Government of India

Ministry of Jal Shakti
Department of Water Resources,
River Development & Ganga Rejuvenation
Central Ground Water Board

DYNAMIC GROUND WATER RESOURCES OF UTTARAKHAND STATE, 2022

Uttaranchal Region
Dehradun
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PREFACE

Groundwater is one of the precious natural resources and also the key driver of India's economic development and food security. It is a major source of water for meeting the drinking, industrial and agricultural requirements. The unplanned and unscientific development of groundwater leads to depletion and quality deterioration. Therefore, it becomes imperative to periodically assess this precious resource using suitable methodology.

The first systematic approach to assess the groundwater resources of the country was made by the Ground Water Exploitation Committee in 1979. The groundwater resources assessment exercise, based on reliable scientific data and norms, was done using the methodology suggested by the Ground Water Resources Estimation Committee, released in March 1984 (GEC 1984). Since then, the Central Ground Water Board, State Ground Water Organisations, Universities and other organisations, had been using the GEC-1984. The data base generated from various studies and changing groundwater scenario demanded a modification of the methodology, developed by the committee in 1984. Accordingly, the methodology was modified in 1997 (GEC 1997) and further in 2015 (GEC 2015).

The dynamic groundwater resources of India for the year 2022 are assessed following the Groundwater Estimation Methodology, 2015 (GEC–2015), which takes into account all the relevant parameters contributing to groundwater recharge and extraction. All computations for the assessment of ground water resources have been automated and done in a GIS environment through a web based application namely "*INDIA GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES)*" developed in collaboration with IIT Hyderabad and Vassar Labs. The report "Dynamic Ground Water Resources of Uttarakhand" is prepared by CGWB, Uttaranchal Region, Dehradun under the supervision of State Level Technical Coordination Committee (SLTCC) and overall guidance of Central Level Expert Committee (CLEG). The present report shows that out of 18 assessment units, 04 assessment units (Blocks) are falling under 'Semi-critical' category and remaining under Safe category.

I express my sincere thanks to Shri H C Semwal, IAS, Secretary, Irrigation Dept., Govt of Uttarakhand and Chairman of the State Level Technical Coordination Committee on Ground Water Resources Estimation and committee members for the approval of the report. The present report is outcome of the constant and untiring efforts made by Ms Chandreyee De, Scientist–B. I acknowledge all the officers of CGWB, UR, Dehradun who were associated with this extensive exercise. The data provided by the various departments of Government of Uttarakhand namely Uttarakhand Jal Sansthan, Irrigation Department, Minor Irrigation Department, Directorate of Industries, Uttarakhand Pey Jal Nigam and Indian Meteorological Department, Dehradun are thankfully acknowledged.

(Sh. Prashant Rai)

Executive Summary

Ground Water Resources Assessment is carried out at periodical intervals jointly by State Ground Water Departments and Central Ground Water Board under the guidance of the respective State Level Committee on Ground Water Assessment at State Levels and under the overall supervision of the Central Level Expert Group. Such joint exercises have been taken up earlier in 1980, 1995, 2004, 2009, 2011, 2013, 2017 and 2020.

The assessment involves computation of dynamic ground water resources or Annual Extractable Ground Water Resource, Total Current Annual Ground Water Extraction (utilization) and the percentage of utilization with respect to annual extractable resources (stage of Ground Water Extraction). The assessment units (Talukas/blocks/ mandals/firkas) are categorized based on Stage of Ground Water Extraction, which are then validated with long-term water level trends. The assessment prior to that of year 2017 were carried out following Ground Water Estimation Committee (GEC) 97 Methodology, whereas 2017, 2020 as well as the present assessment are based on norms and guidelines of the GEC 2015 Methodology.

About 85% of the area of Uttarakhand State is mountainous where groundwater structures do not exist and hence groundwater levels cannot be monitored. Groundwater is developed through springs and hand pumps in the hilly part of the state. The areas with plain topography are confined to districts Dehradun, Haridwar, Udham Singh Nagar and Nainital. The groundwater levels are monitored in these districts only and hence the groundwater resources estimation work is also restricted to these four districts. The mountainous area is unworthy for groundwater resources estimation since the slope is more than 20%.

Total Annual Ground Water Recharge in the State (2022) has been assessed as 2.022 billion cubic meters (bcm). Ground water resources are replenished through rainfall and other sources like return flow from irrigation, canal seepage etc. The main source of annual ground water recharge is rainfall, which contributes nearly 68.72 % of the Total Annual Ground Water Recharge. The Total Annual Extractable Ground Water Resource of the State has been assessed as 1.861 bcm, after keeping a provision for natural discharge. The Annual Ground Water Extraction of the State (2022) is 0.894 bcm, the largest user being irrigation sector. The Stage of ground water extraction for the entire State, which is the percentage of ground water extraction with respect to Annual Extractable Ground Water Recharge, has been computed as 48.04 %.

Out of the 18 assessed blocks of Uttarakhand State, 14 blocks have stage of ground water development below 70 % and are termed as ‘Safe’, whereas remaining 4 blocks have stage of ground water development between 70 and 90 % and they are categorised as ‘Semi Critical’.

REPORT ON DYNAMIC GROUND WATER RESOURCES OF UTTARAKHAND STATE, 2022

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INTRODUCTION

1.1 BACKGROUND

Uttarakhand State, a predominantly hilly state, covers a total geographical area of 53,483 km^2 and is situated between 28°43'20" – 31°28'00" N Latitude and 77°34'06" – 81°01'31" E Longitude. Most of the northern part of the state is covered by high Himalayan peaks and glaciers. The state shares international boundaries with China (Tibet) in the north and Nepal in the East. Uttarakhand State shares the common boundaries with the states of Himachal Pradesh in the Northwest and Uttar Pradesh in the South. The State comprises of thirteen administrative districts **(Fig - 1)** - Almora, Bageshwar, Chamoli, Champawat, Dehradun, Haridwar, Nainital, Pauri Garhwal, Pithoragarh, Tehri Garhwal, Rudraprayag, Udham Singh Nagar and Uttarkashi. Two of the most important and major rivers of this country – the Ganges and the Yamuna originate in the glaciers of Uttarakhand and are fed with glacial melts and streams of different orders along its course.

Uttarakhand, the twenty sixth State of India, was carved out of the northern part of Uttar Pradesh on 9th November, 2000. Prior to the formation of Uttarakhand State, the Ground Water Resources Estimation work was being done by Uttar Pradesh Ground Water Department, which continued up to 1997. Presently, Uttarakhand State does not have a Ground Water Department. However, the state plans to have a '*Ground Water Cell*'. The present work of '*Ground Water Resources Estimation*' has been done by the Central Ground Water Board, Uttaranchal Region, Dehradun. The data support has been provided by the various State Government Departments (Jal Sansthan, Department of Minor Irrigation, Department of Irrigation, Directorate of Industries) and India Meteorological Department, Govt. of India.

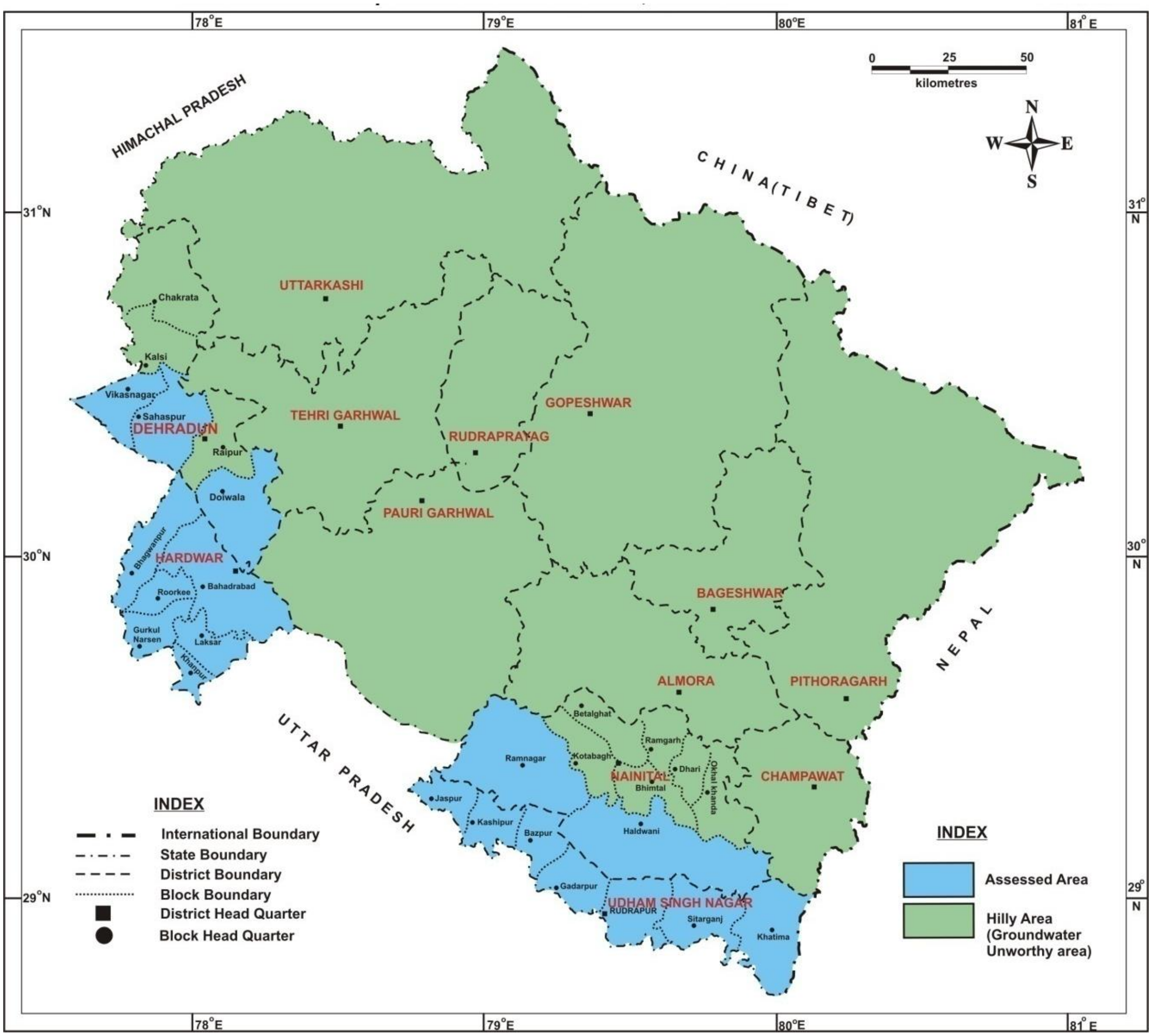


Fig: 1 Administrative Map of Uttarakhand State with highlighted Assessment units considered for Groundwater Resource Assessment (2022)

1.2 STATE LEVEL TECHNICAL COORDINATION COMMITTEE

The State Level Technical Co-ordination Committee (SLTCC) was constituted on permanent basis by the Government of Uttarakhand vide its Letter No. I/22579/2022 dated 10th March, 2022 (**Annexure – I**). The composition of the SLTCC is given below:

Sl No	Name/ Designation	Committee
1	Secretary, Irrigation & Minor Irrigation, GoUK	Chairman
2	Engineer-in-Chief, Irrigation Department, Uttarakhand	Member
3	Chief Engineer, Minor Irrigation Department, Uttarakhand	Member
4	Managing Director, Peyjal Nirman Nigam, Uttarakhand	Member
5	Chief General Manager, Uttarakhand Jal Sansthan	Member
6	Director, Swajal Pariyojna, Uttarakhand	Member
7	Director, Agriculture Department, Uttarakhand	
8	Director, Industries Department, Uttarakhand	Member
9	General Manager, NABARD	Member
10	**Regional Director, CGWB, UR, Dehradun**	**Member Secretary**

The meeting of the State Level Technical Co-ordination Committee (SLTCC) was held on 5th September, 2022 under the Chairmanship of Secretary (Irrigation), Government of Uttarakhand, Dehradun for the approval of the **Dynamic Ground Water Resources (DGWR) of Uttarakhand, 2022 (*Annexure–II*)**. The DGWR report was presented before the SLTCC Committee for suggestions / modifications, if any. The members of the SLTCC approved the Dynamic Groundwater Resources of Uttarakhand state for the year 2022 on 05th September, 2022. (***Annexure - III***).

CHAPTER – 2

HYDROGEOLOGICAL CONDITIONS

CHAPTER –2

HYDROGEOLOGICAL CONDITION

2.1 GEOLOGY

The state of Uttarakhand has distinct geological attributes with a wide spectrum of rock types ranging in age from Achaean to Quaternary. Based on the diversity of geological processes in time and space, the state can be subdivided into two major physiographic-cum-tectonic units, viz.

1. *Gangetic Alluvial Plain*, which separates the Extra-Peninsular Region from the Peninsular Region.
2. *Himalayan Mountain Belt,* which forms the Extra Peninsular Region.

The geology of the state has a direct bearing on its hydrogeology and hence the major geological formations are shown in the hydrogeological map of Uttarakhand in ***Fig. 2.*** The two physiographic-cum-tectonic units are described below:

2.1.1 GANGETIC ALLUVIAL PLAIN

Gangetic Alluvial Plain, a part of the Indo-Gangetic Foreland Basin, occupies the southernmost part of the state. This zone consists of Quaternary fluvial sediments also known as Ganga Alluvium. Subsurface investigations in this belt have revealed a thick pile of alluvium resting conformably over the Siwalik succession of Neogene to Early Pleistocene Period. The thickness of alluvium increases towards north and attains its maximum adjacent to the Foot Hill Fault (FHF), which marks the northern limit of the youngest foreland basin in India i.e. the Ganga Fore deep Basin. The Ganga Fore deep sediments extend up to the south of depositional boundary of the Siwalik succession and rests over Precambrian cratonic rocks of Peninsular Indian Shield.

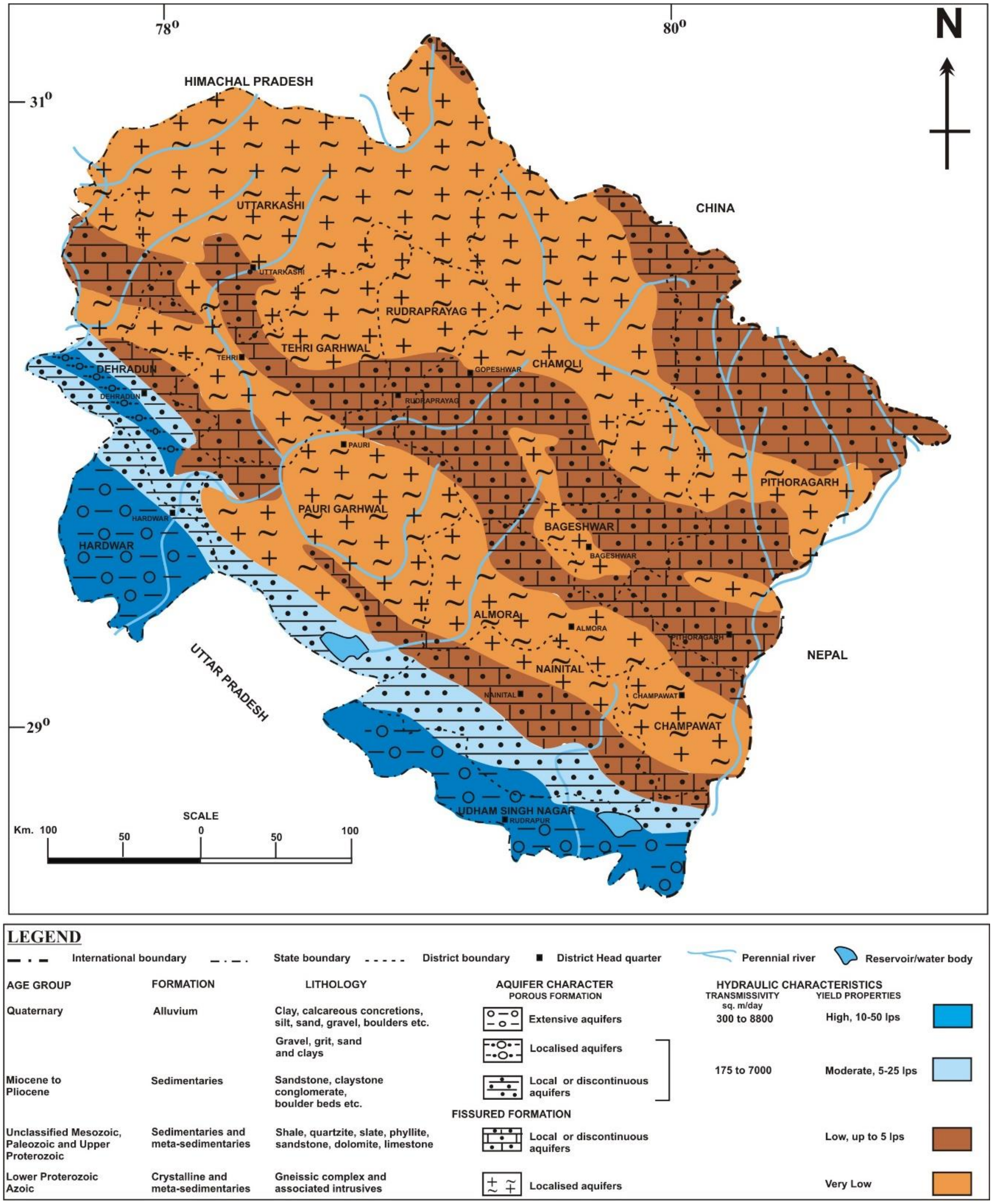


Fig: 2. Hydrogeological Map of Uttarakhand State

2.1.2 HIMALAYAN MOUNTAIN BELT

The Himalayan Mountain Belt is a part of the global belt of Mesozoic to Cenozoic age, which is evolved through the convergence of the Indian Plate and the passive Eurasian Plate by the Continent–Continent Lithospheric Plate Collision. Late Proterozoic (Neo-Proterozoic) to Early Cenozoic sequences form a small part of Himalaya whereas the main mountain chain consists predominantly of Proterozoic rocks representing a part of the Indian Shield. The Proterozoic crystalline rocks have been affected by the various orogenic episodes of Mesozoic to Cenozoic period and shows features of multiple phases of deformation and metamorphism. The Extra Peninsular Region shows a wide spectrum of hard rocks of sedimentary, meta-sedimentary, metamorphic and igneous origin.

The state of Uttarakhand forms part of Western Himalaya. From south to north, the Western Himalaya is divided into four litho-tectonic units viz. (1) Outer Himalaya or Sub Himalaya (2) Lesser Himalaya (3) Central Crystallines and (4) Tethys Himalaya. These units are described below:

2.1.2.1 OUTER HIMALAYA (SUB HIMALAYA)

This litho-tectonic unit constitutes a thick pile of sediments ranging in age from Paleocene to Upper Pleistocene. Its northern and southern boundaries are delineated by the **Main Boundary Thrust** (MBT) and the **Foot Hill Fault** (FHF), which is also known as the **Main Frontal Thrust** (MFT). This zone consists predominantly of continental molasses sediments of Siwaliks ranging in age from Middle Miocene to Upper Pleistocene. The Shiwalik are sub-divided into Lower Siwaliks, Middle Siwaliks and Upper Siwaliks. The estimated thickness of the Siwaliks is 6500 m. The elevation of this zone ranges from 250 to 800 m above MSL and width varies between 25 and 100 km. This zone is also characterized by a number of flat-floored structural valleys of which '*Doon Valley*' is an example.

2.1.2.2 LESSER HIMALAYA

The litho units lying between the Main Boundary Thrust (MBT) in the south and the *Main Central Thrust* (MCT) in the north are included under the Lesser Himalayan Zone, which has the greatest exposed width of about 80 km in the Garhwal and Kumaun regions of Uttarakhand. The rocks of this zone are overlain by crystalline thrust sheets in the form of large klippen masses occupying mostly the higher topographical levels of the mountain ranges. Regionally metamorphosed Proterozoic rocks emplaced by granites of variable ages along with weakly metamorphosed to unmetamorphosed sedimentary rocks (quartzites with interbedded volcanics, carbonates associated with slate, quartzite and shale) occur extensively in this zone. The granitoids are associated with volcano sedimentary sequence (Bhimtal Formation) and are emplaced along with the predominantly metamorphic and metasedimentary rocks of this zone, forming large-scale nappes like the Almora-Ramgarh nappe, Baijnath-Askot nappe and Garhwal nappe.

2.1.2.3 CENTRAL HIMALAYA

This zone consists of thick slabs of Proterozoic crystalline rocks, which thrust southward along the *Main Central Thrust* (MCT), over-riding the Lesser Himalayan Zone. This zone is a 10-15 km wide sequence of metamorphic rocks and granites. This zone represents the Proterozoic basement that has been reactivated due to crustal shortening during the continent-continent collision of the Himalayan Orogeny. The metamorphic rocks exposed in this zone show progressive regional metamorphism ranging from green schist facies to upper amphibolite facies. Both foliated and non-foliated granitoids are emplaced in different structural and tectonic levels within the regionally metamorphosed crystallines.

2.1.2.4 TETHYS HIMALAYA

Tethys Himalaya represents approximately 40 km wide and up to 10 km thick sedimentary sequence ranging in age from Late Precambrian (Neo-Proterozoic) to Lower Eocene. Sediments of marine facies, characteristic of continental shelf to continental slope environments of the Tethys Sea regime, are the predominant litho types of this zone. In Uttarakhand, this zone is well exposed in the Zanskar Mountains and mountain ranges of Kumaun region. This zone is separated from the Central Crystallines by Dar-Martoli Fault, with the Lower Martoli Formation representing the base of Phanerozoic, which is broadly folded and faulted with several local thrusts. The rock sequence comprises phyllite, mica schist and quartzite with lenticular outcrops of limestone.

2.2 HYDROMETEOROLOGY

The climate in Uttarakhand changes from place to place due to variation in the altitude. The plain areas experience subtropical monsoon climate having mild and dry winter and hot summer. In hilly areas the climate varies from sub tropical monsoon to tropical upland. The tropical upland climate has mild, dry winter and warm summer.

In general, Uttarakhand State experiences humid and cold climate. The northernmost part of the state is covered by snow round the year. The summer season starts from April and continues up to June. The southern part of the state experiences hot climate whereas the middle part is pleasant. The northernmost part remains cold even in the summer. The rainy season starts from middle of June and continues up to October. The winter season is from November to March. January is the coldest month. Fog is very common in December and January. The state often experiences winter rains. The south-west monsoons bring the rains in the state. The normal annual rainfall ranges from 1020 to 2183.6 mm.

2.3 HYDROGEOLOGY

The hydrogeology of Uttarakhand is related to geology and physiography. Variable hydrogeological conditions exist in the state due to a wide variation in the geology and land forms. The hydrogeological map of Uttarakhand is shown in ***Fig.2*** and disposition of principal aquifer system of Uttarakhand is shown in ***Fig.3.*** The regional hydrogeological setup can be described on the basis of five hydrogeological units from north to south. The units are briefly described below.

2.3.1 HIMALAYAN Region

This region is confined between the Indo-Gangetic Plains in the south and Zanskar Range in the north. It is represented by mountainous terrain with rugged topography having a variety of rocks ranging in age from Precambrian to Tertiary. The rock types range from unconsolidated and semi-consolidated fluvial and glacial deposits to sedimentary, igneous and metamorphic rocks like limestone, shale, volcanics, granites, migmatite and granite gneiss. The metamorphic rocks are of greenschist facies to upper amphibolite facies. Groundwater occurs in primary porosity of unconsolidated and semi-consolidated rocks. The primary porosity lacks in the igneous and metamorphic rocks and the secondary porosity attributed to jointing, fracturing and weathering processes plays a vital role in storing and transmitting the groundwater. In general, groundwater manifests as springs in the Himalayan Region. Groundwater mainly occurs under unconfined conditions and the regional water table follows the topography. Both hot and cold water springs are found in this region. The hot water springs are generally found in Central Crystallines and are structurally controlled. Genetically they are classified as non-gravitational springs. The temperature of such springs ranges from 32˚C to 90˚C. The spring's discharge ranges from 1 to 10 lps. The cold water springs are classified into various types like gravitational, contact, fracture, seepage, fault bounded and valley floor springs. Out of about 600 cold springs inventoried, 330 are located in undifferentiated crystalline rocks, 180 in quartzites, 50 in shales/slates and 40 in carbonate rocks. Generally, the discharge of cold springs varies from <1 lps in seepages to 30 lps in gadheras/gads. The river terraces are most significant repository of groundwater comprising assorted material such as boulder, cobble, gravel, sand and clay.

The terrace material has been tapped, at few places, through open wells, hand pumps and tube wells. The unconsolidated terrace and channel alluvium has moderately good groundwater potential, which can be utilized by construction of mini tube wells in valley areas. Purola valley (Kamola Nadi), Garur valley (Gomti River), Srinagar valley (Alaknanda River), Pithoragarh valley, Champawat valley etc. have reasonably good groundwater potential.

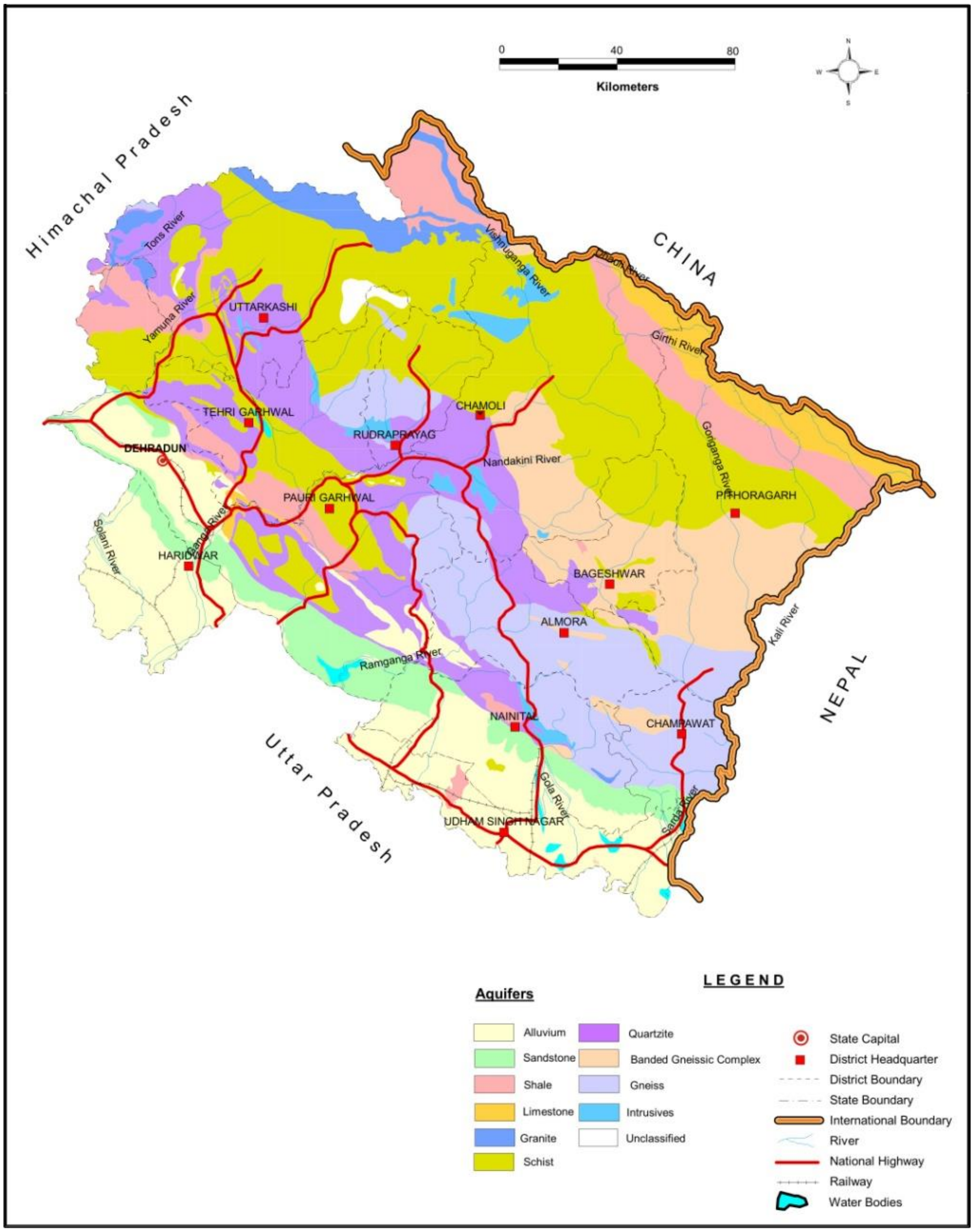


Fig. 3. Disposition of principal aquifer system of Uttarakhand State

2.3.2 SUB HIMALAYAN REGION

The Sub Himalayan Region is exposed to the south of the Himalayan Region and is occupied by Siwalik Hill Range interspersed with *Intermontane Valleys*. In the intermontane valleys, river terraces form prospective groundwater repository. The intermontane valleys are extensive having thick alluvial deposits comprising assorted material. Groundwater occurs mostly under unconfined conditions and less commonly under semi-confined conditions. In general, depth to water level ranges between 10 and 20 m below ground level. Sandstone and shale are the most dominant rock type of Siwalik system, which are followed by mudstone and conglomerate. About 70 gravitational springs have been reported in this region with a discharge varying from less than 1 litre per second (lps) to 113 lps. The fresh water bearing zones are present in the Upper Siwalik Formation comprising conglomerate-boulder succession. The Middle Siwalik Formation is dominated by micaceous sandstone, mudstone and shale with limited groundwater potential. In contrast, the Upper Siwalik Formation has reasonably good groundwater potential.

2.3.3 BHABHAR ZONE

The Bhabhar zone consists of piedmont fan deposits of numerous coalescent fans occupying a narrow tract. The average width of this zone varies from 10 to 20 km along the foot hill region, located to the south of the Sub-Himalayan Region. This zone has a southerly slope of 10–20 m/km and merges with the Tarai zone to the south. The piedmont fans are formed by accumulation of debris brought down by torrential streams descending from higher altitudes. The piedmont fans consist of poorly sorted, unconsolidated sediments of size fractions varying from boulder to clay. The percentage of granular material is higher in the northern part whereas the proportions of finer sediments (silt and clay) are dominant towards the southern part. Presence of thick clay layers over coarser sediments with abrupt reduction of slope marks the southern limit of Bhabhar zone. The porosity and permeability of Bhabar zone material is high due to the presence of well sorted and rounded sediments of variable size fractions.

In Bhabhar zone, groundwater occurs under unconfined conditions. Water level is generally deep - the deepest being 273.71 m bgl, which was recorded at village Panyali, Haldwani, Nainital District. The water table varies from 250 to 300 m above mean sea level. The depth to water level (pre-monsoon, 2021) was found to be varying from 4.7 to 66.48 m bgl, whereas in post-monsoon, it was ranging from 2.58 to 53.31 m bgl. The hydraulic gradient is about 3 m/km. Yield of the tube wells is generally very high, the maximum being 5540 LPM whereas the drawdown was found to be varying from 3 to 10 m. The hydraulic conductivity, as deciphered from pumping test data, ranges between 25 and 250 m/day (CGWB, 2013). Transmissivity of aquifer was also found to be highly variable, ranging from 3696 to 23860 m^2/day. Similar is the case with hydraulic conductivity, the values were found to be ranging from 56 to 825 m/day.

2.3.4 TARAI ZONE

The Tarai zone occurs as a narrow belt to the south of the Bhabhar zone. The contact between Bhabar and Tarai is well marked by a spring line. The southern limit of Tarai zone is not well defined, but it is generally taken as the zone where flowing conditions cease. The Tarai zone gradually merges with the Central Ganga Plains towards south. This zone is characterized by moist, waterlogged areas that are gently sloping southwards with a gradient of 2.5 m/km. This zone is traversed by numerous perennial, sluggish channels that render the area swampy.

The sedimentary deposits of Tarai zone are contemporaneous with the Bhabhars and are predominantly composed of clay with intercalations of pebbles, gravels and sands of various grades and occasional kankars (calcareous nodules). Groundwater occurs under unconfined, semi-confined and confined conditions. The depth to water level in shallow aquifers ranges between 2 and 6 m bgl with an average seasonal fluctuation of 2 to 4 m. The depth to water level in Tarai zone was ranging between 1.58 and 16.71 m bgl (pre-monsoon, 2021), while in the post-monsoon, the depth to water level was ranging between 1.21 and 9.11 m bgl. The slope of the water table is towards south. In deeper aquifers (> 50 m deep), groundwater occurs under confined conditions.

Discharge of the tube wells, tapping deeper confined aquifers, varies from 1500 to 3300 LPM with auto-flow conditions. Drawdown is found to be varying from 2 to 8 m. For tube wells tapping the confined aquifers without auto-flow conditions, the discharge ranges from 600 to 2400 lpm for a drawdown of 4 to 9 m (CGWB, 2013). On the basis of exploratory drilling, various aquifer parameters like transmissivity, hydraulic conductivity and co-efficient of field permeability were determined. Transmissivity was found to be ranging from 1180 to 2500 m^2/day, hydraulic conductivity from 25 to 243 m/day, and the coefficient of field permeability from 17 to 108 m/day. The hydraulic gradient ranges between 1.35 and 4.0 m/km.

2.3.5 CENTRAL GANGA PLAINS

The Central Ganga Plains form one of the richest repositories of groundwater in the world. In Uttarakhand this formation is confined to Haridwar district. These plains are characterized by alluvial plains of low relief and numerous fluvial features such as abandoned channel, natural levee and meander scrolls. In Central Ganga Plains, groundwater mainly occurs under unconfined conditions. The depth to water levels ranges between 1.94 and 64.72 m bgl during pre-monsoon and 1.47 and 55.78 m bgl during post-monsoon, whereas yield of the tubewells ranges from 2205 to 2520 LPM.

2.3.6 GROUND WATER QUALITY

The ground water quality in parts of Dehradun, Haridwar, Udham Singh Nagar, Nainital, Champawat, Almora and Pauri Garhwal districts have been studied using the hydrochemical data of Ground Water Monitoring Stations, which includes dug wells, piezometers, hand pumps and springs. The hydrochemical data (Pre-monsoon, 2020) are given in **Table 1.** A perusal of the data given in *Table 1* indicates that water is generally fresh and potable and as such the groundwater quality is satisfying and within permissible limits.

Sl.No.	Sample Location	pH	EC	CO_3	HCO_3	Cl	F	NO3	SO_4	Hardness as CaCO3	Ca	Mg	Na	K	SiO_2
			µS/cm at 25°C	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	District Dehradun														
1	Kanwali	7.39	903	Nil	342	28	BDL	14	92	400	84	46	22	1.4	25
2	Niranjanpur	7.43	900	Nil	378	43	BDL	31	56	410	92	43	26	BDL	25
3	Harbanswala	8.05	560	Nil	220	14	BDL	BDL	42	240	64	19	8	1.2	16
4	Tarla Nagal	7.87	537	Nil	244	14	BDL	BDL	33	250	44	34	6	BDL	13
5	Nanurkhera	7.84	503	Nil	244	14	BDL	BDL	25	240	36	36	6	BDL	12
6	Maldeota	8.19	2000	Nil	159	206	0.18	BDL	580	210	20	38	375	9.2	9
7	Gularghagti	7.80	872	Nil	268	14	BDL	BDL	150	400	88	43	5	1.2	16
8	Soda Sarauli	7.67	270	Nil	85	7	BDL	5.56	40	100	20	12	14	BDL	27
9	Bhopalpani (Badawali)	7.96	400	Nil	195	14	BDL	BDL	22	180	48	14	14	1.0	36
10	Balliwala	7.71	677	Nil	293	21	BDL	BDL	60	320	68	36	10	BDL	15
11	Rishikesh	7.85	470	Nil	171	7	BDL	BDL	55	200	48	19	8	BDL	23
12	Lal Tappar	7.89	697	Nil	207	7	BDL	BDL	110	290	60	34	7	1.2	16
13	Dujjiawala	7.60	327	Nil	98	14	BDL	BDL	55	140	16	24	12	BDL	15
14	Khandgaon	7.80	502	Nil	220	14	BDL	BDL	44	220	32	34	17	BDL	13
15	Kotimaichak	7.73	200	Nil	98	7	BDL	BDL	34	110	16	17	10	BDL	14
16	Khadak Maaf	7.75	460	Nil	207	7	BDL	BDL	46	200	36	26	18	BDL	13
17	Bhaniawala	8.10	471	Nil	183	14	BDL	BDL	36	200	52	17	7	BDL	20
18	Mothrowala	7.72	687	Nil	305	35	BDL	BDL	50	330	68	38	16	1.3	20
19	Chandmari	7.80	689	Nil	220	21	BDL	BDL	110	330	72	36	5	1.3	13

20	Rampura	7.48	430	Nil	146	35	BDL	30	11	170	44	14	18	1.1	34
21	Jhajra	7.11	220	Nil	61	7	BDL	BDL	46	90	16	12	12	BDL	22
22	Selakui	7.28	260	Nil	110	7	BDL	BDL	29	110	20	14	12	BDL	25
23	Nanda Ki Chowki	7.71	1516	Nil	244	362	BDL	BDL	60	430	120	31	166	1.9	26
24	Redapur	7.41	280	Nil	61	14	BDL	BDL	62	120	12	22	10	BDL	30
25	Shankarpur	7.16	180	Nil	73	7	BDL	BDL	14	60	16	5	13	BDL	30
26	Badowala	7.55	715	Nil	305	28	BDL	BDL	60	350	76	38	8	BDL	28
27	Chhorba	7.62	226	Nil	61	14	BDL	BDL	53	110	16	17	10	BDL	30
28	Telpura	7.58	940	Nil	366	28	BDL	26.5	95	450	104	46	12	BDL	27
29	Sahaspur	7.37	260	Nil	98	7	BDL	BDL	31	100	16	14	13	BDL	23
30	Purukulgaon	7.84	470	Nil	134	14	BDL	BDL	143	280	48	38	7	BDL	20
31	Khandoli	7.04	110	Nil	49	7	BDL	BDL	9	50	4	10	6	BDL	23
32	Bhatta	7.74	506	Nil	268	14	BDL	BDL	53	300	48	43	4	BDL	16
33	Herbertpur	7.40	296	Nil	110	7	BDL	BDL	44	140	32	14	6	2.5	18
34	Dharmawala	8.63	405	0.4	122	28	BDL	BDL	33	140	28	17	25	BDL	24
35	Sabhawala	8.90	351	0.8	24	28	BDL	24	46	130	24	17	16	BDL	25
36	Singhniwala	7.65	725	Nil	317	21	BDL	9.56	68	370	88	36	8	BDL	20
37	Ramgarh	7.43	700	Nil	293	28	BDL	14.2	50	320	92	22	17	BDL	13
38	Judli	7.89	455	Nil	220	7	BDL	BDL	19	190	52	14	13	BDL	14
39	Badripur	7.24	365	Nil	146	14	BDL	BDL	25	150	36	14	10	BDL	20
40	Vikas Nagar	7.41	260	Nil	98	7	BDL	BDL	31	110	24	12	8	BDL	18
41	Dakpatthar	7.66	389	Nil	195	21	BDL	BDL	30	200	44	22	14	1.4	17
42	Barotiwala	7.32	177	Nil	85	7	BDL	BDL	13	80	16	10	8.4	BDL	20
43	Dhakrani	7.11	190	Nil	73	7	BDL	BDL	17	90	16	12	3	BDL	23
44	Timli	7.10	248	Nil	134	7	BDL	BDL	6	120	28	12	6.59	1.3	21

45	Baluwala	7.34	165	Nil	73	7	BDL	BDL	8	70	12	10	7	BDL	20
46	Luxmipur	7.27	150	Nil	73	7	BDL	BDL	5	60	8	10	8	BDL	23
47	Dudhli	7.41	657	Nil	293	28	BDL	21.7	22	310	56	41	12	1.2	19
48	Jamuna Pull/ Barwala	7.09	238	Nil	110	7	BDL	6.5	10	100	20	12	10	BDL	20
49	Haripur	7.50	395	Nil	159	28	BDL	6.5	12	170	40	17	10	2.0	15
	District Haridwar														
50	Bahadrabad	7.61	501	0	232	21	0.46	5.3	46	260	80	14	6.3	1.0	14
51	Dhanpura	7.37	878	0	366	64	NIL	57	49	320	76	31	52	37.0	23
52	Shahpur Shitlakhera	7.92	735	0	366	21	NIL	32	38	340	84	31	12	23.0	21
53	Laldhang	7.51	564	0	256	28	NIL	BDL	52	250	76	14	24	2.6	13
54	Panjanheri	7.76	465	0	220	28	NIL	7.6	28	220	60	17	12	5.8	13
55	Dudhya Diyalwala	7.77	506	0	281	14	NIL	BDL	29	240	72	14	16	2.2	25
56	Shyampur	7.42	518	0	244	21	NIL	11	34	250	84	10	8	2.4	21
57	Jaswawala	7.43	654	0	293	50	NIL	BDL	39	310	88	22	16	1.4	13
58	Dalupuri	7.57	503	0	268	14	NIL	6.1	31	250	76	14	9.7	1.3	17
59	Bhogpur	8.06	970	0	451	57	NIL	13	50	300	84	22	32	116	23
60	Kota Muradnagar	7.51	1086	0	525	64	NIL	BDL	47	430	84	53	69	1.5	17
61	Jassodharpur	7.62	636	0	244	14	NIL	12	35	260	64	24	1.5	2.7	19
62	Bhopatwala	7.57	701	0	342	35	NIL	15	41	300	72	29	34	5.2	22
63	Bandarjud	7.52	591	0	354	14	NIL	5	5	290	60	34	13	1.5	24
64	Rathaura	7.67	653	0	403	14	0.25	BDL	5	280	56	34	33	1.4	25
65	Sarai	7.49	687	0	244	43	NIL	78	46	340	96	24	17	1.5	26

66	Budhwa Shahid	7.61	494	0	281	7	NIL	24	5.5	250	68	19	6.6	1.2	22
67	Shahidwala Grant	7.51	616	0	281	21	NIL	45	6.4	290	64	31	6.3	1.1	20
68	Shahidwala Grant	7.65	420	0	207	14	NIL	24	5.8	210	64	12	4.1	BDL	20
69	Bhagwanpur	8.04	580	0	342	21	0.26	BDL	5	190	40	22	57	1.3	21
70	Bahabalpur	7.94	572	0	354	14	NIL	BDL	5	250	12	53	26	1.5	20
71	Iqbalpur	7.96	494	0	293	14	0.67	BDL	5.3	190	44	19	34	2.1	25
72	Chudiyala	7.94	480	0	268	21	0.60	BDL	12	200	40	24	27	2.7	23
73	Bugawala	7.54	572	0	329	14	NIL	17	6	280	84	17	10	1.5	21
74	Mohammadp ur	7.96	437	0	232	14	0.4	BDL	5.1	90	32	2.4	56	3.7	22
75	Roorkee	7.63	606	0	305	28	NIL	BDL	44	230	52	24	41	7.5	20
76	Imlihhera	7.94	515	0	232	21	NIL	BDL	9.4	80	24	4.8	66	1.7	21
77	Nijampur	7.69	581	0	305	7	NIL	7.6	28	270	68	24	6.5	2.9	29
78	Landhaura	7.54	567	0	305	21	NIL	17	11	260	64	24	22	2.7	30
79	Malakpur Majra	8.01	473	0	244	14	NIL	BDL	5.5	90	28	4.8	62	1.7	26
80	Hussainpur	7.71	602	0	342	21	NIL	BDL	16	240	44	31	37	6.1	24
81	Bhikkampur	7.45	873	0	378	78	NIL	72	5.7	290	68	29	55	50.0	20
82	Laksar	7.56	669	0	403	14	NIL	5	8.9	260	52	31	44	4.2	22
83	Jhabrera	7.44	889	0	342	142	NIL	BDL	11	380	92	36	39	6.3	26
84	Lakhnauta	7.46	642	0	305	21	NIL	38	34	310	64	36	13	3.5	30
85	Gurukul Narsen	7.84	336	0	159	14	NIL	5	23	170	40	17	5.3	2.5	21
86	Libberhedi	7.80	353	0	122	21	0.24	7	25	150	40	12	4.6	3.8	19

87	Mundlana	7.81	417	0	220	21	0.22	BDL	15	200	48	19	10	3.6	22
88	Sikhar	7.79	621	0	354	14	NIL	20	12	300	84	22	16	3.9	33
89	Khera Jat	7.83	426	0	220	14	NIL	BDL	24	210	56	17	6.9	4.2	29
90	Khanpur	7.76	353	0	171	21	NIL	BDL	5	50	16	2.4	53	4.2	21
91	Dallawala	7.98	492	0	281	14	NIL	BDL	16	60	12	7.2	93	5.3	22
92	Goverdhanpur	7.55	692	0	427	14	NIL	BDL	8.2	130	44	4.8	111	4.7	23
	District Nainital														
93	Maldhan Colony	7.82	540	nil	342	21	0.1	BDL	6.2	270	76	19	17	BDL	25
94	Peeru Madara	7.84	460	nil	207	43	BDL	13	21	230	52	24	10	2.0	23
95	Chilkiya	7.91	600	nil	354	21	BDL	5	21	320	96	19	8.3	1.6	20
96	Dhela	7.61	620	nil	342	21	BDL	5	32	330	68	39	12	1.8	22
97	Garjia	8.05	425	nil	238	14	BDL	BDL	28	230	64	17	8	1.9	16
98	Ramnagar	7.85	600	nil	378	14	BDL	BDL	5	310	64	36	16	3.1	21
99	Belparao	7.79	590	nil	342	14	BDL	BDL	37	330	68	39	7	1.3	24
100	Dhoniya	7.83	720	nil	317	21	BDL	BDL	110	400	84	46	8.3	1.1	18
101	Kaladhungi	7.89	590	nil	317	14	BDL	BDL	61	330	60	44	5.1	1.2	18
102	Lamachaur	8.07	415	nil	244	11	BDL	BDL	2.8	210	64	12	5	1.1	11
103	Lalkuan	7.71	515	nil	268	14	BDL	12	25	270	80	17	5.6	2.5	31
104	Khat Baans	7.86	486	nil	281	14	BDL	12	12	260	84	12	7.7	1.3	18
105	Kathgodam	7.67	580	nil	293	25	BDL	20	33	290	72	27	18	3.9	19
106	Dogaon	7.62	450	nil	281	7	BDL	BDL	5.4	230	48	27	10	1.4	17
107	Jyolikot	7.89	350	nil	171	21	BDL	11	19	170	40	17	8.9	2.6	15
108	Kudagath	8.27	440	nil	244	14	BDL	1.2	19	245	28	43	BDL	BDL	10
109	Sipahi Dhara	8.05	680	nil	281	28	BDL	11	100	360	52	56	12	2.6	11

110	Salari	8.07	730	nil	354	21	BDL	25	77	390	106	30	9.5	1.1	25
111	Ranibagh	7.87	360	nil	183	21	BDL	BDL	12	190	36	24	4.6	1.4	32
112	Garam Pani	7.76	190	nil	110	7.1	BDL	BDL	5.1	100	12	17	BDL	BDL	14
	District Udham Singh Nagar														
113	Kanchanpuri (Majhola)	8.10	750	0	403	14	0.31	BDL	5.9	260	64	24	36.9	62.5	31
114	Khatima	8.23	1104	0	415	71	0.50	45	27.9	360	100	26	71.2	120	27
115	Sara Sariya	8.03	796	0	427	7	0.62	BDL	13.9	260	44	36	46.6	79.1	26
116	Chakarpur	8.22	638	0	329	28	0.18	BDL	5.6	280	76	22	4.1	6.9	22
117	Barianjariya	8.21	487	0	256	7	0.39	BDL	10.7	210	60	14	4.5	7.6	25
118	Sitarganj	7.90	800	0	403	36	0.47	10.5	26.2	305	92	18	33.4	56.7	16
119	Nanak mata	8.03	908	0	403	21	0.68	24.9	49.6	360	72	43	21.1	35.7	25
120	Kalyanpur	8.14	480	0	250	7	BDL	BDL	9.2	215	56	18	BDL	1.5	24
121	Tukri	8.20	506	0	262	14	0.26	BDL	10.1	215	52	20	7.7	13.0	25
122	Begur Mod	8.09	592	0	293	14	0.42	BDL	17.5	215	60	16	24.9	42.2	25
123	Bidora	7.90	467	0	281	7	0.25	BDL	9.0	200	48	19	13.5	22.8	26
124	Dhyanpur	7.62	457	0	262	7	0.31	BDL	8.7	190	48	17	10.3	17.5	25
125	Bara	7.93	582	0	323	7	0.48	BDL	20.9	220	52	22	22.4	38.0	26
126	Kichha	7.91	1135	0	476	50	0.43	110	44.4	360	72	43	45.3	76.7	35
127	Kamaria Pakki	7.86	525	0	238	21	0.46	7.23	24.8	205	40	25	15.4	26.2	29
128	Gangapur	7.64	513	0	287	14	BDL	6.63	20.5	240	56	24	8.6	14.6	32
129	Shantipuri	7.78	477	0	244	14	0.24	5.09	22.9	210	52	19	6.4	10.8	32
130	Patthar Chatta	7.61	517	0	275	14	0.15	BDL	19.0	225	60	18	8.4	14.2	33
131	Rudrapur	7.96	492	0	262	21	0.39	BDL	22.9	220	48	24	11.8	19.9	30
132	Kanakpur	7.57	693	0	342	25	0.29	BDL	64.5	330	44	53	16.5	27.9	23

133	Rajpura	7.94	470	0	232	18	0.52	BDL	26.6	200	44	22	8.8	14.9	28
134	Pipiliya	7.92	471	0	238	21	0.54	BDL	25.0	205	48	20	11.3	19.2	30
135	Jhagarpuri	7.89	705	0	390	14	0.35	BDL	47.0	340	44	55	19.0	32.1	27
136	Mahabir Nagar	7.70	786	0	360	18	0.20	BDL	96.9	370	40	65	6.2	10.5	27
137	Beria Daulat	7.50	1630	0	519	149	0.16	BDL	253.3	770	96	127	26.7	45.3	31
138	Koita Signal	7.98	738	0	403	14	0.25	BDL	18.0	330	40	55	5.3	9.0	24
139	Bhagwanpur	7.99	535	0	287	14	0.17	BDL	15.5	230	44	29	9.1	15.3	29
140	Patharpuri	7.90	684	0	329	21	0.39	BDL	70.9	320	36	55	13.7	23.2	29
141	Lalpuri	7.65	643	0	342	14	0.19	BDL	40.3	300	48	43	8.1	13.7	29
142	Bazpur	7.52	1040	0	476	50	0.16	BDL	107.9	440	44	79	38.2	64.8	32
143	Jharkhandi	7.50	927	0	439	21	0.13	8.79	39.7	410	52	67	8.1	13.7	24
144	Jogipura	7.81	745	0	354	21	0.18	BDL	49.7	330	64	41	9.4	16.0	28
145	Banna Khera	7.57	814	0	439	21	0.18	BDL	49.3	390	64	55	8.4	14.3	24
146	Pritpur	7.68	816	0	476	14	0.16	BDL	33.6	410	68	58	12.2	20.6	26
147	Badaripur	7.76	779	0	439	21	0.11	BDL	39.8	380	60	55	10.7	18.1	27
148	Barkhare Pande	7.90	1495	0	488	114	0.13	105	116.2	530	96	70	82.2	####	26
149	Sultanpur Patti	8.07	491	0	207	14	BDL	6.27	35.3	205	40	25	8.6	14.6	26
150	Kashipur	7.97	637	0	256	57	0.28	BDL	29.3	230	36	34	38.1	64.6	28
151	Bharatpur	8.07	606	0	354	7	0.78	BDL	5.6	180	36	22	50.0	84.7	22
152	Dhanauri Patti	7.97	570	0	323	14	0.17	BDL	18.6	240	60	22	16.9	28.7	27
153	Shankehra	7.99	430	0	232	14	0.13	BDL	13.7	215	48	23	10.1	17.2	27
154	Jaspur	7.80	508	0	281	28	0.63	BDL	5.7	240	64	19	16.8	28.5	24

155	Patrampur	8.05	632	0	390	14	0.60	BDL	BDL	270	48	36	29.7	50.4	25
156	Angadpur	7.67	484	0	232	21	0.14	BDL	6.3	200	56	14	10.5	17.8	31
157	Durgapur	7.89	600	0	342	21	0.32	BDL	8.8	270	44	38	19.7	33.4	20
158	Missarwala	7.75	548	0	305	21	0.19	12.7	6.9	250	64	22	18.0	30.4	28

Table 1. Ground Water Chemical Quality Data of the districts of Dehradun, Haridwar, Nainital and Udham Singh Nagar, Uttarakhand State for Pre-monsoon 2021

BDL-below detection limit i. e. <0.1mg/L for F; <5 mg/L for NO3, SO4, SiO2 ; <2mg/L for Na & < 1mg/L for K

2.3.7 AREAS WITH GROUND WATER DEVELOPMENT PROSPECTS

The normal annual rainfall in Uttarakhand ranges between 1020 mm (Haridwar district) and 2183.6 mm (Dehradun district), which is significant (as per data collected from IMD, Govt. of India). Hand pumps are successful in the Himalayan Region. The fairly good amount of rainfall and success of hand pumps are the two observations, which pave path for making attempt to explore rich sources of groundwater where tubewells can be successful.

The Sub Himalayan regions with *Intermontane Valleys* have good prospects of groundwater development. Shallow wells and deep tubewells both are successful here. Some of the pockets have fairly good population density and intensive agriculture activities. It is imperative to go for optimal groundwater development in such areas.

The Bhabhar area proved itself to be a promising zone with high yielding tubewells and has good prospects of groundwater development. The Tarai area has shallow ground water conditions and forms the main paddy belt of Uttarakhand. There are good ground water development prospects in this belt. It is reported that the discharge of auto-flow wells is decreasing in this zone and hence groundwater regime should be monitored along with the development.

Indo-Gangetic Plains are confined to district Haridwar, which have zones with high groundwater potential. Haridwar district is having the highest population density in Uttarakhand. The water intensive crops like sugarcane are grown here. Further, the industrial development, in district Haridwar, is going on at a faster pace. The aquifers are potential, tubewells and dug wells are successful in this terrain. In view of the increasing demand the groundwater development should go with its management.

CHAPTER – 3

Ground Water Resources Estimation Methodology, 2015

CHAPTER – 3

GROUND WATER RESOURCES ESTIMATION METHODOLOGY, 2015

3.1 Background

The present ground water resource assessment of the state is done based on the Ground Water Resource Estimation Methodology–2015 (GEC, 2015). The resource computation has been carried out using IN-GRES software (**INDIA- Groundwater Resource Estimation System**) which has been developed by IIT- Hyderabad in association with Vassar Labs. IN-GRES is the common portal to input, estimate, analyze, and access static and dynamic groundwater resources.

3.1.1 Concept of Aquifer Wise Assessment

The GEC 2015 methodology recommends aquifer wise ground water resource assessment of both the Ground water resources components - ***Replenishable ground water resources or Dynamic Ground Water Resources*** and ***In-storage Resources or Static Resources***. 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 300 m whichever is less. In case of hard rock aquifers, the depth of assessment would be limited to 100 m. 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.
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.

3.1.2 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/ 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 categorisation 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.

3.2 Assessment of Annually Replenishable or Dynamic Groundwater Resources

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

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

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 non -Government 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.

3.2.1 Rainfall Recharge

The GEC-2015 methodology recommended that ground water recharge should be estimated on the basis of ground water level fluctuation and specific yield approach since this method takes into account the response of ground water levels to ground water input and output components. This, however, requires adequately spaced representative water level measurement for a sufficiently long period - for a minimum period of 5 years (preferably 10years), along with corresponding rainfall data and at least three spatially well distributed observation wells in the assessment unit, or one observation well per 100 sq. Km. 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. The rainfall recharge during non-monsoon season is 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.

The two methods (Groundwater level fluctuation method and Rainfall infiltration factor method) are discussed briefly.

Groundwater 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 in non-command areas is given by:

$$\Delta S = RRF + RSTR + RSWI + RGWI + RTP + RWCS \pm VF \pm LF - GE - T - E - B \qquad (3)$$

The water balance equation in command area will have another term Recharge due to canals (RC) and the equation will be as follows:

$\Delta S = RRF + RSTR + RC + RSWI + RGWI + RT + RWCS \pm VF \pm LF - GE - T - E - B$ (4)

Where,

ΔS – Change is storage

RRF – Rainfall recharge

RSTR- Recharge from stream channels

RSWI – Recharge from surface water irrigation (Lift Irrigation)

RGWI- Recharge from ground water irrigation

RTP- Recharge from tank& ponds

RWCS – Recharge from water conservation structures

VF – Vertical flow across the aquifer system

LF- Lateral flow along the aquifer system (through flow)

GE-Ground water Extraction

T- Transpiration

E- Evaporation

B-Base flow

RC- Recharge due to canals

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

$\Delta S = \Delta h * A * SY$ (5)

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 5 for storage increase ΔS in terms of water level fluctuation and specific yield, the equations 3 & 4 for non –command and command sub units respectively becomes:

$RRF = h \times Sy \times A - RSTR - RSWI - RGWI - RTP - RWCS \pm VF \pm LF + GE + T + E + B$ (6)

[Non Command Area]

RRF= h x Sy x A - RC - RSTR -RSWI- RGWI-RTP -RWCS±VF ±LF +GE +T +E +B (7)

[Command Area]

Where base flow/ recharge to/from streams have not been estimated, the same is assumed to be zero.

The rainfall recharge obtained by using equation 6 & 7 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.

Rrf (normal) = a x r (normal) + b (8)

where,

Rrf (normal) = Normalized Rainfall Recharge in the monsoon season.

r = Monsoon season rainfall

a and b = constants.

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:

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

Where

Rrf (normal) = Normalized Rainfall Recharge in the monsoon season.

R_i= Rainfall Recharge in the monsoon season for the i^{th} year.

r (normal) = Normal monsoon Season rainfall.

r_i = Rain fall in the monsoon season for the i^{th} year.

N = Number of years for which data is available.

Rainfall Infiltration Factor method

The ground water extraction estimation included in the computation of rainfall recharge using Water Level Fluctuation approach is often subject to uncertainties. Therefore, it is recommended to compare the rainfall recharge obtained from Water Level Fluctuation approach with that estimated using Rainfall Infiltration Factor Method.

Recharge from rainfall is estimated by using the following relationship –

$$Rrf = RFIF * A * (R - a)/1000 \quad (9)$$

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 ground water recharge in mm

The GEC 2015 methodology 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.

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

$$PD = \frac{\text{Rrf (normal, wtfm) - Rrf (normal, rifm)}}{\text{Rrf (normal, wtfm)}} \times 100 \qquad (10)$$

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.

3.2.2 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. The Estimation Formula and the parameters used for the calculation of recharge from various sources are enlisted in Table 2 below.

Table 2. Estimation Formula and parameters used for the calculation of recharge from various sources

Sl No.	Sources	Estimation Formula	Parameters
1.	**Recharge from Canals**	**RC=WA * SF * Days**	**RC= Recharge from Canals** WA=Wetted Area SF= Seepage Factor Days= Number of Canal Running Days
2.	**Recharge from Surface Water Irrigation**	**RSWI =AD*Days*RFF**	**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
3.	**Recharge from Ground Water Irrigation**	**RGWI =GEIRR*RFF**	**RGWI = Recharge due to applied ground water irrigation** GEIRR= Ground Water Extraction for Irrigation RFF= Return Flow Factor
4.	**Recharge due to Tanks & Ponds**	**RTP =AWSA*RF**	**RTP = Recharge due to Tanks & Ponds** AWSA= Average Water Spread Area RF= Recharge Factor
5.	**Recharge due to Water Conservation Structures**	**RWCS =GS*RF**	**RWCS = Recharge due to Water Conservation Structures** GS= Gross Storage = Storage Capacity multiplied by number of fillings. RF= Recharge Factor

3.2.3 **Lateral flow along the aquifer system (Through flow)**

According to the GEC 2015 Methodology, if the 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. In case Lateral Flow is calculated using computer model, the same should be included in the water balance equation.

3.2.4 Baseflow and Stream Recharge

The GEC-2015 Methodology 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.

3.2.5 Vertical Flow from Hydraulically Connected Aquifers

This parameter 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. Ground water flow modelling is an important tool to estimate such flows. As envisaged in the methodology, regional scale modelling studies will help in refining vertical flow estimates.

3.2.6 Evaporation and Transpiration

The GEC 2015 methodology recommends that the evaporation can be estimated for the aquifer in the assessment unit through field studies. . If field studies are not possible, for areas with water levels within 1.0 m bgl, evaporation can be estimated using the evaporation rates available for other adjoining areas. 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 3.5 m bgl, transpiration can be estimated using the transpiration rates available for other areas. If it is greater than 3.5 m bgl, the transpiration should be taken as zero. Further, for estimating evapo-transpiration, field tools like Lysimeters can be used to estimate actual evapo-transpiration. In case where such data is not available, evapo-transpiration losses can be empirically estimated from PET data provided by IMD.

3.2.7 Additional Potential Resources under Specific Conditions

3.2.7.1 Potential Resource Due to Spring Discharge:

Spring discharge occurs at the places where ground water level cuts the surface topography. It is equal to the ground water recharge minus the outflow through evaporation and evapotranspiration and vertical and lateral sub-surface flow. Spring discharge measurement is carried out by volumetric measurement of discharge of the springs. Spring discharges multiplied with time in days of each season gives the quantum of spring resources available during that season. The discharge measurement is 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 (11)

Where

Q= Spring Discharge

No of days= No of days spring yields.

3.2.7.2 Potential Resource in Waterlogged and Shallow Water Table Areas:

In the area where the ground water level is less than 5 m below ground level or in waterlogged areas, the resources up to 5 m below ground level are potential and would be available for development in addition to the annual recharge in the area. The computation of potential resource to ground water reservoir in 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 (12)

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

3.2.7.3 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

As collection of data on all these factors is time taking and difficult, the potential recharge from flood plain is estimated on the same norms as for ponds, tanks and lakes.

Potential ground water resource in Flood Prone Areas = 1.4 x N x A/1000 (13)

Where

N = No of Days Water is Retained in the Area

A = Flood Prone Area

3.2.8 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.

3.2.9 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.

3.2.10 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.

3.2.11 Annual Extractable Groundwater Recharge (EGR)

The Annual Extractable Ground Water Resource (EGR) is computed by deducting the Total Annual Natural Discharge from Total Annual Ground Water Recharge. The Ground water baseflow contribution limited to the ecological flow of the river is determined using the present practice (allocation of unaccountable natural discharges to 5% & 10% of annual recharge may be retained in water level fluctuation & rainfall infiltration factor method respectively) where river stage data or the detailed data for quantitative assessment of the natural discharge are not available.

3.3 Estimation of Ground Water Extraction

The GEC 2015 Methodology recommends various available methods for estimation of groundwater extraction in each assessment sub unit, as described. Groundwater draft or extraction is to be assessed as follows.

GEALL = GEIRR + GEDOM + GEIND (14)

Where,

GEALL=Ground water extraction for all uses

GEIRR=Ground water extraction for irrigation

GEDOM =Ground water extraction for domestic uses

GEIND = Ground water extraction for industrial uses

The components of Groundwater Extraction are briefly described below.

(a) Groundwater Extraction for Irrigation (GEIRR)

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 (e.g. 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.
- **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.
- **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.

(b) Groundwater Extraction for Domestic Use (GEDOM): The commonly adopted methods for estimation of extraction for domestic use (GEDOM) are described below:

- **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.

$$\text{GEDOM} = \text{Population} \times \text{Consumptive Requirement} \times Lg \qquad (15)$$

Where,

Lg = Fractional Load on Groundwater for Domestic Water Supply

(c) Groundwater Extraction for Industrial use (GEIND)

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 groundwater extraction.

- **Consumptive Use Pattern Method**: In this method, water consumption of different industrial units is 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 (16)

Where,

Lg = Fractional load on groundwater for industrial water supply

3.4 Stage of Groundwater Extraction

The stage of groundwater extraction is defined by,

(17)

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

The stage of ground water extraction is obtained separately for command areas, non-command areas and poor ground water quality areas.

3.5 Validation of Stage of Ground Water Extraction

The assessment based on the stage of ground water extraction has inherent uncertainties. In view of this, the GEC 2015 Methodology recommends that 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 prepared for a minimum period of 10 years for both pre-monsoon and post-monsoon period. 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 in Table 3.

Table 3. Conditions for re-evaluation of GWRE based on groundwater level trend

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

3.6 Categorization of Assessment Units Based on Quality

Based on the available water quality monitoring mechanism and database on ground water quality, the GEC 2015 Methodology 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. 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.

The Criteria for Categorisation is tabulated below in **Table 4.**

Table 4. State of Groundwater Extraction and the categorisation of assessment units/ subunits

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

3.7 **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 **(18)**

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.

3.8 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.

3.9 Assessment of In-Storage or Static Groundwater Resources

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

SGWR = A *(Z2 - Z1) * SY **(19)**

Where,

SGWR = Static or in-storage Ground Water 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

3.10 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.

3.11 Assessment of Groundwater of Confined Aquifer System

The assessment of the ground water resources of the confined aquifers is done by following ground water storage approach. 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 = S*A*Δh **(20)**

Where

Q = Quantity of water confined aquifer can release (m3)

S = Storativity

A = Areal extent of the confined aquifer (m2)

Δh= Change in Piezometric head (m)

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. 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 = S*A*Δh = S*A* (ht – h0) **(21)**

If any development activity is started in the confined aquifer, the assessment is done for both the dynamic as well as in storage resources of the confined aquifer.

3.11.1 Dynamic Ground Water Resources of Confined Aquifer

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

$$QD = S*A*\Delta h = S*A*(hPOST - hPRE) \quad (22)$$

Where

QD = Dynamic Ground Water Resource of Confined Aquifer (m3)

S = Storativity

A = Areal extent of the confined aquifer (m2)

Δh = Change in Piezometric head (m)

hpost =Piezometric head during post-monsoon period (m amsl)

hPRE = Piezometric head during pre-monsoon period(m amsl)

3.11.2 In storage Ground Water Resources of Confined Aquifer

For assessing the in storage ground water potential of a confined aquifer, the resources between the premonsoon piezometric head and bottom of the top confining layer is computed. That can be assessed using the following formula:

$$QI= S*A*\Delta h = S*A* (hPRE - h0) \quad (23)$$

Where

QI =In storage Ground Water Resource of Confined Aquifer (m3)

S = Storativity

A = Areal extent of the confined aquifer (m2)

Δh = Change in Piezometric head (m)

h0 = Bottom level of the top confining layer (m amsl)

hPRE = 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.

$$Qp = SA\Delta h = SA (hPOST - h0) \quad (24)$$

Where

Qp = In storage Ground Water Resource of the confined aquifer or the Quantity of water under pressure (m3)

S = Storativity

A = Areal extent of the confined aquifer (m2)

Δh = Change in Piezometric head (m)

HPOST =Piezometric head during post-monsoon period (m amsl)

h0 = 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.

3.12 Assessment of Groundwater of Semi-Confined Aquifer System

According to the GEC 2015 methodology, the Assessment of Groundwater Resources of a semi-confined aquifer has some complications - uncertainty to determine whether the recharge to this aquifer is computed in the over lying unconfined aquifer or underlying/overlying semi confined aquifers. To avoid the duplication of estimating the same resource by direct computation in one aquifer and as leakage in the other aquifer, the GEC 2015 methodology advices not to assess such aquifer resources separately as long as precise data is available. If it is found through field studies that the resources are not assessed in any of the aquifers in the area, then the resources are assessed following the methodology similar to that used in assessing the resources of Confined aquifers.

3.13 Total Groundwater Availability of an Area

The Total Ground water availability in any area is the Sum of Dynamic Ground Water Resources, the total 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.

3.14 Groundwater Assessment in Urban Areas

The GEC 2015 methodology proposes to have a separate ground water assessment for urban areas with population more than 10 lakhs owing to certain constraints like lack of space for natural recharge due to concretization and slightly different infiltration process and recharge due to other sources due to urbanization. The GEC 2015 methodology proposes the consideration of the following points for Groundwater Assessment in Urban areas.

- It is recommended to use the difference of the actual demand and the supply by surface water sources as the withdrawal from the ground water
- 30% of the rainfall infiltration factor for urban areas is considered as an adhoc arrangement till field studies in these areas are done and documented field studies are available.
- Because of the water supply schemes, there are many pipelines available in the urban
- areas and the seepages from these channels or pipes are huge in some areas. Hence
- this component is also to be included in the other resources and the recharge may be estimated. The percent losses may be collected from the individual water supply agencies, 50% of which can be taken as recharge to the ground water 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.
- 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.

3.15 Groundwater Assessment in Coastal Areas

The Assessment of Groundwater Resources in coastal areas is similar to that of other areas. Because of the nature of hydraulic equilibrium of ground water with sea water, care is taken in assessing the ground water resources of this area. The GEC 2015 Methodology suggests that while assessing the resources in these areas, following few points are considered.

- The ground water resources assessment in coastal areas includes the areas where the influence of sea water has an effect on the existence of fresh water in the area.
- Wherever, the pre monsoon and post monsoon water levels are above mean sea level the dynamic component of the estimation will be same as other areas.

- If both these water levels are below sea level, the dynamic component is taken as zero.
- Wherever, the post monsoon water table is above sea level and pre monsoon water table is below sea level, the pre-monsoon water table is taken as at sea level.
- The static or in storage resources are is restricted to the minimum of 40 times the pre-monsoon water table or the bottom of the aquifer.

CHAPTER – 4

Procedure Adopted and Data Elements considered in the Ground Water Resource Estimation

CHAPTER – 4

PROCEUDRE ADOPTED AND DATA ELEMENTS CONSIDERED IN THE GROUND WATER RESOURCE ESTIMATION

4.1 General

Ground Water Estimation Methodology, 2015 has been used for the present assessment (2022) with the help of IN-GRES software. The results generated through the software have been tallied with manually calculated excel sheets and are found to be matching with very minor differences in values.

4.2 Data Source

The main elements of 'Ground Water Resources Estimation' are the sources of information provided by various departments which are tabulated below in **Table 5**

Table 5. Data Elements used in GWRE 2020 and departments supplying the data for assessing groundwater resources of Uttarakhand State

S.No	Data Element	Used in the Computation of	Data Source
1.	Irrigation Well Census and Unit Draft	Groundwater extraction for irrigation	Minor Irrigation Department, Govt. of Uttarakhand and Irrigation Department, Govt. of Uttarakhand
2.	Domestic Well Census and Unit Draft	Groundwater extraction for domestic needs	Jal Sansthan, Govt. of Uttarakhand
3.	Industrial Well Census and Unit Draft	Groundwater extraction for industrial purposes	Directorate of Industries, Govt. of Uttarakhand and data compiled from NOCAP portal (Central Ground Water Authority)
4.	Population Census	Groundwater extraction for domestic purpose, Future allocation for domestic requirement.	Statistical reports (2018-19) of Dehradun, Haridwar, Nainital and Udham Singh Nagar districts
5.	Rainfall	Recharge due to	India Meteorological Department, Govt. of India

		Rainfall /Normalization of Rainfall Recharge	(IMD), India-WRIS Portal
6.	Area under Rabi and Kharif Crops irrigated through Surface and Ground Water Irrigation	Recharge from Surface and Ground Water Irrigation	Minor Irrigation Department, Govt. of Uttarakhand
7.	Length and Perimeter of canals, number of canal running days	Recharge through Canals	Irrigation Department, Govt. of Uttarakhand
8.	Ground Water Monitoring: Pre-monsoon and Post- monsoon groundwater levels & trends and GW quality monitoring data	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, UR, Dehradun

4.3 Data Elements

4.3.1 Basic Data

The basic data includes the total recharge worth area considered under various assessment units, infiltration factor and specific yield depending on the lithology of the formations which in turn controls factors like groundwater recharge. The rainfall infiltration factors and specific yield are considered according to the norms set in GEC 2015 methodology. The basic data considered for the assessment 2022 is tabulated in Table 6.

Table 6. Basic Data used in Groundwater Resource Estimation in the year 2022 for Uttarakhand State

Sl. No	District	Assessment Unit Name	Area Considered (2017 and 2020) Ha	Rainfall Infiltration factor (2022)	Specific Yield (2022)
1	**Dehradun**	**Doiwala**	51057	0.22	16
2	**Dehradun**	Sahaspur	52,061	0.22	16
3	**Dehradun**	Vikashnagar	22426	0.22	16
4	**Haridwar**	Bahadrabad	33763	0.22	16
5	**Haridwar**	Bhagwanpur	31537	0.22	16
6	**Haridwar**	Gurukul Narsen	23107	0.22	16

7	**Haridwar**	Khanpur	17814	0.22	16
8	**Haridwar**	Luksar	27778	0.22	16
9	**Haridwar**	Roorkee	22836	0.22	16
10	**U S Nagar**	Bazpur	28646	0.22	10
11	**U S Nagar**	Gadarpur	23326	0.22	10
12	**U S Nagar**	Jaspur	23229	0.22	10
13	**U S Nagar**	Kashipur	18517	0.22	10
14	**U S Nagar**	Khatima	35157	0.22	10
15	**U S Nagar**	Rudrapur	31153	0.22	10
16	**U S Nagar**	Sitarganj	33254	0.22	10
17	**Nainital**	Haldwani	11277	0.22	16
18	**Nainital**	Ramnagar	12366	0.22	16

4.3.2 Rainfall

The rainfall data considered in the present assessment has been collected from IMD, INDIA-WRIS portal and the normal rainfall (1981-2010) has been calculated from the data obtained from the rain gauge stations located in Dehradun, Pantnagar, Roorkee and Mukteshwar. Table 7 highlights the annual rainfall as well as normal rainfall considered for GWRE 2022. The recharge through rainfall has been calculated through two methods- Rainfall Infiltration Method and Water Table Fluctuation Method and the method applied for the different assessment units have been tabularised in Table 8.

Table 7. Annual rainfall and normal rainfall data considered for GWRE 2022

Sl. No	District	Year	Annual Monsoon Rainfall in mm	Annual Non-Monsoon Rainfall in mm	Normal Monsoon Rainfall in mm	Normal Non-Monsoon Rainfall in mm
1	**Dehradun**	**2013-14**	1271.8	433.9	1858.9	324.7
		2014-15	1268.1	314.8		
		2015-16	1195.0	148.5		
		2016-17	1718.6	231.0		
		2017-18	1734.1	152.1		
		2018-19	1364.9	263.71		
		2019-20	1648.0	503.2		
		2020-21	979.87	1655		
		2021-22	1060.42	889.51		
2	**Haridwar**	**2013-14**	771.3	264.3	816	204
		2014-15	761.0	257.9		
		2015-16	1000.2	104.0		
		2016-17	927.2	128.6		
		2017-18	1224.3	63.2		
		2018-19	685.6	181.8		
		2019-20	726.3	385.1		
		2020-21	820.65	1641.15		
		2021-22	806.03	733.79		
3	**Udham Singh Nagar**	**2013-14**	584.9	395.5	1261.4	203.9
		2014-15	730.4	169.6		
		2015-16	643.5	93.7		
		2016-17	946.7	44.9		
		2017-18	770	44.6		
		2018-19	2140.52	303		
		2019-20	963.2	339.6		
		2020-21	1397.85	970.21		
		2021-22	752.05	718.62		
4	**Nainital**	**2013-14**	1418.0	375.9	1231.92	479.08
		2014-15	1268.8	426.7		
		2015-16	1544.5	99.4		
		2016-17	1750.9	105.6		
		2017-18	1547.8	135.7		
		2018-19	510.2 (Ramnagar)	143.6 (Ramnagar)		

			2388.2 (Haldwani)	565.1 (Haldwani)		
		2019-20	1014.37 (Ramnagar) 1014.37 (Haldwani)	566.95 (Ramnagar) 566.95 (Haldwani)		
		2020-21	1397.85	970.21		
		2021-22	1182.97	841.45		

Table 8. Method applied for calculating Ground water Recharge due to Rainfall during Monsoon and Non- Monsoon period for the Assessment Units

Sl No.	District	Block	Difference (in percentage) for Rainfall Recharge during Monsoon calculated by WTFM and RFIFM	Methodology Adopted	
				Recharge Due to Rainfall (Monsoon Season)	Recharge Due to Rainfall (Non-Monsoon Season)
1.	**Dehradun**	Doiwala	18.06	WTFM	RFIFM
2.		Sahaspur	32.46	RFIFM	RFIFM
3.		Vikasnagar	16.75	WTFM	RFIFM
4.	**Haridwar**	Bahadrabad	-9.68	WTFM	RFIFM
5.		Bhagwanpur	83.81	RFIFM	RFIFM
6.		Gurukul Narsan	1.3	WTFM	RFIFM
7.		Khanpur	8.12	WTFM	RFIFM
8.		Luksar	46.77	RFIFM	RFIFM
9.		Roorkee	20.58	RFIFM	RFIFM
10.	**Udham Singh Nagar**	Bazpur	-27.36	RFIFM	RFIFM
11.		Gadarpur	-67.79	RFIFM	RFIFM
12.		Jaspur	78.71	RFIFM	RFIFM
13.		Kashipur	6.44	WTFM	RFIFM
14.		Khatima	-16.55	WTFM	RFIFM
15.		Rudrapur	-39.01	RFIFM	RFIFM
16.		Sitarganj	-22.47	RFIFM	RFIFM
17.	**Nainital**	Haldwani	131.65	RFIFM	RFIFM
18.		Ramnagar	31.94	RFIFM	RFIFM

4.3.3 Unit Draft and Number of wells

The Unit Draft method has been considered to estimate groundwater extracted for industrial, irrigation and domestic needs for most of the assessment units except Haridwar district where the domestic groundwater extraction has been computed by Consumptive use Method. For the domestic groundwater extraction, the results have been computed by both unit draft method and consumptive unit method for all assessment blocks of Dehradun, Udham Singh Nagar and Nainital district. If the difference in the computed values (by both methods) lies between -50 to 50, the final result is calculated as the average of values computed by the two methods, else unit draft method is used. The well census considered in GWRE 2017 had been studied carefully and modified in the past assessment (2020) resulting in refinement of the well census data and omission of structures (dugwells and abandoned handpumps) which are currently abandoned or not in use. The data for the current assessment year has been kept the same as the previous assessment since no new MI Census has been published. The number of wells along with the unit draft (irrigation and domestic) have been listed in **Table- 9.**

Table 9. Summary of type and number of abstraction structures used for calculating groundwater draft due to irrigation and domestic purposes along with the value of unit draft used in GWRE 2022

Sl No.	District	Assessment Unit	Purpose	* Type of Structure	* No. of wells in assessment year	* Estimated draft per well (ha.m)	
						Monsoon	Non-Monsoon
1	Dehradun	Doiwala	Domestic	Major TW	46	16	28
2	Dehradun	Doiwala	Domestic	Mini TW	37	9.36	13.93
3	Dehradun	Vikasnagar	Domestic	Major TW	16	16	28
4	Dehradun	Vikasnagar	Domestic	Mini TW	26	9.36	13.93
5	Dehradun	Sahaspur	Domestic	Major TW	15	16	28
6	Dehradun	Sahaspur	Domestic	Mini TW	26	9.36	13.93
7	Dehradun	Doiwala	Irrigation	Pvt well	380	0.65	1.85
8	Dehradun	Doiwala	Irrigation	State TW*	39	7.08	12.79
9	Dehradun	Vikasnagar	Irrigation	Pvt. Tube Well	143	1.65	2.85
10	Dehradun	Vikasnagar	Irrigation	State TW	62	7.08	12.79
11	Dehradun	Sahaspur	Irrigation	Pvt. Tube Well	264	0.65	1.85
12	Dehradun	Sahaspur	Irrigation	State TW*	82	7.08	12.79
13	Haridwar	Roorkee	Irrigation	Pvt. Tube Well	4302	0.21	0.42
14	Haridwar	Roorkee	Irrigation	State TW	87	2	4.1
15	Haridwar	Gurukul Narsan	Irrigation	Pvt. Tube Well	3233	0.23	0.46
16	Haridwar	Gurukul Narsan	Irrigation	State TW	19	2	4.1
17	Haridwar	Khanpur	Irrigation	Pvt. Tube Well	2861	0.23	0.46
18	Haridwar	Khanpur	Irrigation	State TW	32	2	4.1
19	Haridwar	Bhagwanpur	Irrigation	Pvt. Tube Well	3607	0.35	0.75
20	Haridwar	Bhagwanpur	Irrigation	State TW	77	2	4.1
21	Haridwar	Laksar	Irrigation	Pvt. Tube Well	4759	0.23	0.46
22	Haridwar	Laksar	Irrigation	State TW	23	2	4.1
23	Haridwar	Bahadarabad	Irrigation	Pvt. Tube Well	3810	0.35	0.75

24	Haridwar	Bahadarabad	Irrigation	State TW	92	2	4.1
25	U S Nagar	Jaspur	Domestic	Major TW	15	11.6	23.68
26	U S Nagar	Jaspur	Domestic	Mini TW	1	6.91	14.11
27	U S Nagar	Gadarpur	Domestic	Major TW	11	8.95	18.28
28	U S Nagar	Kashipur	Domestic	Major TW	17	12.03	24.56
29	U S Nagar	Kashipur	Domestic	Mini TW	3	5.38	10.98
30	U S Nagar	Bazpur	Domestic	Major TW	11	10	20.42
31	U S Nagar	Bazpur	Domestic	Mini TW	5	5.18	10.58
32	U S Nagar	Sitargunj	Domestic	Mini TW	7	6.17	12.6
33	U S Nagar	Rudrapur	Domestic	Major TW	14	11.33	23.13
34	U S Nagar	Rudrapur	Domestic	Mini TW	1	3.43	7.06
35	U S Nagar	Khatima	Domestic	Major TW	15	9.95	20.31
36	U S Nagar	Khatima	Domestic	Mini TW	1	6.91	14.11
37	U S Nagar	Jaspur	Irrigation	Pvt. Tube Well	4239	0.35	0.95
38	U S Nagar	Jaspur	Irrigation	State TW	75	2	4.1
39	U S Nagar	Gadarpur	Irrigation	Pvt. Tube Well	1835	0.75	2.05
40	U S Nagar	Gadarpur	Irrigation	State TW	90	2.5	5.18
41	U S Nagar	Kashipur	Irrigation	Pvt. Tube Well	3163	0.35	0.44
42	U S Nagar	Kashipur	Irrigation	State TW	23	2	4.1
43	U S Nagar	Bazpur	Irrigation	Pvt. Tube Well	2732	0.35	0.44
44	U S Nagar	Bazpur	Irrigation	State TW	50	2	4.1
45	U S Nagar	Sitargunj	Irrigation	Pvt. Tube Well	4125	0.35	0.44
46	U S Nagar	Sitargunj	Irrigation	State TW	54	2	4.1
47	U S Nagar	Rudrapur	Irrigation	Pvt. Tube Well	3554	0.35	0.44
48	U S Nagar	Rudrapur	Irrigation	State TW	68	2	4.1
49	U S Nagar	Khatima	Irrigation	Pvt. Tube Well	5841	0.35	0.85
50	U S Nagar	Khatima	Irrigation	State TW	90	2	4.1
51	Nainital	Ramnagar	Domestic	Major TW	13	16.22	33.11
52	Nainital	Ramnagar	Domestic	Mini TW	7	4.22	8.62
53	Nainital	Haldwani	Domestic	Major TW	70	11.44	23.36
54	Nainital	Haldwani	Domestic	Mini TW	11	4.92	8.62
55	Nainital	Ramnagar	Irrigation	Pvt. Tube Well	127	0.55	1.65

56	Nainital	Ramnagar	Irrigation	State TW	101	4.82	10.7
57	Nainital	Ramnagar	Irrigation	Pump set	384	0.35	1.05
58	Nainital	Haldwani	Irrigation	Pvt. Tube Well	1	0.55	1.65
59	Nainital	Haldwani	Irrigation	State TW	191	4.82	10.7

***The unit drafts have been kept low for the assessment units where the well density is high and vice versa.**

4.3.4 Canal Data

The canal data has been taken into account in GWRE for Uttarakhand State. The canal system in few of the districts are primarily irrigation canals and majorly supply water for irrigation and agricultural use. These canals are mostly operational throughout the year and thus recharge to groundwater occurring due to canal seepage plays an important role in groundwater resource assessment. The Upper Ganges canal, part of the original Ganges Canal is one of the major canal system of Haridwar district. The Upper Ganges Canal starts at the Bhimgoda Barrage near Har ki Pauri at Haridwar, traverses Bahadrabad and Roorkee blocks and flows to Uttar Pradesh. Apart from the canal system, small channels or guhls are also considered for determining the seepage which contribute to groundwater recharge. The canal and guhl data considered for different assessment units are tabulated in Table- 10.

4.3.5 Groundwater Level Data

Central Groundwater Board, UR has several National Hydrograph Stations (NHS) located all throughout the State which are monitored four times a year. The groundwater level data is then being compiled for pre-monsoon (May) and post-monsoon (November) seasons and the block-wise average is then computed. In the present assessment, the groundwater level for all the assessment blocks have been considered from the year 2015 till 2021. The depth to water level for the different assessment units are tabulated in Table-11

Table 10. Summary of canal and guhl data used for calculating Recharge through Other Sources (canal) used in GWRE 2022

Sl No	District	Assessment Unit	Type of Structure	Length of Canal (m)	Wetted Perimeter (m)	Canal seepage factor (ha.m/d/million sq.m)		No.of canal running days	
						Monsoon	Non-Monsoon	Monsoon	Non-Monsoon
1	Dehradun	Doiwala	Canal	171890	1.47	5.5	5.5	60	120
2		Vikasnagar	Canal	153556	1.47	5.5	5.5	60	120
3		Sahaspur	Canal	94434	1.62	5.5	5.5	60	120
4	Haridwar	Roorkee	Guhl	11310	1.75	10	10	95	100
5		Roorkee	Canal	50040	4.1	15	15	95	234
6		Gurukul Narsan	Guhl	251570	1.75	10	10	95	100
7		Gurukul Narsan	Canal	160070	4.1	10	10	95	234
8		Laksar	Guhl	1920	1.75	10	10	95	234
9		Bahadarabad	Guhl	162580	1.75	10	10	95	100
10		Bahadarabad	Canal	239520	4.1	10	10	95	234
11	Udham Singh Nagar	Jaspur	Canal	212800	2.6	10	10	60	120
12		Gadarpur	Canal	208000	2.25	10	10	60	120
13		Kashipur	Canal	190400	3.49	10	10	60	120
14		Bazpur	Canal	201600	2.25	10	10	60	120
15		Sitargunj	Canal	90510	3.44	10	10	60	120
16		Rudrapur	Canal	130000	2.25	10	10	60	120
17		Khatima	Canal	150149	4.6	10	10	60	120
18	Nainital	Ramnagar	Canal	132230	4.1	10	10	60	100
19		Haldwani	Canal	205480	4.1	10	10	60	100

Table 11. Summary of depth to water level data for calculating Recharge through Rainfall used in GWRE 2022

Sl No	District	Assessment Unit	Year	Pre-Monsoon Water Level (m bgl)	Post- Monsoon Water Level (m bgl)
1.	**Dehradun**	Doiwala	2015	28.2	24.27
			2016	27.41	25.53
			2017	27.02	24.28
			2018	28.07	22.46
			2019	27.88	23.87
			2020	28.64	23.46
			2021	19.81	15.2
2.		Vikasnagar	2015	19.26	18.72
			2016	19.94	19.13
			2017	21.67	18.19
			2018	16.97	16.95
			2019	19.95	16.12
			2020	20.45	19.14
			2021	19.96	17.06
3.		Sahaspur	2015	17.57	15.09
			2016	17.43	15.96
			2017	16.34	13.11
			2018	16.44	12.26
			2019	17.79	13.63
			2020	18.06	14.46
			2021	16.25	12.85
4.	**Haridwar**	Bahadrabad	2015	9.66	9.6
			2016	8.17	7.87
			2017	9.11	7.32
			2018	8.87	7.68
			2019	8.98	8.03
			2020	8.62	8.49
			2021	8.69	6.97
5.		Bhagwanpur	2015	9.43	7.58
			2016	9.3	7.91
			2017	10.64	8.56
			2018	11.17	9.55
			2019	11.01	9.57
			2020	10.76	9.41
			2021	10.56	8.61
6.		Gurukul Narsan	2015	11.11	9.45
			2016	12.68	9.51
			2017	11.28	10.67
			2018	11.2	10.42

			2019	11.79	10.84
			2020	10.37	9.66
			2021	10.22	9.57
7.		Khanpur	2015	2.82	2.15
			2016	2.34	1.98
			2017	2.95	2.17
			2018	3.38	1.76
			2019	3.48	2.27
			2020	2.47	2.41
			2021	2.63	1.56
8.		Luksar	2015	4.32	2.33
			2016	3.72	2.52
			2017	3.48	2.09
			2018	3.97	2.11
			2019	3.9	2.43
			2020	2.61	2.23
			2021	3.27	2.61
9.		Roorkee	2015	12.73	10.84
			2016	11.45	11.42
			2017	12.64	11.29
			2018	10.5	9.35
			2019	12.11	11.88
			2020	12.19	11.03
			2021	11.17	9.48
10.	**Udham Singh Nagar**	Bazpur	2015	4.66	2.75
			2016	3.08	2.98
			2017	5.26	2.77
			2018	4.81	2.45
			2019	5.28	3.1
			2020	4.18	3.2
			2021	4.55	2.45
11.		Gadarpur	2015	4.85	2.63
			2016	4.05	2.55
			2017	3.99	2.72
			2018	4.73	2.16
			2019	5.13	3.05
			2020	4.12	3.54
			2021	4.35	2.34
12.		Jaspur	2015	13.96	10.52
			2016	12.79	10.29
			2017	13.89	10.46
			2018	15.99	9.65
			2019	16.31	9.86
			2020	13.89	10.7
			2021	14.92	9.52
13.		Kashipur	2015	7.69	4.46
			2016	5.52	4.73
			2017	8.02	4.16
			2018	7.28	3.86
			2019	6.93	5.22

			2020	6.86	5.93
			2021	9.11	5.08
14.		Khatima	2015	5.4	3.91
			2016	4.77	3.56
			2017	5.21	3.36
			2018	5.76	2.74
			2019	6.05	3.61
			2020	4.72	3.49
			2021	4.11	2.47
15.		Rudrapur	2015	4.81	3.09
			2016	3.64	3.4
			2017	4.49	3.07
			2018	5.1	2.82
			2019	5.61	3.7
			2020	4.26	3.87
			2021	5.36	3.07
16.		Sitarganj	2015	3.98	2.46
			2016	4.22	2.98
			2017	4.99	1.51
			2018	4.47	1.86
			2019	3.91	2.28
			2020	3.78	2.69
			2021	3.74	1.85
17.	**Nainital**	Haldwani	2015	28.08	25.85
			2016	27.06	23.59
			2017	25.35	22.49
			2018	24.78	21.72
			2019	29.41	26.24
			2020	27.91	24.81
			2021	30.87	26.08
18.		Ramnagar	2015	38.44	35.15
			2016	37.68	35.0
			2017	35.32	31.52
			2018	30.45	27.69
			2019	27.92	26.64
			2020	30.29	28.71
			2021	34.65	33.69

CHAPTER – 5

Ground Water Resource Estimation of Uttarakhand State (GEC 2015 and IN-GRES)

CHAPTER – 5

GROUND WATER RESOURCES ESTIMATION

5.1 General

About 85% of the area of Uttarakhand State is mountainous where groundwater structures do not exist and hence groundwater levels cannot be monitored. Groundwater is developed through springs and hand pumps in the hilly part of the state. The areas with plain topography are confined to districts Dehradun, Haridwar, Udham Singh Nagar and Nainital. The groundwater levels are monitored in these districts only and hence the groundwater resources estimation work is also restricted to these four districts. The mountainous area is unworthy for groundwater resources estimation since the slope is more than 20%.

5.2 Ground Water Assessment Unit

Block is the development unit in the state, which has been taken as the groundwater assessment unit. The administrative boundaries of these blocks are shown in Fig ***– 1.*** Based on the data availability the groundwater resources are estimated for the following blocks (Table 12).

Table 12. Districts and Assessment Units considered for GWRE 2022

District	Blocks (Assessment Units)
Dehradun	Doiwala, Sahaspur and Vikasnagar
Haridwar	Bahadarabad, Bhagwanpur, Gurukul Narsan, Laksar, Khanpur and Roorkee
Udham Singh Nagar	Bazpur, Gadarpur, Sitarganj, Rudrapur, Jaspur, Kashipur and Khatima
Nainital	Ramnagar and Haldwani

5.3 Dynamic Ground Water Resources

Dynamic Ground Water Resources (2022) of Uttarakhand are estimated and future projections are made for the year 2025. The total resources, existing and projected, water development, categorization of assessment units and ground water draft have been assessed for each assessment unit. The parameters used, various inputs and results obtained are summarized in ***Annexure 4.*** All input sheets and results can also be downloaded from **https://ingres.iith.ac.in/gecdataonline/gis/INDIA.**

5.4 Ground water Potential

The district wise details of Ground Water Potential are given in **Annexure 5**. The Annual Ground Water Recharge (AGWR) for the assessed blocks of Uttarakhand State is estimated to be 2,02,216.91 Ham/year and the Annual Extractable Ground Water Resource (AEGWR) after deducting natural discharge is estimated to be 1,86,113.17 Ham/year. Ground water extraction for irrigation is estimated at 62,882.04 Ham/year whereas ground water extraction for Industrial and domestic Draft is estimated at 11,797.85 Ham/year and 14,728.39 Ham/year respectively. Thus, the net ground water availability for future use is estimated to be 95,948.98 Ham/year. The Stage of Ground water Extraction in the State worked out to be 48.04 %.

Out of the 18 assessed blocks of Uttarakhand State, 14 blocks (77.78%) have stage of ground water development below 70 % and are termed as 'Safe', whereas remaining 4 blocks (22.22%) have stage of ground water development between 70 and 90 % and they are categorised as 'Semi Critical', as illustrated in **Fig-4**. According to the GEC (2015) Methodology of Dynamic Groundwater Resource Assessment, no block in Uttarakhand State fall in Critical Category (stage of ground water development above 90 %) and Over Exploited Category (stage of ground water development above 100 %). There are no issues related to groundwater quality in the assessment units and hence there are no poor quality or saline blocks in the State.

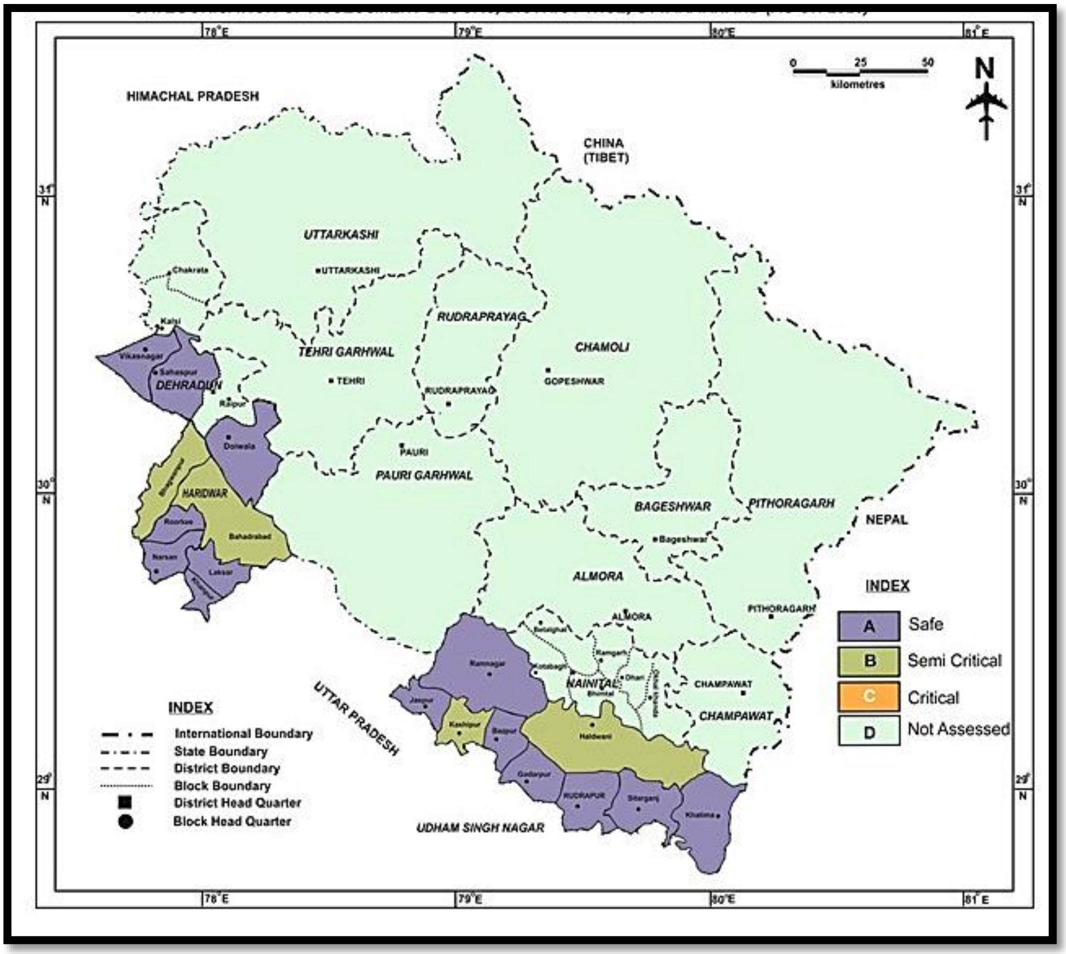


Fig 4. Categorisation of Assessment units of Uttarakhand State as per GWRE 2022

5.5 Comparison of GWRE 2020 and GWRE 2022

The ground water resources of Uttarakhand State have been assessed block-wise. The Total Annual Groundwater Recharge of the State has marginally decreased from 2.023 bcm (2020) to 2.022 bcm (2022). The Annual groundwater extraction has increased from 0.867 bcm (2020) to 0.894 bcm (2022).

As compared to 2020 estimate, there is negligible decrease in the Total Annual Ground Water Recharge and increase in the Annual ground water extraction in the State. The stage of groundwater extraction has also increased from 46.80% to 48.04%. The reason for the marginal decrease in recharge is due to the variations in rainfall during 2020-21 and 2021-22. Since the recharge due to rainfall during monsoon season has been computed using WTFL in many of the assessment units, hence the groundwater level has also played a role in the insignificant decrease of Total Annual Ground Water Recharge. The values of normal monsoon and non- monsoon rainfall considered in the present assessment have not varied from the previous assessment and the values have been rechecked with IMD and India- WRIS data. The increase in Annual groundwater extraction is mainly due to the increase in industrial extraction from 0.087 bcm (2020) to 0.118 bcm (2022) which is quite significant since the number of industries are increasing day by day specially in the Udham Singh Nagar district. Refinement in well census database (reduction in number of dugwells and hand pumps that are currently not in use) and re-evaluation of estimated drafts of the abstraction structures in a block-wise manner after consultation with the State Govt. departments have been attended to in the previous assessment and there is no change in the present assessment. There has been increase in stage of groundwater extraction in all the assessment units except three assessment units (Doiwala, Vikasnagar of Dehradun district and Gadarpur blocks of Udham Singh Nagar District). The stage of groundwater extraction of the assessment units as per the GWRE 2020 and 2022 is illustrated in Table 13. A detailed comparison report of GWRE 2020 and 2022 has been provided in Annexure 6.

Table 13. Comparison of categorisation of Assessment units of Uttarakhand based on Stage of Ground Water Extraction as per GWRE 2022 and GWRE 2020

COMPARISON OF CATEGORIZATION OF ASSESSMENT UNITS (2022 AND 2020)						
S. No	**Name of District**	**Name of Assessment Unit**	**Stage of Ground Water Extraction (%) in 2022**	**Categorization in 2022**	**Stage of Ground Water Extraction (%) in 2020**	**Categorization in 2020**
1	Dehradun	Doiwala	20.72	Safe	21.88	Safe
2	Dehradun	Sahaspur	17.84	Safe	17.66	Safe
3	Dehradun	Vikashnagar	29.68	Safe	30.18	Safe
4	Haridwar	Bahadrabad	71	Semi Critical	70.76	Semi Critical
5	Haridwar	Bhagwanpur	70.51	Semi Critical	70.28	Semi Critical
6	Haridwar	Gurukul Narsen	39.49	Safe	37.77	Safe
7	Haridwar	Khanpur	59.46	Safe	57.9	Safe
8	Haridwar	Luksar	64.54	Safe	64.25	Safe
9	Haridwar	Roorkee	68.96	Safe	67.35	Safe
10	U S Nagar	Bazpur	43.01	Safe	42.97	Safe
11	U S Nagar	Gadarpur	52.03	Safe	52.19	Safe
12	U S Nagar	Rudrapur	52.92	Safe	42.68	Safe
13	U S Nagar	Sitarganj	43.83	Safe	41.66	Safe
14	U S Nagar	Jaspur	64.65	Safe	62.77	Safe
15	U S Nagar	Kashipur	72.16	Semi Critical	70.11	Semi Critical
16	U S Nagar	Khatima	69.5	Safe	66.19	Safe
17	Nainital	Haldwani	87.22	Semi Critical	84.17	Semi Critical
18	Nainital	Ramnagar	35.19	Safe	34.64	Safe

5.6 Conclusion and Recommendation

Total Annual Ground Water Recharge in the State (2022) has been assessed as 2.022 billion cubic meters (bcm). Ground water resources are replenished through rainfall and other sources like return flow from irrigation, canal seepage etc. The main source of annual ground water recharge is rainfall, which contributes nearly 68.72 % of the Total Annual Ground Water Recharge. The Total Annual Extractable Ground Water Resource of the

State has been assessed as 1.861 bcm, after keeping a provision for natural discharge. The Annual Ground Water Extraction of the State (2022) is 0.894 bcm, the largest user being irrigation sector. The Stage of ground water extraction for the entire State, which is the percentage of ground water extraction with respect to Annual Extractable Ground Water Recharge, has been computed as 48.04 %.

Out of the 18 assessed blocks of Uttarakhand State, 14 blocks have stage of ground water development below 70 % and are termed as 'Safe', whereas remaining 4 blocks have stage of ground water development between 70 and 90 % and they are categorised as 'Semi Critical'. According to the GEC 2015 Methodology of Dynamic Groundwater Resource Assessment, there are no block in Uttarakhand State falling in Critical Category (stage of ground water development above 90%).

There is an urgent need of preparation of management plans by the concerned State Departments for the four Semi Critical blocks of Bahadrabad, Bhagwanpur, Kashipur and Haldwani so that there is no further deterioration in the Stage of Development of Groundwater in the coming years. The Government should take proactive measures in implementing recharge measures in parts of these blocks where the groundwater level after monsoon is below 5-7 meters below ground level. Rainwater harvesting should be made compulsory in all Government buildings, schools, colleges and housing societies. The demand side and supply side management interventions should be prioritized in the Semi Critical Blocks.

The cropping patterns of the water- intensive crops like rice, wheat and sugarcane need to be regulated and crop rotation should be encouraged wherever possible. Proper plan should be formulated for adoption of low water intensive crops and horticulture practices and farmers should be encouraged to use drip irrigation, sprinklers and rain guns for irrigation. Public sensitization on Per Drop More Crop Micro Irrigation System should be promoted.

ACKNOWLEDGEMENT

The assignment was carried out under the overall supervision of Sh. Prashant Rai, Head of Office, CGWB, UR, Dehradun. The author is grateful to him for his consistent guidance and immense support. The author express her sincere thanks to the chemists of CGWB, NR, Lucknow for analysis of water samples and officers of CGWB, UR, Dehradun who have carried out NHS monitoring of the State. The author is grateful to Sh. Mohd. Arshad, AHG for compilation of water level data. Thanks and appreciations also go to our colleagues who have willingly helped out with their abilities. Thanks are also due to Ms. Divya Verma, LDC for the typological work and overall formatting of the report. The data provided by the various departments of Government of Uttarakhand namely Uttarakhand Jal Sansthan, Irrigation Department, Minor Irrigation Department, Directorate of Industries, Uttarakhand Pey Jal Nigam and Indian Meteorological Department, Dehradun are thankfully acknowledged.

Annexure 1

Office Order for constitution of Permanent State Level Technical Co-ordination Committee for Estimation of Dynamic Ground Water Resources of Uttarakhand (2022)

1/22579/2022

Government of Utta[illegible]
Department of Mino[illegible]
04 Subhash Road Utta[illegible]

10

[illegible]:**Dated March, 2022**

ORDER

Subject: Regarding to constitute State Level [illegible]hnical Cordination Committee (SLTCC) on permanent basis For Ground W[illegible] Resources Assessment.

The Ground Water Resources for Uttarakhand State is to be jointly carried out along with nodal Department for Ground Water, as per direction recived from Ministry of Jal Shakti, Department of Water Resources, R.D. & G.R., Govt. of India. Therefore Minor Irrigation Department, Uttarakhand is nominating as Nodal Department for liasioning and **State Level Technical Cordination Committee (SLTCC)** is constituted on permanent basis with the following composition:-

Composition:

1	Secretary, Irrigation & Minor Irrigation, Govt. of Uttarakhand	Chairman
2	Engineer in Chief, Irrigation Department, Uttarakhand	Member
3	Chief Engineer, Minor Irrigation Department, Uttarakhand	Member
4	Managing Director, Payjal Nirman Nigam, Uttarakhand	Member
5	Chief Gerenal Manager, Uttarakhand Jal Sansthan, Uttarakhand	Member
6	Director, Swajal Pariyojna, Uttarakhand	Member
7	Director, Agriculture Department, Uttarakhand	Member
8	Director Industries Department, Uttarakhand	Member
9	General Manager, NABARD	Member
10	Regional Director, CGWB, Uttarakhand Region, Dehradun	Member Secretary

The Committee may co-opt any other Member(s)/ special, if necessary.

2- Terms of Reference: The broad terms of reference of the Committee would be as folloes"-

i. To re-assess annual ground water recharge of the state in accordance with the Ground Water Resources Estimation Methodology-2015
ii. To estimate the status of utilization of the annual extractable ground water resource.
iii. To provide contribution for compilation of National Level report on assessment of ground water resources and status of utilization.
iv. To work towards integration of ground water and surface water with a view to facilitate planning for conjuctive use of water resources.

3. Time frame:

S. No.	Activity	Jan	Feb	M[illegible]	[illegible]il	May	Jun	July	Aug	Sept
1	Constitution of of State Level Committee (SLC) on GW Resource Assessment by the concerned States/UTs									
2	Creation of Ground Water Resources (GWR) Assessment Cell and Deployment of District/State level officers by State Agencies									
3	Organizig State Level Meeting between CGWB and Nodal/GW Department of State									
4	Firming up of Assessment units as per latest data and providing Shape File of the same									
5	Compliation of Basic data/map/information available for each assessment units by CGWB and State GW/Nodal Department									
6	Organizean online workshop (Zone-wise) to facilitate interaction with Districe/State Level Officials and IIT-H									
7	Organiz interactive trainings for States those facing difficulties in assessment and software handling with IITH Teams (as per request).									
8	Coordinate with the entire line department to obtain additional required crop/Irrigation data ect as per water year (June 2021 to May 2022)									

9	Planning of Second Workshop to review overall status of assessment exercise and other issues, if any									
10	Software Operation and exercise of assement-wise GW Resource Assesment as per the software protocol.									
11	Approval of the State Ground Water Resources by SLC and Submission of the approved Ground Water Resources to CLEG									
12	Compliationn of Nation Report and secrutiny for Finalizatioin									
13	Approval of the nation Report by Centrl Level Epert Group (CLEG)									
14	Approval by Minister of Jal Shakti, Government of India and Publication of National Report									

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 Merber (if any), will be borne by the Central Ground Water Board as per Govt. norms.

Signed by Sukhbir Singh Sandhu
Date: 10-03-2022 11:54:37

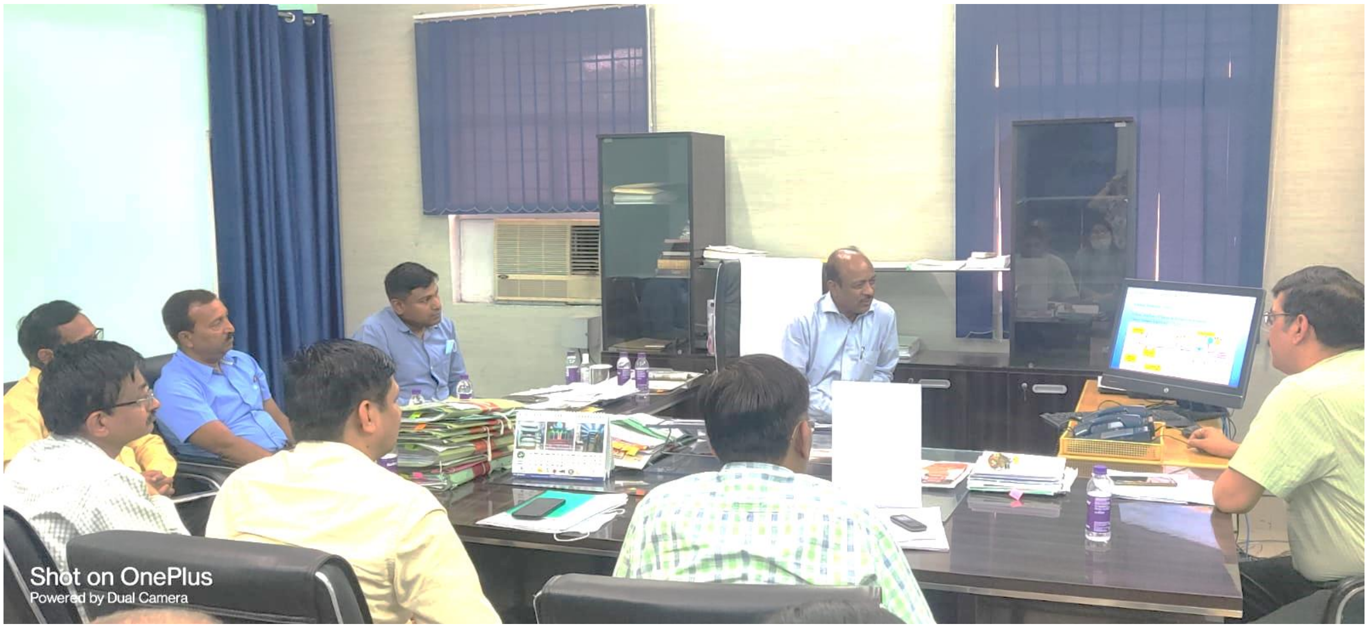
(Dr. Sukhbir Singh Sandhu)
Chief Secretary
Govt. of Uttarakhand

Copy to the following for information:-

1. Secretary, Water Resources, Govt. of Uttarakhand and Chairman of the SLC, Secretariat, 4 Subhash Road, Dehradun.
2. Regional Director, CGWB, Dehradun.
3. The Engineer-in-Chief & HOD, Irrigation Department, Yamuna Colony, Dehradun.
4. The Chief Engineer & HOD, Minor Irrigation Department, Indraprastha Colony, Lane No. 3 Nathanpur Jogiwala, Dehradun.
5. The Chief General Manager, Uttarakhand Jal Sansthan, Nehru Colony, Dehradun.

Annexure 2

Meeting of the First SLCC of Groundwater Resource Estimation (2022) held under the chairmanship of Secretary, Irrigation, Uttarakhand Government on 28th April, 2022



Annexure 3

Minutes of the Meeting of the State Level Technical Coordination Committee (SLCC) for approval of the Assessment of Groundwater Resources of Uttarakhand State, 2022

Annexure 4
Summary of Assessment of Dynamic Ground Water Resources, Assessment Unit-Wise Categorization, of Uttarakhand State (2022)

Sl. No	District	Assessment Unit Name	Total Area of Assessment Unit (Ha)	Recharge from Rainfall-Monsoon Season	Recharge from Other Sources-Monsoon Season	Recharge from Rainfall-Non-Monsoon Season	Recharge from Other Sources-Non-Monsoon Season	Total Annual Ground Water (Ham) Recharge	Total Natural Discharges (Ham)	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 (%)	Categorization (Over-Exploited /Critical/ Semi critical/ Safe/Saline)
1	**Dehradun**	**Doiwala**	51057	21,755.54	850.48	1,194.47	505.83	24,306.32	1,215.32	23,091.00	1724.93	173.29	2,885.73	4,783.94	2,885.73	18,307.06	20.72	Safe
2	**Dehradun**	**Sahaspur**	52,061	22,547.75	564.51	1,217.96	494.16	24,824.38	2,482.44	22,341.94	2289.34	431.40	1,265.54	3,986.28	1,265.54	18,355.66	17.84	Safe
3	**Dehradun**	**Vikashnagar**	22426	9,449.86	877.59	524.65	569.96	11,422.06	571.1	10,850.96	1875.44	35.15	1309.54	3,220.13	1,309.54	7,630.83	29.68	Safe
4	**Haridwar**	**Bahadrabad**	33763	4,789.89	2,482.58	757.64	3,663.27	11,693.38	584.67	11,108.71	4,752.20	2,290.43	844.3	7,886.93	957.48	3,108.60	71	SC
5	**Haridwar**	**Bhagwanpur**	31537	5,944.60	637.40	707.69	755.24	8,044.93	804.49	7,240.44	4,437.40	114.99	552.61	5,105.00	593.77	2,094.28	70.51	SC
6	**Haridwar**	**Gurukul Narsen**	23107	3,677.00	1,751.88	518.52	2,619.98	8,567.38	428.37	8,139.01	2,346.67	307.48	559.56	3,213.70	608.52	4,876.35	39.49	Safe
7	**Haridwar**	**Khanpur**	17814	3,025.35	324.96	399.75	361.93	4,111.99	205.6	3,906.39	2,169.84	0	152.76	2,322.60	172.97	1,563.58	59.46	Safe
8	**Haridwar**	**Luksar**	27778	5,236.04	518.27	623.34	580.31	6,957.96	695.8	6,262.16	3,424.01	139.45	478.3	4,041.76	531.41	2,167.29	64.54	Safe
9	**Haridwar**	**Roorkee**	22836	4,304.49	790.54	512.44	1,248.58	6,856.05	685.6	6,170.45	3,240.96	595.25	418.93	4255.14	423.46	1,910.78	68.96	Safe
10	**Udham Singh Nagar**	**Bazpur**	28646	5,620.84	1251.58	361.55	1201.86	8,435.83	843.58	7,592.25	2,463.28	385.75	416.24	3,265.28	492.29	4,250.92	43.01	Safe
11	**Udham Singh Nagar**	**Gadarpur**	23326	4,576.96	4679.83	294.41	3709.63	13,260.83	1,326.08	11,934.75	5,829.20	45.77	334.13	6,209.10	412.17	5,647.61	52.03	Safe
12	**Udham Singh Nagar**	**Jaspur**	23229	6,836.89	2593.6	293.18	2546.34	12,270.01	1,227.00	11,043.01	5,968.20	621.2	550.22	7,139.62	550.22	3,903.39	64.65	Safe
13	**Udham Singh Nagar**	**Kashipur**	18517	4,834.10	2556.77	233.71	2131.24	9,755.83	487.79	9,268.04	2,639.07	3,377.87	671.11	6,688.05	671.11	2,579.99	72.16	SC
14	**Udham Singh Nagar**	**Khatima**	35157	7,195.95	2222.12	443.73	2640.33	12,502.13	625.1	11,877.03	7,558.20	281.6	414.22	8,254.02	414.22	3,623.01	69.5	Safe
15	**Udham Singh Nagar**	**Rudrapur**	31153	6,112.75	1925.53	393.19	1418.68	9,850.15	985.02	8,865.13	3,222.46	1,041.02	427.71	4,691.19	427.71	4,173.94	52.92	Safe
16	**Udham Singh Nagar**	**Sitarganj**	33254	6,525.00	1914.35	419.71	1497.28	10,356.34	1035.64	9,320.70	3,588.15	365.47	131.39	4,085.01	452.06	4,915.02	43.83	Safe
17	**Nainital**	**Haldwani**	11277	3,158.20	2284.57	764.08	2853.8	9,060.65	906.07	8,154.58	2,968.17	1,559.48	2,584.94	7,112.59	2,584.94	1,041.99	87.22	SC
18	**Nainital**	**Ramnagar**	12366	2,885.98	2870.82	837.87	3346	9,940.69	994.07	8,946.62	2,384.52	32.26	731.17	3,147.94	731.17	5,798.68	35.19	Safe

Annexure 5

Summary of Assessment of Dynamic Ground Water Resources, District-Wise Categorization, of Uttarakhand State (2022)

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 Domestic Use as on 2025	Net Ground Water Availability for future use	Stage of Ground Water Extraction (%)
		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	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Dehradun	53,753.15	2,292.58	2,937.08	1569.95	60,552.76	4,268.86	56,283.90	5889.71	639.84	5460.81	11,990.35	5,460.81	44,293.55	21.3
2	Haridwar	26,977.37	6,505.63	3,519.38	9,229.31	46,231.69	3,404.53	42,827.16	20,371.08	3,447.60	3,006.46	26,825.13	3,287.61	15,720.88	62.64
3	Udham Singh Nagar	41,702.49	17,143.78	2,439.48	15,145.36	76,431.12	6,530.21	69,900.91	31,268.56	6,118.67	2,945.02	40,332.27	3,419.78	29,093.88	57.7
4	Nainital	6,044.18	5,155.39	1,601.95	6,199.83	19,001.34	1,900.14	17,101.20	5352.69	1,591.74	3,316.11	10,260.53	3,316.11	6,840.67	60
	Total (Ham)	1,28,477.19	31,097.38	10,497.89	32,144.42	2,02,216.91	16,103.74	1,86,113.17	62882.04	11,797.84	14,728.40	89,408.28	15,484.31	95,948.98	48.04

Annexure 6

Summary of Comparison of different parameters of Dynamic Ground Water Resources of Uttarakhand State (2022 and 2020)

S.No	DISTRICT	BLOCK	Rainfall recharge (2022) Ham	Rainfall recharge (2020) Ham	Rainfall from other Sources (2022) Ham	Rainfall from other Sources (2020) Ham	Total Annual Ground Water recharge (2022) Ham	Total Annual Ground Water recharge (2020) Ham	Total Natural Discharge (2022) Ham	Total Natural Discharge (2020) Ham	Annual Extractable GW Resource (2022) Ham	Annual Extractable GW Resource (2020) Ham	Total Annual GW Extraction (2022) Ham	Total Annual GW Extraction (2020) Ham
1	DEHRADUN	DOIWALA	22950.01	21301.79	1356.31	1596.67	24306.32	22898.46	1215.32	1144.92	23091	21753.54	4783.94	4760.64
2	DEHRADUN	SAHASPUR	23765.71	23765.71	1058.67	1194.42	24824.38	24960.13	2482.44	2496.01	22341.94	22464.12	3986.28	3967.09
3	DEHRADUN	VIKASHNAGAR	9974.51	10237.41	1447.55	1613.89	11422.06	11851.3	571.1	1185.13	10850.96	10666.17	3220.13	3219.08
4	HARIDWAR	BAHADRABAD	5547.53	5000.43	6145.85	6351.11	11693.38	11351.54	584.67	1135.16	11108.71	10216.38	7886.93	7228.84
5	HARIDWAR	BHAGWANPUR	6652.29	6652.29	1392.64	1392.64	8044.93	8044.93	804.49	804.49	7240.44	7240.44	5105	5088.7
6	HARIDWAR	GURUKUL NARSEN	4195.52	4874.1	4371.86	4371.86	8567.38	9245.96	428.37	924.6	8139.01	8321.36	3213.7	3142.59
7	HARIDWAR	KHANPUR	3425.1	3757.62	686.89	686.89	4111.99	4444.51	205.6	444.45	3906.39	4000.06	2322.6	2316
8	HARIDWAR	LUKSAR	5859.38	5859.38	1098.58	1098.58	6957.96	6957.96	695.8	695.8	6262.16	6262.16	4041.76	4023.24
9	HARIDWAR	ROORKEE	4816.93	3870.2	2039.12	2085.62	6856.05	5955.82	685.6	297.79	6170.45	5658.03	4255.14	3810.77
10	UDHAMSINGH NAGAR	BAZPUR	5982.39	5982.39	2453.44	2453.44	8435.83	8435.83	843.58	843.58	7592.25	7592.25	3265.28	3262.45
11	UDHAMSINGH NAGAR	GADARPUR	4871.37	4871.37	8389.46	8389.46	13260.83	13260.83	1326.08	1326.08	11934.75	11934.75	6209.1	6228.89
12	UDHAMSINGH NAGAR	JASPUR	7130.07	7130.07	5139.94	5281.41	12270.01	12411.48	1227	1241.15	11043.01	11170.33	7139.62	7011.49
13	UDHAMSINGH NAGAR	KASHIPUR	5067.81	5353.73	4688.02	4688.02	9755.83	10041.75	487.79	502.09	9268.04	9539.66	6688.05	6688.05
14	UDHAMSINGH NAGAR	KHATIMA	7639.68	8320.31	4862.45	4862.45	12502.13	13182.76	625.1	659.14	11877.03	12523.62	8254.02	8289.17
15	UDHAMSINGH NAGAR	RUDRAPUR	6505.94	6505.94	3344.21	3344.21	9850.15	9850.15	985.02	985.02	8865.13	8865.13	4691.19	3783.84
16	UDHAMSINGH NAGAR	SITARGANJ	6944.71	7537.64	3411.63	3411.63	10356.34	10949.27	1035.64	547.46	9320.7	10401.81	4085.01	4332.95
17	NAINITAL	HALDWANI	3922.28	3922.28	5138.37	4554.93	9060.65	8477.21	906.07	847.72	8154.58	7629.49	7112.59	6421.41
18	NAINITAL	RAMNAGAR	3723.85	4301.05	6216.84	5755.5	9940.69	10056.55	994.07	1005.66	8946.62	9050.89	3147.94	3135.39

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