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GROUNDWATER RESOURCE AVAILABILITY AND ITS EXPLOITATION IN INDIA: A GEOGRAPHICAL STUDY

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Abstract

The present study explains the groundwater availability and its use in India and determine the significant causes of groundwater over-exploitation. The study is based on secondary data. The data for the study is collected from the report of Dynamic Groundwater Resources of India (as on June 2020) Central Ground Water Board, Ministry of Water Resources, Faridabad, June 2021. The availability of groundwater in India is very different in its various states. In terms of spatial distribution, net annual water availability ranges from 0.20 bcm in Mizoram to 66.88 bcm in Uttar Pradesh. It shows a very high spatial variability of groundwater availability in India. Groundwater availability is very high, with 170.09 bcm or more in the Indo-Ganges and Brahmaputra plains from Punjab to Assam. The groundwater draft for the country has been assessed as 244.92 bcm, about 88.85 per cent of which is utilised for irrigation and the remaining 24.37 bcm (9.95 per cent) for domestic, and 2.94 bcm (1.20 per cent) for industrial uses. In the state of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, and Assam, which are the part of the Indo-Gangetic and Brahmaputra Plains, the percentage of groundwater draft for irrigation is very high and can support the extensive scale of groundwater development. Haryana and Punjab are the two states which have worst situation related to future groundwater availability. The future availability of groundwater in these states are have very low only 0.97 bcm in Haryana and 1.61 bcm in Punjab. This may be associated to the cultivation of water intensive crops like rice and wheat which are the two main crops of these states and extract their groundwater for irrigation above more than 90 per cent. The groundwater development in Punjab state is reported to be most critical with the highest percentage of blocks under the overexploited category, which is as high as 78 per cent, followed by Rajasthan, Haryana, and Delhi, where the percentage of an over-exploited block is 68.8 per cent, 60.28 per cent, and 50 per cent.

Keywords: *Groundwater Availability, Draft, Irrigation, Over-exploitation, India.*

1. Introduction

Groundwater is the most precious natural resource on earth and is of utmost importance in every facet of human life. Although it is a more dynamic renewable natural resource, its availability with good quality and proper quantity is essential. Throughout the world, regions with sustainable groundwater balance are shrinking by the day (Shah, Molden, Sakthivadivel, & Seckler, 2001). The demand for fresh water is rising due to increased demand for food production and growing urbanization and industrialization. While the difference in climatic and geophysical conditions results in variations in groundwater availability across different regions, its development stages are mainly complemented by irrigation development in a region. Greater dependence on groundwater irrigation has led to exploitation and over-exploitation of this precious resource beyond the sustainable limit, creating concerns for groundwater resource use sustainability. In this context, it is pertinent to study groundwater resources' changing status to analyze and understand groundwater resources' availability and utilization in different regions of India. The analysis in this paper deals with the availability and use of groundwater and outlines the extent and causes of over-exploitation in India.

2. Objectives

1. To explain the groundwater availability and its use in India.
2. To find out the major causes of groundwater over-exploitation in India.

3. Database and Research Methodology

The present study is based on secondary data. The data for the study is collected from the report "Dynamic Groundwater Resources of India (as on June 2020) Central Ground Water Board, Ministry of Water Resources, Faridabad, June 2021". To find out the stage of groundwater development following formula is used: -

$$\text{Stage of Groundwater Development} = \frac{\text{Annual Groundwater Draft}}{\text{Net Annual Groundwater Availability}} \times 100$$

4. The scenario of Groundwater in India

India has numerous resources of groundwater. Globally it is the largest user of groundwater (Shah, 2009). Groundwater has consistently evolved as the base for agriculture and drinking water in India. The contribution of groundwater is about 88.85 per cent in the field of irrigation, eighty-five percent in rural areas water supply and forty-five percent in water supply in urban areas. Groundwater also plays a significant part in main flowing in rivers, wetlands and also provides assist to terrestrial vegetation. In 'arid and semi-arid regions' the only source of water supply is groundwater (World Bank Report, 2018). Thus, groundwater has an important role in the socio-economic rising of the nation. Nevertheless, the groundwater resources in India are under a high alarm or threat. Excessive and irregular extraction has led to a speedy and widespread decrease in level of groundwater. The number of tube-wells drilled increased from one million to nearly thirty million between 1950 and 2010, showing an unprecedented scale of development. This excessive use of groundwater has caused overdrafts in many rural regions. The same condition prevails in states of the North and Northeast, along with major urban localities (World Bank Report, 2018).

Table:1 State-Wise Groundwater Resources Availability, Utilization, and Stage of Groundwater Development, 2020

(in bcm)

States/Union Territories	Net Annual Groundwater Availability (Extraction)	Groundwater Draft for Irrigation	Percentage of Groundwater Draft used for Irrigation	Groundwater Availability for Future Use	Stage of Groundwater Development (Percentage)
Andhra Pradesh	22.94	6.60	86.5	15.91	33.26
Arunachal Pradesh	2.92	0.003	30	2.90	0.36
Assam	21.97	1.97	76.36	19.33	11.73
Bihar	25.46	10.33	79.34	12.23	51.14
Chhattisgarh	11.55	4.53	84.67	6.25	46.34
Goa	0.32	0.02	25	0.24	23.48
Gujarat	24.91	12.65	95.11	12.52	53.39
Haryana	8.63	10.47	90.18	0.97	134.56
Himachal Pradesh	0.97	0.20	55.56	0.62	36.83
Jharkhand	5.64	0.93	56.71	4.02	29.13
Karnataka	16.40	9.60	90.31	7.08	64.85
Kerala	5.12	1.16	43.77	2.13	51.68

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Madhya Pradesh	33.38	17.33	91.35	15.25	56.82
Maharashtra	30.25	15.29	91.94	14.20	54.99
Manipur	0.46	0.003	15	0.44	5.12
Meghalaya	1.82	0.03	37.5	1.73	4.22
Mizoram	0.20	0.00	0.00	0.19	3.81
Nagaland	1.95	0.002	10	1.93	1.04
Odisha	15.71	5.50	80.17	8.74	43.65
Punjab	20.59	32.80	96.9	1.61	164.42
Rajasthan	11.07	14.37	86.41	0.99	150.22
Sikkim	0.86	0.00	0	0.85	0.86
Tamil Nadu	17.69	13.52	92.16	5.65	82.93
Telangana	15.03	7.13	89.01	7.14	53.32
Tripura	1.24	0.02	20	1.14	7.94
Uttar Pradesh	66.88	41.29	89.7	21.53	68.83
Uttrakhand	1.85	0.63	72.41	0.98	46.80
West Bengal	26.56	10.84	91.55	14.19	44.60
Total States	**392.37**	**217.22**	**89.22**	**180.76**	**62.04**
			Union Territories		
Andaman & Nicobar	0.28	0.0001	1	0.28	2.60
Chandigarh	0.06	0.01	20	0.01	80.60
Dadara Nagar Haveli	0.07	0.01	33.33	0.03	45.99
Daman & Diu	0.03	0.003	10	0.0002	113.38

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Delhi	0.29	0.07	24.14	0.02	101.40
Jammu & Kashmir	4.22	0.20	22.47	3.32	21.03
Ladakh	0.11	0.001	0.00	0.09	17.90
Lakshadweep	0.005	0.00	33.33	0.002	58.47
Puducherry	0.20	0.10	66.67	0.05	74.27
Total UTs	**5.265**	**0.394**	**26.75**	**3.80**	**27.98**
Grant Total	**397.64**	**217.61**	**88.85**	**184.56**	**61.60**

Source: Compiled and computed from Report on "Dynamics Groundwater Resources of India" (as on June 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

4.1 Groundwater Availability in India

The primary source of fresh water in India is rainfall and groundwater. As per the latest assessment of CGWB, 2020, the annual replenishable groundwater resource in India has been assessed as 436.15 billion cubic meters (bcm), out of which 397.64 bcm is considered to be available for development for various uses after keeping 38.53 bcm for natural discharge during the non-monsoon period for maintaining flows in springs, streams, and rivers (Figure 1).

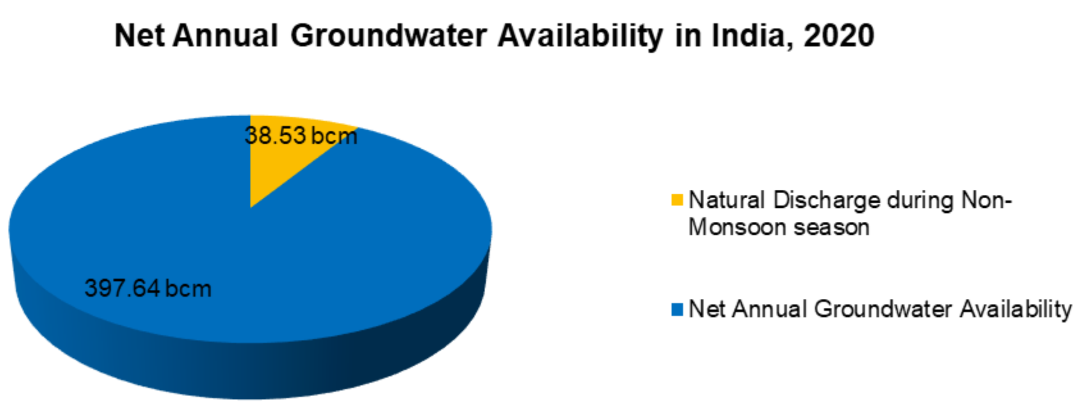

Figure: 1

Source: Compiled and computed from Report on "Dynamics Groundwater Resources of India" (as on June 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

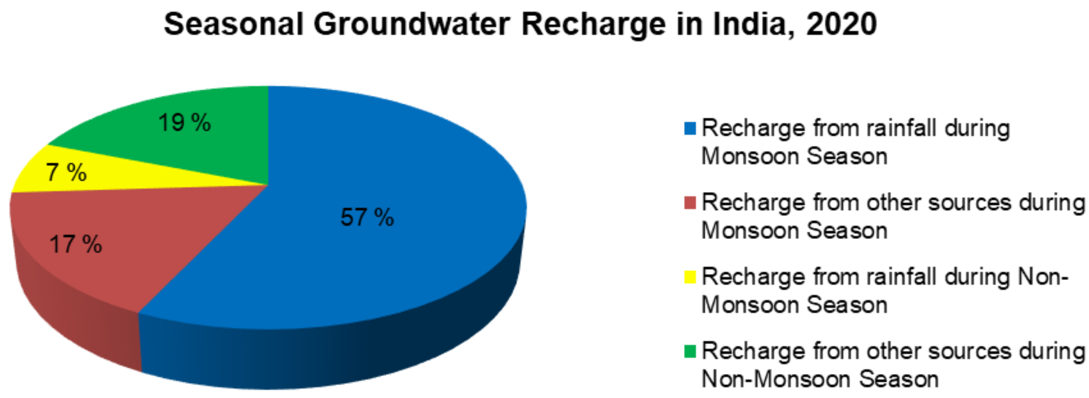

Figure: 2

Source: Compiled and computed from Report on "Dynamics Groundwater Resources of India" (as on June 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

In India the major source of groundwater recharge is the monsoon rainfall, which is 249.65 bcm and about 57 per cent of the total annual groundwater recharge. The overall contribution of rainfall (both monsoon and non-monsoon) recharge to India's total annual groundwater recharge is 64 per cent and the share of recharge from other sources likes canal seepage, return flow from irrigation, recharge from tanks, ponds and water conservation structures taken together is 36 per cent (Figure 2).

It can be seen from the table 1 and figure 3 that in the state of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, and Assam, which are the part of the Indo-Gangetic and Brahmaputra Plains, the Groundwater potential is very high and can support the extensive scale of Groundwater development. Among these states, Uttar Pradesh (66.88 bcm) has the highest net groundwater availability, followed by West Bengal (26.56 bcm), Bihar (25.46 bcm), Assam (21.97 bcm), Punjab (20.59 bcm), and Haryana (8.63 bcm). Groundwater recharge is higher in this region because of porous soil and heavy rainfall. In southern peninsular and hilly states, however, groundwater potential is relatively much lower. Among the southern peninsular states, Andhra Pradesh (22.94 bcm), has the highest net groundwater availability, followed by Tamil Nadu (17.69 bcm) Karnataka (16.40 bcm), Telangana (15.03 bcm), and Kerala (5.12 bcm). In the southern peninsular states, the groundwater availability depends on the secondary porosity development due to high weathering and fracturing. In some southern peninsular areas, groundwater is available at shallow depths of 20 to 40 meters, and in other parts, it may be available at as deep as 100 to 200 meters.

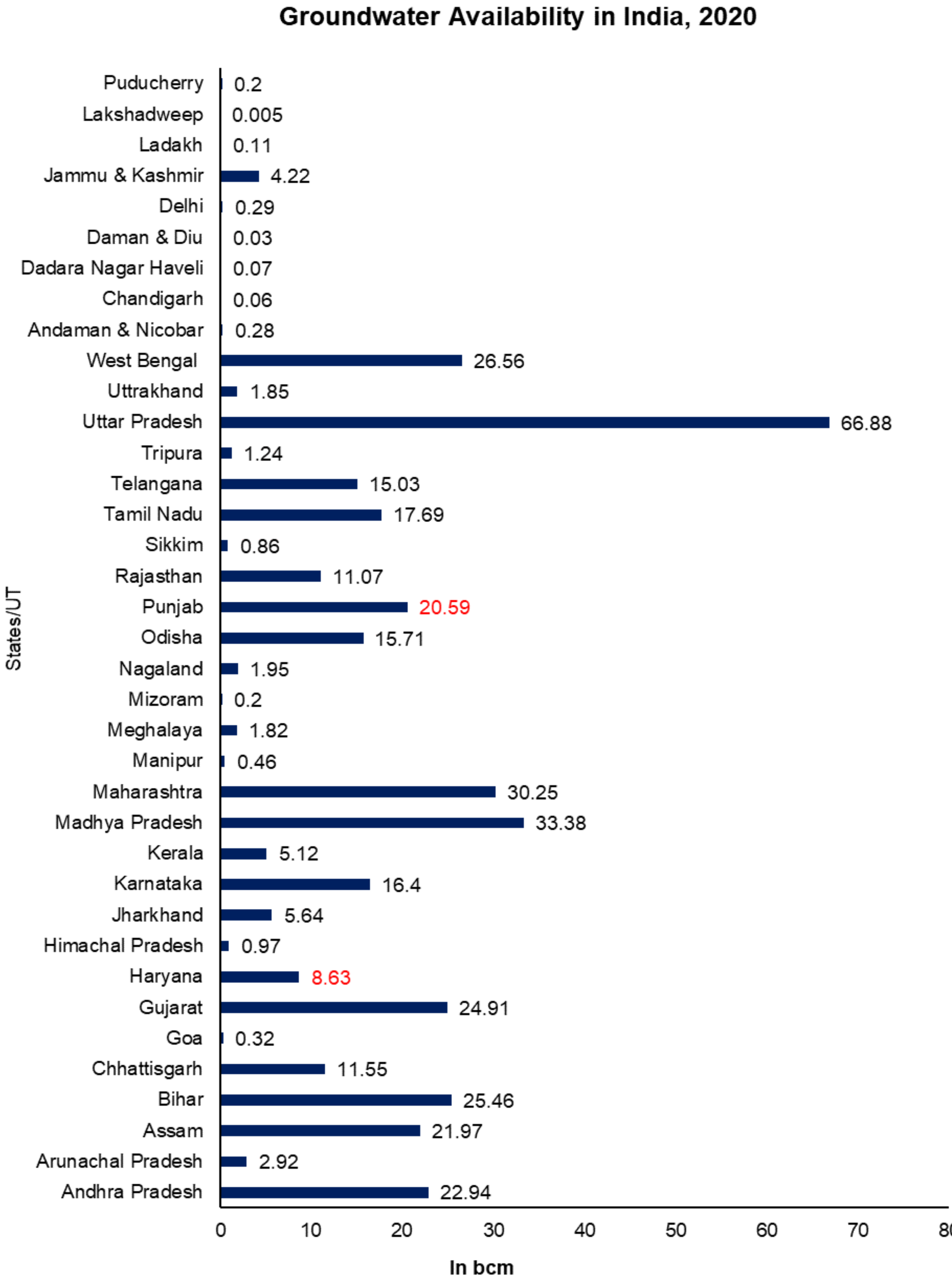
Groundwater Availability in India, 2020
States/UT
Puducherry 0.2
Lakshadweep 0.005
Ladakh 0.11
Jammu & Kashmir 4.22
Delhi 0.29
Daman & Diu 0.03
Dadara Nagar Haveli 0.07
Chandigarh 0.06
Andaman & Nicobar 0.28
West Bengal 26.56
Uttrakhand 1.85
Uttar Pradesh 66.88
Tripura 1.24
Telangana 15.03
Tamil Nadu 17.69
Sikkim 0.86
Rajasthan 11.07
Punjab 20.59
Odisha 15.71
Nagaland 1.95
Mizoram 0.2
Meghalaya 1.82
Manipur 0.46
Maharashtra 30.25
Madhya Pradesh 33.38
Kerala 5.12
Karnataka 16.4
Jharkhand 5.64
Himachal Pradesh 0.97
Haryana 8.63
Gujarat 24.91
Goa 0.32
Chhattisgarh 11.55
Bihar 25.46
Assam 21.97
Arunachal Pradesh 2.92
Andhra Pradesh 22.94
0 10 20 30 40 50 60 70 80
In bcm

Figure: 3

Source: Compiled and computed from Report on "Dynamics Groundwater Resources of India" (as on June, 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

The availability of ground-water in India is very different in its various states. In terms of spatial distribution, net annual water availability which ranges from 0.20 bcm in Mizoram to 66.88 bcm in Uttar Pradesh. It shows very high spatial variability of ground water availability in India. It is clear that groundwater availability is very high, with 170.09 bcm or more in the Indo-Ganges and Brahmaputra plains from Punjab to Assam. It is responsible for the high aquifer recharge in these areas due to the spring soil and heavy rainfall.

In peninsular India and hilly states, however, groundwater availability is relatively low. In this region of India, Kerala has the lowest availability of groundwater, followed by Telangana, Karnataka, Tamil Nadu, and Andhra Pradesh. This can be attributed to low porosity as recharge is mainly dependent on porosity that develops due to weathering and fracturing. Ground water availability in the hilly region (Mizoram, Manipur, Sikkim, Himachal Pradesh, Tripura, Uttrakhand, Meghalaya, Nagaland, Arunachal Pradesh, Jammu and Kashmir) is quite low. The steep slope and low capacity of the soil horizon to store groundwater as a result of rapid runoff are the main factors for this situation. The availability of low groundwater in arid and semi-arid regions such as Rajasthan and Gujarat is mainly due to scanty rainfall.

4.2 Groundwater Draft in India

Groundwater extraction for various uses and evapotranspiration from shallow water table areas constitutes the significant groundwater draft components. In general, the irrigation sector remains the primary consumer of groundwater. The groundwater draft for the country has been assessed as 244.92 bcm (CGWB, 2020), about 88.85 per cent of which is utilized for irrigation and the remaining 24.37 bcm (9.95 per cent) for domestic, and 2.94 bcm (1.20 per cent) for industrial uses (Figure 4).

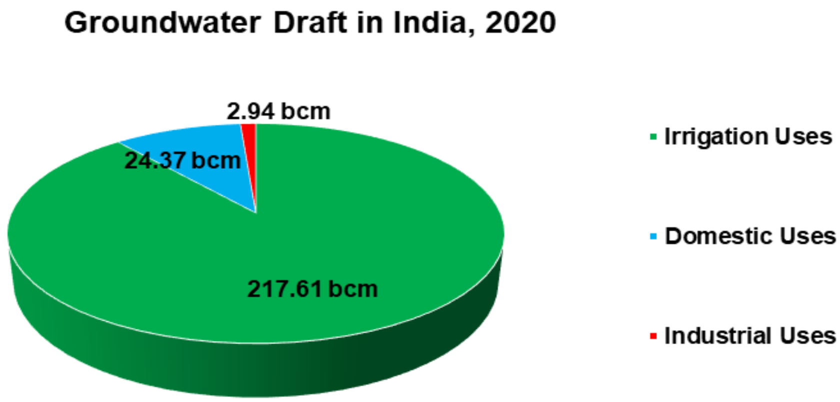

Figure: 4

Source: Compiled and computed from Report on "Dynamics Groundwater Resources of India" (as on June 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

There were significant variations in the draft of groundwater in the states of India. Table 3.1 shows that the net annual draft of groundwater in the country for irrigation is 217.61 bcm in 2020.

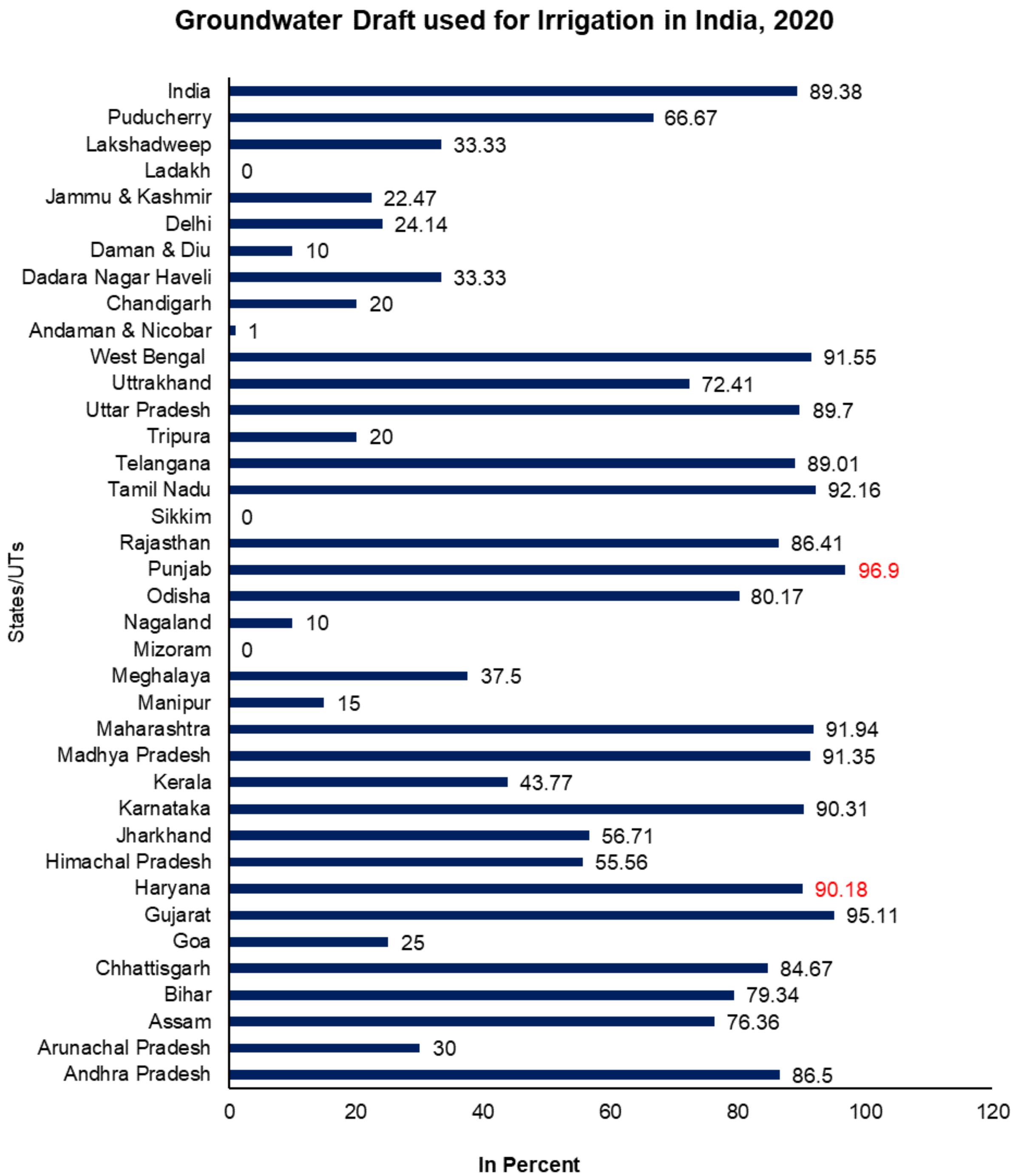

Figure: 5

Source: Compiled and computed from Report on "Dynamics Groundwater Resources of India" (as on June 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

The figure 5 shows that in the state of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, and Assam, which are the part of the Indo-Gangetic and Brahmaputra Plains, the percentage of groundwater draft for irrigation is very high and can support the extensive scale of groundwater development. Among these states, Punjab (96.9 per cent) has the highest percentage of groundwater draft for irrigation, followed by West Bengal (91.55 per cent), Haryana (90.18 per cent), Uttar Pradesh (89.7 per cent), Bihar (79.34 per cent), Assam (76.36 per cent). This may be associated to the cultivation of water intensive crops like rice and wheat which are the main crops of this region. Among the peninsular Indian states, Tamil Nadu (92.16 per cent) has also the highest percentage of groundwater draft for irrigation, followed by Karnataka (90.31 per cent), Telangana (89.01 per cent), Andhra Pradesh (86.5 per cent), and Kerala (43.77 per cent). In hilly states, however, groundwater draft is relatively low. In the remaining states of India, the groundwater draft is noticed less than the annual recharge. This indicates that pressure on groundwater has become more prominent in the Indo-Gangetic Plain resulting in large-scale groundwater mining.

4.3 Groundwater Balance in India

The table 1 shows that India has a net balance of 184.56 bcm for future use in 2020. Fifteen states out of 28 states of the country have recorded less than five bcm of groundwater availability for future use. Among these states Haryana and Punjab are the two states which have worst situation related to future groundwater availability. The future availability of groundwater in these states are have very low only 0.97 bcm in Haryana and 1.61 bcm in Punjab. This may be associated to the cultivation of water intensive crops like rice and wheat which are the two main crops of these states and extract their groundwater for irrigation above more than 90 per cent.

Among all states, Uttar Pradesh has the highest amount of (21.53 bcm) groundwater availability for future use (Figure 6). The ground water availability for future use in the northern and north-eastern hilly region (Himachal Pradesh, Jammu and Kashmir, Ladakh, Uttrakhand, Mizoram, Manipur, Sikkim, Tripura, Meghalaya, Nagaland, and Arunachal Pradesh) is quite low (Figure 6). The steep slope and low capacity of the soil horizon to store groundwater as a result of rapid runoff are the main factors for this situation.

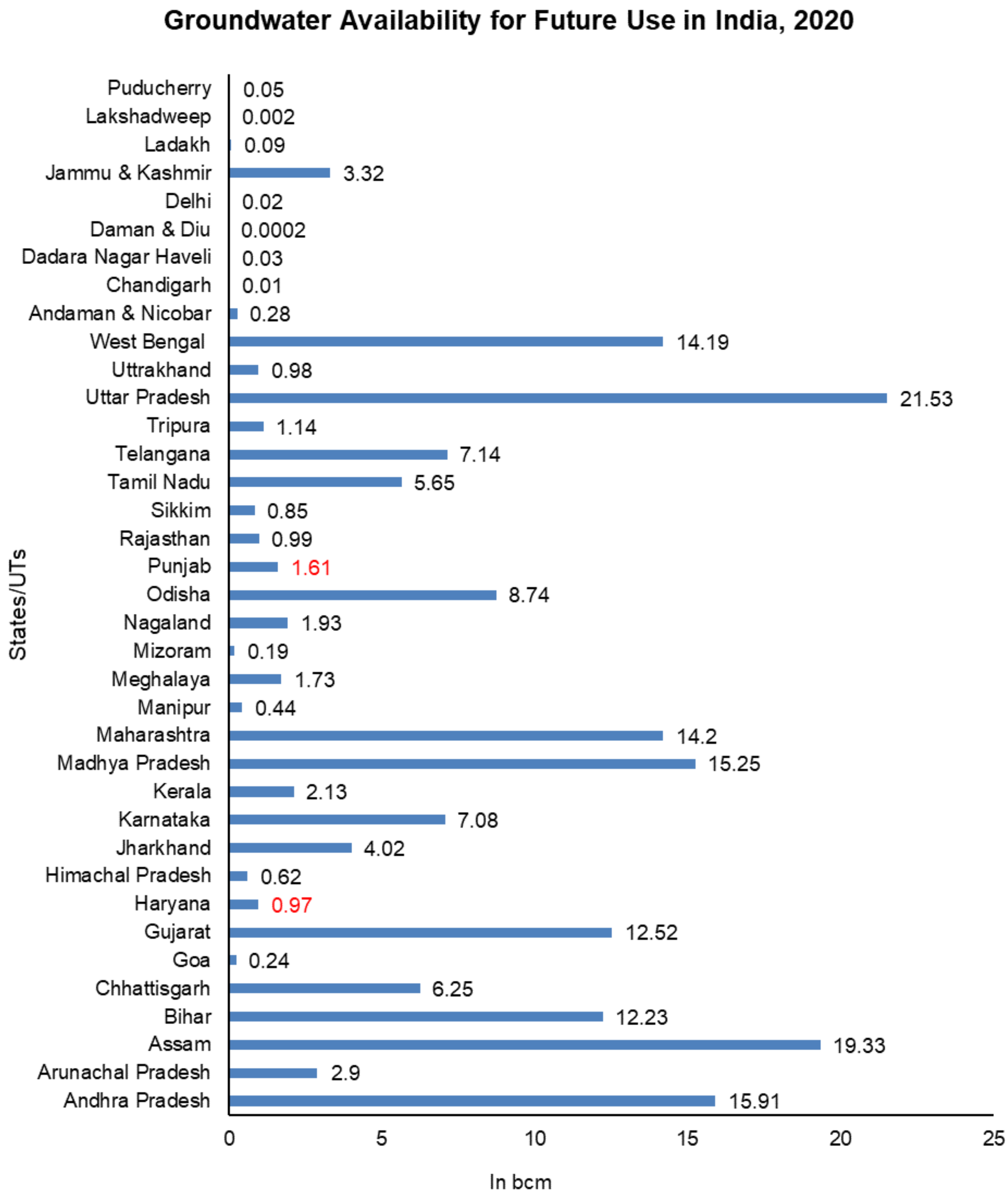

Figure: 6

Source: Compiled and computed from Report on “Dynamics Groundwater Resources of India” (as on June 2020) Central Groundwater Board, Ministry of Water Resources, Faridabad (Haryana), 2021

4.4 Groundwater Development Stages in India

The groundwater development stage, computed as the groundwater draft ratio to total replenishable resource, works out as about 61.60 percent for the country. However, groundwater development in the country is highly uneven and shows considerable variations from region to region. According to the Central Ground Water Board (CGWB) latest assessment, the overall stage of groundwater development in India is 62 percent, indicating a comfortable situation at the aggregate level. This, however, masks the high degree of variability in the availability and development of groundwater throughout the country. It can be seen that there is a high degree of variability in annual groundwater draft, vis-a-vas net availability across all states. There is a high degree of variability in the availability and development of groundwater throughout the country (Singh & Amrita, 2015). In northern and north-eastern Himalayan hilly regions (states of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Manipur, Meghalaya, Sikkim, Tripura, Nagaland, and Arunachal Pradesh) the groundwater availability is low due to the low storage capacity of water in the soil and quick runoff by the high slope. In arid and semi-arid regions like Rajasthan and Gujarat, groundwater availability is also deficient due to scanty rainfall and less groundwater recharge. The little groundwater which is available in this dry region is also found at greater depths. At the national level, Punjab state (164.42 percent) has the highest stage of groundwater development, followed by Rajasthan (150.22 per cent), Haryana (134.56 per cent), and Delhi 101.40 per cent (figure 7).

As regards use, the extent of the draft of groundwater has increased significantly over the years. It is estimated that currently, there are approximately 29.49 million wells are in the country, out of 10.12 million dug wells, 5.38 million shallow tubewells, 68000 public bore/tubewells, 9.34 million electric pump sets, and 4.59 million diesel pump sets (Ministry of Water Resources, GEC, 2017), which are drawing about 244.92 bcm of water – 217.61 bcm for irrigation and 27.31 bcm for domestic and industrial use, out of net annual groundwater availability of 397.64 bcm. The irrigation potential created has exceeded the ultimate potential in many states, showing groundwater mining exploitation beyond the dynamic resource is already taking place. At the national level, 88.85 percent of the groundwater draft is used for irrigation. Nevertheless, it is noteworthy to mention that in some states like Punjab (33.85 bcm), Rajasthan (16.63 bcm), and Haryana (11.61 bcm), groundwater draft for irrigation, industrial, and domestic uses is higher than the net groundwater availability (20.59 bcm, 11.07 bcm, 8.63 bcm) indicating towards groundwater mining or negative groundwater balance. These states, Punjab, Rajasthan, and Haryana shows the negative groundwater balance of 13.26 bcm, 5.56 bcm, and 2.98 bcm, indicating a threat to groundwater resources' future availability and endangering groundwater irrigation sustainability (Singh & Amrita, 2015).

To better understand the groundwater resources availability and status of its utilization in India, categorizations of the states have been done in table 2, where all the districts have been shown in eight categories by regions i e. Northern Himalayan States, North Eastern Hilly States, Eastern

Plain States, North Western Plain States, Western Arid Region, Central Plateau States, Southern Peninsular States, and Islands.

Table:2 Groundwater Resources Availability and Status of its Utilization in India by Regions, 2020

Regions	Net Annual Ground water Availability (bcm)	Ground water Draft (bcm)	Ground water Availability for future use (bcm)	Stage of Ground water Development (%)	Categorization of Assessment Units (Blocks, Mandals, Taluks)		
					Total Assessment Units	Over Exploited Nos (%)	Critical Nos (%)
Northern Himalayan States	7.15	2.14	5.01	29.93	50	0 (0.0)	0 (0.0)
North Eastern Hilly States	31.42	2.83	28.51	9.01	160	0 (0)	0 (0)
Eastern Plain States	67.73	31.72	35.16	46.83	1116	7 (0.63)	6 (0.54)
North Western Plain States	96.45	91.83	24.14	95.21	1156	285 (24.65)	74 (6.40)
Western Arid Region	36.01	29.96	13.51	83.19	545	229 (42.02)	27 (4.95)
Central Plateau States	81.21	42.7	39.99	52.58	1088	39 (3.58)	27 (2.48)
Southern	77.38	43.74	37.96	56.53	2805	554	136

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Peninsular States						(19.75)	(4.85)
Islands	0.285	0.013	0.282	4.56	45	0 (0)	0 (0)
Country Total	397.64	244.92	184.56	61.60	6965	1114 (15.99)	270 (3.88)

Source: Report on "Dynamic Groundwater Resources of India" (as on June 2020), Central Ground Water Board, Ministry of Water Resources, 2021.
Note: Above divisions have been adopted from the article, Jha, B. M & Sinha, S. K (2006), "Towards Better Management of Groundwater Resources in India. CGWB, Bhujal Bhawan, CGO Complex, Faridabad, Haryana.
Northern Himalayan States: - Himachal Pradesh, Jammu & Kashmir, Uttrakhand.
North Eastern Hilly States: - Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura.
Eastern Plain States: - Bihar, Orissa, and West Bengal.
North Western Plain States: - Delhi, Haryana, Punjab, Uttar Pradesh, Chandigarh.
Western Arid Region: - Gujarat, Rajasthan, Daman & Diu.
Central Plateau States: - Chhattisgarh, Goa, Jharkhand, Madhya Pradesh, Maharashtra, Dadra & Nagar Haveli.
Southern Peninsular States: - Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Telangana, Pondicherry.
Islands: - Andaman & Nicobar, Lakshadweep.

5. Extent of Groundwater Over-Exploitation in India

Groundwater Over-Exploitation may be defined as a situation in which, for some years, the average abstraction rate from aquifers is greater than closer to the average recharge rate (Custodio, 2002). The last half-century has witnessed a spectacular development in groundwater use (Kulkarni, Shah, & Shankar, 2015). The Central Ground Water Board (CGWB) norms for the various groundwater exploitation categories are given in table 3. The assessment units are blocks/Mandals/Talukas, and four categories of groundwater exploitation levels are categorized as safe (areas which have groundwater potential for development), Semi-Critical (areas where cautious groundwater development is recommended), Critical and Over-Exploited (areas where there should be intensive monitoring and evaluation and future groundwater development be linked with water conservation measures) according to the different stages of groundwater use (table 4).

Table:3 Criteria for Categorisation of Assessment Units

Stage of Groundwater use	Status of Decline in Groundwater level	Categorization
<=70%	No pre and post-monsoon significant long term decline	Safe
>70% and <=90%	Significant long term decline in either pre-monsoon or post-monsoon	Semi-Critical
>90% and <=100%	Significant long term decline in both pre-monsoon and post-monsoon	Critical
>100%	Significant long term decline in pre or post-monsoon or both	Over-Exploited

Source: Report on "Dynamic Groundwater Resources of India" (as on June 2020), Central Ground Water Board, Ministry of Water Resources, 2021.

Table:4 Categorization of Blocks/Mandals/Talukas in India, 2020

States/Union Territories	Total No. of Assessed Units	Safe		Semi Critical		Critical		Over Exploited	
		Nos.	%	Nos.	%	Nos.	%	Nos.	%
Andhra Pradesh	667	551	82.6	40	6	15	2.3	23	3.5
Arunachal Pradesh	11	11	100	0	0	0	0	0	0
Assam	28	28	100	0	0	0	0	0	0
Bihar	534	471	88.2	51	9.6	5	0.9	7	1.3
Chhattisgarh	146	110	75.3	27	18.5	9	6.2	0	0
Delhi	34	3	8.8	7	20.6	7	20.6	17	50
Goa	12	12	100	0	0	0	0	0	0
Gujarat	248	182	73.4	24	9.7	4	1.6	25	10.1
Haryana	141	30	21.3	14	9.9	12	8.5	85	60.3
Himachal	10	10	100	0	0	0	0	0	0

Pradesh									
Jharkhand	259	244	94.2	10	3.9	2	0.8	3	1.2
Karnataka	227	130	57.3	35	15.4	10	4.4	52	22.9
Kerala	152	120	78.9	29	19.1	3	1.9	0	0
Madhya Pradesh	317	233	73.5	50	15.8	8	2.5	26	8.2
Maharashtra	353	271	76.8	63	17.9	8	2.3	10	2.8
Manipur	9	9	100	0	0	0	0	0	0
Meghalaya	12	12	100	0	0	0	0	0	0
Mizoram	26	26	100	0	0	0	0	0	0
Nagaland	11	11	100	0	0	0	0	0	0
Odisha	314	302	96.2	6	1.9	0	0	0	0
Punjab	150	17	11.3	10	6.7	6	4	117	78
Rajasthan	295	37	12.5	29	9.8	23	7.8	203	68.8
Sikkim	4	4	100	0	0	0	0	0	0
Tamil Nadu	1166	409	35.1	225	19.3	63	5.4	435	37.3
Telangana	589	321	54.5	180	30.6	44	7.5	44	7.5
Tripura	59	59	100	0	0	0	0	0	0
Uttar Pradesh	830	541	65.2	174	21	49	5.9	66	7.9
Uttrakhand	18	14	77.8	4	22	0	0	0	0
West Bengal	268	191	71.3	76	28.4	1	0.4	0	0
Total States	6890	4359	63.3	1054	15.3	268	3.9	1113	16.2
Total UTs	75	68	90.7	3	4	2	2.7	1	1.3
Grant Total	6965	4427	63.6	1057	15.2	270	3.9	1114	16

Source: Report on "Dynamic Groundwater Resources of India" (as on June 2020), Central Ground Water Board, Ministry of Water Resources, 2021

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At the national level, out of 6,965 assessment units assessed jointly by state groundwater departments and central ground water board in the country, 4,427 are safe (63.56 per cent), 1057 are semi-critical (15.18 per cent), 270 are critical (3.88 per cent), and 1,114 are over-exploited (15.99 per cent). The number of over-exploited and critical administrative units is significantly higher in six states and one union territory, Punjab, Rajasthan, Delhi, Haryana, Tamil Nadu, Karnataka, and Uttar Pradesh. Among all the states and union territories, the groundwater development in Punjab state is reported to be most critical with the highest percentage of blocks under the overexploited category, which is as high as 78 percent, followed by Rajasthan, Haryana, and Delhi, where the percentage of an over-exploited block is 68.8, 60.28, and 50.

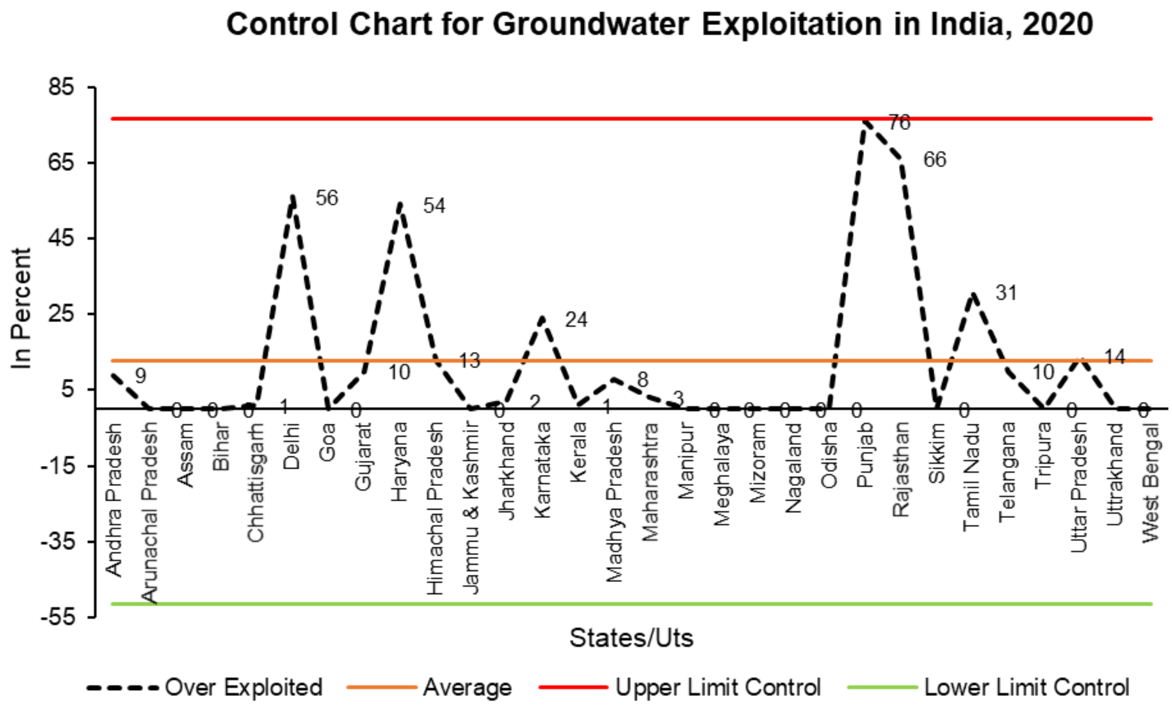

Figure: 9

Source: Report on "Dynamic Groundwater Resources of India" (as on June 2020), Central Ground Water Board, Ministry of Water Resources, 2021

6. The Causes of Groundwater Over-Exploitation in India

The dependence of irrigation on groundwater increased with the green revolution, which depended on an intensive use of inputs such as water and fertilizers to boost farm production (Kumar, 2014). Incentives such as credit for irrigation equipment and subsidies for electricity supply have further worsened the situation (Kasana & Singh, 2017). Low power tariffs have led to excessive water usage, leading to a sharp fall in groundwater tables (Kasana & Singh, 2017; Singh, Kasana, Singh, & Sarangi, 2020). According to the Expert Group's Report on "Groundwater Management and Ownership," 2007, in most parts of the country's over-exploited areas, the prime cause of over-exploitation is the rising demand for groundwater from the agriculture sector (in some parts, it is growing urbanization and industrialization). Further, in many groundwater's' irrigated areas, farmers' decisions on cropping pattern and cropping intensity, which are the predominant determinants of agricultural demand for groundwater, are mainly taken independent of the ease of groundwater availability. Thus, water-intensive crops have tended to be grown even in the face of scarcity of groundwater if these crops are perceived to be relatively remunerative (Gautam & Sangwan, 2021). Such distortions occur partly due to the legal/regulatory regime governing groundwater and partly to the minimum support price policy and agricultural trade policy currently being followed. The problem has been compounded by the availability of cheap subsidized or even free power in many states since power is the main component of the cost of groundwater use. Moreover, the electric supply is not metered, and a flat tariff is charged depending on the pump's horsepower. This makes the marginal cost powerless and provides farmers with little incentive to use power or water more efficiently. Power subsidy has undoubtedly encouraged the greater use of groundwater (Saleth, 1997; Dubash, 2007; Mukherji, Shah, & Verma, 2010; Kumar, Scott, & Singh, 2013). There has been a widespread debate on the reasons for groundwater depletion by several research scholars. Bhatia (1992) has revealed that the green revolution's modern technologies have played a significant part in the current crisis of groundwater overexploitation. Jeet (1999) has concluded about the significant factors of groundwater depletion in Eastern Haryana are intensive irrigation development of the area, groundwater quality, cropping intensity, changing cropping pattern, accessibility to modern Water Extraction Machines (WEM), the inefficiency of traditional irrigation sources like canals and tanks, High Yielding Variety (HYV) of seeds and lack of water recharge due to rainfall below normal. Nagaraj and Chandrakanth (1997) delineated the most worrisome manifestation of politicization in the recent period: political rent-seeking by offering free and highly subsidized electricity for lifting groundwater and providing soft loans to sink tube wells, which has led to the overexploitation of groundwater resources. The massive expansion of the rural electrification network reduced a farmer's capital need for powering his tube well pump set and reduced his unit operational cost wherever he managed to affect a switchover from costlier oil-driven to less expensive electric power pumps. Furthermore, while subsidy schemes have encouraged groundwater development, very little attention has been devoted to maintaining traditional irrigation sources such as canals and ponds. That is why while tube well irrigation has increased by many folds, area irrigated by conventional sources such as canals is on the decline. Canals have dried up in many parts of the state, which played a crucial role in the past in providing irrigation water and recharging groundwater. Overall, groundwater has emerged as a crucial productive resource, although assuming a scarce resource status with time. Groundwater irrigation is more flexible and reliable than canal irrigation, so groundwater uses reached a large extent (Gautam, 2021). The overexploitation of groundwater in many parts of India is being to such an extent that the water table has fallen to the levels that make pumping difficult and too costly. Small farmers with little resources are often insecure about water rights and most affected. The depletion of groundwater has forced the farmers to replace the traditional pump sets with expensive submersible pump sets (Kumar, 2014). The increase in groundwater depth in many regions has three significant hazards: increasing energy requirement for irrigation purpose and cost of groundwater pumping, increasing of tubewell infrastructure, deteriorating groundwater quality and quantity. If the trend of groundwater depletion continues, the water level may reach a depth from where the lifting of it may not be possible for irrigation purposes (Brar and Roychand, 2011). As a result of this, there is an excellent risk of converting this extremely productive area into a barren region.

7. Conclusions

The accelerated pace at which the groundwater resources have been exhausted, without replenishment, has thrown the most valuable ingredient of the modern agricultural system out of gear. Tubewell irrigation that acted as the most powerful harbinger of the green revolution technology was primarily responsible for introducing new crops and reshaping existing crop combinations, and was the most domineering instrument in pushing up cropping intensity, is now inflicting technological and commercial infirmities, not only on the small and marginal farmers but on the medium and large farmers as well. The depletion of groundwater resources now stands among the most serious concerns for irrigation availability, agricultural productivity, cost of production and efficiency, income distribution, and the entire edifice of agriculture in many parts of the Indian economy. As a result, all farmers in an area may be forced to upgrade their pumps or abandon tubewell irrigation. The process is further encouraged by the supply of free and highly subsidized electricity for agricultural use. Given human nature, anything supplied free and highly subsidized charge is likely to be misused. In such a scenario, if all farmers switch to submersible pumps, which are much more energy-intensive than centrifugal pumps, the groundwater exploitation rate will be intensified further. Overexploitation leads to two critical consequences; an increase in pumping depths, reduction in tubewell yields, the rise in the cost of pumping groundwater, and the second widespread and acute scarcity of groundwater in summer months for irrigation and drinking uses. In such cases of groundwater depletion, the cost of cultivation increases leading to declining profitability. On the other, the scarce resource's rising economic cost leads to widespread inequity in the use and accessibility of this common property resource. On both counts stated above, sustainability suffers. With overexploitation, the physical availability of water declines, and due to an increase in pumping depths, it raises severe consequences on the economic accessibility of groundwater to various sections of the society. While depletion of groundwater endangers ecological sustainability, creating intragenerational inequity to groundwater accessibility, the rising costs of extracting the resource endanger economic sustainability, creating inter-generational inequity to accessibility to this precious resource.

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