfate from airborne dust, especially over gypsiferous soils (Hem, 1959). Fine-grained sediments usually have poor groundwater flow but can still contribute highly mineralized seepage with significant sulfate to nearby aquifers. In Gandhidham, sulfate concentrations range from 32 to 314 mg/l during the pre-monsoon season and from 0 to 627 mg/l in the post-monsoon season.

Chloride (Cl^{--}): Sedimentary rocks, especially evaporites, are a major source of chloride in groundwater. Chloride typically comes from trapped ancient seawater, called connate water, found in deposits that formed under the sea or in closed basins (Hem, 1991). When porous rocks are submerged by the sea after forming, they absorb soluble salts like chloride. Compared to sulfate, chloride is the dominant anion in the groundwater of Gandhidham City. Chloride concentrations range from 8 to 1,595 mg/l during the pre-monsoon season and 568 to 2,068 mg/l in the post-monsoon season.

Statistical analysis of pre- and post-monsoon seasons reveals that water quality parameters such as TDS, alkalinity, hardness, chloride, and sulfate exhibit noticeable changes between the two seasons (Table 5.7). Among the analyzed parameters, TDS, hardness, alkalinity, chloride, and sulfate vary within permissible limits during pre- and post-monsoon periods. However, fluoride, nitrate, and cation levels show no significant change in groundwater quality.

Table 5.7 Statistical Analysis of Changes in Concertation in number of Samples Collected During Pre and Post Monsoon Season of Year 2023, in Gandhidham City

Parameter	Pre-Monsoon Season				Post Monsoon Season			
	Within Limit		Beyond Limit		Within Limit		Beyond Limit	
	No	%	No	%	No	%	No	%
pH	10	100	0	100	10	100	0	0
TDS (mg/l)	6	60	4	40	7	70	3	30
Alkalinity (As CaCO3) (mg/L)	8	80	2	20	10	100	0	0
hardness (As CaCO3) (mg/L)	8	80	2	20	10	100	0	0
Calcium (mg/l)	10	100	0	0	10	100	0	0
Magnesium (mg/l)	10	100	0	0	10	100	0	0
Chloride (mg/l)	7	70	3	30	4	40	6	60
Sulphate (mg/l)	10	100	0	0	8	80	2	20
Nitrate (mg/l)	10	100	0	0	10	100	0	0
Fluoride (mg/l)	10	100	0	0	10	100	0	0

6 Water Balance analysis of Gandhidham 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.

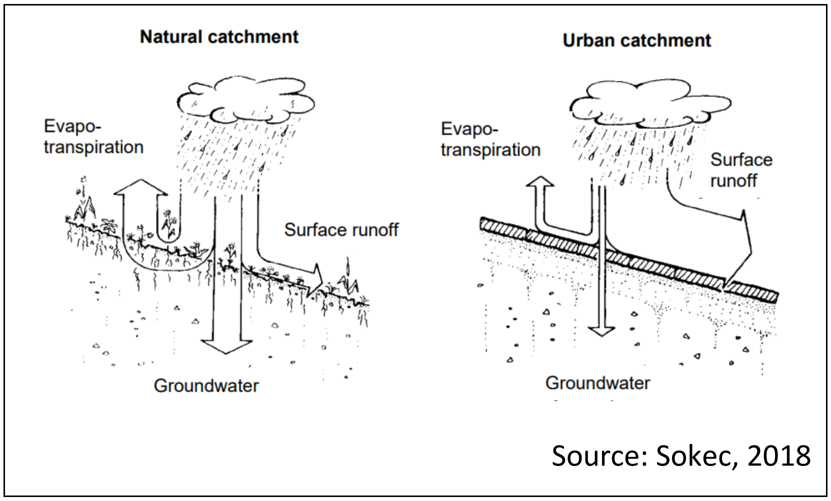


Figure 6.1 Conceptual Representation of Differences in Hydrological Cycle in Natural and Urban Catchment

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.

To understand Gandhidham'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 Gandhidham city water balance estimation is explained in Fig. 6.2.

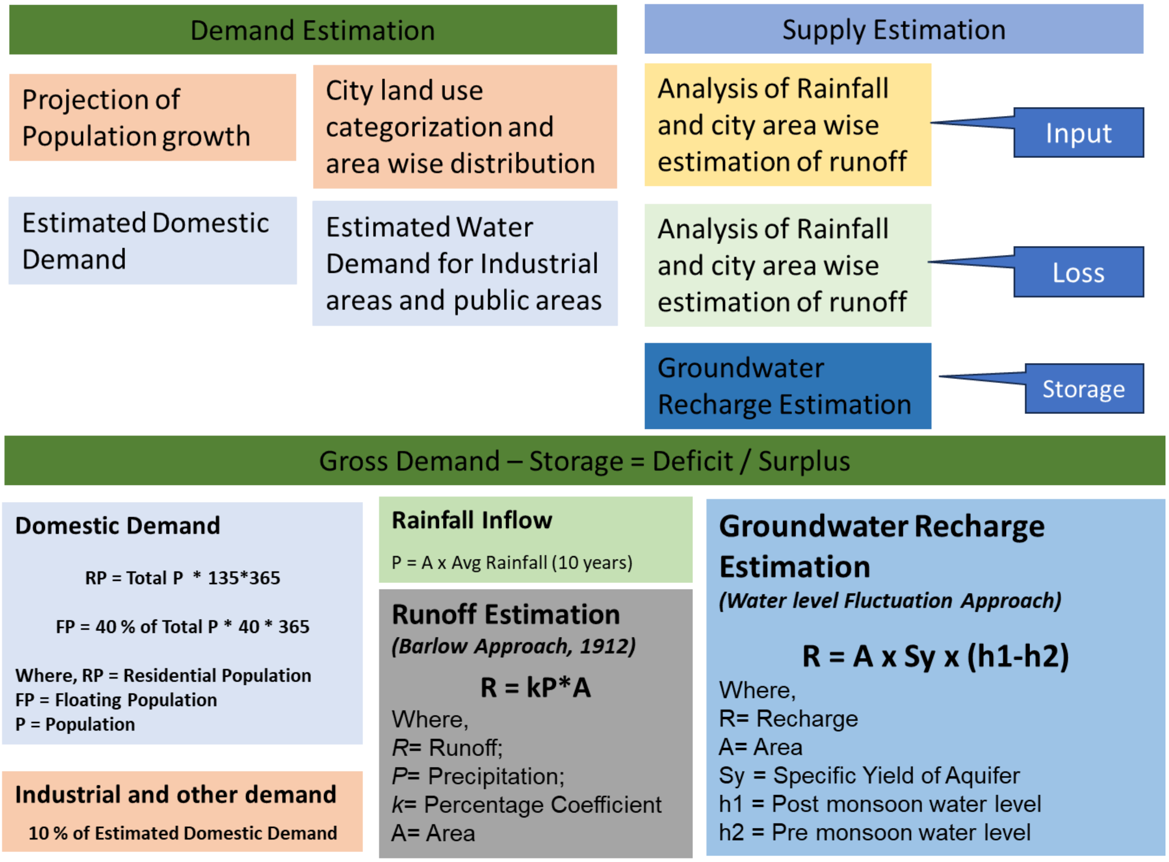


Figure 6.2 Methodology Adopted for Water Balance Estimation of Gandhidham city

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, such as the water supply board. 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 Gandhidham was calculated. This comprehensive approach allows for a more accurate representation of the city's water requirements.so far Gandhidham city is concerned its current population as per population census data, is 3,50,000 that was 2,47,992 persons in year 2011. Based on this 2.93 % annual growth rate of growth has been estimated and accordingly population for year 2050 has estimated (Table 6.2) that stands at 7,41,582 persons.

Table 6.1 Project Population for Gandhidham City up to Year 2050

Year	Project Population @ 2.93 %/Year	Year	Project Population @ 2.93 %/Year	Year	Project Population @ 2.93 %/Year
2024	350000	2033	453885	2042	588604
2025	360255	2034	467184	2043	605851
2026	370810	2035	480872	2044	623602
2027	381675	2036	494962	2045	641874
2028	392858	2037	509464	2046	660680
2029	404369	2038	524392	2047	680038
2030	416217	2039	539756	2048	699963
2031	428412	2040	555571	2049	720472
2032	440965	2041	571849	2050	741582

- **Water Supply Estimation**: three exercises have been held to estimate supply, such as
  - Considering the rainfall as local input, its available volume has calculated by multiplying average annual rainfall with the areas. In case of Gandhidham the average annual rainfall has taken 534 mm
  - Then the runoff as out flow parameter has been estimated by adopting Barlow's approach (1921) as volume of rainfall flowing out from the city (Table 6.3). in case of Gandhidham it is estimated 8.76 MCM considering 60 % of total rainwater flow out from the city as per its landuse and slope.
  - Then the supply from local resources has computed from surface water bodies and groundwater storage (Table 6.4). As there is no any surface water body in Gandhidham, only changes in ground water storage had estimated.

Table 6.2 Water Balance As per Rainfall and Runoff

Details	Qty
Average Annual Rainfall (mm)	534
Catchment area (ha)	2734
Total Rainfall MCM	14.60
Catchment Type	A
Catchment Factor	0.60
Ruoff (MCM)	**8.76**
Water Remains in City (MCM)	5.84
Total Demand of City (MCM)	4.76
Water Balance against Remaining Rainwater (MCM)	**3.51**

Table 6.3 Water Balance As per Rainfall and Runoff

GW Recharge Estimation		
Water level Pre monsoon 2023	13	M
Water level Post monsoon- 2023	14.6	M
Difference	1.6	M
Specific Yield %	22	%
Total Area	27.34	Sq. km.
Total GW recharge	**9.62**	**MCM**

Deficit Analysis: Finally, the total demand was compared against the available water resources to identify deficits and potential strategies for sustainable water management.

Table 6.4 Estimated Water Balance for Gandhidham City

Details			Water Balance – Est.
Demand Estimation	Projected Domestic water for Human (MCM)	Population	741582
		Unit Need lit/day	135
		Total (MCM)	36.54
	Floating Population need		4.33
	Industrial and other need (10 % of domestic need)		4.09
	Gross Demand		**44.96**
Supply Estimation	Rainwater Remains in City		5.84
	Existing Groundwater (MCM)		9.62
	Total (MCM)		**15.46**
Water Balance			**-29.50**

With these considerations estimated water balance of Gandhidham city indicates there is a 29.5 MCM deficit in supply against total demand i.e. 44.96 MCM.

7 Water Management Strategies

Occurrence of groundwater and its movement are results of certain set up of the area. Geology, lineament fabrics, landform characteristics are important physical parameters those have main control over groundwater occurrence as they are the governing factors for runoff generation and infiltration processes. Therefore, to categorize any area hydro-geological these parameters need to be evaluated properly from water point of view. It is also important to mention that in addition to these physical parameters certain dynamic properties of groundwater can also throw significant lights on categorization of area.

7.1 Groundwater recharge strategies

7.1.1 Groundwater Potential Zones

So far Gandhidham City is concerned, geology, landform parameters are not showing major diversity and hence they are not playing major controlling role over groundwater. Therefore, to categorize city's groundwater management zones parameter such as groundwater flow directions and static water levels have been taken into considerations and the city has been categorized into three zones viz., (01) Recharge zone, (02) Demand side management zone and (03) Salinity mitigation zone as shown in fig. 7.1

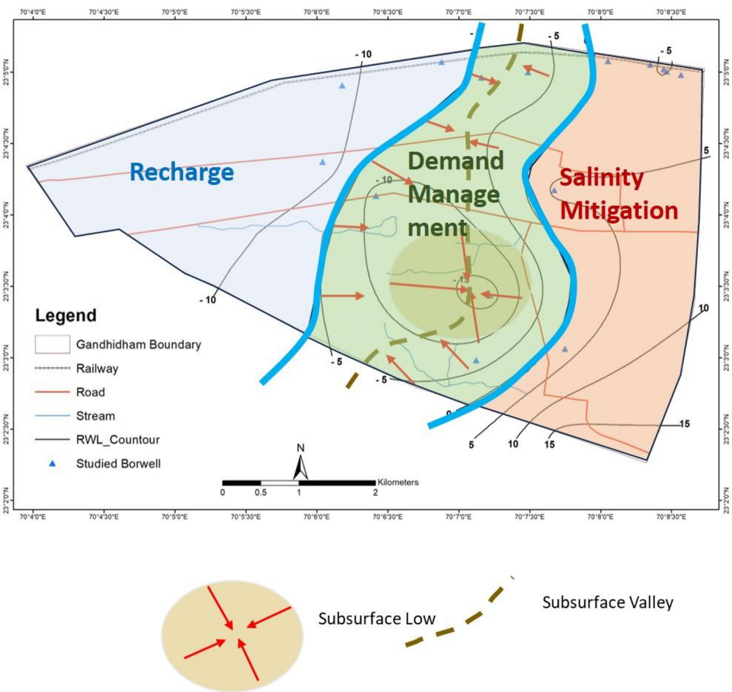


Figure 7.1 Geohydrological Potential Categorization for Management Strategies

7.1.2 Groundwater Management Strategies

It's 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 are crucial to maintain a balance between agricultural needs and groundwater sustainability. Considering this the groundwater management issues (Table 7.1) and strategies for each potential zone have described in fig 7.2.

Table 7.1 Geohydrological Characteristics and Major Issues in Groundwater Management Zones of Gandhidham City

Zone	Geohydrological Characteristics					Major Issue
	Rock type	**Depth M**	**Thickness (M)**	**Characteristic**	**Type**	
Recharge	Black and grayish clay	0-3	3	Clay	Aquiclude	Low percolation
	Sandy soil mixed with Pebble & gravels	2-12	9	Very Good Shallow Aquifer Loose formation	Shallow Semi confined	Groundwater Quality and contamination
	Fine clay	12-42	30	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
Demand Mgmt. Zone	Sandy soil mixed with Pebble & gravels	0-9	9	Very Good Shallow Aquifer Loose formation	Shallow Semi confined	Groundwater Quality and contamination
	Fine clay	9-30	21	No Aquifer		Impermeability doesn't allow recharge
	Kankavati Sandstone	30-70	40	Very Good aquifer Kankavati Sandstone	Shallow and confined	Salinity ingression due to over exploitation
Salinity Mitigation Zone	Fine muddy clay	0-4	4	No Aquifer		Negligible infiltration causes water impounding during rainy season
	Sand pockets	4-8	4	Localized Aquifer in pockets	Shallow	Patchy occurrence and paved area
	Tertiary clay	8-42	36	No Aquifer		Impermeability doesn't allow recharge
	Kankavati Sandstone	42-75	33	Very Good aquifer Kankavati Sandstone	confined	

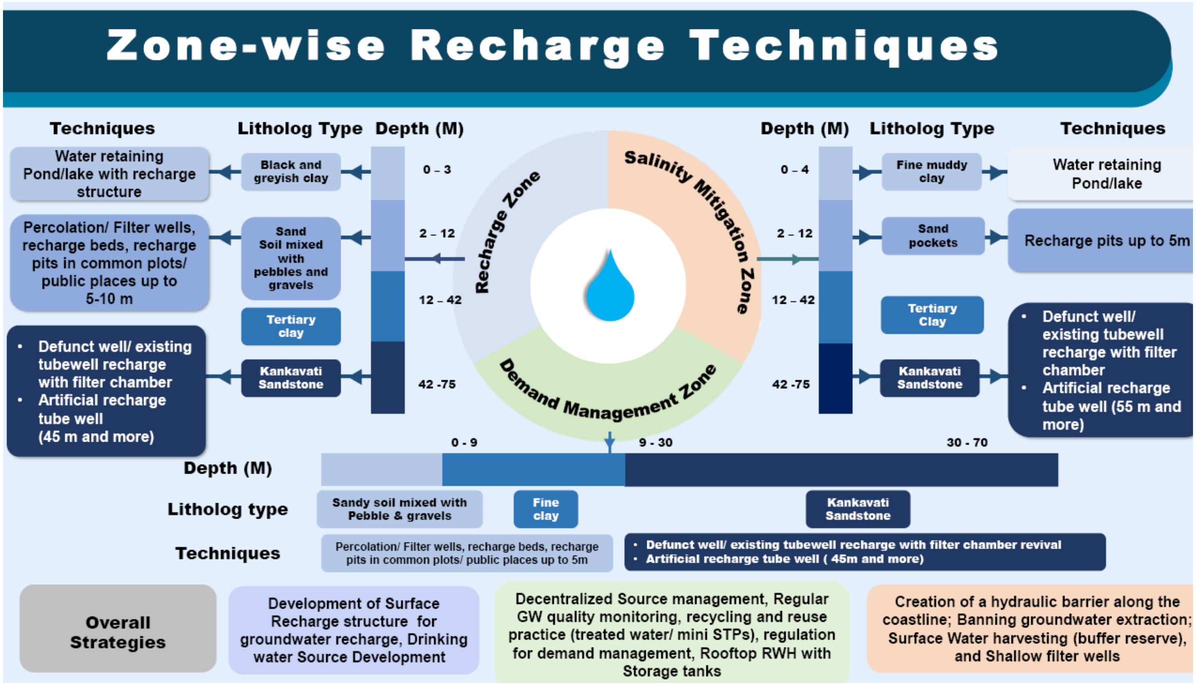


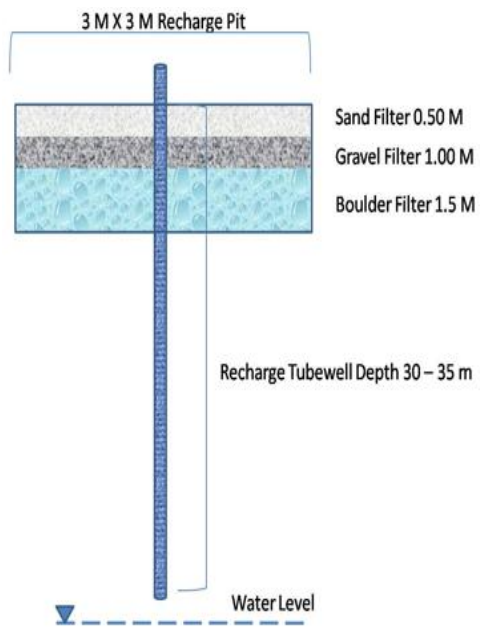
Figure 7.2 Geohydrological Potential Categorization for Management Strategies

7.1.3 Groundwater Recharge Techniques

For effective management of water resources in Gandhidham city, an integrated approach converging on the four categories viz., (01) Groundwater Recharge; (02) Surface Water Development in Peri Urban Areas; (03) Recycle and Reuse and (04) Manage deficit by external resources. As the present study is focused on groundwater potential and management, the present section describes groundwater recharge techniques in various groundwater potential zones in details (fig. 7.1) and list of probable technologies for surface water development in peri urban areas. So far recycling and reuse of water resources and deficit management is concerned separate assessment may require to develop action plan for Gandhidham city.

Groundwater Recharge Techniques: Following are suggested recharge techniques for Gandhidham City

Artificial Recharge Tubewell: This structure is proposed to construct where rainwater impounding happens frequently and remain stagnated for few hours to few days. Fig. 7.3 shows design components and precaution for implementation of this structure.



- **Filter chamber with graded filter**
- **Perforated casing pipe in aquifer zone**
- **Blind casing pipe in no aquifer zone**
- **Depth of tubewell should be slightly above the groundwater level**
- **Gandhidham specific**
    - **Recommended Depth of tubewell between 45 m to 60 m**
    - **Filter chamber atleast 3 m dia and 3 m depth**
- **Estimated approximate costing is around 3.5 to 4.00 lakh INR including site specific geological feasibility and casing designing**

Precautions and Preventive Measures

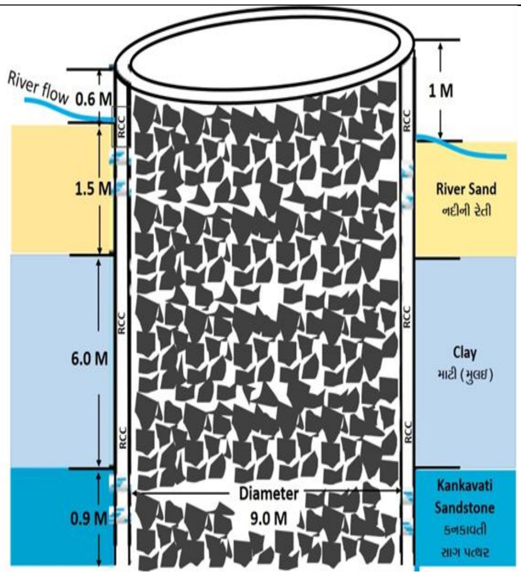
- **catchment where runoff water is approching to location should be polution free**
- **Sewage should not be enter into the structure**

If requires should use activated charcoal to purify minor impurity in inflowing storm water

Figure 7.3 Design Components and Precautionary Suggestion for Implementation of Artificial Recharge Tubewell

Filter Wells: This is a method for groundwater recharge in areas with thin, impermeable layers. In places like Gandhidham, where clayey layers hinder the natural infiltration of surface water into the underlying Kankavati Sandstone aquifer, a filter well could be an effective solution. Construction of filter wells in these locations will facilitate the rapid movement of surface runoff water through the clayey layers into the aquifer. The design of the filter well would likely involve creating a permeable structure that allows water to bypass the impermeable strata, effectively enhancing recharge rates. This structure not only aims to enhance groundwater recharge but also contributes to mitigating salinity issues in the area.

- **Identifying the precise locations where clayey layers are present and understanding their thickness and extent**
- **Ensuring that the filter well is designed to optimize water flow while preventing clogging from sediments**



- **Engaging local communities to raise awareness about the importance of aquifer recharge and sustainable water practices**
- **Gandhidham specific**
    - **Recommended Depth of filterwell between 9 m to 11 m**
    - **Diameter of well between 5-9 m dia**
- **Estimated approximate costing is around 3.5 to 9.50 lakh INR including site specific geological feasibility and casing designing**

Precautions and Preventive Measures

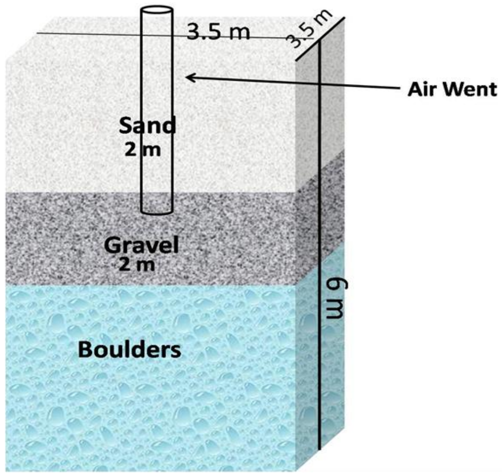
- **Catchment where runoff water is approching to location should be polution free**
- **Sewage should not be enter into the structure**
- **Implementing a management plan to monitor recharge rates and the overall health of the aquifer over time.**

Figure 7.4 Design Components and Precautionary Suggestion for Implementation of Filter Well

Recharge Pits: Recharge pit is a versatile and cost-effective solution for enhancing groundwater recharge and minimizing surface runoff. This is most feasible in area where subsoil strata is permeable i.e. sandy, gravelly, weathered rocks etc. Benefits of this structure can be described as below

- By increasing the infiltration capacity of the soil, filter wells allow more rainwater to percolate into the groundwater system, **reducing surface runoff**.
- Their small size and low construction cost make them accessible for **widespread implementation**, especially in urban and semi-urban areas.
- It can be **constructed in various locations**, such as roadside stormwater drains, roof rainwater outlets, and low-lying areas prone to water accumulation.
- By facilitating quicker absorption of stormwater, they can help **reduce localized flooding** during heavy rainfall events.
- As stormwater passes through the recharge pit, sediments and pollutants may be **partially filtered** out before reaching the aquifer.

- Connecting rainwater outlets from buildings to filter wells can capture excess water during storms, promoting recharge rather than runoff
- Integrating filter wells into existing stormwater drainage systems can significantly improve recharge rates while managing runoff



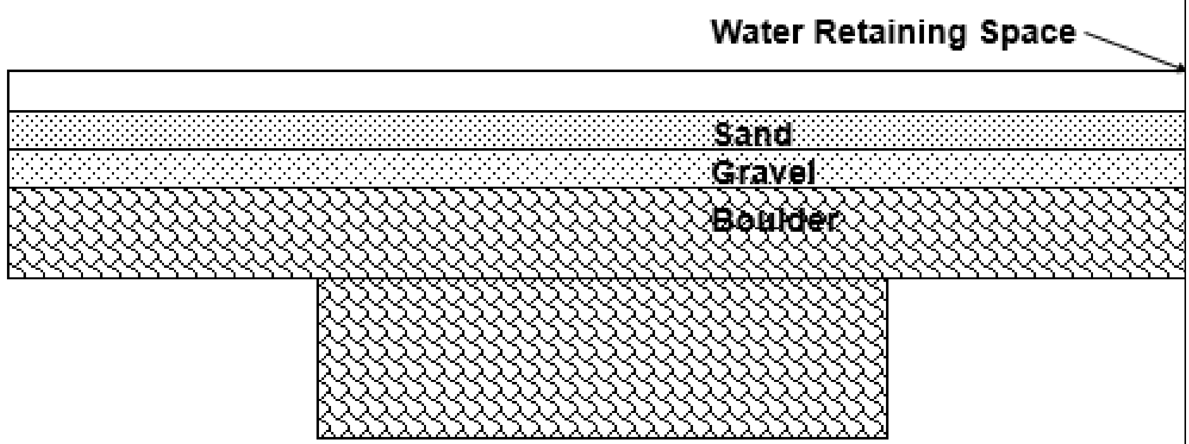
- Constructing filter wells in areas where water naturally accumulates can enhance infiltration and reduce the risk of erosion
- **Gandhidham specific**
  - **Recommended Depth of pit between 3 m to 5 m**
  - **Diameter of well between 2-3 m dia**
- **Estimated approximate costing is around 3.5 to 0.10 lakh INR including site specific geological feasibility and casing designing**

Precautions and Preventive Measures

- **Ensure that the underlying subsoil strata is permeable, such as sandy or gravelly soils, to maximize the effectiveness of the filter wells.**
- **Regular maintenance is essential to prevent clogging and ensure optimal performance. This may include clearing debris and monitoring sediment buildup**
- **Involving local communities in the planning and maintenance process can foster stewardship and ensure the long-term success of the project**
- **Setting up a system to monitor groundwater levels and water quality can help assess the effectiveness of the recharge pits over time**

Figure 7.5 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 and campuses. Here's an overview of their benefits and how they can be integrated with recharge tubewells.



- **Choose locations where water tends to accumulate, and size the percolation bed based on the expected volume of runoff.**

Precautions and Preventive Measures

- **Regular maintenance is crucial for the effectiveness of percolation**

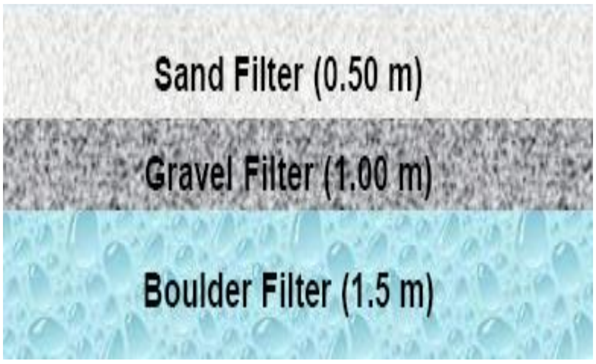
Adequate space should be allocated to allow for proper drainage and infiltration. • **A typical percolation bed consists of layers of gravel and sand, designed to enhance water flow and filtration. The top layer can be filled with vegetation to promote evapotranspiration.** • **Integrating percolation beds with recharge tubewells allows for an efficient water management system** • **Estimated Cost is about 4.25 to 5.25 Lakh INR**	**beds. This includes checking for blockages, managing vegetation, and monitoring water quality.** • **Engaging residents or campus users in the planning and upkeep of percolation beds can foster a sense of ownership and awareness about water management practices.** • **Conduct soil tests to ensure that the underlying strata are conducive to infiltration.** • **Check any local regulations regarding stormwater management and groundwater recharge practices.** • **Establish a monitoring system to evaluate the performance of the percolation bed and recharge tubewell over time.**

Figure 7.6 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 are abandoned by communities either due to dryness or deterioration in water quality. It is recommended to use these type of groundwater sources for recharging the aquifer. This is also a cost-effective solution for enhancing groundwater recharge with strong community participation. Following are major benefits of this technique.

- Repurposing abandoned wells and borewells provides a cost-effective method for enhancing groundwater recharge without the need for extensive new infrastructure.
- Involving local communities in the recharge process can foster stewardship and raise awareness about water conservation. Community-led initiatives are often more sustainable in the long run.
- These existing structures can quickly facilitate the infiltration of surface water into the aquifer, especially during rainy seasons.
- By using wells that have been abandoned due to poor water quality, communities can divert stormwater and rainwater into the aquifer, potentially diluting contaminants and improving overall water quality.

There need a filter chamber and some plumbing work to implement this technique. Use of roof rain water bye end large ensures inflow water quality. Fig. 6.8 shows recommended design and respective criteria for its planning



- **Before reusing the wells, they may need to 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**
- **Setting up systems to collect and direct rainwater or stormwater runoff into the abandoned wells**
- **3 m dia and deep filter chamber**

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

7.2 Overall Citywide Water Management Strategies

A City-Level Groundwater Recharge Plan is an essential strategy to address these challenges, such as depleting water levels, deteriorating quality and flooding during rainy season. This also helps in promoting the sustainable management and restoration of groundwater resources at city level. The Gandhidham city recharge plan aims to implement a variety of methods to recharge depleted aquifers, such as stormwater infiltration, artificial recharge techniques, and the optimization of existing infrastructure. These measures will enhance the capacity of urban landscape specially constructed land to absorb water, improve groundwater levels, and ensure a stable and reliable water supply. Considering the geohydrological characteristics of each management zone—namely the recharge zone, demand management zone, and salinity mitigation zone—specific locations for appropriate recharge techniques have been identified. These locations are strategically selected to optimize groundwater replenishment based on the unique needs and conditions of each zone. (Fig. 7.1)

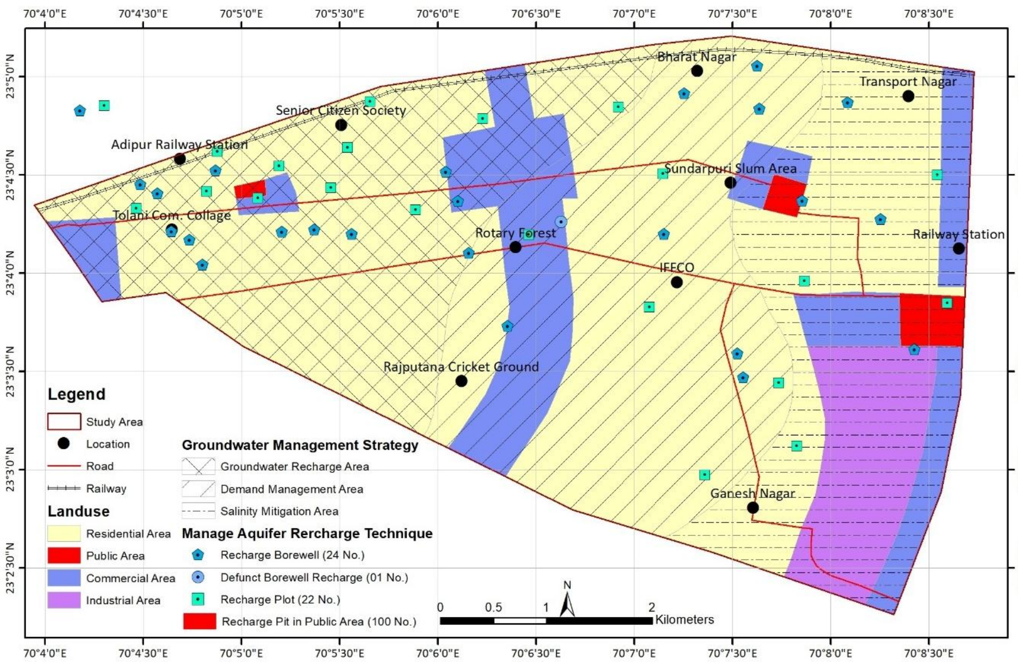


Figure 7.8 Locations for Respective Groundwater Recharge Techniques, Gandhidham City

Largely, four types of activities have been proposed for the city, as outlined in Table 7.2. For each activity, locations have been selected based on factors such as the 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 recharge plan across Gandhidham city has been calculated. According to this total about 2.24 crores INR has been estimated to implement groundwater recharge activities in Gandhidham city (Table 7.1)

Table 7.2 Estimated Investments for Groundwater Recharge for Gandhidham City

Sr. No.	Activity	Qty.	Unit	Unit Cost (INR)	Total Cost (INR)
1	Recharge Borewell with Filter Chaber	24	No.	300000	72,00,000
2	Defunct Borewell Recharge	1	No.	30000	30,000
3	Recharge Borewell with Recharge Plot	22	No.	600000	1,32,00,000
4	Recharge Pit	100	No.	20000	20,00,000
Total Estimated Amount					**2,24,30,000**

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