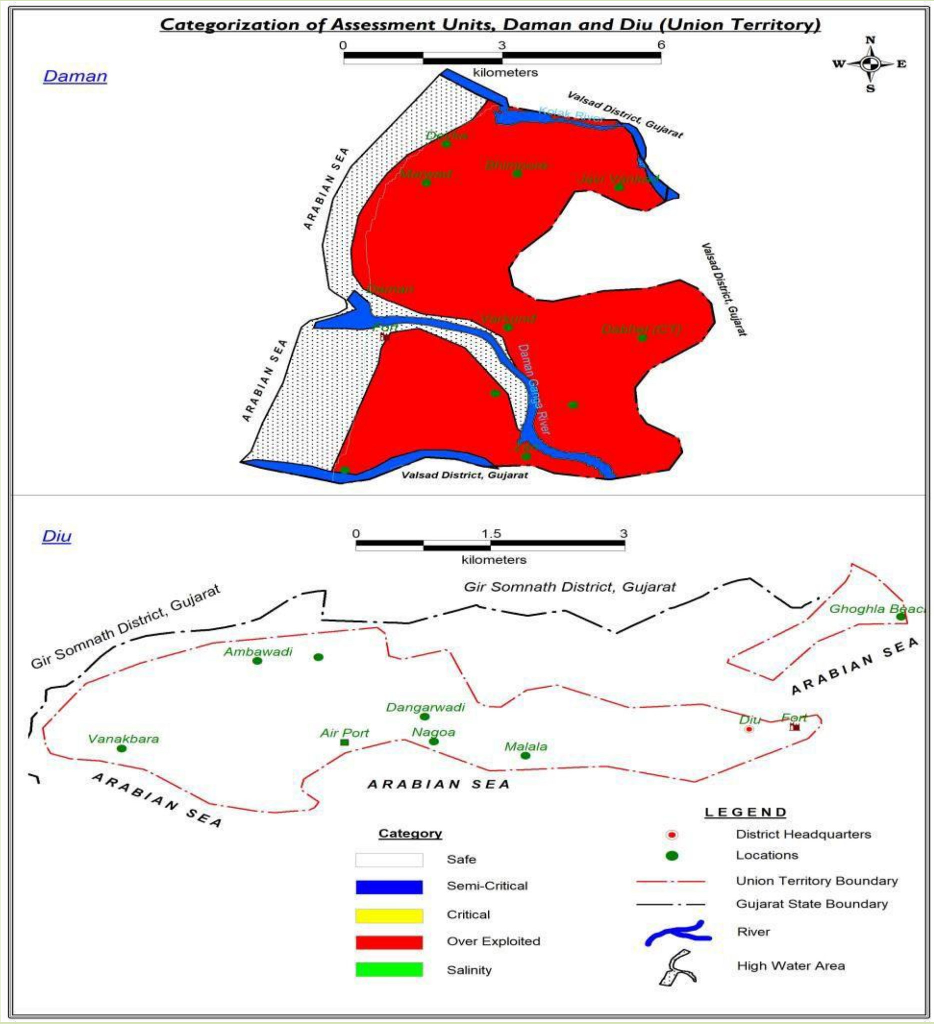
REPORT ON
DYNAMIC GROUND WATER RESOURCES
OF UT OF DAMAN & DIU

(As on March 2020)



CENTRAL GROUND WATER BOARD
WEST CENTRAL REGION
DEPARTMENT OF WATER RESOURCES, RD & GR
MINISTRY OF JAL SHAKTI
GOVERNMENT OF INDIA
AHMEDABAD

NOVEMBER-2021

FOREWORD

The UT of Daman & Diu is moving on a fast track in the field of infrastructure development and industrialization. This has in turn put forth a lot of demand on the natural resources and particularly in the water sector. The availability of Groundwater being easy and being widely distributed in space and time makes it preferred commodity over the surface water resources. This warrants us to estimate precisely the ground water resources available for better management of the resources to sustainably meet the ever increase in its demand with the growth of population, increase in agriculture and modernization and enlargement of industrial sectors.

The Dynamic Ground Water Resources of UT of Daman & Diu have been computed as per the methodology recommended by "Ground Water Resources Estimation Committee" (GEC-2015) set up by Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. These computations shall form important component for water resource management of this UT of Daman & Diu having wide variation in availability of water resources, geology, physiology, landform etc.The present computation clearly brings out the availability and the extent of development in different parts of the UT of Daman & Diu.

The UT government while according approval for these estimated has stressed that, due care must be taken to arrest depletion in water level in Diu by reducing ground water withdrawal and by resorting to surface water supply for sustainability of available fresh water resource and to prevent deterioration in ground water quality. Adoption of Roof Top Rainwater Harvesting should be encouraged in urban areas of Daman district, where the alluvial aquifer has been de-saturated. In these areas regulatory measures for registration of ground water abstraction structures for industries and their monitoring has to be taken up for sustainable development of the ground water resource. Conjunctive use of Ground & Surface water in industrial and Agricultural sector of Daman and Diu should also be implemented where ever feasible.

Central Ground Water Board, West Central Region, Ahmedabad prepared this report with the help from UT Administration Of Daman & Diu, Public Works Department, Irrigation Department, Statistical department, Industrial department, urban development department etc.

I would like to place on record my sincere thanks to the dedicated team of Scientists of Central Ground Water Board, WCR for bringing out this report in a presentable manner.

(Sanjeev Mehrotra)
Scientist "D" & H.O.O
West Central Region
Central Ground Water Board
Dept. of Water Resources, RD & GR
Ministry of Jal Shakti
Government of India

Report on
Dynamic Ground Water Resources of UT OF DAMAN & DIU
as on March 2020

CONTRIBUTORS' PAGE

Name	**Designation**
Principal Author	
Shri Avinash Chandra	Senior Technical Assistant (Hydrogeologist)
Principal Contributor	
Shri B. Mohapatra	Scientist-C (Hydrogeologist)
Shri Lakshmi Narayana Damodara	Scientist-B (Hydrogeologist)
Shri Avinash Chandra	Senior Technical Assistant (Hydrogeologist)
Report Scrutiny	
Dr A K Jain	Scientist-D (Retired) & Consultant, CGWB, WCR, Ahmedabad.
Supervision & Guidance	
Shri Sanjeev Mehrotra	Scientist -D & H.O.O, CGWB, WCR, Ahmedabad & Member Secretary, UT Level Committee.

ACKNOWLEDGEMENT

The Author would like to place on record the valuable guidance given by Shri A. K. Singh, IAS, Advisor to Administrator, UT of DNH & DD & Chairman of the UT Level Committee, Shri Saurabh Mishra, IAS, Secretary (PWD) & Agriculture, DNH & DD, Dr. A. Muthamma, Secretary Industries, DNH & DD, Ms.Tapasya Raghav, Secretary Urban Development, DNH & DD, Shri Gaurav Singh Rajawat, Secretary Panchayat, DNH & DD, Collector Daman, Collector Diu, Shri Pranjal J. Hazarika, Joint Secretary PWD, DNH & DD, Shri M.D.Gohil, Executive Engineer, PWD,Daman and Shri Sanjay Desai AEE, PWD department, Daman for finalisation of the Report on "Dynamic Ground Water Resources of UT of Daman & Diu (As on March 2020)" need a special mention.

The task of assessment of the Dynamic Ground Water Resources of UT of Daman & Diu would have not been possible without the constant support and continued guidance by Shri Sanjeev Mehrotra, Scientist-D, Head of Office, Central Ground Water Board, West Central Region, Ahmedabad. The dedicated and untiring effort of Shri B. Mohapatra, Scientist-C and Shri L. N. Damodara, Scientist-B of Central Ground Water Board, West Central Region, Ahmedabad in assessment and compilation of this report is highly appreciable. The sincere cooperation extended and contribution made by Shri Ankit Vishwakarma, Scientist-B in bringing out this report is gratefully acknowledged.

We are thankful to the team led by Dr.K.B.V.N. Phanindra, Asst. Professor, IIT Hyderabad and special thanks are also due to Shri Yogesh Bandari, Manager and Shri Saneesh Kumar, GIS Engineer, Software professionals of M/s Vassar Labs IT Solutions, Hyderabad who deserve praise for developing & customising the IN-GRES web portal for the assessment as per requirements of Central Ground Water Board.

Sincere acknowledgement is extended to the concerned departments viz, Public Work Department of UT of Daman & Diu, Directorate of Agriculture, Statistics, Irrigation Department, Industrial and BDO office for making the data available for completion of this report.

Avinash Chandra
STA (HG)
Central Ground Water Board (WCR)
Dept. of Water Resources, RD & GR
Ministry of Jal Shakti
Government of India

Table of Contents

1. INTRODUCTION 10
1.1 DEMOGRAPHY 11
1.2 GEOMORPHOLOGY AND SOIL TYPE 11
1.3 RAINFALL: 12
1.4 CLIMATIC CONDTION 13
2. GEOLOGY 15
3. HYDROGEOLOGY 16
3.1 GROUNDWATER REGIME MONITORING 17
3.1.1 Depth to Water Level Pre-Monsoon (May 2019) 18
3.1.2 Depth to Water Level Post-Monsoon (November 2019) 18
3.1.3 Decadal Average (2010-19) depth to water level Pre-monsoon 19
3.1.4 Decadal Average (2010-19) depth to water level Post-monsoon 19
3.1.5 Depth to Water Level Pre-Monsoon (November 2019) 20
3.1.6 Depth to Water Level Post-Monsoon (November 2019) 21
3.1.7 Decadal Average (2010-19) depth to water level Pre-monsoon 21
3.1.8 Decadal Average (2010-19) depth to water level Post-monsoon 22
3.2 WATER LEVEL TREND (2009 – 2019) 22
3.3 HYDROGRAPH OF DAMAN & DIU 23
3.4 QUALITY (ELECTRICAL CONDUCTIVITY): 24
4. GEC 2015 METHODOLOGY: 25
4.1 Concept of Aquifer Wise Assessment 25
4.2 Periodicity of Assessment 25
4.3 Groundwater Assessment Unit & Sub Units 25
4.4 Groundwater Resources of Assessment of Unit 26
4.5 Assessment of Annually Replenishable or Dynamic Groundwater Resources 26
4.6 Rainfall Recharge 26
4.6.1 Water Level Fluctuation (WLF) Method 27
4.6.2 Rainfall Infiltration Factor (RIF) Method 28
4.7 Recharge from other Sources 29
4.7.1 Recharge from Canals 29
4.7.2 Recharge from Surface Water Irrigation 29
4.7.3 Recharge from Groundwater Irrigation 29
4.7.4 Recharge due to Surface Water Bodies 30
4.7.5 Recharge due to Water Conservation Structures 30
4.8 Additional Components Effecting Recharge 30
4.8.1 Lateral flow along the aquifer system (Through flow) 30
4.8.2 Base flow and Stream Recharge 30
4.8.3 Vertical Flow from Hydraulically Connected Aquifers 31

4.8.4 Evaporation and Transpiration 31
4.9 Additional Potential Resources under Specific Conditions 31
4.9.1 Potential Resource Due to Spring Discharge 31
4.9.2 Potential Resource in Waterlogged and Shallow Water Table Areas 31
4.9.3 Potential Resource in Flood Prone Areas 32
4.10 Recharge during Monsoon Season 32
4.11 Recharge during Non-Monsoon Season 32
4.12 Total Annual Groundwater Recharge 33
4.13 Annual Extractable Groundwater Recharge (EGR) 33
4.14 Estimation of Groundwater Extraction 33
4.14.1 Components of Groundwater Extractions 33
4.14.2 Groundwater Extraction for Irrigation (GEIRR) 33
4.14.3 Groundwater Extraction for Domestic Use (GEDOM) 34
4.14.4 Groundwater Extraction for Industrial use (GEIND) 34
4.14.5 Data Base of Industry: - 34
4.14.6 Stage of Groundwater Extraction 35
4.15 Validation of Stage of Groundwater Extraction 35
4.15.1 Categorisation of Assessment Units 35
4.16 Allocation of Groundwater Resource for Utilisation 36
4.17 Net Annual Groundwater Availability for Future Use 36
4.18 Assessment of In-Storage or Static Groundwater Resources 37
4.19 Assessment of Total Groundwater Availability in Unconfined Aquifer 37
4.20 Assessment of Groundwater of Confined Aquifer System 37
4.21 Assessment of Groundwater of Semi-Confined Aquifer System 38
4.22 Total Groundwater Availability of an Area 38
4.23 Groundwater Assessment in Urban Areas 38
4.24 INDIA -GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES) 39
4.25 PROCEDURE FOLLOWED IN THE PRESENT ASSESSMENT 39
4.25.1 Data Sources and Constraint for Various Data Elements 39
4.25.2 Domestic draft and future allocation for domestic use and Industrial Draft 40
4.25.3 Irrigation Draft: 40
4.26 Assessment Unit Area 41
4.27 Norms Followed in the Assessment GWRA 2020 41
4.28 Dynamic Ground Water Resources 41
4.28.1 Ground water Potential 41
4.28.2 Categorization of Districts (Assessment Units) 41
5. Summary of findings of Report on Dynamic Ground Water Resources of UT of Daman & Diu as on 31st March 2020 43
6. Conclusions & Recommendations of State Level Committee on GWRA-2020. 44

LIST OF FIGURES

Figure 1- Administrative Map of UT of Daman & Diu 10
Figure 2- Pictorial Representation of Climatological Data 13
Figure 3- Pictorial Representation of Climatological Data 14
Figure 4- Major Aquifer System of Daman 16
Figure 5- Major Aquifer system of DIU 17
Figure 6- Pre-Monsoon Depth to Water Level Map-2019 18
Figure 7- Post-Monsoon Depth to Water Level Map-2019- Daman 19
Figure 8- Decadal Pre-Monson Depth to Water Level 19
Figure 9- Decadal Post-Monson Depth to Water Level 20
Figure 10- Pre-Monsoon Depth to Water Level Map-2019 20
Figure 11- Post-Monsoon Depth to Water Level Map-2019- Diu 21
Figure 12- Decadal Pre-Monson Depth to Water Level 21
Figure 13- Decadal Post-Monson Depth to Water Level-Diu 22
Figure 14- Hydrograph of Ambawadi village, Daman 23
Figure 15- Hydrograph of Jampore village, Daman 23
Figure 16- Hydrograph of Chakrteeth village, Diu 23
Figure 17- Hydrograph of Diu 23
Figure 18- Electrical Conductivity Map of Daman 2019 24
Figure 19-Electrical Conductivity Map of Diu 2019 24
Figure 20- Categorization Map of Daman district as per GWRA-2020 42
Figure 21- Categorization Map of Diu district as per GWRA-2020 42

LIST OF TABLES

TABLE 1- GENERAL INFORMATION 11
Table 2- RAINFALL (MM) IN UT OF DAMAN & DIU 12
Table 3- Climatological data for IMD station Vapi taluka 13
Table 4- Climatological data for IMD station Veraval 14
Table 5- STRATIGRAPHIC SEQUENCE OF DAMAN DISTRICT 15
Table 6- STRATIGRAPHIC SEQUENCE OF DIU DISTRICT 15
Table 7- Validation Criteria for Stage of GW Extraction (SGWE) 35
Table 8- Criteria for Categorization 36
Table 9- Data Sources Used in the Ground Water Resource Estimation 2020 39
Table 10- Annual Ground Water Extraction Comparison for UT of Daman & Diu 44
Table 11- Dynamic Ground Water Resources for UT of Daman & Diu a comparison 2017 vs. 2020 44

ANNEXURES

Annexure 1- Decadal Pre-Monsoon Water Level of Daman & Diu 45
Annexure 2- Decadal Post-Monsoon Water Level of Daman & Diu 46
Annexure 3- Decadal Pre & Post-Monsoon Water Level Trends of Daman & Diu 47
Annexure 4- District Wise Ground Water Resources, Availability, Utilization and Stage of Ground Water Development for UT of Daman & Diu 48
Annexure 5- General Description of Ground Water Assessment Unit of Daman & Diu 48

CONSTITUTION OF COMMITTEE FOR GWRA 2020 FOR UT OF DAMAN & DIU

UT ADMINISTRATION OF DADRA & NAGAR HAVELI AND DAMAN & DIU
PUBLIC WORKS DEPARTMENT
DIVISION NO.III(DP)
SILAVASSA

No.PWD.III/ASW/GWRA/2013/SLC/DNH/2014/633 **Dated.** 8 /12 /2020.

ORDER

Pursuant to the directions of Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India and as stipulated in the National Water Policy, 2012 for periodic assessment of ground water resources in view of changes observed in ground water level, reassessment of ground water resources have to be carried out for the territory of Dadra & Nagar Haveli and Daman & Diu for 2019-20 based on the revised ground water estimation methodology 2015 (GEC-2015 Methodology) by Central Ground Water Board. A UT Level Committee has to be constitutes as advised by the Government of India, to coordinate and monitor the activities of reassessment of ground water resources and its estimation. Hon'ble Administrator, Dadra & Nagar Haveli and Daman & Diu is pleased to constitute the Union Territory Level Committee for DNH&DD for reassessment of ground water resources of Dadra & Nagar Haveli and Daman & Diu with the following composition.

1.	Advisor to the Administrator, DNH&DD	Chairman
2.	Secretary (PWD), DNH&DD	Member
3.	Secretary, Industries, DNH&DD	Member
4.	Secretary, Urban Development, DNH&DD	Member
5.	Secretary, Panchayat, DNH&DD	Member
6.	Secretary, Agriculture, DNH&DD	Member
7.	Member Secretary, PCC, DNH&DD	Member
8.	Collector, DNH	Member
9.	Collector, Daman	Member
10.	Collector, Diu	Member
11.	General Manager, NABARD	Member
12.	Regional Director, CGWB	Member Secretary

The committee may co-opt any other member or special invitees, if necessary

2. Terms of Reference

The broad terms of reference of the committee would be as follows

(I) To coordinate, monitor and ensure timely completion of reassessment of annual ground water recharge of the territory of Dadra & Nagar Haveli and Daman & Diu through Central Ground Water Board and to estimate the status of utilisation of the annual replenishable ground water resources in accordance with the Ground Water Resources Estimation Methodology-2015.

3. Time Frame: The Central Ground Water Board will submit its report for approval of the SLC and on approval, the report will be submitted to Government of India on or before the stipulated time frame.

4. Expenditure: Expenditure on account of TA/DA to official members of the committee will be met from the source from which they draw their salaries and that of non official members will be borne by. EE, PWD(Irrigation), Dadra & Nagar Haveli, Silvassa and EE, PWD (Irrigation), Daman, for Dadra & Nagar Haveli and Daman & Diu respectively.

By Order and in the name of the Administrator,
Union Territory of Dadra & Nagar Haveli and Daman & Diu

28.11.2020

(Pranjal Hazarika)
Joint Secretary,
Public Work Department, DNH&DD

Approved minutes of the UT Level Committee Meeting held on 31.03.2021

Email **Regional Director, WCR**

Re: Minutes of the second meeting of the UT Level committee on GWRA 2020- UT of Daman & Diu

From : Mr Anil Kumar Singh <devcom-dd@nic.in> Wed, Mar 31, 2021 07:26 PM

Subject : Re: Minutes of the second meeting of the UT Level committee on GWRA 2020- UT of Daman & Diu

To : Regional Director, WCR <rdwcr-cgwb@nic.in>

Sir,

The Minutes of the second meeting of the UT Level committee on GWRA 2020- UT of Daman & Diu is approved by Chairman.. This is for your kind perusal and necessary action..

PA to Adviser to Administrator,
DNH & Daman and Diu..

From: "Regional Director, WCR" <rdwcr-cgwb@nic.in>
To: "Mr Anil Kumar Singh" <devcom-dd@nic.in>
Sent: Wednesday, March 31, 2021 7:23:30 PM
Subject: Minutes of the second meeting of the UT Level committee on GWRA 2020- UT of Daman & Diu

Sir,

in continuation to the discussion held between JS, PWD, UT of DNH and DD and the Regional Director (i/c), CGWB, WCR, Ahmedabad, please find attached herewith the modified minutes of the meeting of the UT level Committee on GWRA 2020 held on 31st March 2021 at 11.00 Hrs for kind approval.

Regards,

TS for Regional Director
CGWB, WCR, Ahmedabad

From: "Regional Director, WCR" <rdwcr-cgwb@nic.in>
To: "Mr Anil Kumar Singh" <devcom-dd@nic.in>
Sent: Wednesday, March 31, 2021 6:12:08 PM
Subject: Minutes of the second meeting of the UT Level committee on GWRA 2020- UT of Daman & Diu

Sir,

With reference to the subject cited above and in continuation to the meeting of the UT level committee held today i.e. 31.03.2021 at 11.00 hrs through video conferencing in respect of the Dynamic Ground water Resources of UT of Daman & Diu as on March 2020, please find attached herewith the Minutes for kind perusal and approval.
An early action in this regard is highly solicited.

Sincere Regards,

Regional Director (I/C)
CGWB, WCR, Ahmedabad

Central Ground Water Board
West Central Region
Swaminarayan College Building
Shahalam Tol Naka
Ahmedabad - 22
Ph: +91 79 25320476
Fax: +91 79 25329379

Minutes of the second Meeting of the UT Level Committee for Assessment of the Ground Water Resources of UT of Daman & Diu as on March 2020

The second meeting of the Union Territory Level Committee for approval of the assessment of Ground Water Resources of UT of Daman & Diu as on March 2020 was held under the Chairmanship of the Joint Secretary, PWD, UT of DNH & DD on 31^{st} March 2021 at 11.00 Hrs. through video conferencing. The list of members present in the meeting is given in Annexure-I.

Gist of discussion held during the meeting is as follows:

1. Shri Sanjeev Mehrotra, Regional Director (I/C) and Member Secretary welcomed the Chairman and all the members present in the meeting and briefed about the purpose for conducting the meeting.

2. Shri Biswarup Mohapatra, Scientist-C, CGWB, WCR, Ahmedabad made presentation on assessment of Ground Water Resources of UT of Daman & Diu using GEC-2015 Methodology through India Ground Water Resource Estimation System (INGRES).

3. The district collector Diu enquired about whether there is provision of regulatory measure for ground abstraction for irrigation and domestic purpose. It was informed that, as of now the abstraction for irrigation and domestic purpose are exempted for obtaining NOC from CGWA. However infrastructure projects requiring ground water abstraction may be advised to apply for obtaining NOC from CGWA.

4. It was also stressed on the fact that, due care must be taken to arrest depletion in water level in Diu by reducing ground water withdrawal and by resorting to surface water supply for sustainability of available fresh water resource and to prevent deterioration in ground water quality.

5. The dynamic ground water resources assessment for UT of Daman & Diu as on March 2020 was approved by the committee.

6. The Regional Director (I/C), expressed his sincere thanks to all the committee members for sparing their valuable time to make it convenient to attend the meeting and to all the department/agencies for providing the required data to make this exercise more realistic

7. The meeting ended with the Vote of Thanks by the Regional Director, CGWB, WCR, Ahmedabad.

List of Members present in the meeting:

1. Shri Pranjal J. Hazarika, Joint Secretary (PWD), UT of DNH & DD on behalf of Secretary (PWD) UT of DNH & DD.
2. Mr. Sandeep Kumar Singh, IAS, Collector, UT of DNH, -Member
3. Mrs. Saloni Rai, IAS, Collector, UT of Diu, -Member
4. Shri Gaurav Kumar, DDM, NABARD, Valsad, Gujarat representing the General Manager, NABARD, Ahmedabad-Member
5. Shri Sanjeev Mehrotra, Regional Director (I/C), Central Ground Water Board, West Central Region, Ahmedabad, -Member Secretary

Other officers present in the meeting:

1. Dr. P. K. Jain, Regional director, CGWB, Central Region, Nagpur
2. Dr. D. Venkateswaran, Scientist D, CGWB, Central Region, Nagpur
3. Shri Biswarup Mohapatra, Scientist-C, CGWB, WCR, Ahmedabad
4. Shri L.N. Damodara, Scientist-B, CGWB, WCR, Ahmedabad
5. Shri Ankit Vishwakarma, Scientist-B, CGWB, WCR, Ahmedabad
6. Shri Avinash Chandra, STA (Hg), CGWB, WCR, Ahmedabad

DYNAMIC GROUND WATER RESOURCES OF UT OF DAMAN & DIU

1. INTRODUCTION

U.T. of Daman and Diu comprises two districts namely Daman and Diu. Both Districts are situated on western coast of India at a distance of about 700 kms. Daman is the head Quarter of this U.T.

UT of Daman is situated between North latitudes 20°22’7.03”N & 20°28’28.4”N and East longitudes 72°48’7.12”E & 72°54’11.9”E and falls in Survey of India toposheet No. 46 D/15. It covers an area of 72 sq. km. Its length measures 11 km from extreme north to south and the width measures 8 km. from east to west. The UT of Daman is bounded on the north, east and south by Valsad district of Gujarat state and west by Arabian Sea (Fig. 1).

UT of Diu is a completely isolated island from mainland Gujarat by a east-west extending marshy low land which remains covered by the tidal waters of the Arabian sea. Diu is situated between North latitudes 20°41’53.66”N & 20°44’47.89”N and East longitudes 70°52’31.02”E & 71°0’51.25”E and falls in Survey of India Toposheet No. 41 L/14. It covers an area of 40 sq. km with 19.2 km length and width varying from 1 to 2.5 km. The UT of Diu is bounded on the east, west and north side by Gir Somnath district, whereas Southern boundary is the Arabian Sea with its partly rocky and partly sandy shore (Fig. 1).

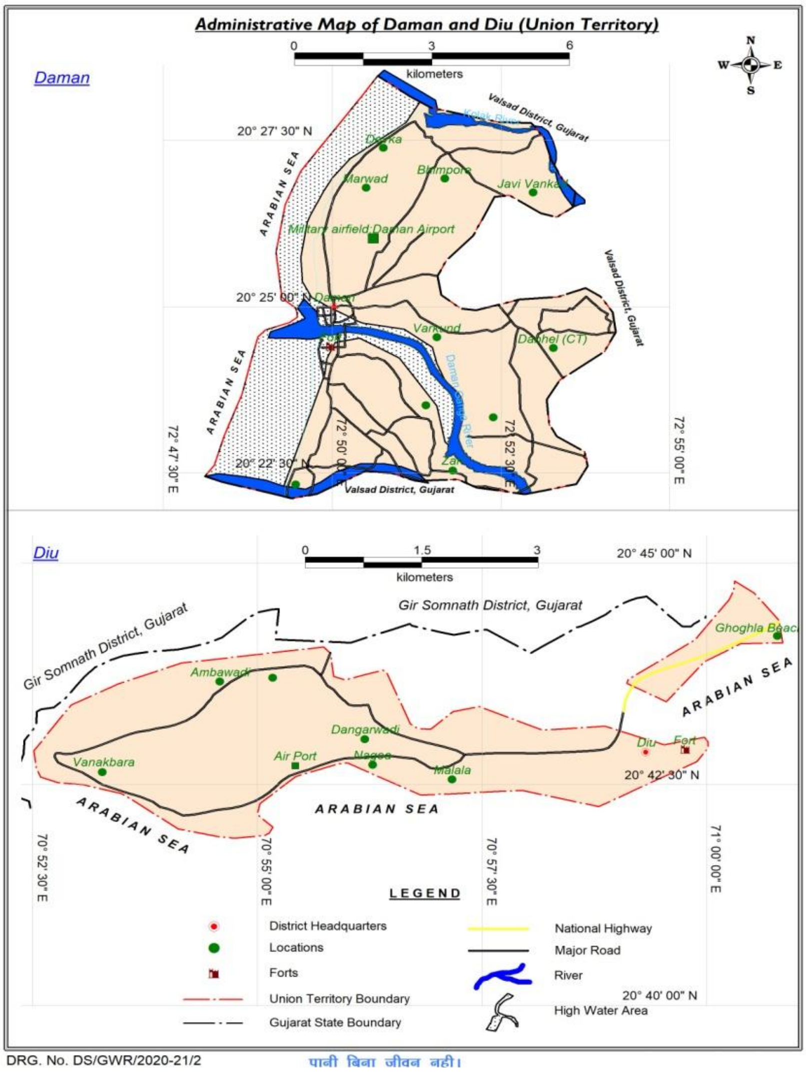


Figure 1- Administrative Map of UT of Daman & Diu

TABLE 1- GENERAL INFORMATION

General Information			
Sr No	Parameters	Daman	Diu
1	Area (KM)	72	40
2	Population (Census-2011)	191173	52074
3	Population Density (Per KM)	2655	1302
4	Villages (Nos.)	21	4
5	Industrial Unit (Nos.)	3510	19
6	Total Agricultural Land (Ha)	3111	597
7	Cultivable Land (Ha)	2832	543
8	Main Crop	Paddy	Bajra

1.1 DEMOGRAPHY

DAMAN:

The total population of the Daman district as per census 2011 is 191173 which include 124659 male and 66514 female. The sex ratio is about 533 female per 1000 male. The rural population is 32313and urban population is 158860.

DIU:

The total population of the Diu district as per 2011 census is 52,074, which include 25642 male and 26432 female. The sex ratio is about 1110 Women per 1000 men. The rural population is 28083 and urban population is 23991.

Population(Census) growth for Daman and Diu		
Census	**Population**	**%±**
1951	49,000	—
1961	37,000	−24.5%
1971	63,000	70.30%
1981	79,000	25.40%
1991	102,000	29.10%
2001	158,204	54.90%
2011	243,247	53.78%

1.2 GEOMORPHOLOGY AND SOIL TYPE

DAMAN:

It has a gently undulating topography with a few isolated hillocks ranging in height from 34 to 49m amsl with the exception of 111 m high hill occupying an area of more than a Km^2 towards east of Delwada village. The general topographic gradient is towards west-northwest.

The soils in the area can be divided into two groups based on their origin. The soils all along the coast and the banks of the creek are alluvial soils where as in rest of the area the soils are derived from the weathering of basaltic rocks. The coastal soil, as they are deposited in saline water, is saline and alkaline with almost uniform texture which is clayey loam to silty loam. The soils are dark grey to black in colour. Both pH and Electrical conductivity values are extremely high. These soils are difficult to reclaim due to higher content, low permeability, high water table and high salinity.

Depending upon the degree of weathering, the basaltic soils show wide variation in texture. The first stage of weathering of basalts gives rise to light soil comprising pieces of weathered basalt (locally known as maroom). The depth of such soil varies from few cm to 50 cm. The colour of the soil is dark yellowish brown in plateau, and around the hillocks, whereas the colour is brownish black to black cotton in the flat valleys. The texture of the soil is medium to fine textured. They are non calcareous with moderate water holding capacity.

DIU:

There is a central high land made up of sand dune and sloping in all the direction and the reduced level comes to around 2 m agl along the coast.

Up to almost a kilometre from the coast, the soils are saline and alkaline with higher percentage of silt. These are formed due to degeneration of coastal soils by salinity ingress. These soils slowly grade into yellowish brown calcareous soils which contain admixture of medium to coarse grained material comprising Miliolite shell pieces. They range in thickness from 0.3 to 1 m. in low lying areas, accumulation of organic material coupled with intense weathering, have given rise to black cotton soil covers varying from few cm to nearly a metre in thickness. The blown sand deposits, on the central high land, are essentially weathered products of the friable Miliolitic limestone and are thus highly calcareous.

1.3 RAINFALL:

DAMAN:

The rainfall occurs during the southwest monsoon, starting from June and extending up to October. The rainfall is inconsistent, with average annual rainfall 1985 mm. Long term monthly means of annual rainfall distribution shows that over 95 % of the rainfall occurs from mid June to mid-September due to southwest monsoon. July is the rainiest month with nearly 900 mm of average rainfall. The rainfall characteristics have a strong impact on the groundwater level and quality of UT of Daman.

DIU:

The rainfall occurs during the southwest monsoon, starting from June and extending up to October. The rainfall is inconsistent, with average annual rainfall 598.60mm in 34 rainy days. The long term average annual rainfall is 664.04 mm. Long term monthly means of annual rainfall distribution shows that over 90 % of the rainfall occur occurs from mid June to mid-September due to southwest monsoon and associated intense low-pressure system. The rainfall characteristics have a strong impact on the groundwater level and quality.

Table 2- RAINFALL (MM) IN UT OF DAMAN & DIU

Rainfall (mm)		
Year	Daman	Diu
2012-13	1439	635
2013-14	2449	919
2014-15	2059	1072
2015-16	1333	642
2016-17	2113	1031
2017-18	1973	939
2018-19	1834	950
2019-20	2962	1100

1.4 CLIMATIC CONDTION

DAMAN:

The mean minimum temperature is 23ºC and the mean maximum temperature is 32ºC. Due to proximity of the sea the humidity is generally high being 100% in the monsoon period and around 28% during summer. The winds are generally moderate except during late summer and monsoon period when they are very strong. The maximum wind speed is 4.1 km/hr. The nearest station is situated is in Vapi taluka in Valsad District and its detail is given table-3and shown in Fig. 2.

Table 3- Climatological data for IMD station Vapi taluka

Table- 1: Climatological data of Vapi taluka, Valsad District						
Month	**Max Temp (°C)**	**Mini Temp(°C)**	**Max Humidity (%)**	**Min Humidity (%)**	**Wind Speed(Km/hr)**	**Eto (mm/ month)**
January	35.4	9.9	86	29.4	1.8	111.3
February	37.5	10.7	82.1	26.1	2	126.3
March	40.1	15.1	81.6	24.4	2.5	185.5
April	41.2	19.6	79.6	27.3	2.9	218.7
May	39.8	23.3	82.6	39.7	3.9	231.7
June	37.1	22.7	96.9	52.7	4.1	148.8
July	32.8	22.9	98.2	71.7	3.5	77.3
August	32.2	22.9	96.8	72.5	2.7	71.7
September	34.2	22.6	97.2	65.8	1.6	96.1
October	37	17.8	91.1	38.5	1.3	132.6
November	36.5	14.6	84.6	33.8	1.3	121
December	35.3	11.6	85.5	34.4	1.3	105.7
Total	-	-	-		-	-
Average	**36.6**	**17.8**	**88.5**	**43**	**2.4**	**135.6**

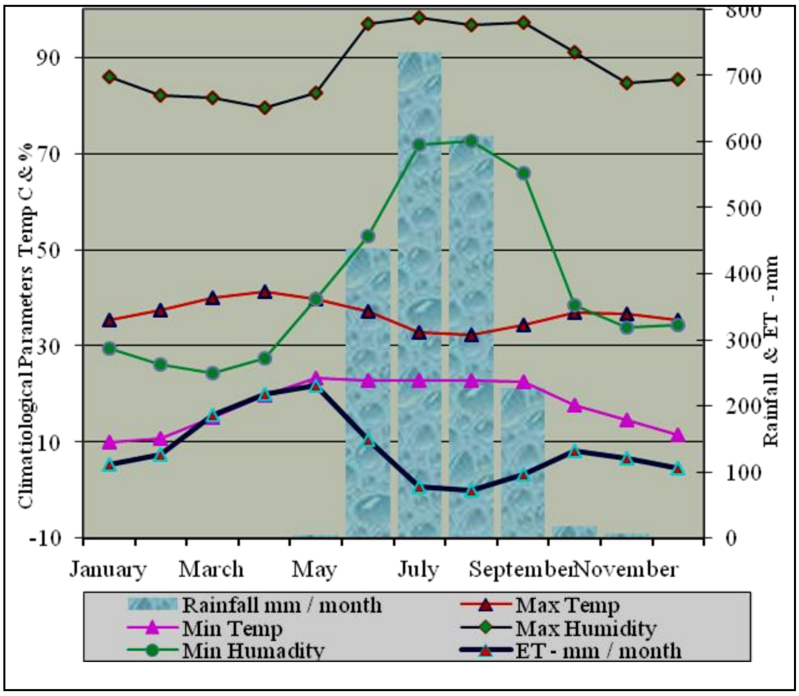


Figure 2- Pictorial Representation of Climatological Data

DIU:

Diu being an island enjoys a maritime climate, with the constant sea breezes affecting its temperature. With a plain topography, the weather remains dry, though pleasant throughout the year. During summers, the climate in Diu ranges between a maximum of 36°C and a minimum of 20°C. However, during winters, it comes down to a maximum of 26°C and the minimum temperature remains about 20°C.

The relative humidity in the nearby Veraval as per IMD varies between 55.5% January and 87.5% during August. The wind velocity in the Veraval varies from about 205 km/d during November to about 561 km/d during July.

The potential Evapo-transpiration, calculated using Penman's Method varies between 3.7 mm/d during August and 6.0 mm/d during April. The nearest station is situated in Veraval district Junagadh (20°54' N: 70 22' E- Altitude 8.0 m amsl) and its detail is given table-4 and shown in Fig. 3.

Table 4- Climatological data for IMD station Veraval

Month	Max Temp (°C)	Mini Temp (°C)	Humidity (%)	Wind Spd. Kmpd	Sunshine (Hours)	Solar Rad. (MJ/m2/d)	Eto (mm/ month)
January	28.8	14	55.5	242.4	9.7	18.5	4.8
February	29.7	15.1	63.5	258.3	10.3	21.3	5.2
March	31.5	18.5	70	291.9	9.9	23	5.8
April	32	21.8	76	318.4	10.5	25.4	6
May	31.8	25.5	81	337.9	10.3	25.5	5.8
June	31.6	27.1	83.5	447.6	7.4	21	5.1
July	30.1	26.1	87	560.8	4	15.8	3.9
August	29.2	25.3	87.5	465.2	4.3	16	3.7
September	30.3	24.4	83.5	311.3	6.2	18	4.2
October	33.3	22	73.5	226.4	9.4	20.8	5.2
November	33.1	19.1	61.5	205.2	9.7	18.9	5
December	30.4	15.9	56.5	217.6	9.5	17.5	4.6
Average	31	21.2	73.3	323.6	8.4	20.1	4.9

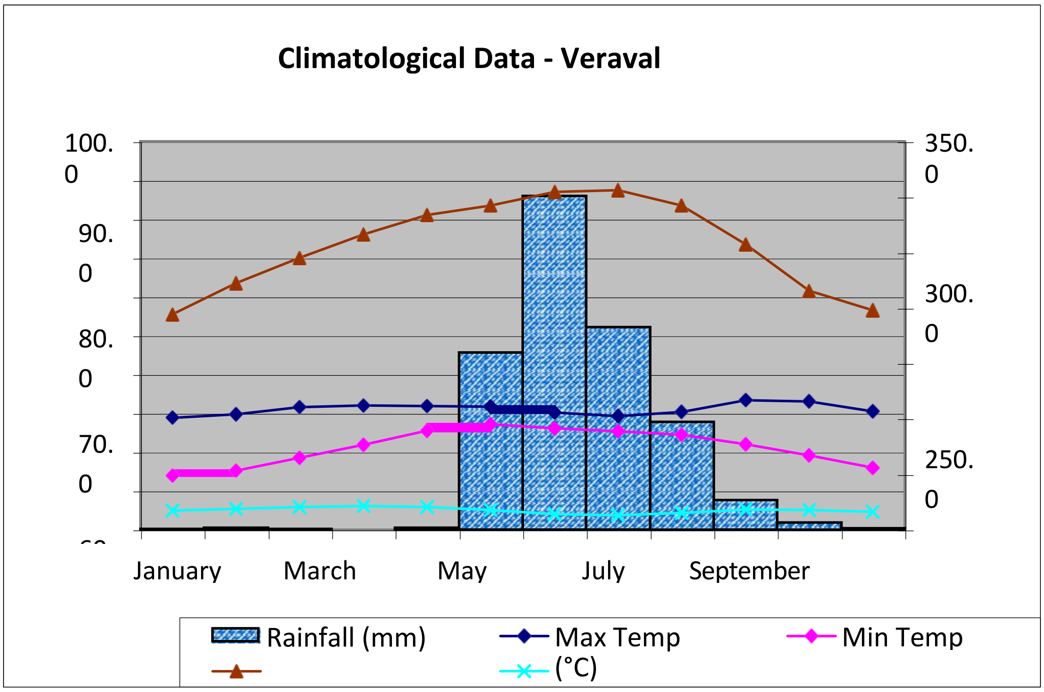


Figure 3- Pictorial Representation of Climatological Data

2. GEOLOGY

DAMAN:

Geologically Daman district is a northern extension of Deccan Plateau of Central India, belonging to late Cretaceous – early Eocene age and here, it is followed by Quaternary sediments. The stratigraphy sequence of Daman district is presented in Table-5.

Table 5- STRATIGRAPHIC SEQUENCE OF DAMAN DISTRICT

Geological Age	Formation	Group	Lithology
Holocene	Mahuva Formation		Younger tidal formation, spit / bar and shoal deposit
	Akhaj Formation		Coastal dune deposit
	Rann Clay Formation		Older tidal flat deposit
	Katpur Formation		Flood plain deposit
Upper Cretaceous to Eocene	Extrusive	Deccan	Granophyre and other basic dykes, sills & plugs
	Intrusive	Volcanic	Basalt & Dacite

DIU:

The area comprises Miliolite limestone of Pleistocene to Recent age and of about 50 m thick. It is a highly porous limestone which is friable except for the one or two layers near the ground surface, where the calcification of the limestone due to calcium carbonate solution has given rise to hard and compact crust. The Miliolite limestone is of high grade with very little contents of magnesium and insoluble. Solution activity has resulted in formation of caverns of varying dimensions. This karstic activity is more predominant in the zone of water level fluctuation and near the lower contact with the underlying clay formations. The limestones exhibits strike which is roughly parallel to sea and the dips are undulating like typical sand-dune deposits.

Miliolite limestone is underlain by Gaj formations of Miocene age. The Gaj formations comprise upper yellowish white clays underlain by interbedded marls, calcareous sandstones and grits, impure limestones and clays. The Gaj formation is found to be extending down to the explored depths of 200m. The base of Gaj Formation rests over the Deccan Trap Basalt.

The generalized geological succession in the area is given below in Table No- 6.

Table 6- STRATIGRAPHIC SEQUENCE OF DIU DISTRICT

Age	Formation	Lithology	Max. thickness/ Remarks
Recent to Pleistocene	Coastal Alluvium & Miliolite limestone	Sand, clays, Miliolite-limestone	40-50 m
Miocene (Tertiary)	Gaj beds	Clay, Marl, calc. sandstone, lime stone etc.	Not Exposed, +200 m
Upper Cretaceous to Eocene	Deccan Trap	Basaltic lava	Not exposed

3. HYDROGEOLOGY

DAMAN:

Basalt is the main basement rock which occurs at variable depths in most parts of Moti Daman and also exposed at surface in the north west part of Daman namely in Marwad, Devka, Kadiya. Basalt sheet rocks are exposed in river beds of Daman Ganga, Kalu and kolak rivers bordering UT of Daman. Alluvial deposits are found overlying the basalts, all along Moti Daman area and also in Dabhel and Kachigam areas having depth of 12 to 40m bgl. Alluvium deposits are river terrace type along the banks of river Daman Ganga.

The basalt occurs in the form of flows comprising massive and compact basalt in the bottom and gradually passes into vesicular basalt at the top. The basalts vary in colour from dark green to pink and show different sets of joints. All the joint systems are restricted to the individual flow seldom cutting across other flows. The surface weathering is characterized by spheroidal weathering. The major Aquifer system of Daman district is represented in below Figure No.4

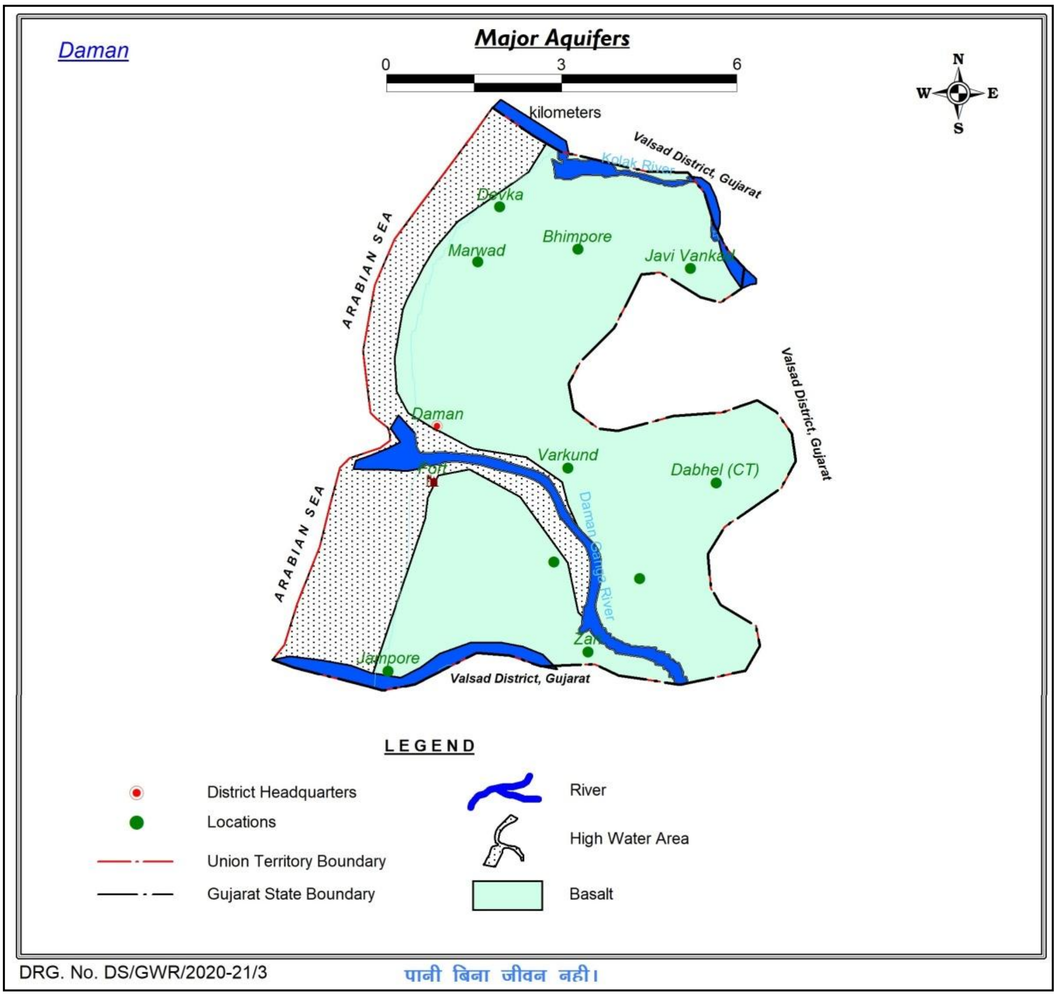


Figure 4- Major Aquifer System of Daman

DIU:

Ground water occurs under water table condition in the Miliolite limestone. The depth to water table varies from 12 m bgl in the central high land to 3 m bgl in the area up to 1 km inland from the high tide water line. Close to salt pans or sea, the water levels are almost same as high water line levels. This suggests that the central high land is the main ground water recharge area and sub-surface flow of ground water is from the central high land to the coastal area. The seasonal fluctuation in the water table level is 2 to 5 m in the central high land but along the coastal strip, the seasonal water level fluctuations are insignificant. The yields of wells are very high (50 m^3 to 240 m^3/ day) and drawdown ranging from 0.5 to 1.25 m.

The ground water occurs in inter-bedded calcareous sandstones, grits and arenaceous limestones of the deeper Gaj formation. Ground water is in confined condition in this formation with piezometric levels varying from 1.5 m to 3.0 m bgl. The quality of the water is saline in the upper Gaj formations, which is inherent as the deposition of Gaj formation was in marine condition. The intercalated marls and clay formations, which restrict the circulation of ground water, cause further deterioration in quality.

Pumping tests in two Dugwells (Large Diameter wells) were carried out by A.Ahmed (1980). The results of the short duration pumping test conducted at Sarwari, near airfield and Phophrona village revealed the specific capacities of the dugwells were (as determined by Slitcher's formula) 566.39 lpm/m and 31 lpm/m respectively. The rates of infiltration were 322.8 lpm and 40.92 lpm respectively (After Ahmed, 1980). The major Aquifer system of Diu District is represented in below Figure No.5

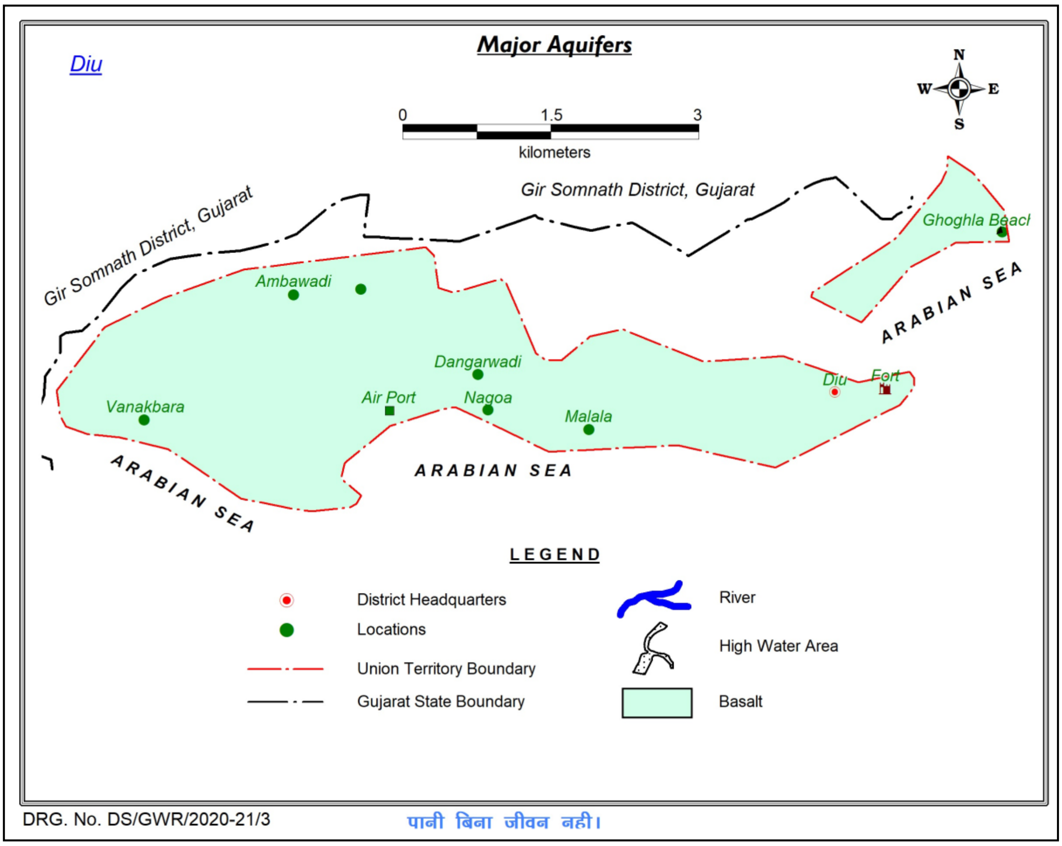


Figure 5- Major Aquifer system of DIU

3.1 GROUNDWATER REGIME MONITORING

Central Ground Water Board periodically monitors 09 Ground Water monitoring wells in the Daman district and 06 Ground Water monitoring wells in the Diu district , four times a year i.e. in January, May (Pre-monsoon), August and November (Post-monsoon). Ground water regime monitoring is the basic component of groundwater management and it is carried out in parts of UT of Daman & Diu district through National Hydrograph Network Stations (NHNS). These hydrograph stations comprised of dug wells and Piezometers and Observation wells. There are 8 Dug wells and 1 Piezometers in Daman district whereas 4 Dug Wells and 2 PZ in Diu District as part of the NHS monitoring. These water level data have been used for preparation of depth to water level maps of the district to understand the behaviour of ground water regime.

DAMAN:

3.1.1 Depth to Water Level Pre-Monsoon (May 2019)

The depth to water levels in Daman district during May 2019 ranges between 3.50 (Jampore Village, Daman District) and 9.05 mbgl (Daman PZ, Daman District). It is observed that depth to water level ranges in 6 m to more than 8 m bgl in most part of the Daman. Shallow water level less than 6 m bgl is observed on the South western parts of the Daman. The pre-monsoon depth to water level map is depicted in **Fig. 6**

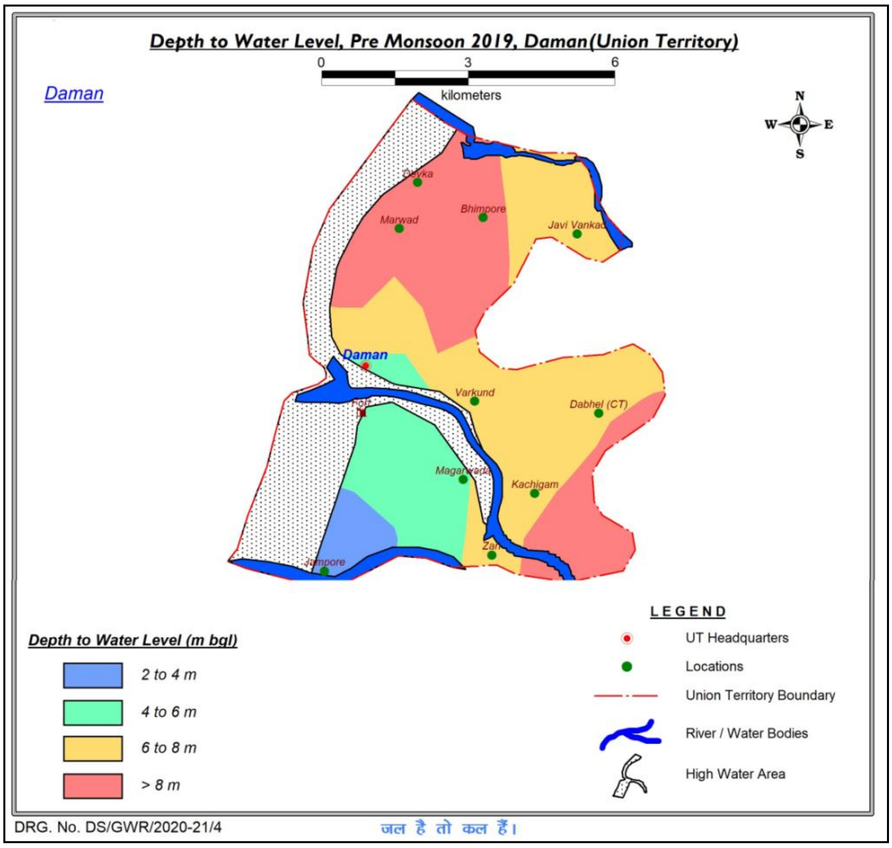


Figure 6- Pre-Monsoon Depth to Water Level Map-2019

3.1.2 Depth to Water Level Post-Monsoon (November 2019)

The depth to water levels in Daman district during May 2019 ranges between 0.85 (Jampore Village, Daman District) and 3.60 mbgl (Morwad, Daman District). It is observed that, most of the area is occupied by the DTWL between 2m and 4m bgl due to recharge during the monsoon period. The post-monsoon depth to water level map is depicted in **Fig. 7.**

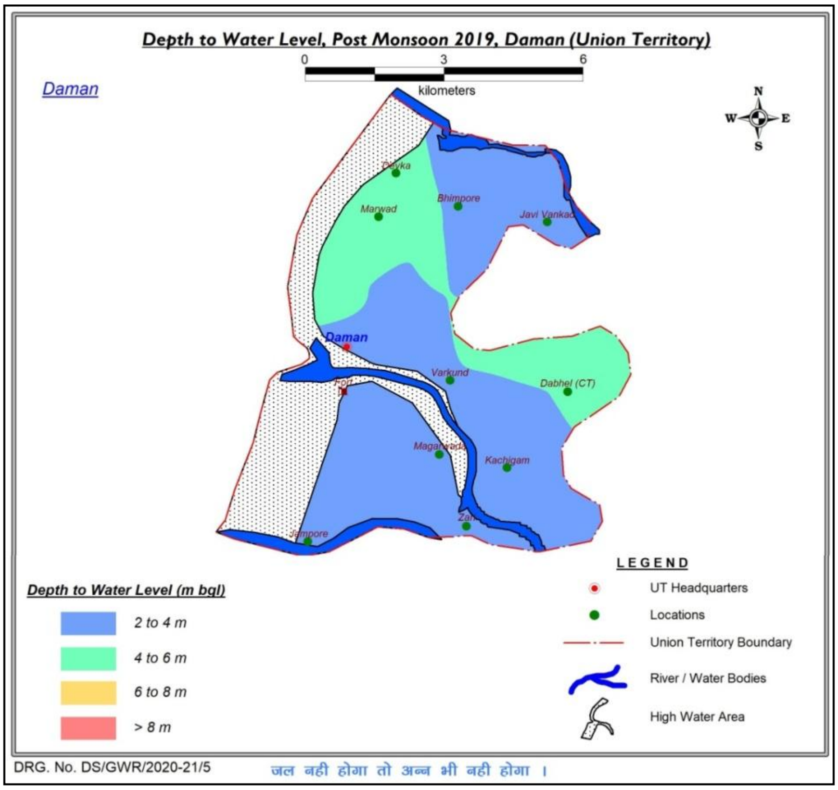


Figure 7- Post-Monsoon Depth to Water Level Map-2019- Daman

3.1.3 Decadal Average (2010-19) depth to water level Pre-monsoon

Decadal average of May 2010 to May 2019 depth to water level (DTWL) in m below ground level (bgl) has been presented in Fig.8. Most of the area of Daman is observed depth to water level 4 to 6 m bgl. Deep water level more than 6 m bgl is occurring in the northern half of the Daman close to coast.

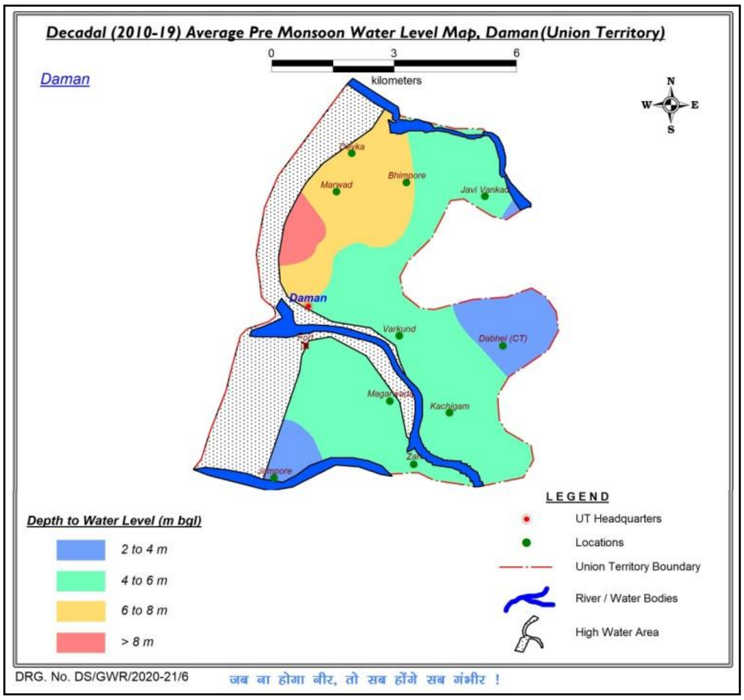


Figure 8- Decadal Pre-Monson Depth to Water Level

3.1.4 Decadal Average (2010-19) depth to water level Post-monsoon

Decal average water level for the period of November 2010 to 2019 is presented in Fig. 9. Most of the area of Daman is observed DTWL between 4 and 6 m bgl. Small isolated patch of deep water level 6 to 8 mbgl is shown near to Daman town close to coast.

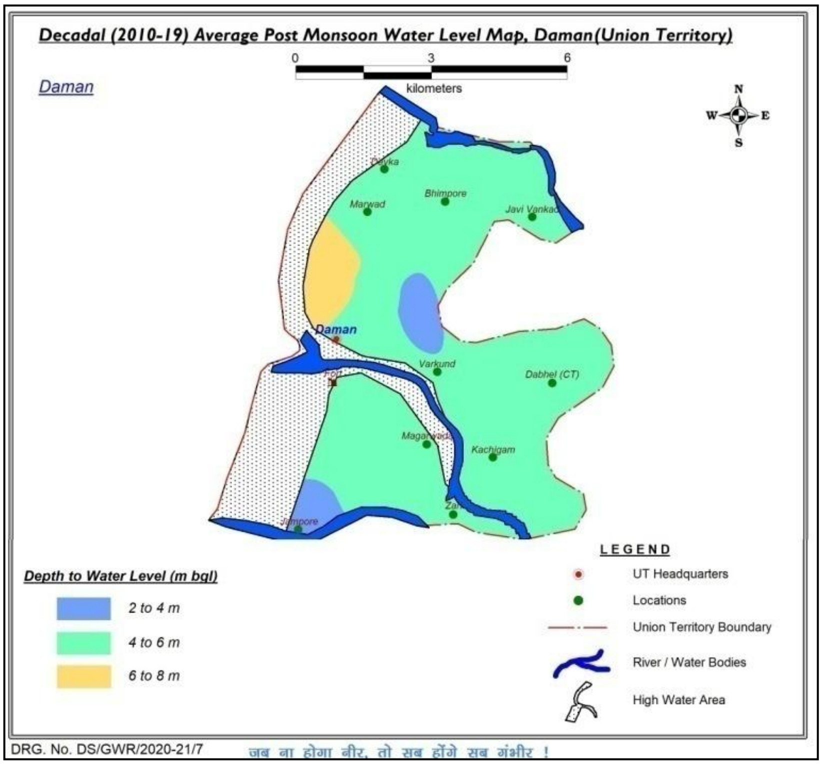


Figure 9- Decadal Post-Monson Depth to Water Level

DIU:

3.1.5 Depth to Water Level Pre-Monsoon (November 2019)

It is observed that depth to water level is ranges 6 to 8 m bgl in most of the area of Diu. Deep water level more than 8 m bgl is shown in small isolated patches in the southern part of Diu. The pre-monsoon depth to water level map is depicted in **Fig. 10.**

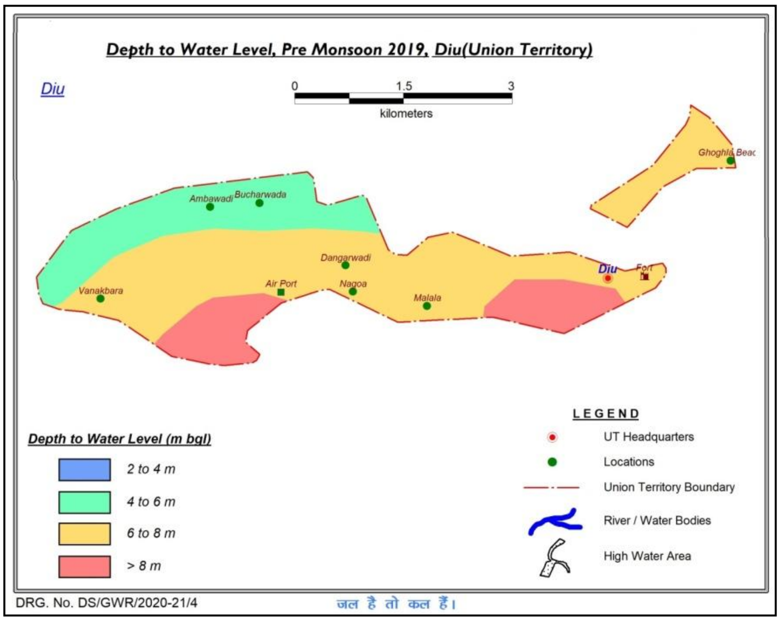


Figure 10- Pre-Monsoon Depth to Water Level Map-2019

3.1.6 Depth to Water Level Post-Monsoon (November 2019)

The depth to water levels in Diu district during November 2019 ranges between 2.0 (Vanakbarh village, Diu District) and 5.58 mbgl (Chakarteeth PZ, Diu District). It is observed that depth to water level is deeper in eastern part of district. The post-monsoon depth to water level map is depicted in **Fig. 11.**

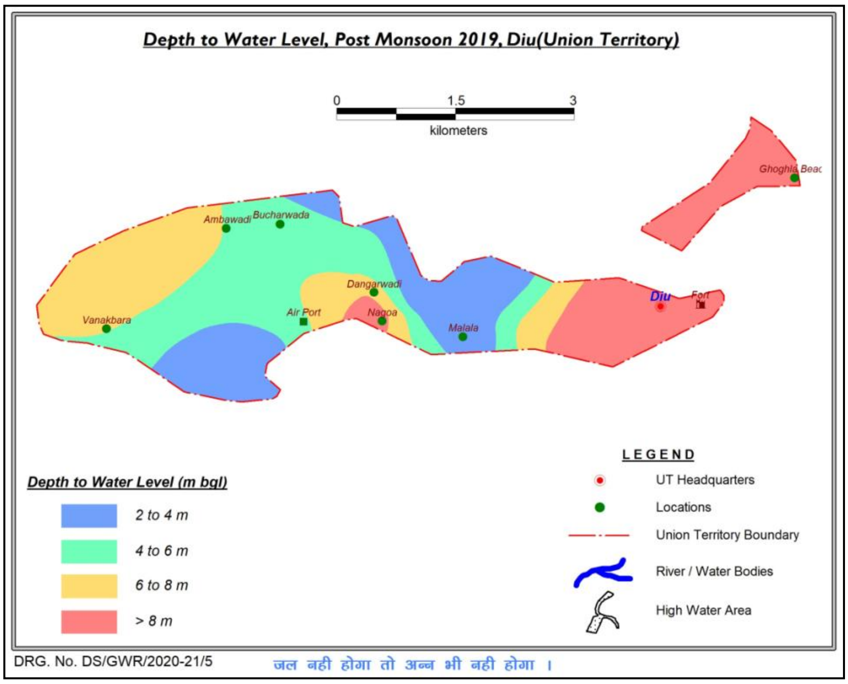


Figure 11- Post-Monsoon Depth to Water Level Map-2019- Diu

3.1.7 Decadal Average (2010-19) depth to water level Pre-monsoon

Decal average DTWL for the period of May 2010 to 2019 is personated in Fig. 12. Maximum part of Diu is occupied by DTWL between 4 and 6 m bgl. Water level between 6 and 8 m bgl is shown in isolated patches in eastern and western part of Diu.

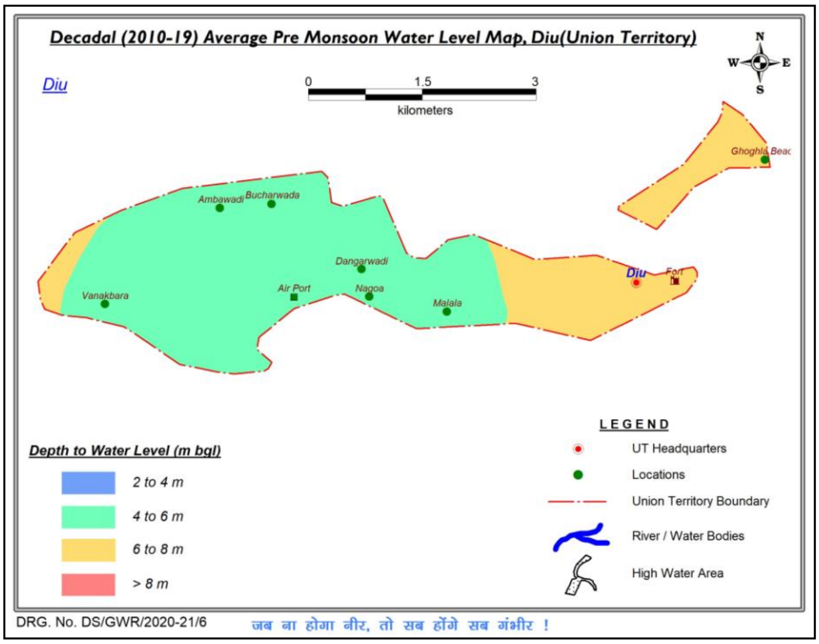


Figure 12- Decadal Pre-Monson Depth to Water Level

3.1.8 Decadal Average (2010-19) depth to water level Post-monsoon

Decadal average for the period of November 2010 to 2019 is shown in Fig. 13. Most of the area is presented the depth to water level 4 to 6 m bgl.

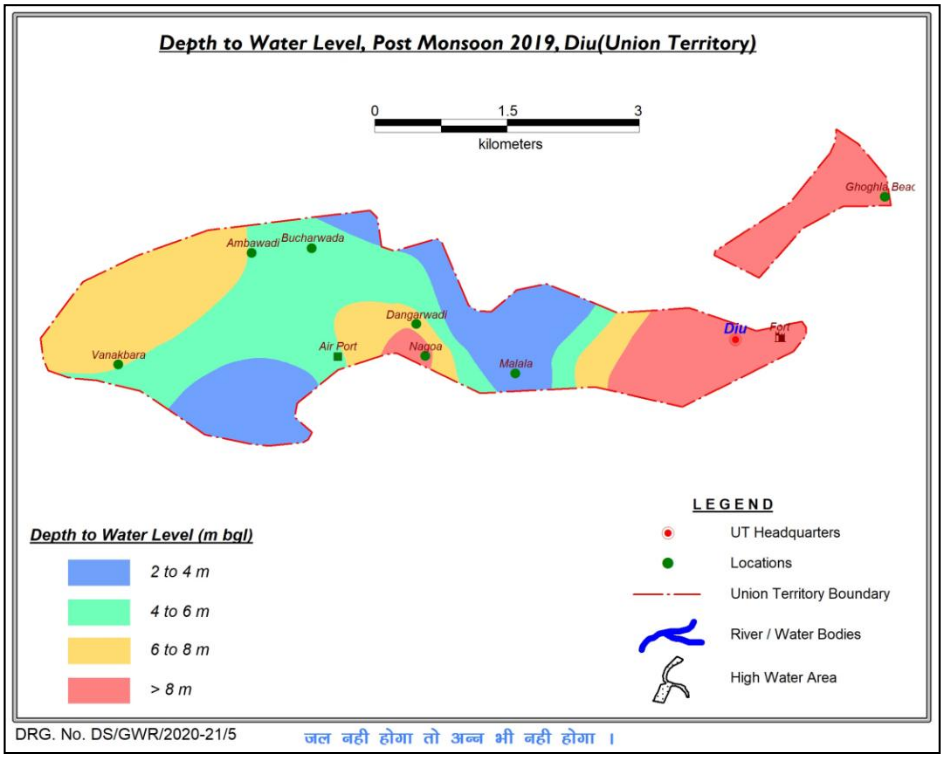


Figure 13- Decadal Post-Monson Depth to Water Level-Diu

3.2 WATER LEVEL TREND (2009 – 2019)

DAMAN:

During pre-monsoon, decline in water level trend has been recorded at 2 stations and ranges from 0.0519 (Jampore village) to 0.1330 m/year (Ambawardi village) while rising trend was observed in 4 stations varying from 0.0583 m/year (Warkund village) to 0.5472 m/year (Morwad village).

During post-monsoon, decline in water level trend has been recorded at 5 stations and ranges from 0.0140 (Delwada village) to 0.1269 m/year (Ambawardi village) while rising trend was observed in 2 stations varying from 0.1489 m/year (Khariwad village) to 0.2621 m/year (Dabhel village).

DIU:

During pre-monsoon, rise in water level trend has been recorded at all the 2 stations and ranges from 0.0083 (Chkrateeth village) to 0.1497 m/year (Diu) while declining trends were not observed at any location.

During post-monsoon, rise in water level trend has been recorded at 2 stations and ranges from 0.0278(Chkrateeth village) to 0.1814 m/year (Gomtimata village) while declining trend was observed in 1 stations 0.0134m/year (Jalwadi village).

Details of water level and trends for Daman and Dui are given in Annexure-3. Selected hydrographs are presented in Fig 14 to 17.

3.3 HYDROGRAPH OF DAMAN & DIU

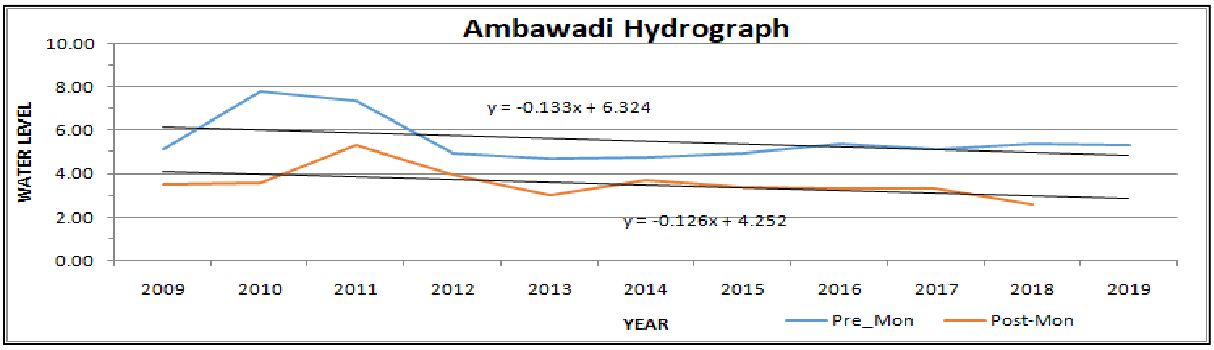


Figure 14- Hydrograph of Ambawadi village, Daman

This hydrograph shows both Pre-Monsoon and Post-Monsoon falling water level trends of 0.133 m/year and 0.126 m/year respectively.

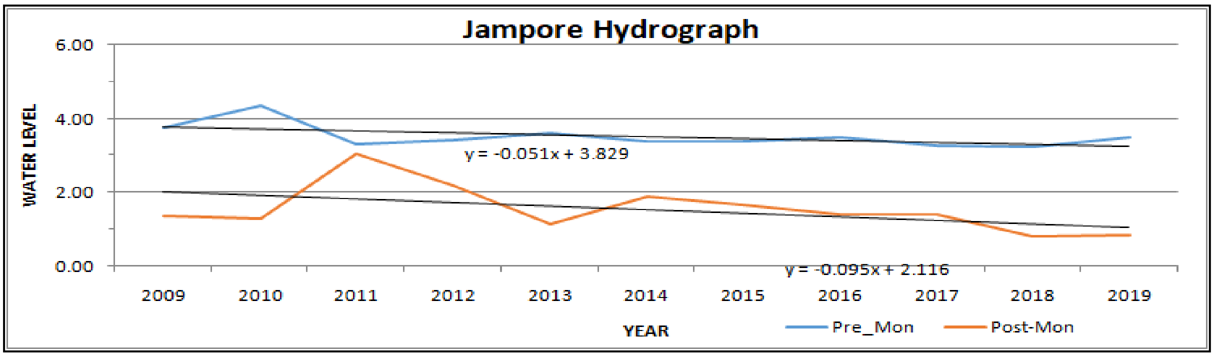


Figure 15- Hydrograph of Jampore village, Daman

This hydrograph shows both Pre-Monsoon and Post-Monsoon falling water level trends of 0.051 m/year and 0.095 m/year respectively.

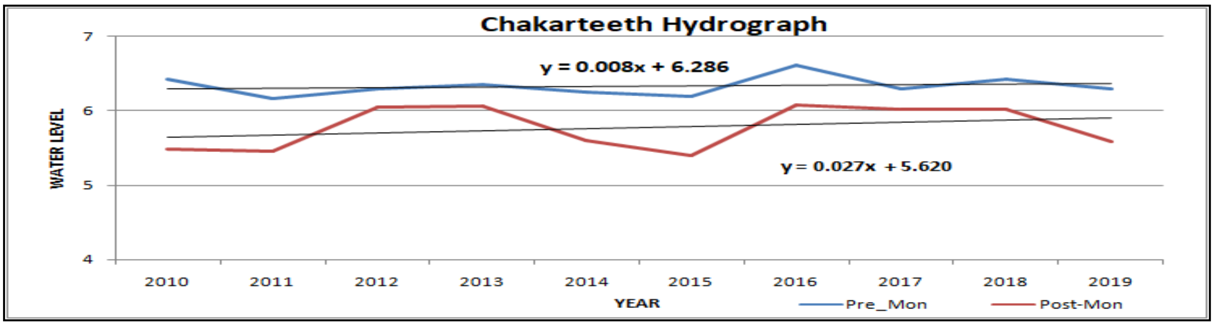


Figure 16- Hydrograph of Chakrteeth village, Diu

This hydrograph shows both Pre-Monsoon and Post-Monsoon rising water level trends of 0.008 m/year and 0.027 m/year respectively.

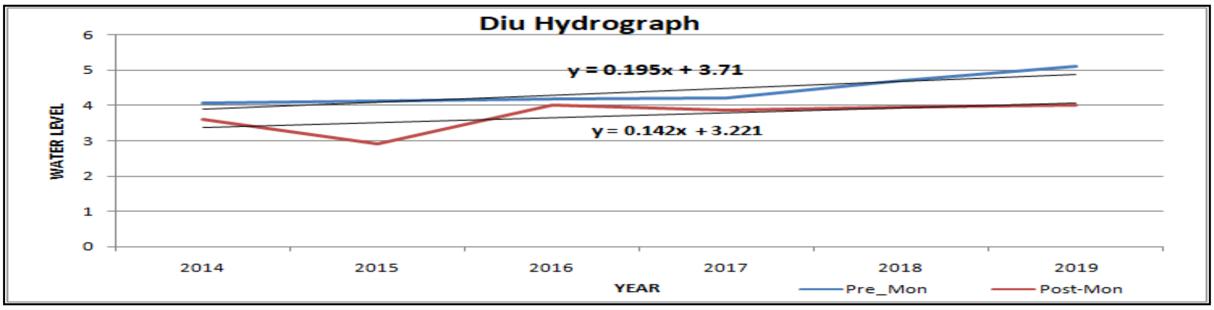


Figure 17- Hydrograph of Diu

This hydrograph shows both Pre-Monsoon and Post-Monsoon rising water level trends of 0.195 m/year and 0.142 m/year respectively.

3.4 QUALITY (ELECTRICAL CONDUCTIVITY):

DAMAN:

Electrical conductivity during pre-monsoon season 2019 ranges between 750 to 3000 µs/cm. It is observed that quality of GW is comparatively poor in eastern part of the Daman district (Fig. 18).

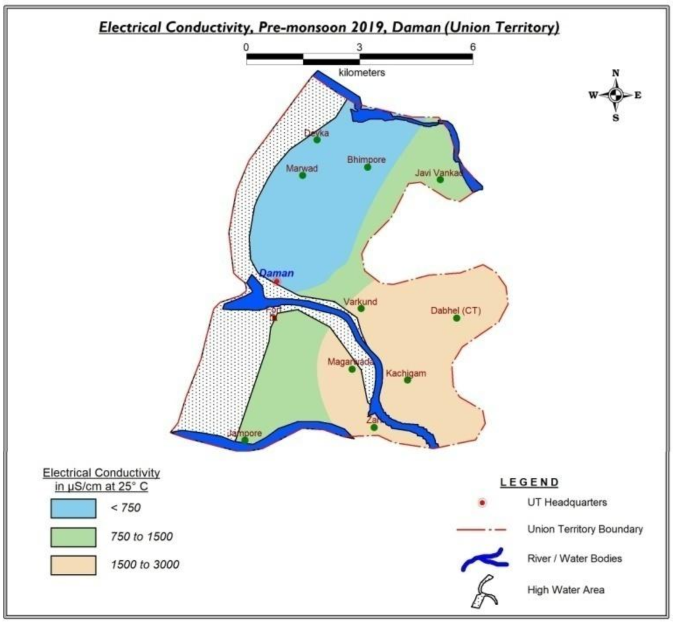


Figure 18- Electrical Conductivity Map of Daman 2019

DIU:

Electrical conductivity during pre-monsoon season 2019 ranges between 750 to 3000 µs/cm. It is observed that quality of GW is comparatively better in eastern part of the Diu district, which ranges between 750-1500 µs/cm (Fig. 19).

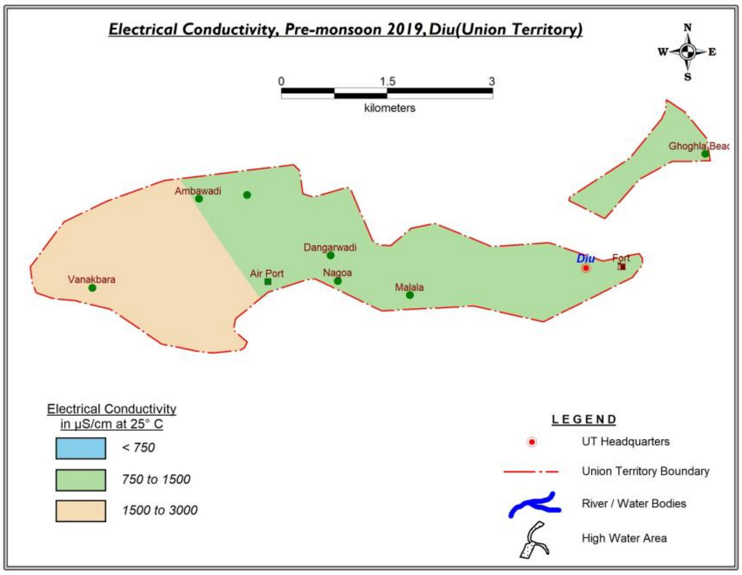


Figure 19-Electrical Conductivity Map of Diu 2019

4. GEC 2015 METHODOLOGY:

Present Groundwater Resource Estimation 2020 (GWRE 2020) has been carried as per revised methodology, known as Groundwater Estimation Committee 2015 (GEC 2015)[10]. The foremost recommendations of revised GEC 2015 methodology are summarized as follows. Detailed report on GEC 2015 is available on CGWB web site (http://cgwb.gov.in/).

4.1 Concept of Aquifer Wise Assessment

GEC 2015 recommends aquifer wise groundwater resource assessment for *Replenishable* ground water resources or *Dynamic* groundwater resources and also for *In-storage* groundwater resources or *Static* groundwater resources for both Unconfined and Confined aquifer. Wherever the aquifer geometry has not been firmly established for the unconfined aquifer, the in-storage groundwater resources have to be assessed in the alluvial areas up to the depth of bed rock or 300m whichever is less. In case of hard rock aquifers, the depth of assessment would be limited to 200m. In case of confined aquifers, if it is known that groundwater extraction is being taken place from this aquifer, the dynamic as well as in-storage resources are to be estimated. If it is firmly established that there is no groundwater extraction from this confined aquifer, then only in-storage resources of that aquifer has to be estimated

4.2 Periodicity of Assessment

GEC 2015 methodology recommends that the groundwater resources should be assessed once in every three years as per the present practice such that time lag between assessment and publication of the results is minimized. Hence it recommends to make all out efforts to reduce the time lag and so that groundwater assessment report be issued in the successive water year without delay.

4.3 Groundwater Assessment Unit & Sub Units

GEC 2015 methodology recommends aquifer wise groundwater resource assessment. However, until aquifer geometry is established on appropriate scale, it recommends that the existing practice of using watershed in hard rock areas and blocks/talukas/ mandals/ firkas in soft rock areas may be continued. It is recommended that wherever spring discharge data is available, the same may be assessed as a proxy for ‘groundwater resources’ in hilly areas. The assessment of spring discharge would constitute the ‘replenishable potential groundwater resource’ but it will not be accounted for in the categorization of groundwater assessment, at least not in the near future.

Like earlier GEC methodology, out of the total geographical area of the assessment unit, hilly areas wherever slope is greater than 20%, are to be identified and subtracted as these areas have more runoff than infiltration.

The groundwater resource beyond the permissible quality limits in terms of the salinity has to be computed separately. The remaining area after excluding the area with poor ground water quality is to be delineated as follows:

Non-command areas which do not come under major/medium surface water irrigation schemes. (Command area <100 Ha should be ignored).Command areas under major/medium surface water irrigation schemes which are actually supplying water (>100 Ha of command area.)

GEC 2015 methodology recommends that after the assessment is done, a quality flag may be added to the assessment unit for parameters salinity, fluoride and arsenic. It is proposed to have all these areas of an assessment unit in integer hectares to make it national database with uniform precision.

4.4 Groundwater Resources of Assessment of Unit

The groundwater resources of any assessment unit is the sum of the total groundwater availability in the principal aquifer (mostly unconfined aquifer) and the total ground water availability of semi-confined and confined aquifers existing in that assessment unit. The total groundwater availability of any aquifer is the sum of Dynamic groundwater resources and the In-storage or Static resources of the aquifer.

GEC 2015 advocate that the development planning should be on dynamic resource only as it gets replenished every year. Changes in static or in-storage resources reflect impacts of groundwater mining. Such resources may not be replenishable annually and may be allowed to be extracted only during exigencies with proper recharge planning in the succeeding excess rainfall years.

4.5 Assessment of Annually Replenishable or Dynamic Groundwater Resources

The elementary concept of GEC 2015 methodology for groundwater resources estimation is based on basic principle of water balance as given below –

$$\textbf{Inflow – Outflow = Change in Storage (of an aquifer)} \qquad \textbf{(1)}$$

Equation 1 can be further elaborated as -

$$\Delta S = Rrf + RSTR + RC + RSWI + RGWI + RTP + RWCS \pm VF \pm LF - GE - T - E - B \qquad (2)$$

Where,

ΔS –	Change is storage
Rrf –	Rainfall recharge
RSTR-	Recharge from stream channels
Rc –	Recharge from canals
RSWI –	Recharge from surface water irrigation
RGWI-	Recharge from groundwater irrigation
RTP-	Recharge from Tanks & Ponds
RWCS –	Recharge from water conservation structures
VF –	Vertical flow across the aquifer system
LF-	Lateral flow along the aquifer system (through flow)
GE-	Groundwater Extraction
T-	Transpiration
E-	Evaporation
B-	Base flow

GEC 2015 has observed that although above mentioned components of water balance equation are imperative, the present status of database available with Government and nongovernment agencies is not adequate in most of the assessment units. Therefore, it is proposed that at present the water budget may be restricted to the major components only taking into consideration certain reasonable assumptions. The estimation is to be carried out using lumped parameter estimation approach keeping in mind that data from many more sources if available may be used for refining the assessment.

4.6 Rainfall Recharge

GEC 2015 recommended that monsoon rainfall recharge should be estimated on groundwater level fluctuation and specific yield approach. This, however, requires adequately spaced representative water level measurement for a sufficiently long period. It is proposed that there should be at least three spatially well distributed observation wells in the assessment unit, or one observation well per 100 sq km. Water level data should also be available for a minimum period of 5 years (preferably 10years), along with corresponding rainfall data. Regarding frequency of water level data, three water level readings during pre and post monsoon seasons and in the month of January/ May preferably in successive years, are the minimum requirements. It would be ideal to have monthly water level measurements to record the peak rise and maximum fall in the ground water levels. In units or subareas where adequate data on ground water level fluctuations are not available as specified above, groundwater recharge may be estimated using rainfall infiltration factor method only. The rainfall recharge during non-monsoon season may be estimated using rainfall infiltration factor method only. These two basic approaches recommended by the GEC - 1984, namely groundwater level fluctuation method and rainfall infiltration factor method, still form the basis for groundwater assessment in GEC 2015 methodology.

4.6.1 Water Level Fluctuation (WLF) Method

Under this method the change in storage is computed by multiplying water level fluctuation between pre and post monsoon seasons with the area of assessment and specific yield.

Change in Storage = **$\Delta S = h*Sy*A$ .... (i)**

Where

h = rise in water level due to monsoon (fluctuation between pre-monsoon and post-monsoon water level),

A = area for computation of recharge, and

Sy = specific yield of aquifer formation

The Specific yield of a soil or rock is the ratio of the volume of water that, after saturation, can be drained by gravity to its own volume (Todd & Mays, 2005). The Specific yield data have either been arrived through field studies, including long-duration pumping tests and dry season groundwater balance (in hard-rock areas) or adopted from the norms recommended by GEC-1997, which were derived from the various water-balance studies carried out by CGWB, SGWDs and academic/research institutions.

Substituting the expression in equation 1 for storage increase ΔS in terms of water level fluctuation and specific yield, rainfall recharge in non-command will be as follow:

$$RRF = h \times Sy \times A - RSTR - RSWI - RGWI - RTP - RWCS \pm VF \pm LF + GE + T + E + B \qquad 3$$

And considering another term **Rc** as Recharge due to canals, rainfall recharge equation in command will be as follows:

$$RRF = h \times Sy \times A - RC - RSTR - RSWI - RGWI - RTP - RWCS \pm VF \pm LF + GE + T + E + B \qquad 4$$

The recharge calculated from equation 3 in case of non-command sub units and equation 4 in case of command sub units and poor groundwater quality sub units gives the rainfall recharge for the particular monsoon season. However, it may be noted that in case base flow/ recharge from stream and through flow have not been estimated, the same may be assumed to be zero.

The rainfall recharge obtained by using equation 3 & equation 4 provides the recharge in any particular monsoon season for the associated monsoon season rainfall. This estimate is to be normalized for the normal monsoon season rainfall as per the procedure indicated below.

4.6.1.1 Normalization of Rainfall Recharge

The recharge from rainfall estimated as per the above is for the particular monsoon season. It should be normalized for estimating recharge corresponding to the normal monsoon rainfall. GEC 2015 methodology follows the same procedures of earlier GEC 1997 methodology for normalizing monsoon recharge, which is summarized below.

The computational procedure to be followed is as given below:

$$R_{rf}(\text{normal}) = \frac{\sum_{i=1}^{N}\left[R_i \times \frac{r(\text{normal})}{r_i}\right]}{N}$$

Where

Rrf (normal) = Norma [illegible] l.

R_i= Rainfall Recharge in the monsoon season for the ith year.

r (normal) = Normal monsoon Season rainfall.

r_i = Rain fall in the monsoon season for the ith year.

N = Number of years for which data is available

4.6.2 Rainfall Infiltration Factor (RIF) Method

Like earlier GEC methodology, GEC 2015 recommended to compare the rainfall recharge obtained from Water Level Fluctuation method with that of the estimated recharge using Rainfall Infiltration Factor Method.

Recharge from rainfall is estimated by using the following relationship –

Rrf = RFIF * A* (R – a)/1000

Where,

Rrf = Rainfall recharge in ham

A = Area in Hectares

RFIF = Rainfall Infiltration Factor

R = Rainfall in mm

a = Minimum threshold value above which rainfall induces groundwater recharge in mm

GEC 2015 suggests that 10% of Normal annual rainfall be taken as Minimum Rainfall Threshold and 3000 mm as Maximum Rainfall limit. While computing the rainfall recharge, 10% of the normal annual rainfall is to be deducted from the monsoon rainfall and balance rainfall would be considered for computation of rainfall recharge. The same recharge factor may be used for both monsoon and non-monsoon rainfall, with the condition that the recharge due to non-monsoon rainfall may be taken as zero, if the normal rainfall during the non-monsoon season is less than 10% of normal annual rainfall. In using the method based on the specified norms, recharge due to both monsoon and non-monsoon rainfall may be estimated for normal rainfall, based on recent 30 to 50 years of data.

4.6.2.1 Percent Deviation

After computing the rainfall recharge for normal monsoon season rainfall using the Water level Fluctuation method and Rainfall Infiltration Factor method these two estimates have to be compared with each other. A term, Percent Deviation (PD) which is the difference between the two expressed as a percentage of the former is computed as

$$PD = \frac{R_{rf}(normal,) - R_{rf}(normal, rifm)}{R_{rf}(normal, wlfm)} \times 100$$

Where,
Rrf (normal, wtfm) = Rainfall recharge for normal monsoon season rainfall estimated by the water level fluctuation method
Rrf (normal, rifm) = Rainfall recharge for normal monsoon season rainfall estimated by the rainfall infiltration factor method
The rainfall recharge for normal monsoon season rainfall is finally adopted as per the criteria given below:

- If PD is greater than or equal to -20%, and less than or equal to +20%,Rrf (normal) is taken as the value estimated by the water level fluctuation method.
- If PD is less than -20%, Rrf (normal) is taken as equal to 0.8 times the value estimated by the rainfall infiltration factor method.
- If PD is greater than +20%, Rrf (normal) is taken as equal to 1.2 times the value estimated by the rainfall infiltration factor method.

4.7 Recharge from other Sources

Recharge from other sources constitute recharges from canals, surface water irrigation, groundwater irrigation, tanks & ponds and water conservation structures in command areas where as in non-command areas the recharge due to surface water irrigation, groundwater irrigation, tanks & ponds and water conservation structures are possible.

4.7.1 Recharge from Canals

Recharge due to canals is to be estimated based on the following formula:

RC = WA * SF * Days

Where:

RC = Recharge from Canals

WA = Wetted Area

SF = Seepage Factor

Days = Number of Canal Running Days.

4.7.2 Recharge from Surface Water Irrigation

Recharge due to applied surface water irrigation, either by means of canal outlets or by- lift irrigation schemes is to be estimated based on the following formula:

RSWI=AD*Days*RFF

Where:

RSWI = Recharge due to applied surface water irrigation

AD = Average Discharge

Days = Number of days water is discharged to the Fields

RFF = Return Flow Factor

4.7.3 Recharge from Groundwater Irrigation

Recharge due to applied groundwater irrigation is to be estimated based on the following formula:

RGWI = GEIRR*RFF

Where:

RGWI	=	Recharge due to applied groundwater irrigation
GEIRR	=	Groundwater Extraction for Irrigation
RFF	=	Return Flow Factor

4.7.4 Recharge due to Surface Water Bodies

Recharge due to surface water bodies, like tanks & ponds etc is to be estimated based on the following formula:

RTP =AWSA*RF

Where:

RTP	=	Recharge due to Tanks & Ponds
AWSA	=	Average Water Spread Area
RF	=	Recharge Factor

4.7.5 Recharge due to Water Conservation Structures

Recharge due to Water Conservation Structures is to be estimated based on the following formula:

RWCS =GS*RF

Where:

RWCS	=	Recharge due to Water Conservation Structures
GS	=	Gross Storage (Storage Capacity multiplied by number of Fillings).
RF	=	Recharge Factor

4.8 Additional Components Effecting Recharge

GEC 2015 methodology has introduced prescribed procedure to estimate additional recharge on account of some natural hydraulic and climatic parameters, which effect overall groundwater recharge of assessment unit. These components are as follow.

4.8.1 Lateral flow along the aquifer system (Through flow)

GEC 2015 prescribes that if the assessment unit area under consideration is a watershed, the lateral flow across boundaries can be considered as zero in case such estimates are not available. If there is inflow and outflow across the boundary, theoretically, the net inflow may be calculated using Darcy law, by delineating the inflow and outflow sections of the boundary. Besides such delineation, the calculation also requires estimate of transmissivity and hydraulic gradient across the inflow and outflow sections. These calculations are most conveniently done in a computer model. It is recommended to initiate regional scale modeling with well-defined flow boundaries. Once the modeling is complete, the lateral through flows (LF) across boundaries for any assessment unit can be obtained from the model and the same should be included in the water balance equation.

4.8.2 Base flow and Stream Recharge

GEC 2015 recommends that if stream gauge stations are located in the assessment unit, the base flow and recharge from streams can be computed using Stream Hydrograph Separation Method, Numerical Modelling and Analytical solutions. If the assessment unit is a watershed,a single stream monitoring station at the mouth of the watershed can provide the required data for the calculation of base flow. It is further suggested that Base flow assessment and Stream recharge should be carried out in consultation with Central Water Commission in order to avoid any duplicity in the estimation of total water availability in a river basin.

4.8.3 Vertical Flow from Hydraulically Connected Aquifers

This component can be estimated using the Darcy's law if the hydraulic heads in both aquifers and the hydraulic conductivity and thickness of the aquitard separating both the aquifers are known. GEC 2015 suggests that the regional scale groundwater flow modeling is an important tool to estimate such flows.

4.8.4 Evaporation and Transpiration

GEC 2015 recommends that the evaporation component can be estimated for the aquifer in the assessment unit, through field studies or from adjoin areas data, for areas with water level within 1.0 m bgl. If depth to water level is more than 1.0 m bgl, the evaporation losses from the aquifer should be taken as zero. Similarly the transpiration through vegetation can be estimated for the aquifer in the assessment unit, through field studies if water levels in the aquifer are within the maximum root zone of the local vegetation. If water levels are within 3.5m bgl, transpiration can be estimated using the transpiration rates available for other areas. If it is greater than 3.5m bgl, the transpiration should be taken as zero. Further, for estimating evapotranspiration, field tools like Lysimeters can be used to estimate actual evapotranspiration. In case where such data is not available, evapotranspiration losses can be empirically estimated from PET data provided by IMD.

4.9 Additional Potential Resources under Specific Conditions

GEC 2015 methodology recommends additional potential recharge estimation under specific conditions, if any, in the assessment unit, as described follows.

4.9.1 Potential Resource Due to Spring Discharge

Spring discharge constitutes an additional source of groundwater in hilly areas which merges at the places where groundwater level cuts the surface topography. The spring discharge is equal to the groundwater recharge minus the outflow through evaporation and evapotranspiration and vertical and lateral sub-surface flow. Thus Spring Discharge is a form of 'Annual Extractable Groundwater Recharge'. It is a renewable resource, though not to be used for Categorization. Spring discharge measurement is to be carried out by volumetric measurement of discharge of the springs. Spring discharges multiplied with time in days of each season will give the quantum of spring resources available during that season. The committee recommends that in hilly areas with substantial potential of spring discharges, the discharge measurement should be made at least 4 times a year in parity with the existing water level monitoring schedule.

Potential ground water resource due to springs = Q x No of days

Where,

Q	=	Spring Discharge
No of days	=	No of days spring yields.

4.9.2 Potential Resource in Waterlogged and Shallow Water Table Areas

In the area where the groundwater level is less than 5m below ground level or in waterlogged areas, the resources up to 5m below ground level are potential and would be available for development in addition to the annual recharge in the area. It is therefore, like earlier GEC 1997, GEC 2015 also recommends that in such areas, ground water resources may be estimated up to 5m bgl only assuming that where water level is less than 5m bgl, the same could be depressed by pumping to create space to receive recharge from natural resources. The computation of potential resource to groundwater reservoir, form such shallow water table areas, can be done by adopting the following equation:

Potential ground water resource in shallow water table areas = (5-D) x A x SY

Where

D = Depth to water table below ground surface in pre-monsoon period in shallow aquifers.

A = Area of shallow water table zone.

SY = Specific Yield

The planning of future minor irrigation works in the waterlogged and shallow water table areas as indicated above should be done in such a way that there should be no long term adverse effects of lowering of water table up to 5m and the water level does not decline much below 5m in such areas. The behavior of water table in the adjoining area which is not water logged should be taken as a bench mark for development purposes.

This potential recharge to groundwater is available only after depression of water level up to 5m bgl. This is not an annual resource and should be recommended for development on a very cautious approach so that it does not adversely affect the ground water potentials in the overall area.

4.9.3 Potential Resource in Flood Prone Areas

Ground water recharge from a flood plain is mainly the function of the following parameters-

- Areal extent of flood plain
- Retention period of flood
- Type of sub-soil strata and silt charge in the river water which gets deposited and controls seepage

GEC 2015 recommends that potential recharge from flood plain may be estimated on the same norms as for ponds, tanks and lakes. This has to be calculated over the water spread area and only for the retention period using the following formula.

Potential ground water resource in Flood Prone Areas = 1.4 x N x A/1000

Where

N = No of Days Water is Retained in the Area

A = Flood Prone Area

4.10 Recharge during Monsoon Season

The sum of normalized monsoon rainfall recharge and the recharge from other sources and lateral and vertical flows into the sub unit and stream inflows during monsoon season is the total recharge during monsoon season for the sub unit. Similarly this is to be computed for all the sub units available in the assessment unit.

4.11 Recharge during Non-Monsoon Season

The rainfall recharge during non-monsoon season is estimated using Rainfall Infiltration Factor method only when the non-monsoon season rainfall is more than 10% of normal annual rainfall. The sum of non-monsoon rainfall recharge and the recharge from other sources and lateral and vertical flows into the sub unit and stream inflows during non-monsoon season is the total recharge during non-monsoon season for the sub unit. Similarly this is to be computed for all the sub units available in the assessment unit.

4.12 Total Annual Groundwater Recharge

The sum of the recharge during monsoon and non-monsoon seasons is the total annual groundwater recharge for the sub unit. Similarly this is to be computed for all the sub units available in the assessment unit.

4.13 Annual Extractable Groundwater Recharge (EGR)

The National Water Policy, 2012 stresses that the ecological flow of rivers should be maintained. Accordingly GEC 2015 recommends that groundwater base flow contribution limited to the ecological flow of the river should be determined which will be deducted from Annual Groundwater Recharge to determine Annual Extractable Groundwater Resources (EGR). The ecological flows of the rivers are to be determined in consultation with Central Water Commission and other concerned river basin agencies. In the assessment units, where river stage data are not available and neither the detailed data for quantitative assessment of the natural discharge are available, present practice (GEC 1997) of allocation of unaccountable natural discharges to 5% or 10% of annual recharge may be retained. If the rainfall recharge is assessed using Water Level Fluctuation method this will be 5% of the annual recharge and if it is assessed using Rainfall Infiltration Factor method, it will be 10% of the annual recharge. The balance will account for Annual Extractable Groundwater Resources (EGR).

4.14 Estimation of Groundwater Extraction

Like earlier methodology, GEC 2015 recommends various available methods for estimation of groundwater extraction in each assessment sub unit, as described below. Moreover, GEC 2015 also recommends that the groundwater extraction obtained figures from different methods need to be compared and based on field checks, the seemingly best value may be adopted. At times, groundwater extraction obtained by different methods may vary widely. Moreover unit draft adopted needs to be normalized as per annual rainfall of period for which assessment is being carried out. In general, the value matching the field situation should be considered. It is also suggested that the storage depletion during a season where other recharges are negligible can be taken as groundwater extraction during that particular period.

4.14.1 Components of Groundwater Extractions

Groundwater draft or extraction is to be assessed as follows.

$$GE_{ALL} = GE_{IRR} + GE_{DOM} + GE_{IND}$$

Where,

GE_{ALL} = Groundwater extraction for all uses

GE_{IRR} = Groundwater extraction for irrigation

GE_{DOM} = Groundwater extraction for domestic uses

GE_{IND} = Groundwater extraction for industrial uses

4.14.2 Groundwater Extraction for Irrigation (GEIRR)

- **Unit Draft Method**: – In this method, season-wise unit draft of each type of well in an assessment unit is estimated. The unit draft of different types (eg. Dug well, Dug cum bore well, shallow tube well, deep tube well, bore well etc.) is multiplied with the number of wells of that particular type to obtain season-wise groundwater extraction by that particular structure. It is recommended that a single source of well census should be maintained for resources computation at all India level. Minor Irrigation Census of

MoWR, RD & GR would be the preferred option.

- **Crop Water Requirement Method**: – For each crop, the season-wise net irrigation water requirement is determined. This is then multiplied with the area irrigated by groundwater abstraction structures. The database on crop area is obtained from Revenue records in Tahsil office, Agriculture Census and also by using Remote Sensing techniques.
- **Power Consumption Method**: – Groundwater extraction for unit power consumption (electric) is determined. Extraction per unit power consumption is then multiplied with number of units of power consumed for agricultural pump sets to obtain total groundwater extraction for irrigation.

4.14.3 Groundwater Extraction for Domestic Use (GEDOM)

- **Unit Draft Method**: – In this method, unit draft of each type of well is multiplied by the number of wells used for domestic purpose to obtain the domestic groundwater draft.
- **Consumptive Use Method**: – In this method, population is multiplied with per capita consumption usually expressed in litre per capita per day (lpcd). It can be expressed using following equation.

  GEDOM= Population X Consumptive Requirement X Lg

  Where,

  Lg = Fractional Load on Groundwater for Domestic Water Supply

The data about load factors on groundwater sources can be obtained from the concerned water supply agencies / departments.

4.14.4 Groundwater Extraction for Industrial use (GEIND)

- **Unit Draft Method**: - In this method, unit draft of each type of well is multiplied by the number of wells used for industrial purpose to obtain the industrial groundwater extraction.
- **Consumptive Use Pattern Method**: – In this method, water consumption of different industrial units are determined. Numbers of Industrial units which are dependent on ground water are multiplied with unit water consumption to obtain groundwater draft for industrial use, as suggested below.

  GEIND= Number of industrial units X Unit Water Consumption X Lg

  Where,

  Lg = Fractional load on groundwater for industrial water supply

The load on Groundwater for Industrial water supply can be obtained from water supply agencies in the Industrial belt.

4.14.5 Data Base of Industry: -

Other important sources of data on groundwater extraction for industrial uses are - Central Ground Water Authority, State Ground Water Authority, National Green Tribunal and other Environmental Regulatory Authorities.

4.14.6 Stage of Groundwater Extraction

The stage of groundwater extraction is defined by,

$$Stage\ of\ Ground\ Water\ Extraction\,(\%) = \frac{\text{Existing gross ground water extraction for all uses}}{\text{Annual Extractable Ground water Resources}} \times 100$$

The existing gross groundwater extraction for all uses refers to the total of existing gross groundwater extraction for irrigation and all other purposes. The stage of groundwater extraction should be obtained separately for command areas, non-command areas and poor groundwater quality areas.

4.15 Validation of Stage of Groundwater Extraction

Taking into consideration of inherent uncertainties associated with various components of both extracted and extractable groundwater resources, GEC 1997 has recommended validating the "Stage of Groundwater Extraction (SGE)" with long term trend of groundwater levels for a minimum period of 10 years for both pre-monsoon and post-monsoon period. GEC 2015 refine these concept further and suggest that if the pre and post monsoon water levels show a fairly stable trend, it does not necessarily mean that there is no scope for further groundwater development. Such a trend indicates that there is a balance between recharge, extraction and natural discharge in the unit. However, further groundwater development may be possible, which may result in a new stable trend at a lower groundwater level with associated reduced natural discharge. If the groundwater resource assessment and the trend of long term water levels contradict each other, this anomalous situation requires a review of the groundwater resource computation, as well as the reliability of water level data. The mismatch conditions are enumerated below table 7.

Table 7- Validation Criteria for Stage of GW Extraction (SGWE)

Stage of GW Extraction	Groundwater Level Trend	Remarks
≤ 70 %	Significant decline in trend in both pre-monsoon and post- monsoon	Not acceptable and needs reassessment
>100 %	No significant decline in both pre-monsoon and post- monsoon long term trend	Not acceptable and needs reassessment

In case, the category does not match with the water level trend given above, a reassessment should be attempted. If the mismatch persists even after reassessment, the sub unit may be categorized based on Stage of Groundwater Extraction of the reassessment. However, the sub unit should be flagged for strengthening of observation well network and parameter estimation.

4.15.1 Categorisation of Assessment Units

Present categorization of assessment units, as per GEC 1997 methodology takes into account long term groundwater level trends and stage of groundwater extraction of period under consideration. The National Water Policy, 2012 emphasis a convergence of quantity and quality of groundwater resources while assessing the groundwater extraction status in an assessment unit so as to aid appropriate management decisions. Therefore, GEC 2015 recommends separate estimation of resources where water quality is beyond permissible limits for the parameter salinity. Moreover, if any of the three quality hazards in terms of Arsenic, Fluoride and Salinity are encountered in the assessment sub unit in mappable units, the assessment sub unit may be tagged with the particular Quality hazard. Accordingly, GEC 2015 recommends that each assessment unit, in addition to the quantity based categorization (safe, semi-critical, critical and over-exploited) should bear a quality hazard identifier (table 8). Such quality hazards are to be based on available groundwater monitoring data of State Ground Water Departments and /or Central Ground Water Board.

Table 8- Criteria for Categorization

Stage of Groundwater Extraction	Category	Quality Tag
$\leq 70\,\%$	Safe	Tag for sub unit / unit in terms of Salinity, Arsenic, Fluoride, if any
$>70\,\%\ and \leq 90\,\%$	Semi Critical	
$>90\,\%\ and \leq 100\,\%$	Critical	
>100 %	Over Exploited	

4.16 Allocation of Groundwater Resource for Utilisation

The Annual Extractable Groundwater Resources are to be apportioned between domestic, industrial and irrigation uses. Among these, as per the National Water Policy, requirement for domestic water supply is to be accorded priority. This requirement has to be based on population as projected to the year 2025, per capita requirement of water for domestic use, and relative load on groundwater for urban and rural water supply. The estimate of allocation for domestic water requirement may vary for one sub unit to the other in different states. In situations where adequate data is not available to make this estimate, the following empirical relation is recommended.

Alloc = 22 X N X Lg mm per year

Where

Alloc = Allocation for domestic water requirement

N = population density in the unit in thousands per sq. km.

Lg = fractional load on groundwater for domestic and industrial water supply (≤ 1.0)

In deriving equation above, it is assumed that the requirement of water for domestic use is 60 lpd per head. The equation can be suitably modified in case per capita requirement is different. If by chance, the estimation of projected allocation for future domestic needs is less than the current domestic extraction due to any reason, the allocation must be equal to the present day extraction. It can never be less than the present day extraction as it is unrealistic.

4.17 Net Annual Groundwater Availability for Future Use

The water available for future use is obtained by deducting the allocation for Domestic use and current extraction for Irrigation and Industrial uses from the annual extractable groundwater recharge. The resulting groundwater potential is termed as the Net Annual Groundwater Availability for future use.

The net annual groundwater availability for future use should be calculated separately for non-command areas and command areas. As per the recommendations of the R&D Advisory committee, the groundwater available for future use can never be negative. If it becomes negative, the future allocation of domestic needs can be reduced to current extraction for domestic use. Even then if it is still negative, then the groundwater available for future uses will be zero.

4.18 Assessment of In-Storage or Static Groundwater Resources

Presently there is no fine demarcation to distinguish the dynamic resources from the static resources. While water table hydrograph could be an indicator to distinguish dynamic resources, at times it is difficult when water tables are deep. Therefore, the GEC 2015 recommends the computation of the static or in-storage groundwater resources be done after delineating the aquifer thickness and specific yield of the aquifer material as follows:-

SGWR = A *(Z2 - Z1) * SY

Where,

SGWR	=	Static or in-storage Groundwater Resources
A	=	Area of the Assessment Unit
Z2	=	Bottom of Unconfined Aquifer
Z1	=	Pre-monsoon water level
SY	=	Specific Yield in the In storage Zone

4.19 Assessment of Total Groundwater Availability in Unconfined Aquifer

The sum of Annual Exploitable Groundwater Recharge and the In-Storage Groundwater Resources of an unconfined aquifer is the Total Groundwater Availability of that aquifer.

4.20 Assessment of Groundwater of Confined Aquifer System

GEC 2015 recommends using groundwater storage approach to assess the groundwater resources of the confined aquifers. The co-efficient of storage or storativity of an aquifer is defined as the volume of water it releases or takes into storage per unit surface area of the aquifer per unit change in head. Hence the quantity of water added to or released from the aquifer (Δ V) can be calculated as follows:

$$\Delta V = S \Delta h$$

If the areal extent of the confined aquifer is A then the total quantity of water added to or released from the entire aquifer is

$$Q = A \Delta V = SA \Delta h$$

Where

Q = Quantity of water confined aquifer can release (m^3)

S = Storativity

A = Areal extent of the confined aquifer (m^2)

Δ**h** = Change in Piezometric head (m)

GEC 2015 points out that most of the storage in confined aquifer is associated with compressibility of the aquifer matrix and compressibility of water. Once the Piezometric head reaches below the top confining bed, it behaves like an unconfined aquifer. Hence the resources available under pressure are only considered as the confined groundwater potential. The quantity of water released in confined aquifer due to change in pressure can be computed between Piezometric head (ht) at any given time 't' and the bottom of the top confining layer (ho) by using the following equation.

$$Qp = SA\Delta h = SA\ (ht - h0)$$

If any development activity is started in the confined aquifer, then there is a need to assess the dynamic as well as in storage resources of the confined aquifer. To assess the groundwater resources of the confined aquifer, there is a need to have sufficient number of observation wells tapping exclusively that particular aquifer and proper monitoring of the piezometric heads is also needed.

4.21 Assessment of Groundwater of Semi-Confined Aquifer System

GEC 2015 observes that the Assessment of Groundwater Resources of a semi-confined aquifer has some more complications, apparently uncertainty about its relation with respect to underlying / overlying other aquifers. To avoid the duplication of estimating the same resource by direct computation in one aquifer and as leakage in the other aquifer, GEC 2015 advices not to assess such aquifer resources separately as long as precise data is available. Till then, if any such aquifer system identified as not assessed, its groundwater resources are to be assessed following the methodology similar to that used in assessing the resources of confined aquifers.

4.22 Total Groundwater Availability of an Area

The Total Groundwater availability in any area is the Sum of Dynamic Groundwater Resources, the total Static/ In-storage groundwater resources in the unconfined aquifer and the Dynamic and In-storage resources of the Confined aquifers and semi confined aquifers in the area.

4.23 Groundwater Assessment in Urban Areas

GEC 2015 propose to have a separate ground water assessment for urban areas with population more than 10 lakhs. Taking note of difficulties to have groundwater draft data in most of the urban areas and constraints to natural recharge, by rainfall infiltration and recharge due to other sources on account of urbanization, GEC 2015 has suggested the following few points are to be considered for Urban Areas Groundwater Resources Estimation.

- The difference of the actual demand and the supply by surface water sources as the withdrawal from the ground water resources.
- Consider 30% of the rainfall infiltration factor for urban areas as an adhoc arrangement till field studies are done and documented.
- The 50 % percent losses reported by piped water supply may be taken as recharge to the groundwater system.
- The seepages from the sewerages, which normally contaminate the ground water resources with nitrate, also contribute to the quantity of resources and hence same percent as in the case of water supply pipes may be taken as norm for the recharge on the quantity of sewerage when there is sub surface drainage system.
- Recharge on account of seepage from open drainage system / open channels, (like lined / unlined canal) may be considered, till further documented field studies are done.
- If estimated flash flood data is available, the same percent can be used on the quantum of flash floods to estimate the recharge from the flash floods.

4.24 INDIA -GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES)

INDIA-GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES) is a Software/Web-based Application developed by CGWB in collaboration with IIT-Hyderabad. It will provide common and standardized platform for Ground Water Resource Estimation for the entire country and its pan-India operational (Central and State Governments). The system will take 'Data Input' through Excel as well as Forms, compute various ground water components (recharge, extraction etc.) and classify assessment units into appropriate categories (safe, semi-critical, critical and over-exploited). The Software uses GEC 2015 Methodology for estimation and calculation of Groundwater resources. It allows for unique and homogeneous representation of groundwater fluxes as well as categories for all the assessment units (AU) of the country.

URL of IN-GRES - http://ingres.iith.ac.in

4.25 PROCEDURE FOLLOWED IN THE PRESENT ASSESSMENT

The Dynamic Ground Water Resource Assessment (GWRA-2020) of UT of Daman & Diu has been computed as per GEC-2015 Methodology. Since the area of Daman and Diu districts are very small, therefore the district administrative boundary has been taken as assessment unit and for computing the district wise ground water resources. The Resource Estimation has been done by IN-GRES Software. In absence of requisites data or inadequacy if any, the constraints and the procedure followed in the present assessment are described below.

4.25.1 Data Sources and Constraint for Various Data Elements

All-out efforts were made to collect the data from the respective UT of Daman & Diu. However, it is felt necessary to mention that due to non availability/constraint of some data, certain assumptions have been made while making the computations. The data sources for the various data elements used in the present exercise are presented in the following table.

Table 9- Data Sources Used in the Ground Water Resource Estimation 2020

S.No	Data Element	Used in the Computation of	Data Source
1	Areas and Maps of 2 administrative /assessment Units.	Assessment unit wise recharge & draft component.	Revenue Dept, Govt. of Gujarat, Gandhinagar.
2	Irrigation Well.	Groundwater extraction for irrigation	Irrigation department, Daman & Diu.
3	Ground Water Abstraction Details.	Groundwater extraction for Industrial.	Industrial development department, Daman Diu & DNH.
4	Ground Water Abstraction Details	Groundwater extraction for Domestic.	PWD Department and BDO office of Daman & Diu.
5	Population Census	Groundwater extraction for domestic purpose, Future allocation for domestic requirement.	Census of India Data (2011)
6	Load Factor (Lg)	As above	PWD Department of Daman & Diu
7	Details of Pump sets (HP) used in irrigation wells	Ground water extraction for irrigation purpose	BDO office of Daman & Diu.
8	Canal details	Return Seepage Recharge due to Canals / Drains	PWD Department of Daman & Diu
9	Details of Tanks & Ponds, Check dams	Recharge due to Tanks & ponds & water conservation	PWD Department & BDO office of Daman & Diu.
10	Rainfall	Recharge due to Rainfall / Normalization of Rainfall Recharge	IMD/State Water Data Centre

12	Ground Water Monitoring: Pre-monsoon and Post-monsoon groundwater levels & trends and GW quality monitoring data of last decade (2010-19).	Water Level Fluctuation method and validation of Stage of ground water extraction, GW Quality data for identification of poor quality area.	Central Ground Water Board, WCR, Ahmedabad and Gujarat Water Resources Development Corporation Ltd, Govt. of Gujarat
13	Data for Demarcation of Hilly Areas.	Hilly Area with slope less than 20% for Recharge.	BISAG, Gandhinagar

Long term 10 years (2010-19), pre-monsoon (May) and post-monsoon (November) water level data of observation wells monitored by CGWB, WCR, Ahmedabad are considered for calculating estimating zone of dynamic fluctuation and Water Level Trend. Water level fluctuations between pre-monsoon and post-monsoon have been calculated for hard rock and alluvial terrains separately. The Pre-monsoon and Post Monsoon water Level data is given in **Annexure 1, 2**.

Due to insufficient/non availability of data the following components were not considered while estimating the dynamic resources

- Lateral inflow/outflow across boundaries: insufficient data points / Piezometers for determination of the parameters.
- Subsurface inflow/outflow from hydraulically connected streams: sufficient nos. of stream gauge stations is required for determination of the parameters which were not available.
- Evaporation and Transpiration: water level is more than 3.5 mbgl in most of the areas for which data was available. Hence the same was not taken into account.

4.25.2 Domestic draft and future allocation for domestic use and Industrial Draft

Ground water draft for domestic use has been estimated and projected based on district wise population. Population data of Census 2011 has been considered and has been projected till 2019 based on the annual growth rate of population as per Census 2011 data. The average consumption of 135 lpcd for Daman district 120 lpcd for Diu district and load factor (Lg) as collected from public work department Daman and has been considered while estimating the domestic draft. Similarly future allocation for domestic use has been estimated up to 2025 based on projected population in 2025 using Census 2011 data.

Ground water draft for industrial use of 2 district ground water abstraction details provided by Daman Diu & DNH Industrial Development department has been considered for estimating the Industrial Draft.

4.25.3 Irrigation Draft:

District wise ground water extraction for irrigation was estimated based on the number of structures and the unit draft of different structures. As in the UT of Daman & Diu, major irrigation draft is through energized wells, data of HP wise number of irrigation connections in each taluka, average ground water draft based on HP of pump used in alluvial and hard rock formation and duration of pumping were used for estimation the irrigation draft.

4.26 Assessment Unit Area

The groundwater resource assessment of the UT of Daman & Diu has been carried out taking district (administrative boundary) as assessment unit. In total there are two (02) districts as assessment units. The details of ground water assessment units district wise is given as **Annexure-5**.

4.27 Norms Followed in the Assessment GWRA 2020

The GEC 2015 recommends that the state agencies should be encouraged to conduct field studies for various norms and use such computed norms in the assessment. In absence of such computed norms by the field study, GEC 2015 suggests to use recommended norm values for assessment, unless sufficient data based on field study are available to justify the minimum, maximum or other intermediate values.

Whereas specific yield values based on the field tests conducted by Central Ground Water Board & Gujarat Water Resources Development Corporation has been used in assessment, norms as suggested in GEC 2015 methodology like rainfall infiltration factor, canal seepage factor, factors for return flow from surface and ground water irrigation, recharge from water conservation structures, tanks and ponds etc, have been used.

4.28 Dynamic Ground Water Resources

4.28.1 Ground water Potential

The assessment unit (District) wise details of Ground Water Potential are given in **Annexure–4.** The Total Annual Ground Water Recharge (TAGWR) for UT of Daman & Diu is estimated to be 2900.68 Ham/year and the Annual Extractable Ground Water Recharge (AEGWR) after deducting natural discharge is estimated to be 2755.65Ham/year. Ground water extraction for irrigation is estimated at 257.3 Ham/year whereas ground water extraction for Industrial and domestic Draft is estimated at 2867 Ham/year and 0 Ham/year. Thus the net ground water availability for future use is estimated to be 15.22 Ham/year. The Stage of Ground water Extraction for the UT of Daman & Diu worked out to be 113.378 % as on March 2020. And The UT of Daman & Diu in whole categorize as Over-exploited.

4.28.2 Categorization of Districts (Assessment Units)

For groundwater resources categorization 2 districts of the UT of Daman & Diu are considered. As per the Dynamic Ground Water Resources Assessment as on March 2020, **assessment units Daman** is categorized as **OVER-EXPLOITED** and another **assessment unit Diu is** categorized as **Safe (Fig 20 & 21) .**

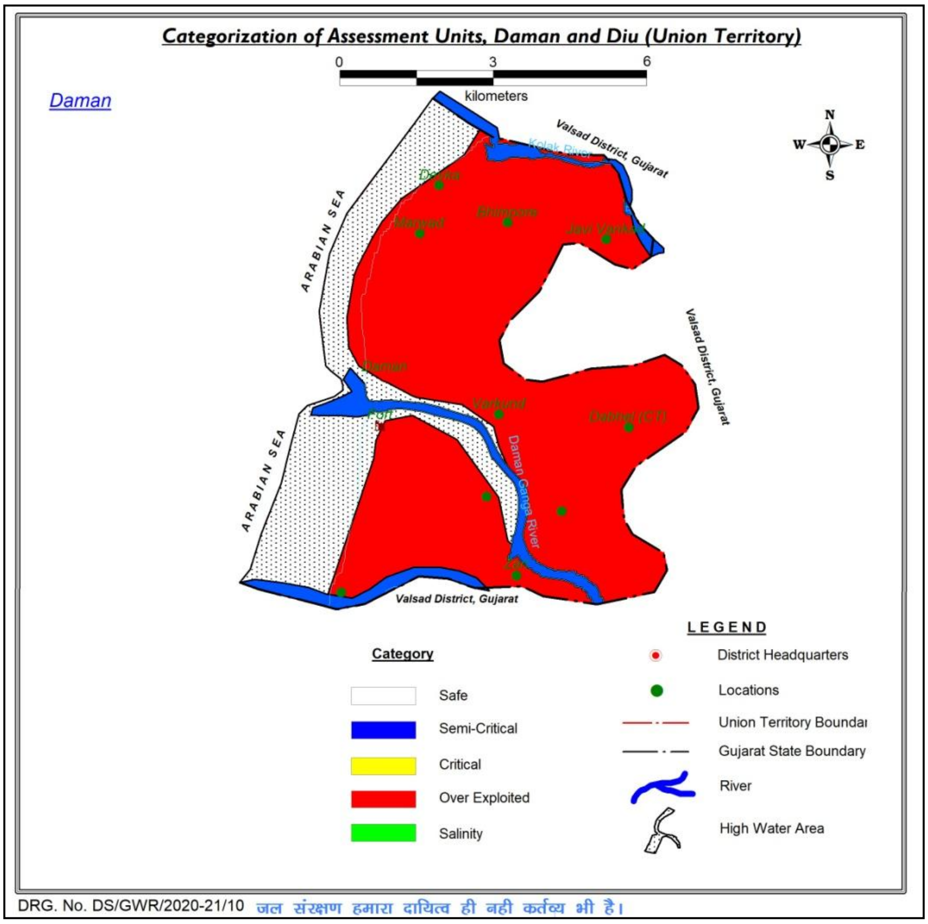


Figure 20- Categorization Map of Daman district as per GWRA-2020

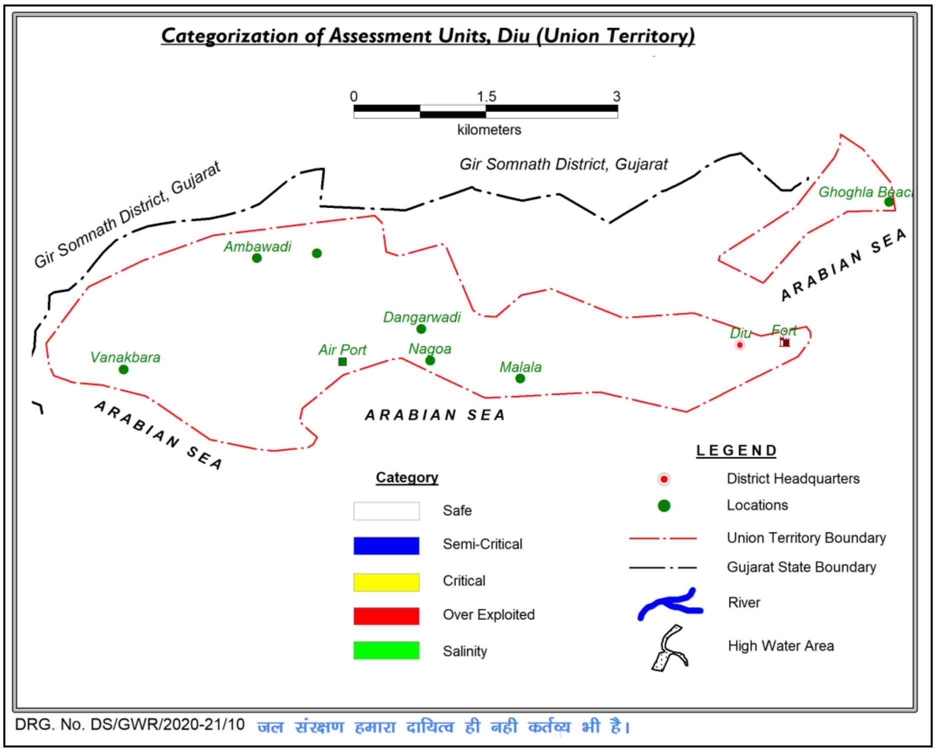


Figure 21- Categorization Map of Diu district as per GWRA-2020

5. Summary of findings of Report on Dynamic Ground Water Resources of UT of Daman & Diu as on 31st March 2020.

The Ground Water Resource Assessment of UT of Daman & Diu has been computed as per GEC-2015 Methodology. The administrative district boundary has been taken as assessment unit and for computing the district wise ground water resources. The Resource Estimation has been done by IN-GRES Software.

The assessment of groundwater resources has been carried out district-wise. Out of 2 assessment units (districts), 1 unit (50 %) have been categorized as 'Over- exploited', 1 unit (50%) as 'Safe' categories.

S.No.	Total No. of Assessed Units	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
		Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%
1	2	1	50	-	-	-	-	1	50	-	-

Total Annual Ground Water Recharge of the UT of Daman & Diu is assessed 29.01 mcm and Annual Extractable Ground Water Resources is 27.56 mcm. The Annual Ground Water Extraction has been assessed as 31.24 mcm and Stage of Ground Water Extraction arrived 113.38 %.

Sl. No	Assessment Unit	Total Area of Assessment Unit (Ha)	Total Annual Ground Water (mcm) Recharge	Total Natural Discharges (mcm)	Annual Extractable Ground Water Resource (mcm)	Total Extraction (mcm)	Stage of Ground Water Extraction (%)	Categorization
1	Daman	7200	26.5531	1.3277	25.2254	30.821	122.18	over exploited
2	Diu	4000	2.4537	0.1226	2.3311	0.422	18.10	safe

Total recharge worthy area for UT of Daman & Diu is 110.90 sq km. Out of which 70.90 sq km (63.93 %) area are under 'Over-Exploited 'and 40.00 sq km (36.07 %) under 'Safe' categories of assessment units. Similarly out of total 27.56 mcm annual extractable ground water resources for UT of Daman & Diu, 25.23 mcm (91.55 %) are under 'Over-exploited' and 2.33 mcm (8.45 %) are under 'Safe' categories of assessment units. It has been observed that one unit has shown change to higher category owing to increased ground water draft for industrial purpose in Daman and another unit has shown change to lower category due to increase replenishable recharge, reduction in draft for Diu.

Out of 2 assessment units, Diu has been categorized as 'Safe' and Daman as 'Over Exploited'. As compared to 2017 assessment, there is substantial increase in total annual ground water extraction from 0.0091 bcm to 0.031 bcm, whereas the ground water recharge has marginally increased from 0.016 bcm in 2017 to 0.029 bcm in 2020. Consequently, the stage of groundwater extraction has increased from 61.4% to 113.38 % (Table10 & 11).

Table 10- Annual Ground Water Extraction Comparison for UT of Daman & Diu

Annual Ground Water Extraction Comparison for UT of Daman & Diu				
Year of Assessment	**Ground Water Extraction for Irrigation Use (Bcm)**	**Ground Water Extraction for Industrial Use (Bcm)**	**Ground Water Extraction for Domestic Use (Bcm)**	**Total**
GWRA-2017	0.0072	0.000099	0.0018	0.0091
GWRA-2020	0.0025	0.028	0.00	0.031

Table 11- Dynamic Ground Water Resources for UT of Daman & Diu a comparison 2017 vs. 2020

Dynamic Ground Water Resources for UT of Daman & Diu a comparison 2017 vs. 2020			
Sl No		GWRE 2017	GWRA 2020
		(values in BCM)	(values in BCM)
1	Annual Replenishable Ground Water Resources	0.018	0.029
2	Natural Discharge During non-monsoon Season	0.002	0.0014
3	Annual Extractable Ground Water Recharge	0.016	0.029
4	Current Annual Ground Water Extraction	0.0097	0.031
5	Stage of Ground Water Extraction (%)	61.4	113.38
6	Total no of Assessment Units	2	2
7	Categorization	Daman (Safe) Diu(Critical)	Daman (OE) Diu(Safe)

6. Conclusions & Recommendations of State Level Committee on GWRA-2020.

- It is stressed that, due care must be taken to arrest depletion in water level in Diu by reducing ground water withdrawal and by resorting to surface water supply for sustainability of available fresh water resource and to prevent deterioration in ground water quality.

- Adoption of Roof Top Rainwater Harvesting in urban areas of Daman district, where the alluvial aquifer has been de-saturated. In these areas regulatory measures for registration of ground water abstraction structures for industries and their monitoring has to be taken up for sustainable development of the ground water resource. Conjunctive use of Ground & Surface water in industrial and Agricultural sector of Daman and Diu should also be implemented where ever feasible.

- Restoration of all the existing tanks should be taken up with the view of accommodating the available surface run off and thus augmentation of the ground water resources by artificial recharge. Periodical maintenance of these tanks is to be ensured.

- Disposal of industrial effluents, solid waste and urban sewerage should be disposed off safely and after treatment, so that the phreatic aquifer does not get adversely polluted.

- Creating awareness (Mass Awareness Campaign for public and farmers, slideshows, display boards on water conservation, Water Management Training Programme for personnel related with water sector, painting/elocution competition for school students etc.) regarding water conservation through judicious use of water.

Annexure 1- Decadal Pre-Monsoon Water Level of Daman & Diu

Sr No.	Village	District	Well Type	Latitude	Longitude	Geol	Pre-Monsoon 09	Pre-Monsoon 10	Pre-Monsoon 11	Pre-Monsoon 12	Pre-Monsoon 13	Pre-Monsoon 14	Pre-Monsoon 15	Pre-Monsoon 16	Pre-Monsoon 17	Pre-Monsoon 18	Pre-Monsoon 19
1	Jempore	Daman	Dw	20.37778	72.82694	Basalt	3.74	4.34	3.30	3.43	3.59	3.38	3.40	3.50	3.28	3.24	3.50
2	Ambawadi	Daman	Dw	20.40278	72.84444	Basalt	5.13	7.81	7.40	4.93	4.68	4.77	4.93	5.34	5.11	5.39	5.30
3	Warkund	Daman	Dw	20.40806	72.85972	Basalt	7.00	4.80	6.10	5.04		6.85	7.19	7.05	6.42	6.16	6.00
4	Dabhel	Daman	Dw	20.41111	72.88611	Basalt	3.77	4.08	0.80	0.99	4.60	5.45	6.22	6.26	5.56	6.08	
5	Daman	Daman	Pz	20.42417	72.85028	Basalt	6.72		7.13	8.91		8.53	10.15	10.41			9.05
6	Khariwad Daman	Daman	Dw	20.42500	72.84583	Basalt	3.21	6.46	2.13	2.48	2.13	2.21	5.02	6.97	7.13	7.13	1.83
7	Morwad	Daman	Dw	20.43528	72.83111	Basalt		8.40	3.30	6.46	8.93	8.75	8.73	9.10	11.80	11.80	8.80
8	Dalwada	Daman	Dw	20.44306	72.85194	Basalt		8.20	6.95	6.94	6.68	7.63	8.24	9.44	7.93	8.35	
9	Bhimpor K.Falia	Daman	Dw	20.45833	72.87083	Basalt	7.00	7.00	7.00	8.22		8.25	8.25	8.25			
10	Chakarteeth	Diu	Pz	20.7083	70.9689	Miloliti c Lmstn		6.43	6.16	6.3	6.35	6.25	6.2	6.61	6.3	6.42	6.3
11	Diu	Diu	Dw	20.7147	70.9486	Miloliti c Lmstn	3.8	3.35	3.26			4.07	4.13		4.2		5.1

Annexure 2- Decadal Post-Monsoon Water Level of Daman & Diu

Sr No.	Village	Well Type	District	Latitude	Longitude	Geol	Post-Monsoon 2009	Post-Monsoon 2010	Post-Monsoon 2011	Post-Monsoon 2012	Post-Monsoon 2013	Post-Monsoon 2014	Post-Monsoon 2015	Post-Monsoon 2016	Post-Monsoon 2017	Post-Monsoon 2018	Post-Monsoon 2019
1	Jempore	Dw	Daman	20.3778	72.8269	Basalt	1.35	1.30	3.05	2.17	1.15	1.87	1.65	1.40	1.40	0.80	0.85
2	Ambawadi	Dw	Daman	20.4028	72.8444	Basalt	3.50	3.55	5.30	3.91	3.00	3.71	3.40	3.30	3.30	2.57	
3	Warkund	Dw	Daman	20.4081	72.8597	Basalt	2.78	1.95	1.16	4.47	0.80	3.71	2.30	1.63	2.20	0.55	1.95
4	Dabhel	Dw	Daman	20.4111	72.8861	Basalt	0.98	0.88	0.84	1.57	1.42	4.24	4.20	4.10	4.90	1.12	2.55
5	Daman	Pz	Daman	20.4242	72.8503	Basalt	3.15	2.70	2.92	3.52	2.55	3.84	1.75				1.85
6	Khariwad Daman	Dw	Daman	20.4250	72.8458	Basalt	1.34	3.43	1.58	1.93	1.63	1.92	1.73	6.33	3.63	1.31	
7	Morwad	Dw	Daman	20.4353	72.8311	Basalt	2.50	5.58	5.20	6.25	5.20	5.46	4.40	4.40	6.00	2.02	3.60
8	Dalwada	Dw	Daman	20.4431	72.8519	Basalt	2.49	1.98	2.00	2.24	1.85	2.36	2.38	1.85	3.25	1.02	2.25
9	Bhimpor Falia	Dw	Daman	20.4583	72.8708	Basalt	4.51	4.00	3.87			6.31	4.45	3.75	5.35		
10	Diu	Dw	Diu	20.7150	70.9490	Milolitic Limestone						4.70	2.90	4.01			4.00
11	Chakarteeth	Pz	Diu	20.7080	70.9690	Milolitic Limestone		5.98	6.05	6.35	6.26	6.60	5.40	6.28	6.52	6.02	5.58
12	Vanakbarh	Pz	Diu	20.7110	70.8780	Milolitic Limestone		8.20	9.15								2.00
13	Jalawadi	Dw	Diu	20.7220	70.9330	Milolitic Limestone						3.70	4.92		4.17	2.49	4.00
14	Gomtimata	Dw	Diu	20.7080	70.8760	Milolitic Limestone						4.05	3.80	3.42	4.72	3.90	5.00
15	Pothia Bapa	Dw	Diu	20.7020	70.9120	Milolitic Limestone								6.63	6.83	6.16	3.00

Annexure 3- Decadal Pre & Post-Monsoon Water Level Trends of Daman & Diu

Year	Jampore		Ambawadi		Warkund		Dabhel		Khariwad daman		Morwad		Delwada		Diu		Chkarteeth	
	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon	Pre_Mon	Post-Mon
2009	3.74	1.35	5.13	3.50	7.00	2.78	3.77	0.98	3.21	1.34		2.50		2.49	3.8			
2010	4.34	1.30	7.81	3.55	4.80	1.95	4.08	0.88	6.46	3.43	8.40	5.58	8.20	1.98	3.35		6.43	5.48
2011	3.30	3.05	7.40	5.30	6.10	1.16	0.80	0.84	2.13	1.58	3.30	5.20	6.95	2.00	3.26		6.16	5.45
2012	3.43	2.17	4.93	3.91	5.04	4.47	0.99	1.57	2.48	1.93	6.46	6.25	6.94	2.24	3.42		6.3	6.05
2013	3.59	1.15	4.68	3.00		0.80	4.60	1.42	2.13	1.63	8.93	5.20	6.68	1.85	3.86		6.35	6.06
2014	3.38	1.87	4.77	3.71	6.85	3.71	5.45	4.24	2.21	1.92	8.75	5.46	7.63	2.36	4.07	3.60	6.25	5.60
2015	3.40	1.65	4.93	3.40	7.19	2.30	6.22	4.20	5.02	1.73	8.73	4.40	8.24	2.38	4.13	2.90	6.2	5.40
2016	3.50	1.40	5.34	3.30	7.05	1.63	6.26	4.10	6.97	6.33	9.10	4.40	9.44	1.85	4.18	4.01	6.61	6.08
2017	3.28	1.40	5.11	3.30	6.42	2.20	5.56	4.90	7.13	3.63	11.80	6.00	7.93	3.25	4.2	3.86	6.3	6.02
2018	3.24	0.80	5.39	2.57	6.16	0.55	6.08	1.12	7.13	1.31	11.80	2.02	8.35	1.02	4.69	3.94	6.42	6.02
2019	3.50	0.85	5.30		6.00	1.95		2.55	1.83		8.80	3.60		2.25	5.1	4.00	6.3	5.58
Trends	-0.0519	-0.0954	-0.1330	-0.1269	0.0583	-0.0983	0.4545	0.2621	0.2059	0.1489	0.5472	-0.0985	0.1683	-0.0140	-0.1753	-0.0675	0.0927	0.1360

Annexure 4- District Wise Ground Water Resources, Availability, Utilization and Stage of Ground Water Development for UT of Daman & Diu

District Wise Ground Water Resources, Availability, Utilization and Stage of Ground Water Development (2020) (in Ham)																
UT of Daman & Diu																
S. No.	Name of District	Ground Water Recharge					Total Natural Discharges	Annual Extractable Ground Water Resource	Current Annual Ground Water Extraction				Annual GW Allocation for for Domestic Use as on 2025	Net Ground Water Availability for future use	Stage of Ground Water Extraction (%)	Safe/SC/Critical/OE/Saline
		Monsoon Season		Non-monsoon Season		Total Annual Ground Water Recharge			Irrigation	Industrial	Domestic	Total				
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources											
1	**Daman**	2551.89	35.50	0	67.92	2655.31	132.77	2522.54	215.1	2867	0.00	3082.10	1412.67	0	122.18	Over Exploited
2	**Diu**	208.15	14.13	0	23.09	245.37	12.26	233.11	42.2	0	0.00	42.20	175.69	15.22	18.10	Safe
Total		2760.04	49.63	0	91.01	2900.68	145.03	2755.65	257.3	2867	0.00	3124.3	1588.36	15.22	113.38	

Annexure 5- General Description of Ground Water Assessment Unit of Daman & Diu

S.No	District	Assessment Unit	*Total Geographical Area (ha)	*Hilly Area (ha)	*Total Recharge Worthy Area (ha)
1	DAMAN	DAMAN	7200	110	7090
2	DIU	DIU	4000	0	4000