American Journal of Water Resources, 2016, Vol. 4, No.1, 16-21
Available online at http://pubs.sciepub.com/ajwr/4/1/2
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DOI:10.12691/ajwr-4-1-2

Sustainable Drinking Water Resources in Difficult Topography of Hilly State Uttarakhand, India

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Abstract Uttarakhand state is blessed with major water resources including large reverine system with its tributaries. In spite of the plethora of water resources, the people of the state are facing the problem of safe fresh water due to slope factor, management issues, urban conglomeration, deforestation and other environmental factors as discussed in the article. Besides this, an integrated approach considering the national water policy in state context is urgently required in difficult topographic and changing climatic conditions. The present article highlights the hydrogeology of the state, sustainable water resources including traditional water resources, drinking water supply system in state, Uttaranchal Koop, bank filtration technology. Furthermore, various suggestions are also incorporated for the fortification of water resources of the state.

Keywords: *Drinking Water Resources, Topography, Himalayan state, Uttarakhand, India, Sustainability, Climate Change*

Cite This Article: Bhavtosh Sharma, "Sustainable Drinking Water Resources in Difficult Topography of Hilly State Uttarakhand, India." *American Journal of Water Resources*, vol. 4, no. 1 (2016): 16-21. doi: 10.12691/ajwr-4-1-2.

1. Introduction

The term sustainability has become a key factor in the current environmental conservation process. Now a days, the natural process of our planet earth are not very safe in developmental process globally. Fresh water, which is very essential for the survival of living beings, is also in critical stage due to unplanned industrialization, urbanization and lack of awareness among most of the people. India, which is a developing country, possess its some of the states in Himalayan lap, among northern Himalayan region, Uttarakhand is 27th state of India which has been carved out from Uttar Pradesh in 2000.

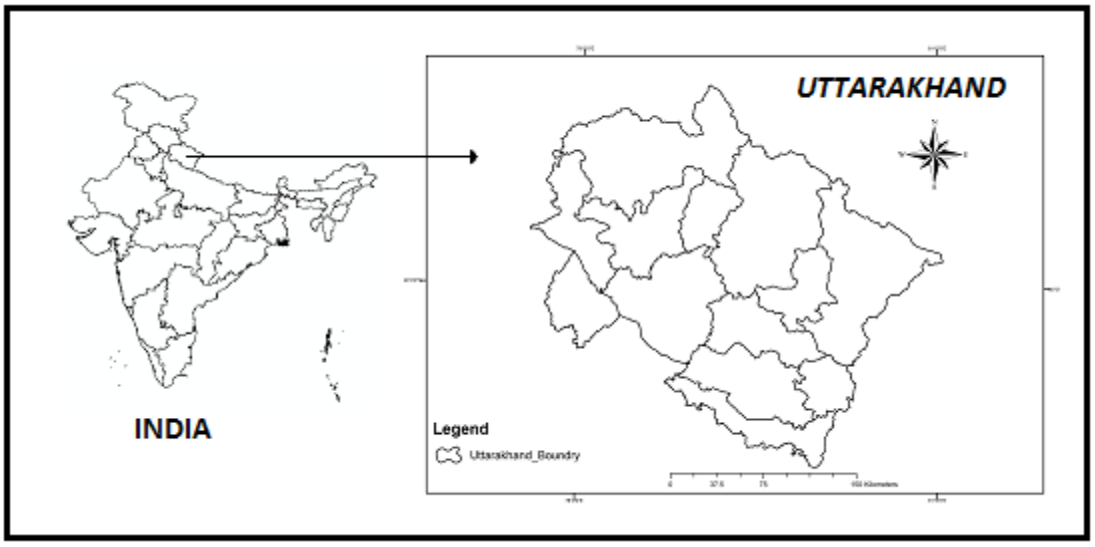

Figure 1. Map of Uttarakhand with its all districts

Uttarakhand is well situated at the foothills of the Himalayan ranges with mountainous topography. The state is also well known as 'Dev Bhumi' due to presence of so many religious places in state. There are two regions in the state namely Garhwal and Kumaun region having 13 districts in difficult geographic conditions (Figure 1 and Figure 2). Uttarakhand has a large forest cover area approximately 38000 square km in 2014 [1]. Rawat [2]

reported that the state has 8 catchments, 26 watersheds, 116 sub watersheds, 1120 micro-watersheds. It is evident that the state is rich with several natural resources especially water with many glaciers, rivers, springs and lakes etc.

Figure 2. Various water resources and difficult geography of Uttarakhand

The perennial sources of water in the state are regularly snow covered high altitude mountain ranges. The population of the state has reached up to 101.16 lacs with 4.88% increase in urban population in last decade [3]. Confederation of Indian Industries (CII) has reported that only 52% population of the state possess full access of safe drinking water [4]. According to Bureau of Indian Standard, atleast 70-100 litre per head per day water is required for domestic needs in urban communities without flushing requirement [5]. The availability of fresh drinking water in ample quantity is an important criterion for the selection of place for settlement purposes in the hilly terrain. However, there is also deficit of water in developed cities like Dehradun, Haridwar, Rudrapur and Kashipur due to huge number of settlements [6]. During rainy season, the fresh water of glacial fed major rivers of the state is not suitable for human consumption due to the presence of excessive suspended and dissolved solids.

The availability of fresh and pure water quality has become a serious issue not only in urban areas but in rural areas of the state besides this, hilly as well as plain area of the state also facing with the problem of standard water quality [7-19].

Therefore, the present article highlights the difficult topography of Himalayan and hilly state Uttarakhand. Several surface ground water resources, technical devices, drinking water supply system of the state are also discussed which are providing the drinking water to the state population.

2. Hydrogeology of Uttarakhand Area

The state possesses a very assorted hydrogeological set-up and can be divided in two hydrogeological regimes as Gangatic Alluvial Plain and Himalayan Mountain Belt [20,21,22,23].

2.1. Gangatic Alluvial Plain

This zone is further divided into 3 parts as:

(i) Axial Belt (Alluvial Plains):

The aquifers of this zone are of unconfined to confined nature and in general ground water potential in this zone is good.

(ii) Tarai:

Several potential aquifers with good quality of ground water occur in this zone due to the presence of highly porous and permeable nature of the sedimentary derived constituting material.

(iii) Bhabar:

It has a potential hydrogeological unit but the ground water occurs at much deeper levels (> 100 m below ground level).

2.2. Himalayan Mountain Belt

This regime constitutes a major part of whole geographical area of the state and can be studied in to following units:

(i) Outer Himalaya (Siwalik Mountain Range):

This part has potential ground water holding units with highly fractured or jointed rocks.

(ii) Lesser Himalaya:

Springs as a major source of groundwater occurs in this part. Many hand pumps have been installed satisfactorily and some tube wells in river valleys also.

(iii) Central Himalaya:

There are cold water and hot water springs (i.e. thermal springs) in this zone.

(iv) Tethys Himalaya:

Usually this is an appropriate zone for ground water development because of the presence of porous and permeable nature of the litho structures present in the zone.

3. Precipitation in Uttarakhand

A heavy rain fall occurs in monsoon season and snowfall during January to March. Approximately, 1606 mm annual rainfall in state is enough to accomplish the water demand of the state [1] but unfortunately, 95% of the total precipitation flows as runoff due to high slopes of hills [24]. However, the seventy years data from 1901 to 1970 of nine districts of the state for normal monthly and annual describes that maximum rainfall occurs in July and August and the annual precipitation varies from 1256 mm to 2426 mm in Haridwar and Pithoragarh district of state, respectively [25]. Presently, there is 23% less annual precipitation in Almora in comparison to its 53 years record while Manora peak of Nainital is receiving 16% less rainfall than last 39 years (1964-2003) [26].

4. Water Supply Resources in Uttarakhand

In the beginning, peoples of hilly areas of the state utilized the water from the local sources fed by water from hilly slopes. Later on, they have developed the art that how to tap the water in hilly parts. Traditionally in hilly areas of the state naula, gul, dhara, lake, kund, khal, water mill (Gharat) are the main water harvesting structures and are also in trend in rural parts to fulfill the water needs of the local people [11].

Since, Uttarakhand is a hilly state, therefore there are several natural as well as manmade water sources. Rivers, lakes, springs or gadheras, tube wells, dug wells, Uttaranchal Koops, River Bank Filtration units etc. are the major drinking and irrigation water sources. Moreover, “chal and khal” are also supplying water for rural areas. Uttarakhand Jal Sansthan (UJS) which is a key water supply department of the state has rejuvenated 1804 khals from 2000 to 2008. Out of these, Pauri district has a maximum number of khals [27]. After, the study of year-wise discharge data of gadheras and springs of the state for the year 2005, 2006 and 2008, UJS has reported that Almora district of Kumaun region has maximum number of this type of water sources [28].

4.1. Surface Water Sources

Uttarakhand is an origin place of several Indian rivers including glacial fed rivers, non-glacial fed rivers and rainfed rivers. Ganga, Yamuna, Ramganga, Kali, Koshi rivers and their tributries constitute surface water bodies. The National Commission for Integrated Water Resources Development (NCIWRD, 1999) [29] has estimated the basin-wise average annual flow in Indian river systems as 1953 km^3 and the utilizable annual surface water of the country as 690 km^3. However, an attempt has been made to capture and present the best possible data available. The total catchment area of 12 major river basins of India is more than 20000 km^2. The total catchment area of these rivers is about 25.3 lakh km^2. Uttarakhand possess three main river basins as Bhagirathi (Alaknanda basin and Ganga basin), Yamuna (Tons basin) and Kali system.

In addition of these rivers, glaciers, lakes, numerous streams, springs etc. also contribute as a major part of surface water resources. A total 968 Himalayan glaciers are also important which have 213.74 km^3 total ice volume and cover 31449.3 km^2 basin area and 2883.37 km^2 (i.e. 9.17%) glaciered area including Chorbani, Gangotri, Khatling, Nandadevi glaciers etc. [30].

The tals such as Bhimtal, Sat tal, etc. of Nainital district of Kumaun region are important sources for drinking and irrigation purposes. Besides this, Hemkund, Rupkund and Vasukital are some of the glacial lakes whereas Nachiketatal, Nainital, Dodital, Bhimtal and Naukuchiatal are the renowned lakes of middle Himalaya. The total high altitude wetlands area in the state is 103882 ha including 231 ha of high altitudinal lakes i.e. 0.22% of total wetland area for 118 lakes which covers <1% of total wetland area of the state [31]. The lakes and tals in upper parts and middle Himalaya form an important part of total drainage system.

4.1.1. River Ganga and Yamuna

The Ganga River has been declared as the "National River" of India in November, 2008 by Govt. of India. The Ganga basin is the biggest river basin in India which covers the whole of the state, and is bound in the north by the Himalayas and in the south by the Vindhyas. Yamuna River, which is also a major and holy river, is the largest tributaries of river Ganga. This river originates from Yamunotri Glacier of Uttarkashi district and merges with Ganga at Triveni Sangam in Allahabad of Uttar Pradesh (Table 1) [32,33].

4.2. Ground Water Sources

Usually, there is no permanent water table in the hilly area just like as in plain areas. Therefore, for the utilization of subsurface water, more and exact attempt is necessary to locate and hit the perched aquifers. Himalayan areas have very much fractured rock structures

which results in rapid diffusion of precipitation below the ground and makes it very tough to tap the groundwater.

Table 1. Some Salient features of River Ganga and Yamuna [32,33]

River Ganga	
Origin	Gangotri Glacier
Length in Uttarakhand and Uttar Pradesh	1,450 km
Average annual discharge	4,93,400 million cubic metre
Tributaries	Yamuna, Ramganga, Gomti, Ghaghara, Gandak, Kosi and Kali
River Yamuna	
Origin	Yamunotri Glacier
Total length upto Dak Patthar barrage	160 km
Main tributries in Uttarakhand	Rishi Ganga, Unta and Hanuman Ganga, Kamal, Giri, Tons, Asan
Total catchment area in Uttarakhand	3771 km^2

The Gangatic Alluvial Plain is a capable zone for groundwater development where as in hilly areas ground water occurs mainly in fissures and fractures. These structures emerge in the form of water streams like gadheras or springs.

Rainfall plays a key role in the management of ground water. The ground water is a renewable reserve and is recharged annually by precipitation. There are several factors including diversified geological formations, complex tectonic framework, different climatic and hydro-chemical conditions which are responsible for the difficult performance of ground water in Uttarakhand. The dynamic of ground water resources and per hour yields of tube wells in various zones of Uttarakhand state are provided in Table 2 [1,25,34]. The block-wise details of the dynamic ground water resources of plain areas of 4 districts are described in Table 3 [35].

Table 2. Dynamic of ground water resources and yields of tube wells in Uttarakhand [1,25,34]

Ground water resources	
Annual replenishable ground water resources	2.27 BCM
Net annual ground water availability	2.10 BCM
Annual ground water draft	1.39 BCM
Stage of ground water development	66 %
Yield of Tube Wells	
Zone	Yield per hour
(i) Shivalik	50.4 – 79.2 m^3
(ii) Bhabar	Upto 332.4 m^3
(iii) Tarai	36 – 144 m^3
(iv) Indo-Gangetic	90 – 198 m^3

Table 3. Block-wise details of the dynamic ground water resources [35]

District	Block	Available ground water (in ham)	Ground water draft (in ham)	Stage of GW development	Status
Nainital	Haldwani	5628.91	2589.98	46.38	Safe
	Ramnagar	4788.75	1866.19	39.23	Safe
Udham Singh Nagar	Bazpur	13354.94	10491.72	79.7	Safe
	Gadarpur	9361.59	8705.39	94.59	Semi critical
	Jaspur	7145.79	5669.77	80.54	Critical
	Kashipur	8894.88	7625.11	87.09	Critical
	Khatima	15880.86	12592.21	80.45	Safe
	Rudrapur	11076.08	8124.81	74.37	Semi critical
	Sitarganj	17111.29	11627.80	68.081	Safe
Dehradun	Doiwala	14756.02	1079.40	7.34	Safe
	Sahaspur	15358.10	1478.28	9.67	Safe
	Vikasnagar	6500.10	1948.88	30.1	Safe
Haridwar	Bahadarabad	16650.39	7587.40	47.31	Safe
	Bhagwanpur	8930.04	8530.95	97.12	Semi critical
	Gurukul Narsan	16259.9	4772.59	47.63	Safe
	Khanpur	6077.04	4772.59	80.71	Semi critical
	Laksar	9412.74	7313.72	79.81	Semi critical
	Roorkee	16847.00	6537.89	41.56	Safe

5. Uttaranchal Koop

"Uttaranchal Koop" is a valuable indigenous device to tap the sub-surface flow of a stream in the state and is developed by Uttarakhand Jal Sansthan. In this technique water is obtained from aquifers, which are directly association with the surface water source. It is designed to tap the continuous sub-surface flow through saturated strata. Less construction cost, negligible maintenance cost, better earth quake resistance, less chances of getting damaged during monsoon, lower turbidity, less suspended particles and removal of coliform etc. make it a choice of people specially in hilly areas. The water obtained from

Uttaranchal Koop was found suitable for drinking purposes as per Indian and WHO criterion. UJS has installed total 1690 Uttaranchal Koop up to 2013-14 in state [1].

6. Bank Filtration (BF)

BF or river bank filtration (RBF) is a natural, sustainable water treatment and production technique along the banks of rivers or lakes in which the abstraction of water occurs from the wells located near river banks or lake banks. In this process surface water from rivers, channels and lakes is induced by pumping from nearby production wells to flow through the natural aquifer soil. However, a filtration well primarily derives water from the river or lake seepage. These infiltration wells have been installed in the foothill areas of Haridwar and Rishikesh adjacent to the Ganga River and also in Nainital nearby to Naini lake [36,37].

The drinking water production of Haridwar is about 60,000m^3/day and 38% of this drinking water supply is being produced by 16 large diameter vertical caisson wells having 6.5 – 10.7 m depth below ground level. A total 16 RBF wells and Tube wells in Haridwar are producing a total 25050 litre per minute discharge successfully to fulfil the water demand of the city. In the same way, 62% of total water supply in Muni Ki Reti of Rishikesh is abstracted through two infiltration wells situated on the bank of river Ganga [36,37,38].

Recently, UJS has installed four new RBF wells successfully at Srinagar, Karanprayag, Agastmuni and Satpuli on the banks of Alaknanda, Alaknanda, Mandakini and East Nayar rivers respectively, with the support of University of Applied Sciences Dresden Germany and Uttarakhand State Council for Science & Technology (UCOST). These RBF wells have an average daily production capacity of 852-937, 432-706, 220 and 756 (m^3) for all these four units respectively. Thus RBF has become a choice of the day not only in urban areas but also for rural community to supply the safe drinking water in sustainable manner [39,40,41].

7. Drinking Water Supply System in State

In the state, the drinking water is being supplied and managed mainly by the department of drinking water. The department is mainly concern with Uttarakhand Jal Sansthan (UJS), Peyjal Vikas Evam Nirman Nigam (UPJN) and Swajal Project. Currently, 13 Project Management Units of Swajal Project are working in state i.e. one in each district [27]. According to Directorate of Economics and Statistics Dehradun, 31915 and 8459 hand pumps were installed up to 2013-2014 by UPJN and UJS, respectively in the state [1].

However, Many schemes of UJS are under going in the state to cater the drinking water supply in different blocks of the state. Besides this, the decrease in discharge of many schemes has been occurred due to certain environmental conditions including climatic changes in certain areas. A list of schemes of UJS with decrease in discharge of more than 50% in last three years has been provided in the Table 4 [42].

Table 4. Various UJS scheme's with decrease in discharge [42]

Sr. No.	District	Block	50-75 %	75-90 %	> 90 %	Total
1.	Pauri	Ekeshwar	3	18	6	27
		Beeronkhal	3	11	3	17
		Kot	3	33	2	38
		Khirsu	3	9	8	20
		Pokhara	3	11	1	15
		Kalgikhal	3	20	19	42
		Pauri	3	7	-	10
		Thailisain	3	2	-	5
		Pabo	2	9	-	11
		Total	26	120	39	185
2.	Dehradun	Raipur	2	1	-	3
		Sahaspur	1	-	1	2
		Cakrata	2	1	1	4
		Doiwala	1	2	-	3
		Total	6	4	2	12
3.	Rudraprayag	Augustmuni	12	-	3	15
		Total	12	-	3	15
4.	Chamoli	Karanprayg	1	-	-	1
		Pokhari	2	2	-	4
		Dasoli	2	3	-	5
		Narayan Bagar	2	-	-	2
		Ghat	3	-	-	3
		Tharali	3	4	-	7
		Garsain	2	-	-	2
		Total	15	9	-	24
5.	Tehri	Kirtinagar	2	4	1	7
		Chamba	2	3	5	10
		Jakhinidhar	3	15	4	22
		Jaunpur	-	1	1	2
		Thauldhar	3	2	2	7
		Devprayag	3	-	-	3
		Narendranagar	3	9	2	14
		Pratapnagar	3	5	2	10
		Bhilangana	3	5	2	10
		Total	22	47	20	89
6.	Uttarkashi	Bhatwari	1	-	1	2
		Dunda	3	1	-	4
		Chinyalisaur	3	1	-	4
		Naugaon	3	-	-	3
		Total	10	2	1	13
7.	Champawat	Lohaghat	3	9	5	17
		Barakot	3	10	5	18
		Champawat	1	1	2	4
		Pati	-	15	-	15
		Total	7	35	12	54
8.	Nainital	Kotabag	3	-	-	3
		Okhalkanda	3	-	-	3
		Ramgarh	3	6	-	9
		Dhari	3	-	-	3
		Betalghat	3	1	-	4
		Bhimtal	3	-	-	3
		Total	18	7	-	25
9.	Bageshwar	Bageshwar	3	3	-	6
		Total	3	3	-	6
10.	Pithoragarh	Munakot	3	2	1	6
		Gangolihat	-	1	-	1
		Vin	3	2	1	6
		Kanalichina	3	11	4	18
		Total	9	16	6	31
11.	Almora	Tarikhet	4	13	4	21
		Bhikyasain	2	7	6	15
		Chaukhutiya	2	-	-	2
		Syaldey	3	5	-	8
		Total	11	25	10	46
		Grand Total	139	268	93	500

8. Conclusion

In general, the state has abundant water of good quality except geologically hard rocks at some places. However, more proper management of natural water resources is required to conserve the resources as well as for rainwater also. Now it has become necessary to ensure the participation of local people in planning preparation, management and operation of water resources. Besides, different organizations either govt. or non govt. sector should work in collaboration to preserve the nectar of this planet earth for future generations and for the development of the state in sustainable manner. National water policy should be implemented effectively. State water policy may also be prepared as per requirement of the state. The knowledge of Water (Prevention and Control of Pollution) Act should be given to the people, communities, students etc. and it should also be followed strictly to protect the water bodies.

Acknowledgement

The author is thankful to the Director USERC Dehradun for the providing necessary infrastructure to complete this work.

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