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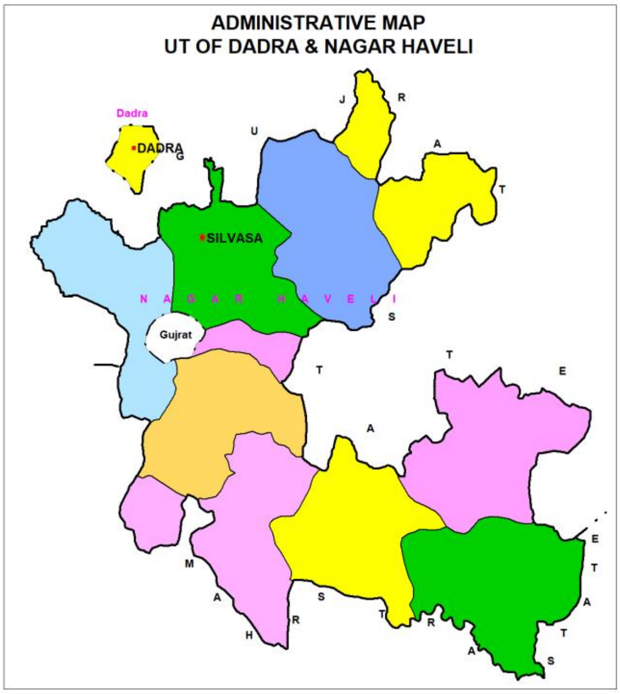
Government of India
Ministry of Jal Shakti
Department of Water Resources, River Development & Ganga Rejuvenation

केंद्र शासित प्रदेश दादरा और नगर हवेली के परिवर्तनशील भूजल संसाधन - 2020

DYNAMIC GROUNDWATER RESOURCES OF UNION TERRITORY OF DADRA & NAGAR HAVELI - 2020



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FOREWORD

Central Ground Water Board, under Ministry of Jal Shakti, Department of Water Resources, River Development & Ganga Rejuvenation, Government of India (GoI) is the National Apex Organisation for Scientific and Sustainable development and management of Ground Water Resources and has been actively pursuing surveys, exploration and estimation of ground water resources in the Union Territory of Dadra and Nagar Haveli through its Regional Office located at Nagpur. The CGWB in association with the respective State Ground Water Departments/UTs has been periodically assessing ground water resources of all the States and Union Territories of the country over the last three decades based on the norms recommended by the Government of India. The precise and reliable estimation of ground water is necessary for its optimal and sustainable development.

Based on Ground Water Estimation Methodology 2015 (GEC-2015) guidelines, the last assessment of state-wise annual replenishable ground water resources for the entire country was made in the year 2017. Since then changes in ground water scenario have been observed in many parts of the country. The Ministry of Jal Shakti, Dept. of Water Resources, River Development & Ganga Rejuvenation, Govt. of India desires to reassess the Ground Water Resources for the entire country biennially once in three years and hence so the current re-estimation of resources as in March 2020 has been taken up in view of the changes that has been observed in the ground water scenario.

The CGWB, Central Region, Nagpur as per the protocol, completed the assessment for the base year 2020. At the outset, the basic data needed for the assessment viz; geographical area, forest area, rainfall, details of canal and command area, net irrigated area, etc. were provided from the Administration of Dadra & Nagar Haveli. For the three basic parameters viz., water level, specific yield and unit draft, the CGWB data has been used. The, draft data of industries was also included in the assessment for the first time in addition to the draft data for domestic and irrigation use. The present report is outcome of the efforts made by Shri. D. Venkateswaran, Sc-D (Retd. on 31.05.2021), Ms. Anu V., Sc-B (transferred to KR, Thiruvananthpuram), Shri Rahul R. Shende, Sc-B, Ms Nelofar, Sc-B of Central Region, CGWB, Nagpur is highly appreciable.

The ground water assessment of UT of Dadra Nagar Haveli (DNH) will be very much useful to the planners, policy makers and other stake holders for effective and proper management of precious ground water resources.

03/11/2021

Nagpur

(Dr. P.K. Jain)

Regional Director

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CHAPTER 1

1. INTRODUCTION

The estimation of ground water resources of the Union Territory of Dadra & Nagar Haveli as on 2020 has been carried out as per the recommendations of Ground Water Estimation Methodology-2015 (GEC-15). Earlier methodology, GEC 97 is based on 'Water Balance Approach' and the GEC 97 norms were used for estimation of dynamic ground water resources of the country considering 2004, 2009, 2011 and 2013 as base years. The methodology underwent comprehensive revisions in 2015 and a revised methodology, namely GEC 2015 methodology has been prescribed for ground water assessment. This methodology is being followed for assessment carried out from 2017 onwards. The revised methodology GEC 2015 recommends aquifer wise ground water resource assessment. Wherever the aquifer geometry has not been firmly established for unconfined aquifer, the in-storage ground water resources have to be assessed in alluvial areas upto depth of bed rock or 300 m whichever is less. In case of hard rock aquifers, the depth of assessment would be limited to 100m. In case of confined aquifers, if it is known that ground water extraction is being taken place from this aquifer, the dynamic as well in-storage resources are to be estimated. If it is firmly established that there is no ground water extraction from this confined aquifer, then only in-storage resources of that aquifer have to be estimated.

The resource estimation of UT of DNH commenced with the collection, collation, compilation and validation of relevant data from various sources. It involves estimation of annual ground water recharge from rainfall and other sources and quantification of ground water extraction. The various inputs needed for the estimation of ground water resources namely the details of domestic wells, Irrigation wells and details on were collected from PWD, Civil Division No. III (DP), Irrigation. The data on major reservoir, canal and outlet details were collected from PWD, Civil Division No. II (Road). The rainfall data was collected from Department of Planning & Statistics.

Central Ground Water Board, Central Region, Nagpur has been monitoring ground water levels in Dadra and Nagar Haveli through its network of observation wells four times in a year i.e., during January, May, August and November. The data on depth to ground water levels from these wells has been used in the present assessment. The ground water assessment has been made separately for command and non-command areas, separately for monsoon and non-monsoon seasons. The entire geographical area of D&NH has been considered as a single assessment unit being hard rock terrain.

The ground water resource estimation is mainly dependent on the quality of the data. Many a times because of the lack of adequate data the resource assessment misleads the planners, administrators and technocrats in formulating various developmental activities. Systematic information on groundwater withdrawal by various sectors like domestic, irrigation and industry through different groundwater structures like dug wells and borewells is not available. The data on area irrigated by various sources like surface and ground water separately during monsoon and non-monsoon seasons for paddy and non-paddy crops is very important in estimating the return flow due to recycled water. The recharge due to check dams, nala bunds, percolation tanks etc. are required to be estimated.

1.1 BACKGROUND

CGWB, Central Region, Nagpur has been carrying out ground water resource assessment of UT of D&NH from time to time. The previous assessment was carried out on March 2017 by CGWB, Nagpur based on the recommendations of GEC 2015 Methodology. The Ministry of Jal Shakti, Dept. of Water Resources, River Development & Ganga Rejuvenation, Govt. of India desires to reassess the Ground Water Resources for the entire country biennially once in three years and hence so the current re-estimation of resources as in March 2020 has been taken up in view of the changes that has been observed in the ground water scenario. The data provided by the administration of D&NH and water level and industrial abstraction data of CGWB have been used in the present ground water assessment. During current assessment, a software named “INGRES” has been introduced for re-assessing the ground water resources of India. The data collected were compiled as per format in INGRES and was uploaded in the software and the results generated were validated with the manual calculations for ensuring the error-free functioning of software.

1.2 CONSTITUTION OF COMMITTEE FOR DADRA & NAGAR HAVELI

The Administrator of UT of DNH has constituted a SLC committeee vide Order No. PWD-III/ASW/GWRA/2013/SLC/DNH/2014 dated 28/11/20. The first SLC meeting on Ground Water Resource Estimation 2020 for UT of D&NH was held under the Chairmanship of Advisor to Administrator and Chairman of SLC for GWRE 2020 on 31th March 2020 between 11.00 to 13.00 hrs. Shri. Sandeep Kumar Singh, IAS, District Collector represented D&NH. In the said meeting, Sh. Sandeep Kumar Singh advised for inclusion of industrial draft in the present assessment and submit revised estimates for approval of SLC. In pursuance to above advise, the ground water resources were re-assessed by including industrial data and was approved vide mail dated 2.4.2021. The minutes of the first meeting was approved vide email dated 6.4.2021.

CHAPTER 2

2. ABOUT UT OF DADRA & NAGAR HAVELI

2.1 SALIENT FEATURES OF DADRA & NAGAR HAVELI

The salient features of the UT of DNH are presented below.

A	***Location***	
	Latitude	E 20°02’ to 20°22’
	Longitude	N 72°57’ to 73°14’
	Area	49100 Ha
B	***Physiography***	
	Residual Plateaus	Elevation ranges from 100-300 m.amsl
	Denudational Slopes	Elevation ranges from 50-100 m.amsl.
	Valley Plains	Elevation below 50 m.amsl.
C	***Rainfall Zone***	
	Average Normal Rainfall	2265.77 mm
D	***Land Use***	
	Area under Forest	20321 Ha
	Area under Agriculture	20212 Ha
	Net Irrigated Area	5981 Ha
	Gross Irrigated Area	7507 Ha
E	***Soils***	Lateritic Soil, Shallow Black cotton soil, Deep Black cotton soil
F	***Geology***	Basalts
G	***Cropping Pattern***	Paddy, Millets, Pulses, wheat, sugarcane etc.
H	***River Basins***	Damanganga and its tributaries, Kolak river and its tributaries & Kalunadi and its tributaries.

2.2 LOCATION AND AREAL EXTENT

The Union Territory of Dadra & Nagar Haveli is situated on the western coast of India between Maharashtra and Gujarat States with a geographical area of 491 sq.km. It lies between north latitudes 20°02’ and 20°22’ and 72°57’ and 73°14’. The Union Territory consists of two enclaves namely Dadra and Nagar Haveli, which are separated by the Valsad district of Gujarat State. There are 72 villages in Dadra and Nagar Haveli, 3 villages in Dadra and 69 villages in Nagar Haveli. These 72 villages are divided into 11 Patelads for collection of revenue. Administratively, Dadra & Nagar Haveli forms a single District and single Taluka Union Territory. The administrative division map of the Union Territory of Dadra & Nagar Haveli is shown in **Map 1**.

2.3 PHYSIOGRAPHY AND DRAINAGE

Topographically, the area can be divided into two parts: Hilly terrain in the eastern part characterised by steep hills and deep valleys with elevation ranging between 60 and 400 m.amsl. and ii) northern and western plain and undulating area with elevations ranging between 30 and 60 m.amsl. The area is drained by the Damanganga river and its tributaries viz; Sakartond, Dongarkhed, Piparia Kinai and Murree.

2.4 POPULATION

The Union Territory Dadra & Nagar Haveli is predominantly a tribal belt whose population is mostly engaged in agriculture and forest-based works. The total population was 3,43,709 as per 2011 census out of which 1,93,760 were Male and 1,49,949 were Female. The urban population in the last 10 years has increased by 216.73%. The total population growth in this decade was 55.58 % while in previous decade it was 59.22 %. The Territory has two urban towns i.e., Silvassa, the capital of U.T. and another village Amli are treated as non-statutory census town in population census of 2011.

2.5 AGRICULTURE

Agriculture is the main occupation and an area of about 20212 Ha is under cultivation and 20321 Ha under forest cover which is about 40 % each. Paddy is the staple crop in the Union Territory along with other crops like millet, pulses, jowar under rain-fed condition. Wheat, sugarcane, banana, mustard, vegetables and hot weather paddy etc. are grown under irrigated conditions.

2.6 CLIMATE AND RAINFALL

The climate of the Union Territory of Dadra and Nagar Haveli is characterised by an oppressive summer, dampness in the atmosphere nearly throughout the year, heavy south-west monsoon rainfall and a mild winter. The year can be divided into four seasons. The winter season lasts for three months from December to February, which is followed by summer season from March to May. The south-west monsoon season is from June to September. The post-monsoon season generally extends for two months between October and November.

The area receives heavy rainfall from the south west monsoon between June to September. The normal rainfall in this area varies from 1281 mm in the east to about 3829 mm in the west. Rainfall increases from east to west. The probability of occurrence of normal annual rainfall over the UT of DNH was studied. It was observed that the chances of receiving normal annual rainfall are around 42 %. The coefficient of variation of annual rainfall from normal is around 28%. The percentage probability of receiving excess rainfall (i.e., 25% or more in excess of the normal) is around 15% i.e., once in 6 to 7 years.

2.7 GEOLOGY

The entire area of UT of DNH is mainly underlain by Deccan Trap Basalts. The stratigraphic succession of the geologic formations in the U.T. is given in Table 1.

Table-1: Geological Succession in UT of DNH.

Age	Geology	Rock types	Geographical distribution in the State
Recent-Quaternary	Alluvium	Sand, Clay and gravel and its admixture	Along the river course
Lower Eocene Upper Cretaceous	Deccan Trap Volcanic Lava flows	Weathered, Vesicular and amygdaloidal basalts and Jointed basalts.	Entire U.T.

2.7.1 Deccan trap Basalt: The basaltic lava flows occupy the major part of the area and has been divided into two groups.

a) The older flows occur in plains of the western part of the UT of DNH between altitude 25 and 65 m amsl. These are mainly 'pahoehoe' type. Each flow in the older group has been differentiated into three units namely upper vesicular unit, middle dense and compact unit and a lower unit with pipe amygdules.

b) The younger flows occurs in the hilly areas of the eastern part of the U.T of DNH between the altitude 65and 180 m.amsl. These are mainly 'aa' flows with two units namely top vesicular or amygdaloidal units and lower massive units.

The individual flows are separated by red bole beds and some times by inter trappeans limestone.

Dykes: At places dykes of dolerites and trachy-andesites have traversed the lava flows. These dykes have north-south trend and occasionally NW-SE trend direction.

2.7.2 Alluvium: The alluvium comprising of sand, gravel and clays and its admixture is generally confined along the river course. It occurs in small linear patches and attains a maximum thickness of about 10-12 m. It is not a mappable unit.

2.8 HYDROGEOLOGY

Basaltic lava flows form the predominant aquifer system in the area. The ground water occurs under water table conditions in weathered basalts and vesicular basalts. The thickness of vesicular units ranges from 2 to 8 m. The density, interconnection of vesicles, depth of weathering and topography is responsible for the occurrence and movement of ground water in these units. Ground water is developed by means of dug wells and dug cum bore wells. The sustainable yield of dug wells for 3 to 4 hours of pumping is 30 m^3/day. The specific capacity of dug wells ranges from 3 to 300 lpm/m of drawdown in basalts. The transmissivity of shallow aquifer ranged between 5.5 to 305 m^2/day. The CGWB has constructed 9 exploratory wells with a maximum depth of 80 m.bgl. The yield of wells ranged from 0.52 to 10.28 lps. The transmissivity of these wells varied from 0.40 to 804 m^2/day. The hydrogeological map of the area is presented as **Map 2**.

2.8.1. Water Level Scenario: To understand the ground water level scenario of the UT of DNH, the water level data of CGWB ground water monitoring wells have been used. During 2019, the pre-monsoon depth to water levels in these wells ranged from 4.20 (Chinsda) to 14.29 (Dudhani) m.bgl, while the post-monsoon depth to water levels varied from 1.53 (Chinsda) to 8.9 (Dapada) m.bgl. The seasonal ground water fluctuation during 2019 varied from 2.52 (shelti) to 11.19 m (Dudhani).

The long-term water level data of CGWB ground water monitoring wells for the period 2012 to 2019 was analysed. The average long term pre-monsoon water level trend is 0.22 and 0.11 m in command and non-command areas respectively showing falling trend. The pre-monsoon depth to water level map for May 2019 is presented as **Map 3.**

2.9. GROUND WATER QUALITY

Central Ground Water Board (CGWB) is monitoring the overall ground water quality of the Union Territory of Dadra and Nagar Haveli for the past two decades through its 10 monitoring stations representing shallow basaltic aquifers. In 2019, twelve ground water samples were collected in pre-monsoon period and were analysed for 6 parameters viz. pH, EC, TH, TA, NO_3 and F. The chemical analysis results of the ground water samples collected from the CGWB monitoring wells during May-2019 is presented in Table-2. The classification of the ground water for its suitability for drinking and irrigation purpose is given in Table-3.

Table 2: Ground Water Quality Data of Monitoring Wells (2019)

Well No.	**Village**	**pH**	**EC** micromohos/cm at 25^0C	**TDS** (mg/l)	**TH** (mg/l)	**NO_3** (mg/l)	**F** (mg/l)	**RSC**
C/DN-005	Chinsda	7.84	421	273.65	98.43	2	0.52	-0.88
C/DN-016	Khedi Ghodamba	7.7	676	439.4	83.13	5	0.27	-3.4
C/DN-014	Moolpada	7.7	270	175.5	53.55	2	0.52	-0.19
C/DN-013	Naroli-1	7.9	990	643.5	98.94	6	1.13	-1.17
C/DN-015	Rakhali	7.3	1001	650.65	209	5	0.27	-3.4
C/DN-017	Rudana	7.5	226	146.9	56.1	6	0.5	-0.53
C/DN-007	Samarvani	7.7	959	623.35	123.42	10	0.8	-1.6
C/DN-006	Shelti	7.6	333	216.45	82.11	6	0.47	-0.55
C/DN-018	Surangi	7.4	487	316.55	86.19	4	0.49	-0.93
C/DN-021	Kherdi	7.8	1226	796.9	385.56	3	1.3	-5.4
C/DN-022	Mandoni	7.5	235	152.75	73.44	3	0.58	-0.38
C/DN-024	Waghchipada	8	734	477.1	135.15	20	0.95	-0.6

It is observed from Table-2 that the ground water is alkaline in nature. The ground water in the monitoring wells were having F less than the Desirable Limit (DL) of BIS standards of 1 mg/L. The distribution of EC in shallow ground water is presented in **Map 4**.

The classification of ground water based on the BIS drinking water standards (Table 3) for the parameters pH, TDS, TH, Ca, Mg, Cl, SO_4, NO_3 and F shows that it is suitable for drinking purpose as all the water samples are having the concentration within the desirable limit.

Table 3: Suitability of Ground Water for Drinking Purpose (2019)

Parameters	BIS Drinking Water Standards IS:10500-1993 Revised)		Total No. of Wells	<DL	DL-MPL	>MPL
	Desirable Limit (DL)	**Max. Permissible Limit (MPL)**				
pH	6.5-8.5	No relaxation	-	0	12	
TDS (mg/L)	500	2000	12	8	4	-
TH (mg/L)	300	600	12	11	1	-
Ca (mg/L)	75	200	12	11	1	-
Mg (mg/L)	30	100	12	11	1	-
Cl (mg/L)	250	1000	12	12	-	-
SO_4 (mg/L)	200	400	12	12	-	-
NO_3 (mg/L)	45	No relaxation	12	12	-	
F (mg/L)	1.0	1.5	12	10	2	-

The concentrations of the parameters analysed in all the stations were found within the maximum permissible limits prescribed by Bureau of Indian Standards (BIS) for drinking purpose. Overall, the ground water quality of the Union Territory of Dadra and Nagar Haveli is good for drinking and irrigation purposes.

CHAPTER 3

3.GROUND WATER RESOURCE ESTIMATION METHODOLOGY, 2015

The ground water assessment of the country is being carried out jointly by State Ground Water Departments and Central Ground Water Board based on “Ground Water Estimation Methodology, 1997” (GEC-97). Previous such joint exercises based on GEC-97 Methodology was carried out in 2004, 2009, 2011 and 2013. A number of changes have taken place since 1997 and with this background, the Ministry of Water Resources, River Development & Ganga Rejuvenation has constituted a committee headed by Chairman, CGWB to review and revise the existing GEC-97 Methodology and to incorporate new advancements/practices/tools so as to suggest a new methodology known as *“Ground Water Estimation Methodology, 2015” (GEC-2015 Methodology)*. The Committee has submitted a report on “Ground Water Estimation Methodology, 2015” incorporating refinement in the assessment methodology, database used for estimation and alternative approach for assessment involving Advanced Technology. The revised methodology as recommended has incorporated number of changes compared to the recommendations of Ground Water Estimation Committee- 1997.

3.1 APPROACH OF GEC-2015

The revised methodology GEC 2015 recommends aquifer wise ground water resource assessment. Ground water resources have two components – Replenishable ground water resources or Dynamic ground water resources and In-storage resources or Static resources. GEC 2015 recommends estimation of Replenishable and in-storage ground water resources for both unconfined and confined/ semi-confined aquifers. Wherever the aquifer geometry has not been firmly established for the unconfined aquifer, the in-storage ground water 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 100m. In case of confined aquifers, if it is known that ground water 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 ground water extraction from this confined aquifer, then only in-storage resources of that aquifer has to be estimated

3.2 GROUND WATER ASSESSMENT UNIT AND ITS SUB UNITS

This methodology recommends aquifer wise ground water resource assessment. An essential requirement for this is to demarcate lateral as well as vertical extent and disposition of different aquifers. A watershed with well-defined hydrological boundaries is an appropriate unit for ground water resource estimation if the principal aquifer is other than alluvium. Ground water resources worked out on watershed as a unit, may be apportioned and presented on administrative units (block/ taluka/ mandal/ firka).

It is recommended that ground water recharge may be estimated for the entire assessment unit. Out of the total geographical area of the unit, hilly areas wherever slope is greater than 20%, are to be identified and subtracted as these areas have more runoff than infiltration. The hilly areas wherever slope is more than 20% may be demarcated using DEM data and geomorphological maps. Apart from this it is also important that the areas where the quality of ground water is beyond the usable limits (for drinking water in particular) in terms of salinity is to be identified and handled separately. This methodology recommends that after the assessment is done, a quality flag may be added to the assessment unit for parameters salinity, fluoride and arsenic.

The ground water 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:

(a) Non-command areas which do not come under major/medium surface water irrigation schemes.

(b) Command areas which come under major/medium surface water irrigation schemes which are actually supplying water

3.3 GROUND WATER RESOURCES OF AN ASSESSMENT UNIT

The ground water resources of any assessment unit is the sum of the total ground water 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 ground water availability of any aquifer is the sum of dynamic ground water resources and the in-storage or static resources of the aquifer.

3.4GROUND WATER ASSESSMENT OF UNCONFINED AQUIFER

Assessment of ground water resources includes the assessment of dynamic and in-storage ground water resources. The development planning should mainly depend on dynamic resource only as it gets replenished every year. Changes in static or in-storage resources reflect impacts of ground water 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.

Assessment of Dynamic Ground Water Resources

The methodology for ground water resources estimation is based on the principle of water balance as given below –

Inflow – Outflow = Change in Storage (of an aquifer) **1**

Equation 1 can be further elaborated as -

$$\Delta S = R_{RF}+R_{STR}+R_{C}+R_{SWI}+R_{GWI}+R_{TP}+R_{WCS}\pm VF \pm LF - GE - T - E - B \qquad 2$$

Where,

ΔS – Change is storage

R_{RF} – Rainfall recharge

R_{STR}- Recharge from stream channels

R_c – Recharge from canals

R_{SWI} – Recharge from surface water irrigation

R_{GWI}- Recharge from ground water irrigation

R_{TP}- Recharge from Tanks & Ponds

R_{WCS} – Recharge from water conservation structures

VF – Vertical inter aquifer flow

LF- Lateral flow along the aquifer system (through flow)
GE-Ground Water Extraction
T- Transpiration
E- Evaporation
B-Base flow

It is preferred that all the components of water balance equation should be estimated in an assessment unit.

Rainfall Recharge

It is recommended that ground water recharge should be estimated on ground water level fluctuation method and rainfall infiltration factor method during monsoon season and the rainfall recharge during non-monsoon season may be estimated using rainfall infiltration factor method only.

Ground water level fluctuation method

The ground water level fluctuation method is to be used for assessment of rainfall recharge in the monsoon season. The ground water balance equation is given by

$$\Delta S = R_{RF} + R_{STR} + R_C + R_{SWI} + R_{GWI} + R_{TP} + R_{WCS} \pm VF \pm LF - GE - T - E - B \quad 3$$

Where,
ΔS – Change is storage
R_{RF} – Rainfall recharge
R_{STR}- Recharge from stream channels
R_C – Recharge due to Canals
R_{SWI} – Recharge from surface water irrigation (Lift Irrigation)
R_{GWI}- Recharge from ground water irrigation
R_{TP}- Recharge from tanks & ponds
R_{WCS} – Recharge from water conservation structures
VF – Vertical inter aquifer flow
LF- Lateral flow along the aquifer system (through flow)
GE-Ground water Extraction
T- Transpiration
E- Evaporation
B-Base flow

This change in storage can be estimated using the following equation:

$$\Delta S = \Delta h * A * S_Y \quad 4$$

Where

ΔS – Change is storage
Δh - rise in water level in the monsoon season
A - area for computation of recharge
Sy - Specific Yield

Substituting the expression in equation 4 for increase in storage i.e. ΔS in terms of water level fluctuation and specific yield, the equations 3 becomes,

$$R_{RF} = h \times Sy \times A - R_{STR} - R_C - R_{SWI} - R_{GWI} - R_{TP} - R_{WCS} \pm VF \pm LF + GE + T + E + B \qquad 5$$

The recharge calculated from equation 5 gives the rainfall recharge for the particular monsoon season. This rainfall recharge is specific to a particular monsoon season for the associated monsoon season rainfall. This estimate is to be normalised for the normal monsoon season rainfall as per the procedure indicated below.

Normalization of Rainfall Recharge

Let Ri be the rainfall recharge and ri be the associated rainfall. The subscript i takes values 1 to N where N is the number of years for which data is available. This should be at least 5. The rainfall recharge, Ri is obtained as per equation 5 for which the normalization is to be done using any of the following two procedures. This normalisation procedure is to be carried out for obtaining the rainfall recharge corresponding to the normal monsoon season rainfall. Let r(normal) be the normal monsoon season rainfall obtained as the average of recent 30 to 50 years of monsoon season rainfall. Two methods are possible for the normalisation procedure.

The first method is based on a linear relationship between recharge and rainfall of the form

$$R = ar \qquad 6$$

where,

R = Rainfall recharge during monsoon season

r = Monsoon season rainfall

a = a constant

The second method is also based on a linear relation between recharge and rainfall. However, this linear relationship is of the form,

$$R = ar+b \qquad 7$$

where,

R = Rainfall recharge during monsoon season

r = Monsoon season rainfall

a and b = constants.

The rainfall recharge during monsoon season for normal monsoon rainfall condition is computed as below:

$$R_{rf}\,(normal) = a \times r(normal) \qquad 8$$

or

$$R_{rf}\,(normal) = a \times r(normal) + b \qquad 9$$

Rainfall Infiltration Factor method

Recharge from rainfall is estimated by using the following relationship -

$$R_{rf} = RFIF * A * (R - a)/1000 \qquad 10$$

Where,

R_{rf} = Rainfall recharge in ham

A = Area in Hactares

RFIF = Rainfall Infiltration Factor

R = Rainfall in mm

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

The threshold limit of minimum and maximum rainfall event which can induce recharge to the aquifer is to be considered while estimating ground water recharge using rainfall infiltration factor method. It is suggested that 10% of Normal annual rainfall may be taken as minimum rainfall threshold and 3000 mm as maximum rainfall limit. 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.

Percent Deviation

After computing the rainfall recharge for normal monsoon season rainfall using the ground 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 later is computed as

$$\text{PD} = \frac{R_{rf}(normal, wtfm) - R_{rf}(normal, rifm)}{R_{rf}(normal, rifm)} \times 100 \qquad \textbf{11}$$

where,

Rrf (normal, wlfm) = Rainfall recharge for normal monsoon season rainfall estimated by the ground 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 ground 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.

Recharge from other Sources

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

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

$$R_C = WA * SF * Days \quad (12)$$

Where:
R_C= Recharge from Canals
WA=Wetted Area = Wetted Perimeter X Length of Canal Reach.
SF= Seepage Factor
Days= Number of Canal Running Days.

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:

$$R_{SWI} = AD*Days*RFF \quad (13)$$

Where:
R_{SWI} = Recharge due to applied surface water irrigation
AD= Average Discharge
Days=Number of days water is discharged to the Fields
RFF= Return Flow Factor

Recharge from Ground Water Irrigation: Recharge due to applied ground water irrigation is to be estimated based on the following formula:

$$R_{GWI} = GE_{IRR}*RFF \quad (14)$$

Where:
R_{GWI} = Recharge due to applied ground water irrigation
GE_{IRR}= Ground Water Extraction for Irrigation
RFF= Return Flow Factor

Recharge due to Tanks & Ponds: Recharge due to Tanks & Ponds is to be estimated based on the following formula:

$$R_{TP} = AWSA*N*RF \quad (15)$$

Where:
R_{TP} = Recharge due to Tanks & Ponds
AWSA= Average Water Spread Area
N=Number of days Water is available in the Tank/Pond
RF= Recharge Factor

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

$$R_{WCS} = GS*RF \quad (16)$$

Where:
R_{WCS} = Recharge due to Water Conservation Structures
GS= Gross Storage = Storage Capacity multiplied by number of fillings.

RF= Recharge Factor

Lateral flow along the aquifer system (Through flow)

If the area under consideration is a watershed, the lateral flow across boundaries can be considered as zero. 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.

Base flow and Stream Recharge

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.

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.

Vertical Inter Aquifer Flow

This can be estimated provided aquifer geometry and aquifer parameters are known. This can be calculated 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.

Evaporation and Transpiration

Evaporation can be estimated for the aquifer in the assessment unit if water levels in the aquifer are within the capillary zone. It is recommended to compute the evaporation through field studies. If field studies are not possible, for areas with water levels within 1.0 mbgl, evaporation can be estimated using the evaporation rates available for other adjoining areas. If depth to water level is more than 1.0m bgl, the evaporation losses from the aquifer should be taken as zero.

Transpiration through vegetation can be estimated if water levels in the aquifer are within the maximum root zone of the local vegetation. It is recommended to compute the transpiration through field studies. Even though it varies from place to place depending on type of soil & vegetation, in the absence of field studies the following estimation can be followed. 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.

Recharge/ Accumulations 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/ accumulation during monsoon season for the sub unit. Similarly, this is to be computed for all the sub units available in the assessment unit.

Recharge/ Accumulations 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/ accumulation during non-monsoon season for the sub unit. Similarly, this is to be computed for all the sub units available in the assessment unit.

Total Annual Ground Water Recharge

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

Annual Extractable Ground Water Resource (EGR)

The Total Annual Ground Water Recharge cannot be utilised for human consumption, since ecological commitments need to be fulfilled, before the extractable resources is defined. The National Water Policy, 2012 stresses that the ecological flow of rivers should be maintained. Therefore, ground water base flow contribution limited to the ecological flow of the river should be determined which will be deducted from Annual Ground Water Recharge to determine Annual Extractable Ground Water 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 case base flow contribution to the ecological flow of rivers is not determined then following assumption is to be followed. 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 Ground Water Resources (EGR).

Estimation of Ground Water Extraction

Ground water draft or extraction is to be assessed as follows.

$$GE_{ALL} = GE_{IRR} + GE_{DOM} + GE_{IND} \quad (17)$$

Where,

GE_{ALL}=Ground water extraction for all uses

GE_{IRR}=Ground water extraction for irrigation

GE_{DOM} =Ground water extraction for domestic uses

GE_{IND} = Ground water extraction for industrial uses

The single largest component of the ground water balance equation in large regions of India is the ground water extraction and the precise estimation of ground water extraction is riddled with uncertainties.

Ground Water Extraction for Irrigation(GE_{IRR}): The Ground Water Extraction for Irrigation is to be assessed employing at least two of the three methods recommended for estimation of ground water extraction for irrigation. The methods for estimation of ground water extraction are as follows.

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 ground water extraction by that particular structure. This method is being widely practiced in the country. There are several sources which maintain records on well census. These include Minor Irrigation Census conducted by MoWR, RD, GR, Government of India, and data maintained at the Tahsil level. 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 ground water 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: **–** Ground water 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 ground water extraction for irrigation.

Ground Water Extraction for Domestic Use (GE_{DOM}): There are several methods for estimation of extraction for domestic use (GE_{DOM}). Some of the commonly adopted methods are described here.

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 ground water extraction.

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.

$$GE_{DOM} = \text{Population X Consumptive Requirement X Lg} \quad (18)$$

Where,

Lg = Fractional Load on Ground Water for Domestic Water Supply

The Load on Ground water can be obtained from the Information based on Civic water supply agencies in urban areas.

Ground water Extraction for Industrial use (GE_{IND}): The commonly adopted methods for estimating the extraction for industrial use are as below:

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 ground water extraction.

Consumptive Use Pattern Method: **–** In this method, water consumption of different industrial units is determined. Number of Industrial units which are dependent on ground water are multiplied with unit water consumption to obtain ground water extraction for industrial use.

$$GE_{IND} = \text{Number of industrial units X Unit Water Consumption X Lg} \quad (19)$$

Where,

Lg = Fractional load on ground water for industrial water supply

The load on ground water for industrial water supply can be obtained from water supply agencies in the Industrial belt. Other important sources of data on ground water extraction for industrial uses are - Central Ground Water Authority, State Ground Water Authority, National Green Tribunal and other Environmental Regulatory Authorities.

Ground water extraction obtained from different methods need to be compared and based on field checks, the seemingly best value may be adopted. At times, ground water extraction obtained by different methods may vary widely. In such cases, the value matching the field situation should be considered.

Stage of Ground Water Extraction

The stage of ground water extraction is defined by,

$$Stage\ of\ Ground\ Water\ Extraction(\%) = \frac{\text{Existing gross ground water extraction for all uses}}{\text{Annual Extractable Ground water Resources}} \times 100 \quad \textbf{20}$$

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

Validation of Stage of Ground Water Extraction

The assessment based on the stage of ground water extraction has inherent uncertainties. The estimation of ground water extraction is likely to be associated with considerable uncertainties as it is based on indirect assessment using factors such as electricity consumption, well census and area irrigated from ground water. The denominator in equation 20, namely Annual Extractable Ground Water Resources also has uncertainties due to limitations in the assessment methodology, as well as uncertainties in the data. In view of this, it is desirable to validate the ‘Stage of Ground Water Extraction’ with long term trend of ground water levels.

Long term water level trends are to be prepared for a minimum period of 10 years for both pre-monsoon and post-monsoon period. The water level trend would be average water level trend as obtained from the different observation wells in the area.

If the ground water resource assessment and the trend of long term water levels contradict each other, this anomalous situation requires a review of the ground water resource computation, as well as the reliability of water level data. The mismatch conditions are enumerated below.

SOGWE	Ground Water 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

Categorization of Assessment Units Based on Quantity: The categorization based on status of ground water quantity is defined by Stage of Ground Water Extraction as given below:

Stage of Ground Water Extraction	Category
≤70%	Safe
> 70%and ≤90%	Semi-Critical
> 90% and ≤100%	Critical
> 100%	Over Exploited

Quality Tag

If any of the three quality hazards in terms of Arsenic, Fluoride and Salinity are encountered in the assessment sub unit in mappable units on 1:50000 scale, the assessment sub unit may be tagged with the particular quality hazard.

Allocation of Ground Water Resource for Utilisation

The Annual Extractable Ground Water 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 ground water for urban and rural water supply. The estimate of allocation for domestic water requirement may vary from 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.

$$\textbf{Alloc} = \textbf{22 X N X } \mathbf{L_g} \textbf{ mm per year} \qquad \textbf{21}$$

Where

Alloc= Allocation for domestic water requirement

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

L_g = fractional load on ground water for domestic water supply (≤ 1.0)

In deriving equation 21, 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.

Net Annual Ground Water 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 Ground Water Recharge. The resulting ground water potential is termed as the net annual ground water availability for future use. The Net annual ground water 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 ground water 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 ground water available for future uses will be zero.

Additional Potential Resources under Specific Conditions

Potential Resource Due to Spring Discharge: Spring discharge constitutes an additional source of ground water in hilly areas which emerges at the places where ground water level cuts the surface topography. Even though, the Spring Discharge is a form of 'Annual Extractable Ground Water Recharge', It is a considered as a potential resource because of the limited data available as on today. 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 **22**

Where

Q = Spring Discharge

No of days= No of days spring yields.

Potential Resource in Waterlogged and Shallow Water Table Areas: In the area where the ground water 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 recommended 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. It is further evident that this potential recharge would be available mostly in the shallow water table areas which would have to be demarcated in each sub-basin/ watershed/ block/ taluka/ mandal/ Firka. The computation of potential resource of the ground water reservoir can be done by adopting the following equation:

Potential ground water resource in shallow water table areas = (5-D) x A x S_Y **23**

Where

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

A = Area of shallow water table zone.

S_Y = Specific Yield

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

Since collection of data on all these factors is time taking and difficult, in the meantime, the potential resource 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 24

Where

N = No of Days Water is Retained in the Area

A = Flood Prone Area

Apportioning of Ground Water Assessment from Watershed to Development Unit:

Where the assessment unit is a watershed, there is a need to convert the ground water assessment in terms of an administrative unit such as block/ taluka/ mandal/ firka. This may be done as follows.

A block may comprise of one or more watersheds, in part or full. First, the ground water assessment in the subareas, command, non-command and poor ground water quality areas of the watershed may be converted into depth unit (mm), by dividing the annual recharge by the respective area. The contribution of this subarea of the watershed to the block, is now calculated by multiplying this depth with the area in the block occupied by this sub-area. This procedure must be followed to calculate the contribution from the sub-areas of all watersheds occurring in the block, to work out the total ground water resource of the block.

The total ground water resource of the block should be presented separately for each type of sub-area, namely for command areas, non-command areas and poor ground water quality areas, as in the case of the individual watersheds.

Assessment of In-Storage Ground Water Resources or Static Ground Water Resources

The quantum of ground water available for development is usually restricted to long term average recharge or dynamic resources. For sustainable ground water development, it is necessary to restrict it to the dynamic resources. Static or in-storage ground water resources could be considered for development during exigencies that also for drinking water purposes. It is also recommended that no irrigation development schemes based on static or in-storage ground water resources be taken up at this stage.

The computation of the static or in-storage ground water resources may be done after delineating the aquifer thickness and specific yield of the aquifer material. The computations can be done as follows: -

$$\mathbf{SGWR = A * (Z_2 - Z_1) * S_Y} \qquad \mathbf{25}$$

Where,

SGWR = Static or in-storage Ground Water Resources

A = Area of the Assessment Unit

Z_2 = Bottom of Unconfined Aquifer

Z_1 = Pre-monsoon water level

S_Y = Specific Yield in the In storage Zone

Assessment of Total Ground Water Availability in Unconfined Aquifer

The sum of Annual Exploitable Ground Water Resource and the In storage ground water resources of an unconfined aquifer is the Total Ground Water Availability of that aquifer.

3.5 GROUND WATER ASSESSMENT OF CONFINED AQUIFER SYSTEM

Assessment of ground water resources of confined aquifers assumes crucial importance, since over-exploitation of these aquifers may lead to far more detrimental consequences than to those of shallow unconfined aquifers.

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 and directly dewaters the aquifer and there is a possibility of damage to the aquifer as well as topography. Hence ground water potential of a confined aquifer is nothing but the water available for use without damaging the aquifer. Hence the resources available under pressure are only considered as the ground water potential. The quantity of water released in confined aquifer due to change in pressure can be computed between piezometric head (h_t) at any given time 't' and the bottom of the top confining layer (h_o) by using the following equation.

$$\mathbf{Q_p = SA\Delta h = SA\,(h_t - h_0)} \qquad \mathbf{26}$$

Where

Q_P = Ground Water Potential of Confined Aquifer

S = Storativity

A = Areal extent of the confined aquifer

Δh = Change in Piezometric head

h_t = Piezometric head at any particular time

h_0 = Bottom of the top Confining Layer

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 ground water 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.

To assess the dynamic ground water resources of the confined aquifer the following equation can be used with the pre and post monsoon piezometric heads of the particular aquifer.

$$\mathbf{Q_D = SA\Delta h = SA\,(h_{POST} - h_{PRE})} \qquad \mathbf{27}$$

Where

Q_D = Dynamic Ground Water Resource of Confined Aquifer (m^3)

S = Storativity

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

Δh = Change in Piezometric head (m)

h_{post} =Piezometric head during post-monsoon period (m amsl)

h_{PRE} = Piezometric head during pre-monsoon period (m amsl)

In storage Ground Water Resources of Confined Aquifer

For assessing the in-storage ground water potential of a confined aquifer, one has to compute the resources between the pre-monsoon piezometric head and bottom of the top confining layer. That can be assessed using the following formula:

$$Q_I = SA\Delta h = SA(h_{PRE} - h_0) \qquad 28$$

Where

Q_I =In storage Ground Water Resource of Confined Aquifer (m^3)

S = Storativity

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

Δh = Change in Piezometric head (m)

h_0 = Bottom level of the top confining layer (m amsl)

h_{PRE} = Piezometric head during pre-monsoon period(m amsl)

If the confined aquifer is not being exploited for any purpose, the dynamic and static resources of the confined aquifer need not be estimated separately. Instead the in storage of the aquifer can be computed using the following formula.

$$Q_p = SA\Delta h = SA(h_{POST} - h_0) \qquad 29$$

Where

Q_p = In storage Ground Water Resource of the confined aquifer or the Quantity of water under pressure (m^3)

S = Storativity

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

Δh = Change in Piezometric head (m)

H_{POST} =Piezometric head during post-monsoon period (m amsl)

h_0 = Bottom of the Top Confining Layer (m amsl)

The calculated resource includes small amount of dynamic resource of the confined aquifer also, which replenishes every year. But to make it simpler this was also computed as part of the static or in-storage resource of the confined aquifer.

Assessment of Total Ground Water Availability of Confined Aquifer

If the confined aquifer is being exploited, the Total Ground Water Availability of the confined aquifer is the sum of Dynamic Ground Water Resources and the in-storage ground water resources of that confined aquifer. Whereas if it is not being exploited, the Total Ground Water Availability of the confined aquifer comprises of only one component i.e. the in-storage of that confined aquifer.

GROUND WATER ASSESSMENT OF SEMI-CONFINED AQUIFER SYSTEM

The Assessment of Ground Water Resources of a semi-confined aquifer has some more complications. Unless and until, it is well studied that the recharge to this is not computed either in the over lying unconfined aquifer or underlying/overlying semi confined aquifers, it should not be assessed separately. If it is assessed separately, there is a possibility of duplication of estimating the same resource by direct computation in one aquifer and as leakage in the other aquifer. As it is advisable to under estimate rather than to overestimate the resources, it is recommended not to assess these resources separately as long as there is no study indicating its non-estimation. If it is found through field studies that the resources are not assessed in any of the aquifers in the area, these resources are to be assessed following the methodology similar to that used in assessing the resources of Confined aquifers.

TOTAL GROUND WATER AVAILABILITY OF AN AREA

The Total Ground Water Availability in any area is the Sum of Dynamic Ground Water Resources, the static/ in-storage ground water resources in the unconfined aquifer and the dynamic and In-storage resources of the Confined aquifers and semi-confined aquifers in the area.

TERMINOLOGY CHANGE There are minor changes in the terminology used in GEC-2015 methodology and the corresponding changes for the terms have been tabulated below:

GEC- 97 Methodology	GEC-2015 methodology
Annual Replenishable Resources	Total Annual Groundwater Recharge
Net Groundwater Availability	Annual Extractable Groundwater Resources
Groundwater Draft	Groundwater Extraction
Annual Groundwater Draft for all uses	Current Annual Groundwater Extraction for all uses
Projected Demand for Domestic and Industrial uses up to 2025	Annual ground water allocation for domestic water supply as on 20 25
Groundwater Availability for future irrigation	Net Annual Groundwater Availability for future Use
Stage of Groundwater Development	Stage of Ground Water Extraction

CHAPTER 4

4. PROCEDURE FOLLOWED FOR GROUNDWATER ESTIMATION 2017

4.1 DATA SOURCE

The data on geographical area, forest area, population census, growth rate etc are provided by the Department of Planning and Statistics, Silvassa. The cropping pattern, area irrigated by paddy and non-paddy crops, irrigation potential created etc. is provided by the Department of Agriculture, Silvassa. The various inputs needed for the estimation of ground water resources namely the details of domestic wells, Irrigation wells and details on were collected from PWD, Civil Division No. III (DP), Irrigation. The data on major reservoir, canal and outlet details were collected from PWD, Civil Division No. II (Road). The command area of the irrigation project as notified by Irrigation Department, has been used in this assessment. There are no major or medium irrigation projects in this U.T. except the Damanganga Reservoir Project which is a common venture of Govt. of Gujarat, U.T. of Daman and U.T. of Dadra & Nagar Haveli. The irrigation through canal network is undertaken by the Damanaganga Canal Authority. The revised command area of the above project falling under the U.T of Dadra & Nagar Haveli is 4235 Ha. The total length of main canal is 98.30 kms, out of which 38.10 Kms runs within this UT. The irrigation water is supplied as per rotation fixed and it is about 174 days during non-monsoon and 41 days during monsoon season. The average design discharge of minor canal is 1.09 hectare meter considering all seasons and crop pattern and number of watering. The total number of outlets in this UT is 526 Nos. and the total number of days of irrigation as per the rotation period for non-monsoon is 174 days and for monsoon season is 41 days.

The minor irrigation schemes are developed by the UT Administration. There are limitations in the well census data. Their physical number is available; however, their draft or abstraction details are not available with any of the organizations in the U.T. Hence, the unit draft norms as prescribed in GEC 97 Methodology has been used.

Rainfall

The rainfall for the assessment year and for the last 10 years has been taken from Department of Planning & Statistics, Silvassa.

Ground Water Levels

Central Ground Water Board, Nagpur is monitoring the groundwater levels during January, May, August and November every year. There are 16 observation wells established by CGWB in the Union Territory. The pre- and post-monsoon water level during 2019 and water level during pre-monsoon interval during 2012 has been used as the base year data. The groundwater level data for the period 2012 to 2019 has been considered for the Pre- and Post monsoon decadal water level trend.

Population

The 2011 census data has been used in the computations.

*4.*2 VARIOUS NORMS USED

4.2.1 Assessment area: Out of the total geographical area, the hilly area (slope > 20%), hill tops and rocky waste land were identified and subtracted and the remaining area is considered as a recharge worthy or assessment area.

4.2.3 Specific yield: The specific yield value of 2 % for Deccan Traps is considered as per the GEC 1997 norms

4.2.4 Rainfall infiltration factor: The coefficients for RIF are as per the recommended value in GEC norms i.e., 7% for weathered basalts.

4.2.5 Recharge due to canal seepage: The canals are lined and hence the recharge factor of 3.5 hectare meter per day/million sq. m wetted area has been used.

4.2.6 Recharge from Tanks and Ponds: The recommended value for recharge from storage tanks and ponds is 1.4 mm/day for which the period has water, based on the average of water spread. for weathered basalts. As the data on tank and ponds were available, 1.4 mm/day value was used for computation.

4.2.7 Recharge from water conservation structure: As per the data provided the recharge due to check dams was computed as per norms, i.e., 40% of gross storage (assuming annual de-silting maintenance exists) with half of this recharge occurring in the monsoon season and the balance in the non monsoon season.

4.2.8 Unit Draft: The unit draft recommended computed for different abstraction structures representing typical geological formations in GEC 2015 norms have been used for the estimation. The current gross ground water draft for ‘Irrigation’ during monsoon and non-monsoon periods is computed by considering the recommended value of unit draft @1.57 ham/ year/dugwell with pumpset, out of which 0.52 ham is considered during monsoon season and 1.05 ham for non-monsoon season. Similarly, the current gross ground water draft for 'Domestic Water Supply' is estimated separately by considering the unit draft 60 lpcd. As per GEC 2015, the value of unit draft shall be calculated after conducting field studies rather than using default value for unit drafts as per GEC 97 methodology.

4.2.9 Return flow from irrigation: The return flow factor as per the norms was considered and is given below.

SWL<10	Paddy	Non Paddy
GW -	0.45	0.25
SW -	0.50	0.30

4.2.10 Stage of ground water Extraction & Categorisation: The GEC 2015 norms have been used for the computation of the Stage of Development and Categorisation.

CHAPTER 5

5.COMPUTATION OF GROUNDWATER RESOURCES ESTIMATION IN UT OF DNH

5.1 SALIENT FEATURES

The salient features of the dynamic groundwater resources of UT of DNH as on March 2020 are as under.

5.2 GROUND WATER RESOURCE ASSESSMENT

5.2.1 Resources Assessment Unit

Administratively, Dadra and Nagar Haveli is a Union Territory. The region is considered to be a uni-district and uni-taluka. In view of this, the entire geographical area of D&NH has been considered as a single assessment unit and it is a hard rock terrain. This assessment unit is sub-divided into one command unit and one non-command unit.

Out of the total area of 491 sq.km. the hilly and non-worthy area of 75 sq.km. is deducted and only the worthy area of 416 sq.km. is considered for this assessment. This worthy area is further sub-divided into command (42.35 sq.km.) and non-command (373.65 sq.km.). The poor-quality unit is not reported. These details of these areas are given in **Annexure I A**. The recharge is estimated for the groundwater worthy area of all the sub-units.

5.2.2 Base Year of Data

The monsoon rainfall of the year 2019 has been considered in the computations. The groundwater levels since 2015 up to May 2019 have been used in the calculations. Based on this database, the sub-unit wise average pre-monsoon and post-monsoon groundwater levels and fluctuations are calculated and used in the assessment. The sub-unit wise rainfall, average pre-monsoon and post-monsoon groundwater levels and water level fluctuation are given in **Annexure I B**. However, the wells data as provided by administration of UT of DNH as on March 2020 have been used in the draft calculations. The number of abstraction structures, being used for irrigation purposes, within the sub-units are listed in **Annexure I B (contd)**.

The sub-unit wise parameters, like specific yield, rainfall infiltration factor, season wise unit draft for different usages, used during this assessment are given in **Annexure I C**.

5.2.3 Groundwater Resource Assessment Method

The water table fluctuation method is adopted in computing the rainfall recharge for both the command and non-command sub units. The recharge from rainfall and recharge due to *'other sources'* have been worked out separately for monsoon and non-monsoon seasons for both the command and non-command areas. For command areas, the recharge from *'other sources'* correspond to recharge due to seepage from canals, recharge from applied surface and ground water irrigation, recharge from storage tanks and ponds and recharge from water conservation structures etc.

The return seepage from irrigation water applied is computed by any one of the following methods : viz., a) based on water delivered at the out let b) based on the cropping pattern c) based on power consumption. Presently, the computations have been made based on the water delivered at the outlet, as the other reliable data are not readily available. In order to estimate the return seepage due to applied irrigation, the following steps are to be carried out:

a) Computation of the actual water released from each outlet during monsoon and non-monsoon seasons. The irrigation water applied during these two seasons are obtained as the sum of water released from all outlets in the canal system. The irrigation water applied in hectare meters from each outlet is obtained based on the following criteria:

Design discharge of the outlet (ham) x Number of running days (day) x a factor 0.60

b) The recharge due to return seepage from applied surface water irrigation can be computed as the product of the following parameters:

Irrigation water applied (ham) x Return flow factor expressed as a fraction.

The return flow factor has to be assigned based on the norms recommended in GEC 2015. The return seepage factor depends on the following factors: a) whether the crop irrigated is paddy or non-paddy, b) whether the range of DTW is less than 10m, 10-25m or >25m.bgl, and c) whether the release from outlets is continuous or rotational.

The return seepage due to ground water irrigation is to be computed as the product of the volume extracted from the aquifers and return seepage factor expressed as a fraction. In GEC 2015, the norms are linked with water levels. And the norms are 25% for non-paddy crops and 45% for paddy crops. The following steps are involved in the computation:

a) The gross ground water draft for irrigation during the monsoon and non-monsoon season are considered as the irrigation water applied by ground water irrigation.
b) The characteristics of DTW for the area is noted and c) the applying the return flow factor based on the above norms has to be applied to workout the finally computation of recharge.

5.2.4 Total Dynamic Groundwater Resources

The total annual ground water potential refers to the available annual recharge after allowing for unaccounted natural discharge in terms of base flow, and sub surface in flow/outflow, In GEC 2015, 5 to 10% of the total annual ground water potential is assigned to account for environmental flow and the balance is the Annual Extractable Groundwater Resources for withdrawal and potential for future development. The total dynamic ground water resources of UT of Dadra and Nagra Haveli i.e. existing development, balance available for future development, stage of development, categorization of assessment units and other details is presented in **Annexure I D and I D (contd)**. As per this, the Annual Extractable Groundwater Resources in the UT of DNH are computed as 67.52 MCM and the present gross groundwater extraction for all purposes is 31.05 MCM whereas annual ground water allocation for domestic water supply as on 20 25 is 17.98 MCM. The net ground water availability for future use development is 34.16 MCM. The stage of groundwater extraction for the UT, as a whole, is 45.99 %.

5.2.5 Categorization of Assessment Unit

The categorization of assessment unit is done as per the norms. The assessment unit-wise details of stage of ground water extraction and their categorization are given in **Annexure I E**. The categorization of UT of DNH, which was considered as a single unit, is also shown on **Map 5**. The abstract showing number of OE/Critical/SC/Safe & PQ blocks is given in **Annexure I F**.

5.3 SPATIAL VARIATION

5.3.1 Groundwater Recharge

The groundwater recharge is a function of rainfall, geomorphology and geology. The UT of DNH is spread in a small area of 49100 ha, out of which recharge worthy area is 41600 ha, hence there is not be much apparent heterogeneity in the parameters. Based on the total Annual Groundwater Recharge (as computed in col 12 of Annexure I D) and the Area of Assessment (Row 6 of Annexure I A), the unit annual replenishable groundwater recharge has been computed as 0.17 m.

5.3.2 Stage of Groundwater Extraction

The stage of ground water extraction for the UT of DNH, as a whole, is low around 45.99% and it falls under the **'Safe'** category. Being a tribal belt, whose population is engaged in rain-fed agriculture, ground water based irrigation is very less. Therefore, the ground water development is also very less, thus there is ample scope for the development of ground water.

5.4 COMPARISON WITH THE EARLIER ASSESSMENTS

5.4.1 Assessment Units

The assessment units remained the same during 2009, 2011, 2013 and 2017 assessment years. Recharge worthy area in Command and non-command are considered as 4235 and 37365 hectares respectively. Hilly area of 75 sq.km. has been deduced to work out the ground water worthy area.

5.5 FIELD VALIDATION

The field validation has not been carried out in UT of DNH.

5.6 GROUNDWATER RECHARGE IN POOR QUALITY ZONE

The poor ground water quality zone is not present in the UT of DNH, hence the ground water resources have not been computed.

5.7 ANNUAL POTENTIAL RECHARGES

In UT of DNH, the water logged and shallow water table areas are not mappable and are not being monitored. Hence, computation of potential recharge to ground water reservoir i.e., potential ground water resource was not computed.

ANNEXURES

Annexure-I A: General Description of Ground Water Assessment Unit

Name of Ground Water Assessment Unit		**D&NH**
Principal Aquifer		**BASALT**
Major Aquifer		**BS-01, WEATHERED BASALT**
Assessment Year		**2020**
1	Reference number(s) of Survey of India Toposheet (s) of 1;50,000 scale in which the Ground Assessment Unit is located	46 D/15 & 16, 46 H/3 & 4
2	Latitudes within which the Ground Water Assessment Unit is located	
	i) Starting	20°02’00”
	ii) Ending	20°22’00”
3	Longitudes within which the Ground Water Assessment Unit is located	
	i) Starting	72°54’00”
	ii) Ending	73°14’00”
4	Total area in hectares of the 'Ground Water Assessment Unit'	49100
5	Area in hectares of the **‘Hilly Area’**	7500
6	Area in hectares of the portion of the Ground Water Assessument Unit in which ground water recharge is possible [(4) - (5)]	41600
7	Area in hectares of the 'Poor Ground water Quality Area'	0
8	Quality Hazard (Salinity/ Arsenic/Fluoride/Others)	No
9	Area in hectares of the **‘Command Area’**	4235
10	Area in hectares of the **‘Non - command Area’**	37365

Annexure-I B: Data variables used in the assessment of dynamic ground water resources of UT of DNH

Name of Ground Water Assessment Unit	**D&NH**
Principal Aquifer	**BASALT**
Major Aquifer	**BS-01, WEATHERED BASALT**
Assessment Year	**2020**

	Name	Year	Rainfall(mm)	Depth to water table below ground level in metres in the observation well as recorded		
				Pre-Monsoon	Post-monsoon	Fluctuation
Observation wells in command area						
1	Dapada	2019	2265.7	11.14	7.6	3.54
2	Naroli-1	2019	2265.7	8.7	2.61	6.09
3	Rakhali	2019	2265.7	7.1	4.31	2.79
4	Samarvarni	2019	2265.7	9.9	3.05	6.85
5	Surangi	2019	2265.7	12.2	4.8	7.4
Observation wells in non-command area						
6	Chinsda	2019	2683.7	4.2	1.53	2.67
7	Dudhani	2019	2683.7	14.29	3.1	11.19
8	Khedi Ghodamba	2019	2683.7	12.1	4.03	8.07
9	Rudana	2019	2683.7	14.2	3.34	10.86
10	Shelti	2019	2683.7	4.6	2.08	2.52
11	Umarkui (Hathpada)	2019	2683.7	10.29	1.58	8.71

Annexure-I B (Contd.): Data variables used in the assessment of dynamic ground water resources of UT of DNH

	Name of Ground Water Assessment Unit		**D&NH**	
	Principal Aquifer		**BASALT**	
	Index Number of Ground Water Assessment Unit		**BS-01, WEATHERED BASALT**	
	Ground Water Assessment Year		**2020**	
	Major Aquifer		**D&NH**	
S. No.	Type of Well	No. of structures		
		Irrigation	Domestic	Industrial
Command Area				
1	Rural Water Supply open wells	152	Domestic calculation computed on the basis of projected population, per capita requirement and fractional load of ground water	Industrial extraction data taken from CGWA NOCAP software
2	Rural Water Supply bore wells	105		
3	Bore wells with hand pump	316		
Non Command Area				
1	Dugwells with electric pump	379		
2	Bore wells	2		
3	LIS on open wells	67		
4	LIS on bore wells	4		

Annexure-I C: Parameter used in the assessment of dynamic ground water resources of UT of DNH

Name of Ground Water Assessment Unit						D&NH			
Principal Aquifer						BASALT			
Index Number of Ground Water Assessment Unit						1			
Ground Water Assessment Year						2016-17			
Major Aquifer						BS-01, WEATHERED BASALT			
S. No.	Type of Well	Specific Yield	Rainfall Infiltration Factor	Estimated number of wells currently in actual use	Estimated unit ground water extraction per well for irrigation use in hectare meters during		Estimated gross ground water extraction for irrigation from all wells of a given type in hectare meters during		
					Monsoon Season [From Table 3.1]	Non-monsoon Season [From Table 3.1]	Monsoon Season [(3)*(4)]	Non-monsoon Season [(3)*(5)]	Annual [(6) + (7)]
Command Area									
1	Dugwells with electric pump	0.02	0.07	95	0.52	1.05	49.4	99.75	149.15
2	Bore wells	0.02	0.07	2	0.52	1.05	1.04	2.1	3.14
3	LIS on open wells	0.02	0.07	15	0.52	1.05	7.8	15.75	23.55
4	LIS on bore wells	0.02	0.07	2	0.52	1.05	1.04	2.1	3.14
Current gross ground water extraction for Irrigation use using unit draft method in command area in hectare meters (Total of all the types of wells considered)							**59.28**	**119.7**	**178.98**
Non Command Area									
1	Dugwells with electric pump	0.02	0.07	379	0.52	1.05	197.08	397.95	595.03
2	Bore wells	0.02	0.07	2	0.52	1.05	1.04	2.1	3.14
3	LIS on open wells	0.02	0.07	67	0.52	1.05	34.84	70.35	105.19
4	LIS on bore wells	0.02	0.07	4	0.52	1.05	2.08	4.2	6.28
Current gross ground water extraction for Irrigation use using unit draft method in Non-command area in hectare meters (Total of all the types of wells considered)							**232.96**	**470.4**	**703.36**

Annexure-I C: Parameter used in the assessment of dynamic ground water resources of UT of DNH

Name of Ground Water Assessment Unit				D&NH		
Principal Aquifer				BASALT		
Index Number of Ground Water Assessment Unit				1		
Ground Water Assessment Year				2016-17		
Major Aquifer				BS-01, WEATHERED BASALT		
S. No.	Type of Well	Specific Yield	Rainfall Infiltration Factor	Estimated gross ground water extraction for industrial from all wells of a given type in hectare meters		
				Monsoon Season	Non-monsoon Season	Annual
	Command Area	0.02	0.07	137.06	274.13	411.20
	Non commandArea	0.02	0.07	79.28	158.56	237.84

Annexure-I D: Assessment of dynamic ground water resources of UT of DNH

Sl. No	State	District	Assessment Unit Name	Assessment Unit Type	Total Area of Assessment Unit (Ha)	Recharge Worthy Area (Ha)	Recharge from Rainfall-Monsoon Season (Ham)	Recharge from Other Sources-Monsoon Season (Ham)	Recharge from Rainfall-Non-Monsoon Season (Ham)	Recharge from Other Sources-Non-Monsoon Season (Ham)	Total Annual Ground Water (Ham) Recharge (Ham)	Total Natural Discharges (Ham)	Annual Extractable Ground Water Resource (Ham)
1	DNH	DNH	DNH	Taluka	49100	41600	4306.48	661.93	329.73	1948.12	7246.26	494.21	6752.05

Annexure-I D (Contd.): Assessment of dynamic ground water resources of UT of DNH

Sl. No	State	District	Assessment Unit Name	Assessment Unit Type	Annual Extractable Ground Water Resource (Ham)	Ground Water Extraction for Irrigation Use (Ham)	Ground Water Extraction for Industrial Use (Ham)	Ground Water Extraction for Domestic Use (Ham)	Total Extraction (Ham)	Annual GW Allocation for Domestic Use as on 2025 (Ham)	Net Ground Water Availability for future use (Ham)	Stage of Ground Water Extraction (%)
1	DNH	DNH	DNH	Taluka	6752.05	888.62	649.04	1,568.14	3,105.80	1798.23	3416.16	45.99

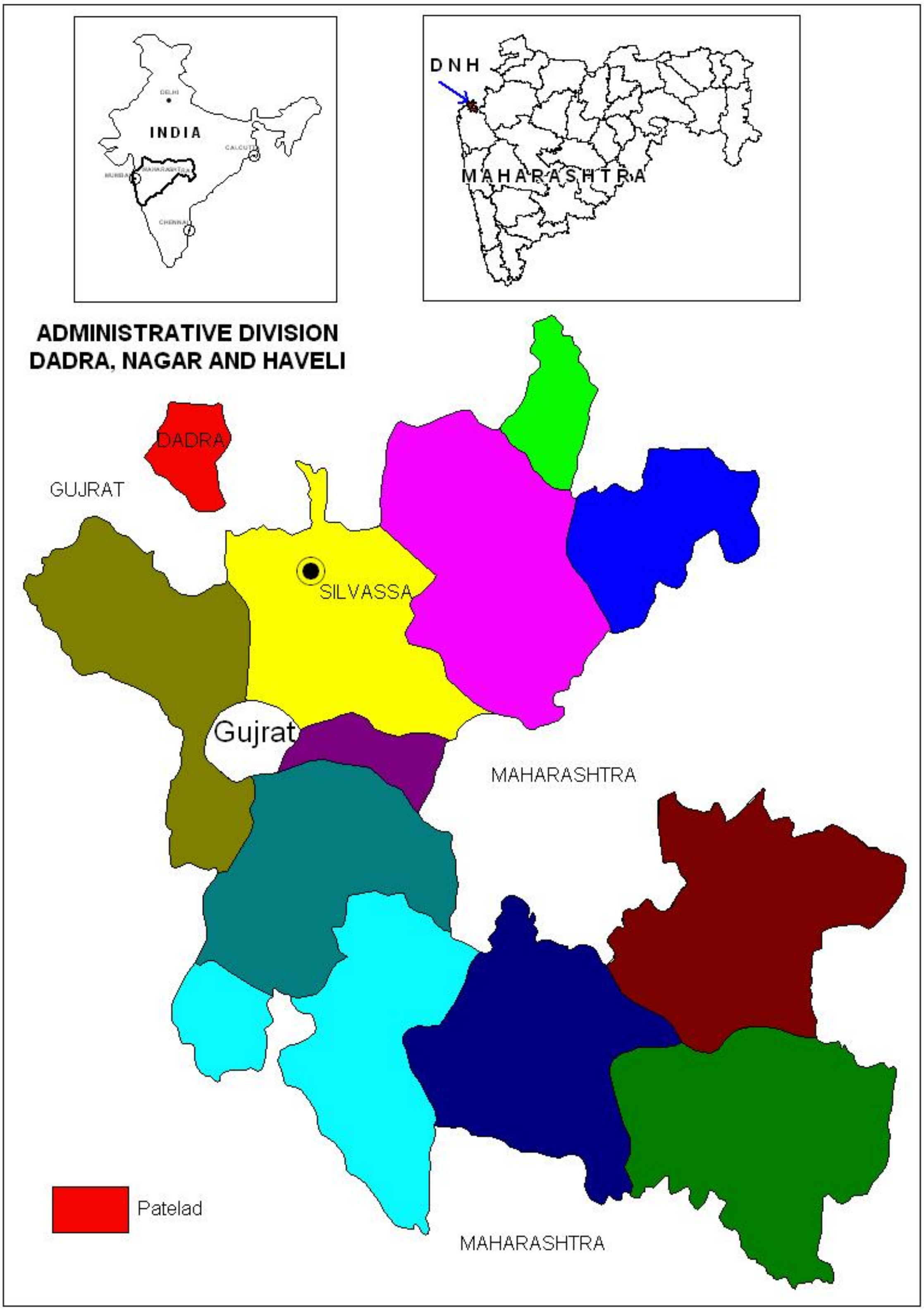
Annexure-I E: Assessment of dynamic ground water resources of UT of DNH

Sl. No	State	District	Assessment Unit Name	Assessment Unit Type	Total Area of Assessment Unit (Ha)	Recharge Worthy Area (Ha)	Stage of GW Extraction (%)	Category
1	Dadra & Nagar Haveli	Dadra & Nagar Haveli	Dadra & Nagar Haveli	Taluka	49100	41600	45.99	SAFE

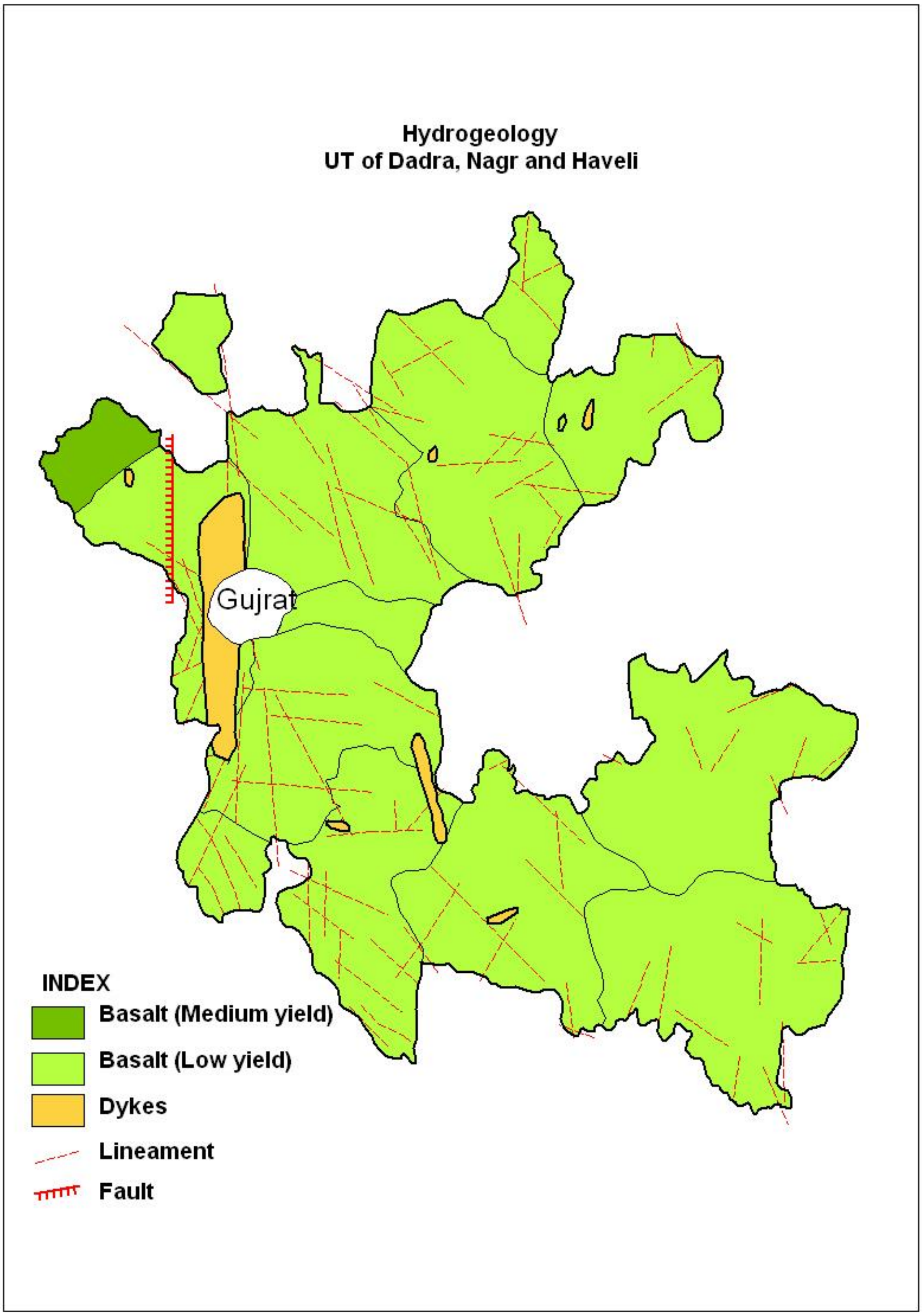
Annexure-I F: Abstract showing number of OE/Critical/SC/Safe & PQ blocks

S. No	Name of District	Total No. Of Assessed Units	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
			No.	%	No.	%	No.	%	No.	%	No.	%
1	Dadra & Nagar Haveli	1	1	100	0	0	0	0	0	0	0	0

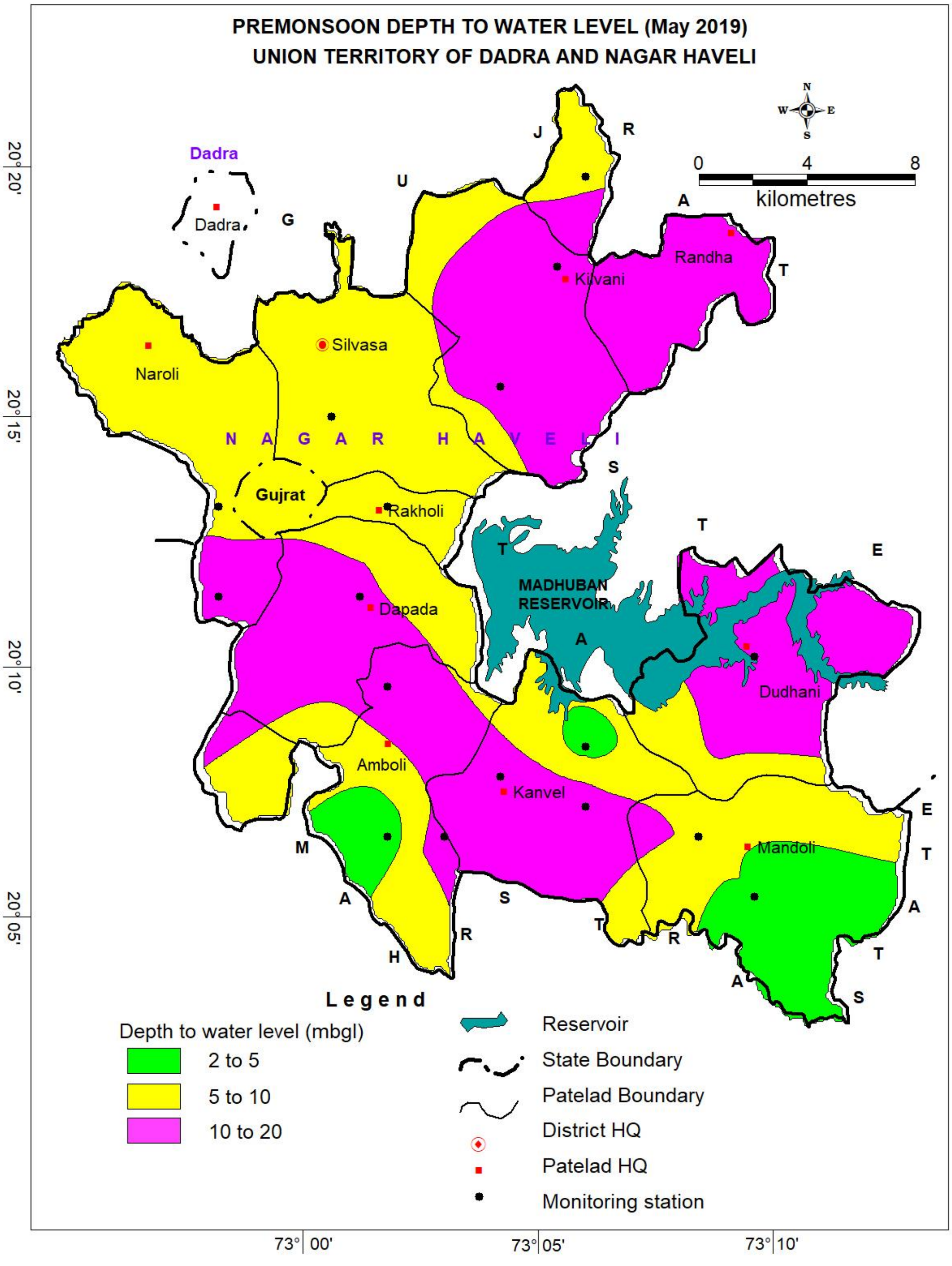
Map 1: Location of UT of DNH



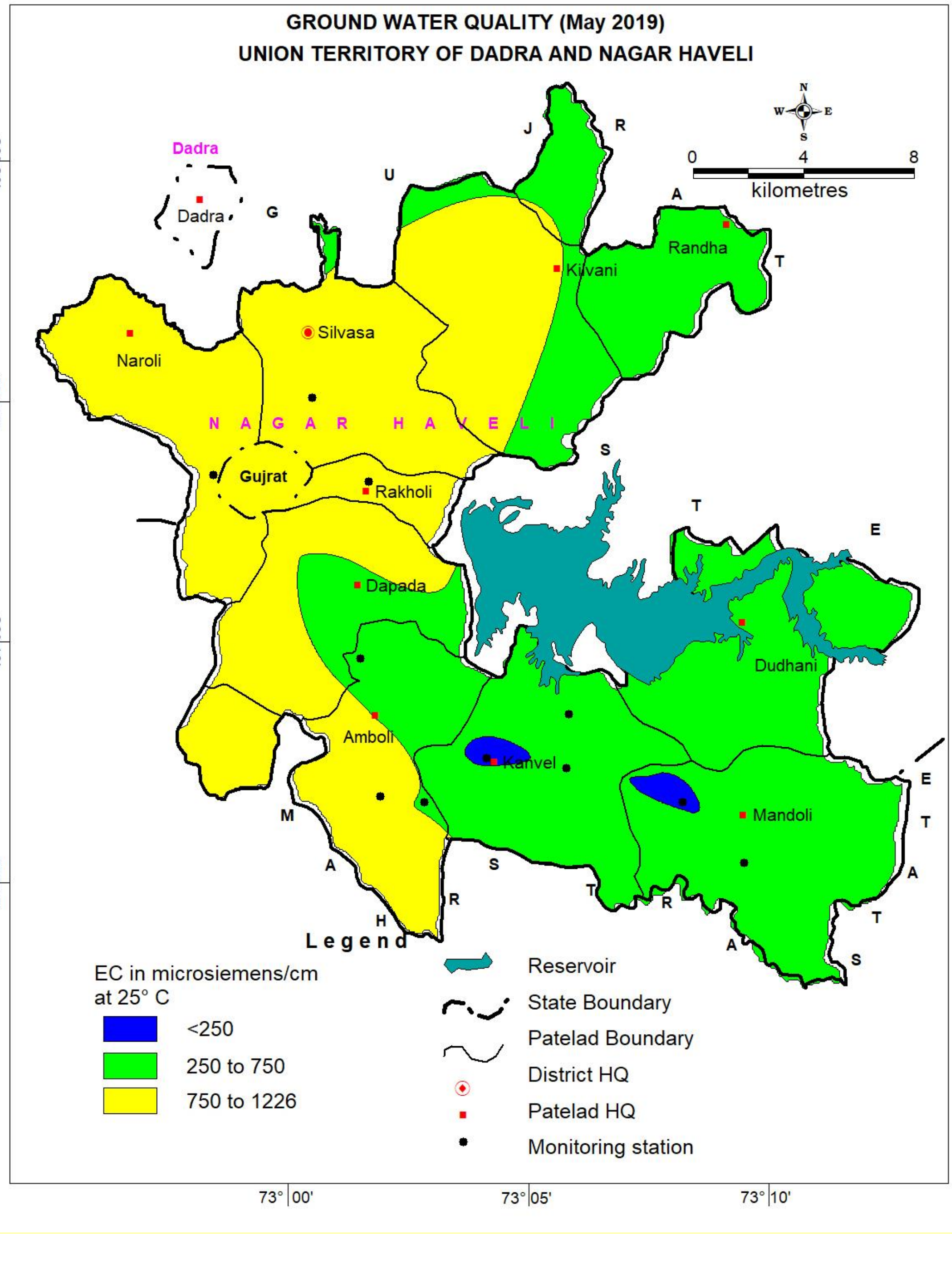
Map 2: Hydrogeology of UT of DNH



Map 3: Premonsoon Depth to Water Level (May 2019) of UT of DNH



Map4: Distribution of EC in UT of DNH



Map 5: Categorization of UT of DNH