FINAL TECHNICAL REPORT

"Modelling for Enhancing Water Quality in Uttarakhand using Geospatial Technology"

Submitted to:

सत्यमेव जयते

Department of Science and Technology, Govt. of India (WTI Division)
Technology Bhavan, Mehrauli Road, New Delhi-110016

Submitted by:

Uttarakhand State Council for Science and Technology (UCOST), Govt. of Uttarakhand, Dehradun

Collaborative Institutes:

TERI School of Advanced Studies, New Delhi

DAV (PG) College, Dehradun

Uttarakhand Jal Sansthan (UJS), Dehradun

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Project Team

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1. Introduction

Research Gap

The proposed study has selected the entire state of Uttarakhand for water quality modeling. The representative watersheds/catchments of 13 districts of Uttarakhand namely Dehradun, Haridwar, Pauri, Tehri, Chamoli, Uttarkashi, Rudraprayag, Nainital, Almora, Pithoragarh, Bageshwar, Champawat and Udham Singh Nagar have been selected for the study of water quality. Monitoring data obtained from 2010 to 2016 by Uttarakhand State Council for Science and Technology (UCOST), Dehradun and Uttarakhand Jal Sansthan (UJS), Dehradun and DAV (PG) College Dehradun under different joint WTI, DST sponsored research projects on water quality of Uttarakhand is used for assessment of water quality. The study also looked at the seasonal variations on water quality during pre-monsoon and post-monsoon seasons.

Several types of researches have been conducted on both raw and supply water separately; it was observed that limited studies were conducted to find out the severity of water quality. Therefore, under the current study, the severity of water quality in raw water (water in natural form) in the Spatio-temporal domain was evluated. Most of the earlier studies have been conducted either in the urban or rural domain and were confined at a local scale. In the present study, both the spatial domain and temporal domain have been selected to see the intra-regional variations.

Moreover, the earlier studies were undertaken for planning and execution purposes only and not for research methodology development. However, the present study also tends to develop hydro-geospatial models for water quality at the catchment/watershed level.

The study assessed the maximum 20 water quality parameters namely turbidity, pH, alkalinity, total hardness, calcium, magnesium, chloride, fluoride, sulphate, nitrate, total dissolved solids (TDS), copper, iron, manganese, arsenic, aluminium and coliform bacteria (i.e. total coliform and E Coli), analyzed as per BIS-10500, (2012) along with sodium and Potascium under different water quality monitoring programmes. Thus, the study covered all aspects of quality assessment, which is the first attempt of its kind, where line department of drinking water supply i.e. Uttarakhand Jal Sansthan (UJS), Dehradun can use the outcome of the project for the water sector development of Uttarakhand with the help of geospatial technology.

Background

Uttarakhand provides a large amount of fresh river water for a major part of the Ganga basin (Figure 1) where habitation and agriculture are dominant. Contamination mentioned (CPCB, 2009) by Central Pollution Control Board (CPCB) and low per capita water availability (DST, 2015) reported by the Department of Science and Technology, Govt. of India, Delhi are the two key issues of this state. Contamination of water resources has become a major threat to human security. Water quality problems are caused by pollution and over-exploitation. Both human and natural activities can change the physical, chemical, and biological characteristics of water and have specific ramifications for the health of humans and ecosystems.

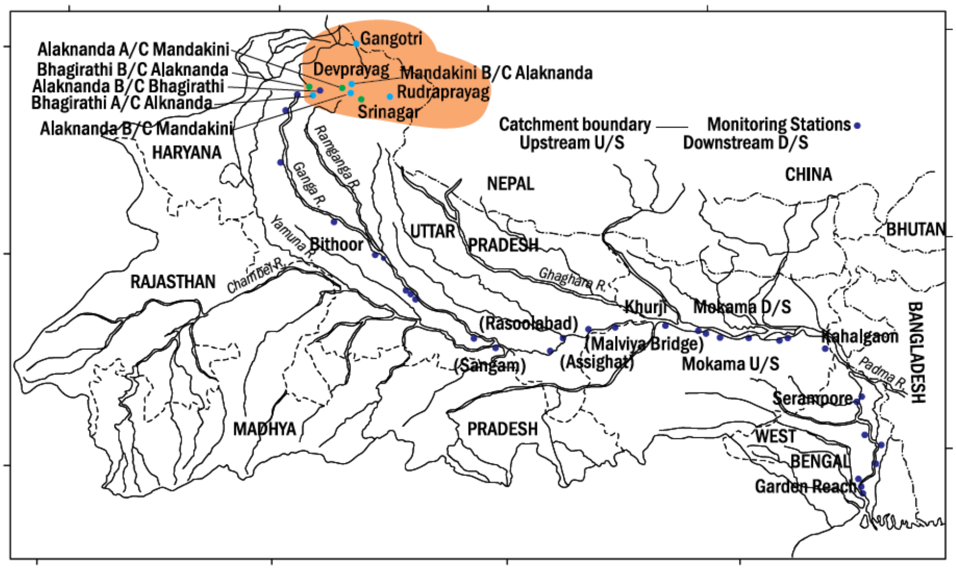


Figure 1: Quality monitoring stations (CPCB, 2009)

Over the years, rising population, growing industrialization and expanding agriculture have pushed up the water demand. It is the need of the hour to understand surface and groundwater resource potential concerning aquifers augmentation. Water quality (Carr et al., 2010) decides the extent to which it can be used for the purpose. Thus, the quality and quantity aspects of water need to be evaluated thoroughly to meet the ever-increasing needs of water for different uses, especially for drinking.

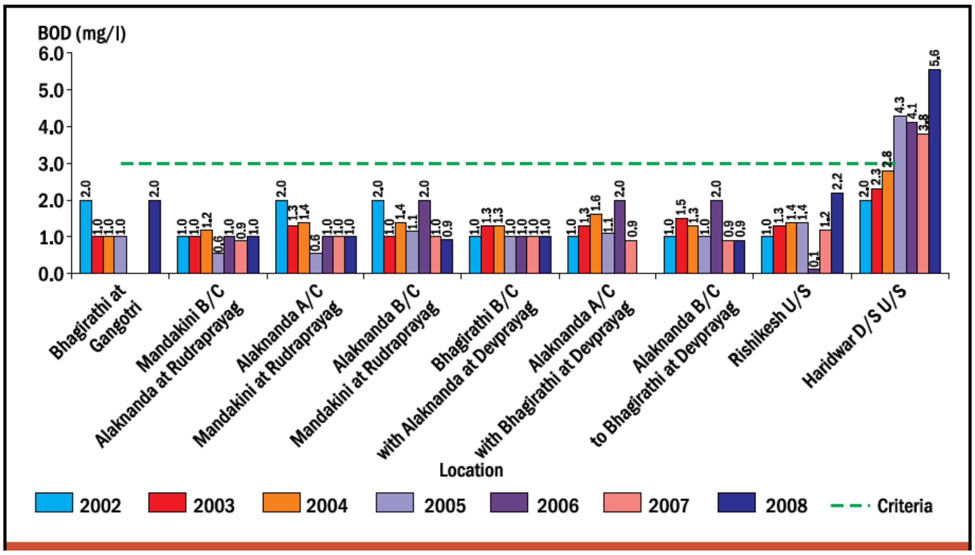


Figure 2: Time series BOD concentration from Gangotri to Haridwar (CPCB, 2009)

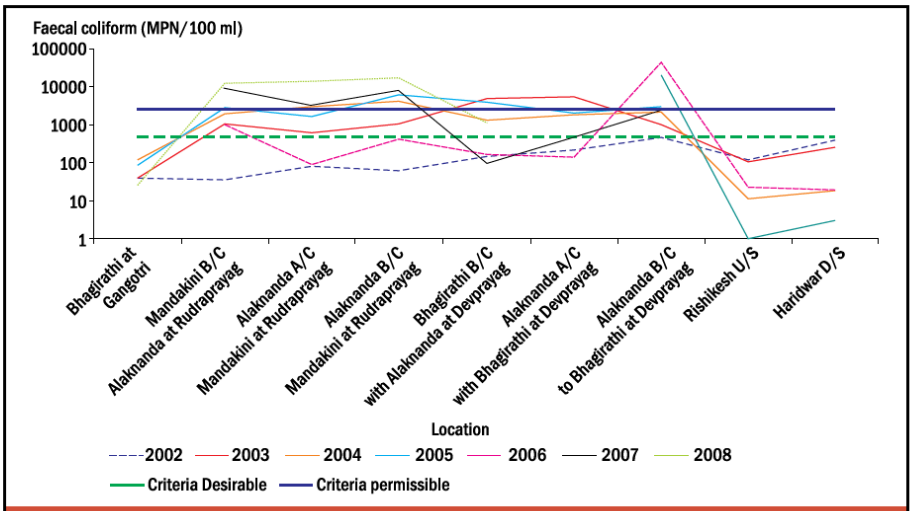


Figure 3: Time series Faecal coliform concentration from Gangotri to Haridwar (CPCB, 2009)

Researchers have reported that contamination of chromium, mercury, lead and cadmium as well as zinc is present under municipality waste. Biological degradation (Figure 2) like Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Fecal bacteria (FC) are exceeded above threshold limits (Figure 3) at major pilgrimage locations and cities of major river banks.

The rationale of the study

Unplanned management of water resources at an individual and sectoral level has resulted in poor quality and availability of safe water for drinking especially in water-scarce zones, which enters into humans and animals through food cycles, causing an increased risk of various diseases in rural and urban areas. Of course, poor people have tended to suffer the greatest health burden from inadequate and poor quality water supplies and as a result of poor health, have been unable to escape from the cycle of poverty and waterborne diseases. The major source of drinking water for the hilly area is fresh surface water, which is more vulnerable to contamination by various processes of human and natural activities.

On the other hand, the key characteristic of fresh safe drinking water is their uneven distribution and variability concerning time and space. The challenges being faced by water resource managers for any given location are a unique combination of mainly physical, cultural and engineering factors. Challenges to be met out by the water managers are of three types: shortage, surplus, and quality. It seems rationalized that effective mitigation measures are needed to cope up with climate change along with an adaptive strategy. Innovations in institutional arrangements and management structures are a necessary pre-condition for tackling the problems of management of supply of good quality and adequate quantity of water for its citizens. Waste and inadequate management of water are the main culprits behind growing problems, particularly in poverty-ridden regions of the difficult hilly state Uttarakhand.

Objectives

To provide a feasible solution of sustainable quality water availability in the Himalayan state of Uttarakhand, under which various sub-objectives are also included:

a. To undertake modeling of water quality of Uttarakhand by using primary data generated by the Uttarakhand State Council for Science & Technology under different projects using geospatial technologies.

b. To identify the quality vulnerability study of various sources of drinking water.

c. To quantify water quality at the regional and local levels to provide sufficient quality water.

d. Provide Spatio-temporal water quality dynamics and trends of future status.

e. To prepare an action plan for aquifer augmentation and sustainability of life and livelihoods.

Study area

Uttarakhand state (Figure 4) is known to be bestowed upon with a lot of natural resources. However, in the recent past, there have been reports of the state encountering problems in water resources due to its geographical constraints. Most of the districts of Uttarakhand are reported to have a poor quality of drinking water sources reported by Project Investigator's and Co-PI's groups as well as other reports have also shown higher contamination as per BIS 10500, (2012). Hence, there is a need for systematic hydrological study, which can provide a solution to the water resource problems of the mountainous state and region. The present study is an attempt to find those research-based solutions.

At present, the most exploited source for drinking and irrigation in the hilly region has been surface water (rivers and rainwater). Due to the non-availability of proper rainwater harvesting structures, rainwater is hardly available and river water becomes available only to people living nearby river banks and upstream of the area suffers low water availability due to difficult terrain conditions. Also, due to largely varied population density, water supply doesn't become accessible to the population especially in the urban areas, thereby local sources of water e.g. springs and dug wells become important for the majority of the people.

Groundwater, if properly developed, can be a good sustainable and alternative source of water for meeting the requirements of the whole state. Effects of various anthropogenic developmental activities–construction of roads, tunnels, etc groundwater storage and flow need to be studied. Moreover, the geogenic factor also affects water quality to a large extent. Under this study representative selected watershed (sub-basin) of Uttarakhand (Figure 4) have been covered for geospatial modeling of water quality and aquifer augmentation aspects. All the 13 Districts of Uttarakghnad State covering all 13 districts of both Garhwal and Kumaon regions have been the overall study area of thew project.

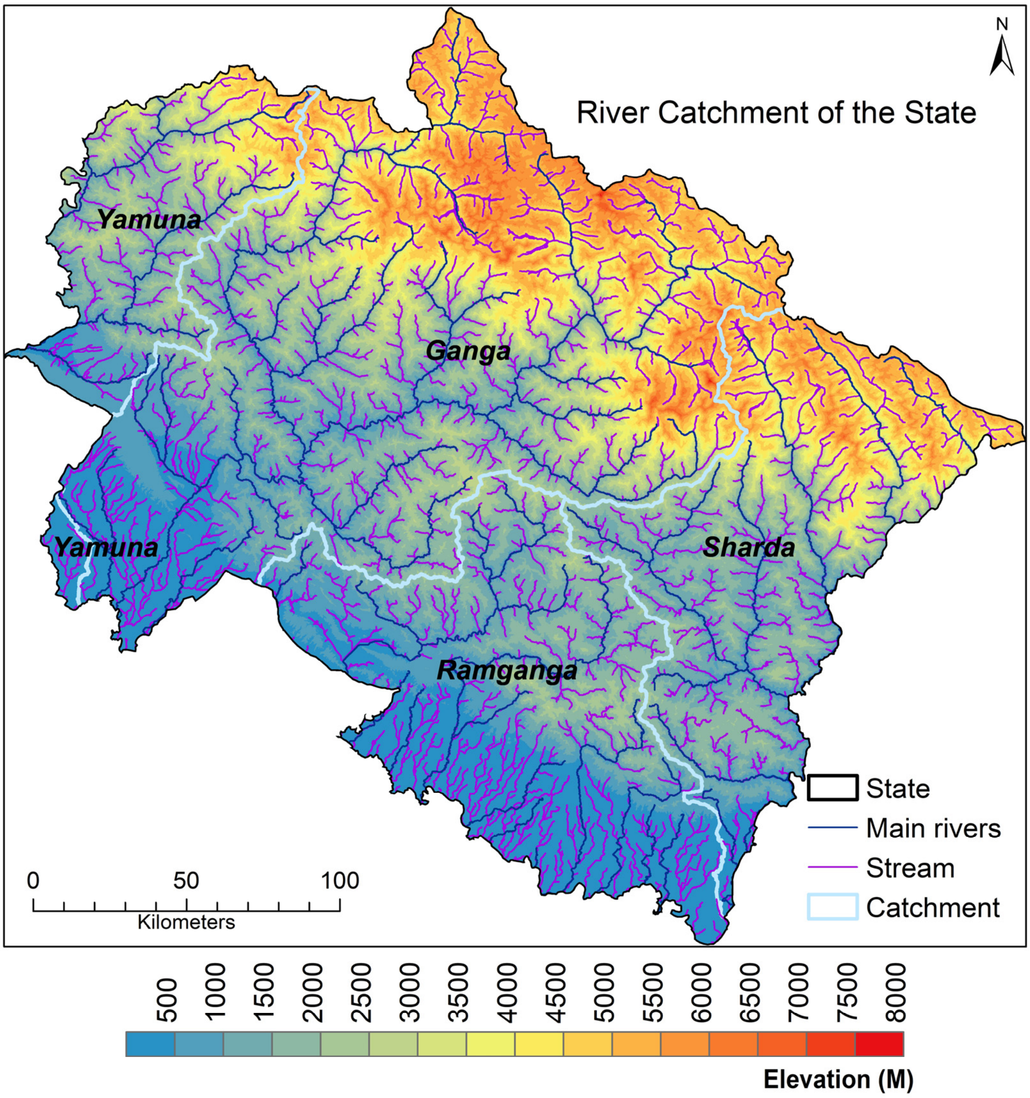


Figure 4: Four different catchments of Uttrakhand

2. Literature review

Substantial transformations have also been affecting naturally occurring drainage systems at varying scales. Assessment of water resources depends on many factors such as rainfall, natural recharge of groundwater and surface water harvesting, groundwater level trend, runoff of watershed, etc. Quantity and quality aspects of surface and groundwater need to be evaluated thoroughly to meet the ever-increasing needs of water for different uses. An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials, from which groundwater can be extracted using a water well or springs. The surface and groundwater are not able to replenish to achieve the domestic demands of water. Evapotranspiration and percolation can be assessed through any spatial model tools like Soil and Water Assessment Tools (SWAT) and used for simulating the impact of different types of water demands and practices whereas, the water quality varies considerably even at shorter distances.

Our ancient religious texts and epics give a good insight into the water storage and conservation systems that prevailed in those days. Over the years rising populations, growing industrialization, and expanding agriculture have pushed up the water demand. Efforts have also been made to collect water by building dams and reservoirs and digging wells. Water conservation has become the need of the day. The idea of groundwater recharging by harvesting rainwater is gaining much importance. Technically sound, economically viable, environmentally non-degradable and socially acceptable use of country's natural resources like land, water and genetic endowment to promote sustainable development of area either sustainable cities or sustainable water resources have been accepted as the ultimate goal.

Some of these goals can be achieved through Geo-informatics technologies. Geo-informatics is a fast emerging science encompassing the modern technology of Remote Sensing (RS), Geographic information system (GIS), Global Positioning System (GPS) and simulation spatial models like hydrological modeling, water balance model, site suitable model and multi-criteria analysis tools. A combination of these technologies provides cost-effective means of acquiring high-resolution real-time data through remote sensing, data management and analysis through GIS and geo-referencing the ground truth data with GPS, putting all the data in an information system and utilization of the information for a specific purpose. In India GIS has been introduced in various fields like optimizing resource planning land use plans, characterization of ground water quality, analyzing the aquifer behavior with respect to supply and demand in the time domain.

Spatial variation in water quantities and qualities occurs due to variation in underlying rock strata. Ground and Surface water is an essential parameter to be studied for the sustainable development of urban and rural human life. The advent of information technology has developed tools like GIS, which help in the spatial characterization of water resource availability and qualitative analysis.

The maps generated through RS, GPS and GIS delineate homogenous units to decide on the size and collecting a systematic set geo-referenced samples and generating spatial data about water availability and quality. A comprehensive understanding of spatial variability in water resources has become essential in safe drinking purposes. Water resources vary spatially from the field to a large regional scale and are influenced by urbanization, industrialization, geology, topography, climate as well as soil use. Quality variability of water can also occur as a result of land use and management strategies.

Keeping these things in mind and view of such advantages of Geo-informatics, GPS and GIS technologies, the current proposal has been formulated for a Himalayan state like Uttarakhand for moving towards the geospatial study on water resource issues in various sectors concerning environmental aspects, human health to serve the society and remove the regional disparity in the form of quality water availability in the urban and surrounding areas of the state.

Geo-spatial models and tools help to target the hot spot zones and take a decision to sort out the problems of the water sector. This technology can link various basic sciences/disciplines and provide a platform for sustainable practices of resources. Poor quality of water availability is the key issue, which is dealt with by water resource engineers/planners, environmentalists, agriculturists and academia. Geospatial tools and remote sensing data provide the knowledge and solution to these communities about referred issues.

(a) To undertake modeling of water quality of Uttarakhand by using primary data generated by the Uttarakhand State Council for Science & Technology under different projects using geospatial technologies.

Under the Uttarakhand State Council for Science and Technology (UCOST), Dehradun; Uttarakhand Jal Sansthan (UJS), Dehradun with DAV (PG) College, Dehradun and WTI/DST sponsored projects and programme during 2010-16, a very large number of water sources (which are being used by state's drinking water supply and maintenance agency UJS, Dehradun for domestic supply for drinking purpose) have been analyzed.

The above voluminous water quality data resource of the representative selected watershed of 13 districts of Uttarakhand is available with UCOST, Dehradun in association with UJS, Dehradun and DAVPGC, Dehradun. This primary data is the basis of the formulation of the current project for water quality modeling work for a larger perspective as depicted under the research gap.

Moreover, as per requirement secondary water quality data from the literature survey with regards to Uttarakhand's all 13 districts has also be gathered and used. In addition to it, wherever required, water samples have been collected from sources/sites of districts for better horizontal and vertical representation under the modeling work. Besides, other aspects as per description under technical details and methodology, have been duly assessed and incorporated for improvement and finalization of the spatial decision support system developed under the proposal. The pre-monsoon and post-monsoon data collected for the years 2010 and 2011, pre-monsoon for the years 2012, 2014 and 2016 as well as pre- and post-monsoon data of 2018 and 2019 were analyzed. The following parameters (Table 1) were assessed for a feasible solution to sustainable quality water availability in the Himalayan state of Uttarakhand. The table shows the method and techniques used as per BIS10500 (2012).

Table 1: Technique and methods for twenty drinking water quality parameters

No	Name of Parameter	Technique Used	Test Method	Standards (BIS-10500, 2012)	
				Desirable	Permissible
1	pH	pH meter	IS 3025 pt-11-2002	6.5-8.5	No relaxation
2	Alkalinity	Titration	IS 3025 pt-23-2003	200	600
3	Turbidity	Turbidity meter	IS 3025 pt-10-2006	1	5
4	Total Dissolved Solids (TDS)	Hot Air Oven Method	IS 3025 pt-16-2006	500	2000
5	Chloride (Cl)	Spectrophotometer	APHA 23rd-4500-Cl-B	250	1000
6	Fluoride (F)	Spectrophotometer	APHA 23rd 4500 F-D	1	1.5
7	Sulphate (SO_4)	Spectrophotometer	APHA 23rd 4500 SO4-E	200	400
8	Nitrate (NO_3)	Spectrophotometer	APHA 23rd 4500 NO3-B	45	No relaxation
9	Total Hardness (as $CaCO_3$)	Titration	IS 3025 pt-21-2002	200	600

10	Calcium (Ca)	Atomic absorption spectrophotometer (AAS)	APHA 23rd-3111B	75	200
11	Magnesium (Mg)	AAS	APHA 23rd-3111B	30	100
12	Sodium (Na)	AAS	APHA 23rd-3111B	20* (WHO)	-
13	Potassium (K)	AAS	APHA 23rd-3111B	-	-
14	Arsenic (As)	AAS	APHA 23rd-3114 C	0.01	0.05
15	Copper (Cu)	AAS	APHA 23rd-3111B	0.05	1.5
16	Aluminium (Al)	AAS	APHA 23rd-3111D	0.03	0.2
17	Manganese(Mn)	AAS	APHA 23rd-3111B	0.1	0.3
18	Iron (Fe)	AAS	APHA 23rd-3111B	1	No relaxation
19	Total Coliform (TC)	Enzyme substrate method	APHA 23rd-9223B	Absent	Absent
20	E.Coli	Enzyme substrate method	APHA 23rd-9223B	Absent	Absent

(b) To identify quality vulnerability study of various sources of drinking water

The water quality of any area is very much influenced by its surroundings. The variation in the water quality is the function of physical and chemical parameters, which is greatly influenced by geological (weathering of rocks, erosion, heavy rainfall, etc.) and anthropogenic activities i.e urbanization, agriculture, industrialization (Subramani et al., 2005; Tyagi et al., 2013).

The water samples were collected and analyzed by various laboratory methods and instruments using the standard methods suggested by the American Public Health Association (APHA). The hydrochemical evaluation of the water sample have been understood by plotting the major cations and anions in the Piper trilinear diagram (Subramani et al., 2005). It is the graphical representation of hydrochemistry of the water samples, which is evaluated by plotting the cations and anions in percent of total meq/l (Jasrotia et al., 2018).

(c) To quantify water quality at the regional and local level to provide sufficient quality water

Water quality index (WQI) was initially developed by (Horton, 1965) in the United States by selecting the ten most common water quality parameters. Further, it was developed and modified by Brown in 1970, which was based on weights of individual water quality parameters (Tyagi et al., 2013). The water quality index of an area is based on the significance of the chemistry of water. The water quality index is used as an effective tool to obtain an overall scenario about the water. The importance of WQI has been explained by many researchers and scientists to provide a general idea about the water quality

(Ramakrishnaiah et al., 2009; Ravikumar et al., 2013; Sahu & Sikdar, 2008; Singh et al., 2015).

Building a WQI involves four main steps: the selection of parameters, the creation of sub-indices, determining parameter weights, and the aggregation process to generate the final water quality score (Abbasi & Abbasi, 2012; Berry et al., 2020). The creation and handling of these four steps are described below:

f. Parameter selection

There are numerous water quality parameters used to check the suitability of water for various purposes. However, one needs to select the optimum set of parameters, which together reflect the overall water quality concerning a given end-use (Sarkar & Abbasi, 2006). Therefore, parameter selection is fraught with uncertainty and subjectivity as it is crucial to the usefulness of any index. Enormous care, attention, experience and consensus-gathering skills are required to ensure the most representative parameters are included in a WQI (Abbasi & Abbasi, 2012). However, Abbasi and Abbasi (2012) explained that there is no method by which 100% objectivity or accuracy can be achieved in the selection of parameters. In general, the WQI decided by some initial approaches like literature review, data availability and redundancy of parameters. Parameters should represent the overall water quality status and initial use of water body are taken into consideration for parameter selection (Sutadian et al., 2016).

To minimize the subjectivity and uncertainty, two methods namely expert judgment and statistical method have been preferred by the researchers. The first method includes three approaches namely individual interviews, interactive groups and the Delphi Method. The Delphi method is developed by group communication and allows the individual to solve the complex problem. The second one is the statistical approach, which is commonly used for the selection of significant parameters. It includes Pearson's coefficient of correlation and principal component (PCA) /factor analysis (FA). In this method, the water quality parameters are selected based on their correlation and factor loadings (Sutadian et al., 2016). Tripathi and Singal (2019) selected the water quality parameters based on the correlation analysis, where only those parameters were selected that were least correlated and exclude other parameters (Tripathi & Singal, 2019). In this study, 20 water quality parameters were analyzed for samples collected from Gadhera (small streams) located throughout Uttarkhand.

The correlation analysis has been performed and only those parameters have been selected that were least correlated (>0.5; positive or negative) (Vishwakarma et al., 2018). After this analysis, 17 water quality parameters (pH, Alkalinity Chloride, Turbidity, Nitrate, Total dissolved solids, Fluoride, Sulphate, Total hardness, Calcium, Magnesium, Arsenic, Copper, Aluminium, Manganese, Iron and Total coliform) have been selected, which were least correlated with each other. Total Coliform (TC) bacteria are a group of bacteria that are regularly present in environmental waters. Fecal coliforms (FC) and *E.coli* are a sub-group of TC that is more associated with the feces of people and warm-blooded animals (EPA, 2012). Therefore, only total coliform count has been considered in the analyses, which represents fecal coliform and *E.coli* together in a single water quality parameter.

g. Transformation of the parameters of different units and dimensions into a common scale (selection of sub-indices)

Different water quality parameters occur in different ranges and are expressed in different units, and have different behaviors in terms of the concentration-impact relationship. Before, an index can be formulated; all this has to be transformed into a single scale (Abbasi & Abbasi, 2012). In most of the WQI's, the parameters can only be aggregated, when they have the same common scales. The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) developed a multivariate statistical procedure to aggregate the actual values of the parameters without transforming them into a common scale. In general, using the sub-index values, the index developer establishes sub-index functions or rating curves. Sub-index functions are mathematical relationships between actual values of parameters monitored and the sub-index values. The actual values of the parameters can be converted to sub-index values using sub-index functions. In most WQI's, different sub-index functions are used for computing the sub-index values of different parameters. To establish the sub-index functions or rating curves of different parameters, three different methods are commonly employed (Sutadian et al., 2016) a) Expert judgment, b) Use of the water quality standards and c) Statistical methods.

The expert judgment is based on the Delphi method water expert's opinion, where the judgments come from various possible measurements of the water respective parameters. Another approach to establishing rating curves or sub-index function is based on the permissible limits from the legislated standards, such as technical regulations, national water requirements and WHO standards or international directives (Sutadian et al., 2016).

h. Determining parameter weights

The weights are assigned to the parameters concerning their relative importance and their influence on the final index value. Some of the researcher put equal weightage to avoid the biases and subjectivity of the parameters whereas some of them assign a weight for their relative importance (Sarkar & Abbasi, 2006; Sutadian et al., 2016).

i. Aggregation methods

Different indices have employed different variants of aggregation techniques depending upon the type of end-use. Some of the commonly employed aggregation functions are weighted sum (Sarkar & Abbasi, 2006; Şener et al., 2017). Most of these indices are based on the WQI developed by the U.S National Sanitation Foundation (NSF) in 1970 and it is commonly used (Şener et al., 2017).

j. Calculation of Water quality index

There are several water quality indices i.e. weight arithmetic water quality index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI), etc. have been formulated by various national and international organizations (Şener et al., 2017; Tyagi et al., 2013).

(d) Provide Spatio-temporal water quality dynamics and trend of the future status .

Surface and subsurface water carry residual from the surface substances from land and underground substance geology and may contain various contamination (Tong et al., 2016). This depends on the land cover based on the characteristics of surface and subsurface geology and soil. Minerals and ores of rocks (Smedley & Kinniburgh, 2002); flora & fauna (Cerejeira et. al., 2003), industrial residual (Carneiro et al., 2010) and urban run-off (Lapworth, et al., 2012) increases the level of contamination. Therefore, it is important to characterize water and identify changes or trends in water quality over time for human health and aquatic lives. The cause of exceeding limit was identified based on land practices and geology of the given area. Finally, the most problematic area was covered under a unit of a watershed (sub-basin) to assess the potential use of water resources for those watersheds (sub-basin), where water quality parameters are present in more than permissible Limits.

(e)To prepare an action plan for aquifer augmentation and sustainability of life and livelihood

To meet out the needs of the growing population, issues of water quality and quantity have got increasing significance at this juncture. The issue of livelihood is dependent directly on local practices and adaptive strategies by community participation, which in turn ensures the sustainability of resources and development scenarios to promote rural development and economic development as well to protect and conserve the water resources for future and sustainable utilization.

Water budget (Wb) provides a quantitative basis for water resources at any size of the hydrological unit (Blackburn, 2007). However, the water budget at the sub-micro watershed level can serve as a basic tool in water resource management at the grass-root level. The water budget incorporates all the basic elements of hydro-meteorological, soil-water response processes and the existing land use pattern (Sambasiva et al 2015) induced processes found in a given area.

Each of the variables of the water cycle an account "budget" of water as it travels through the hydrologic cycle within the micro geomorphic unit or local landscape (Lapidus, 1987). A surplus occurs when the input from precipitation, soil moisture, or other processes is greater than any withdrawal of water from the system. A shortage is when all withdrawals are greater than the inputs. Both conditions are the outcome of different physical and human processes. A water budget analysis is essential for comprehending the shortage and movement of water in a given hydrogeomorphic unit.

Water balance is useful to understand the hydrologic behaviour of the study area. It is essential to use it as a tool in water resource management. The concept of Wb is finding increasing application to the problems of water resources agriculture specifically to the irrigation scheduling and stands out as the most fundamental and decisive factor.

3. Methodology

Geo-spatial models and tools will help to target the hot spot zones and take a decision to resolve the problems of water quality stress in Uttarakhand. The approaches adopted in this study are Water quality assessment, Water quality index, Stress index, Social issues, Geospatial analysis of poor water quality, aquifer dynamics study, etc. Finally, a sustainable spatial model is provided to remove poor water quality availability in hilly areas, especially in the Himalayan context.

To cater to the prescribed *objective* and deliverables, the methodology used for the study comprises three steps:

- **Step 1**: Hydro-Geospatial model and tools are used to target the hot spot zone and take a decision to resolve the problems of water quality in the various districts/ catchment areas with the sustainability of the environment as a key issue.
- **Step 2**: The Quality vulnerability, water quality index, quality metabolism of water, social issues, geospatial analysis of poor water quality, aquifer dynamics study, etc as main approaches.
- **Step 3**: Finally, a sustainable spatial model is be provided to track the cause and sources of quality deterioration and suggest the enhancement techniques in hilly areas especially in the Himalayan context suitable for execution through the state's line department.

The required framework has been developed to achieve all five objectives of the work. The flow starts with primary and secondary data collection, testing of water quality, geospatial mapping of water type, quality and index then hydrological modeling for aquifer augmentation using the hydro-geospatial model (Figure 5).

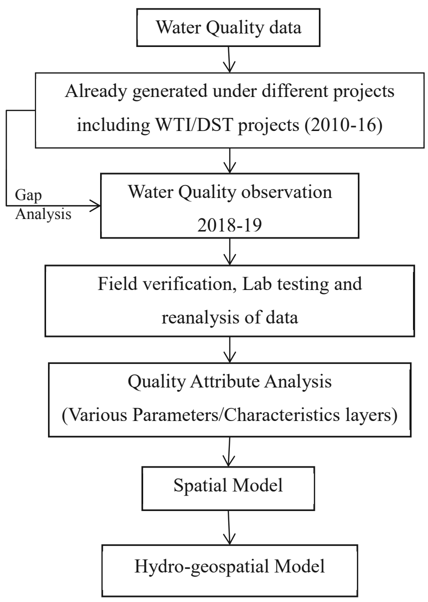


Figure 5: Flow chart of the overall work includes all objectives

(a)To undertake modeling of water quality of Uttarakhand by using primary data generated by the Uttarakhand State Council for Science & Technology under different projects using geospatial technologies.

Physical, chemical and biological properties of the water were captured either from primary water quality data/results available with collaborators (UCOST, UJS & DAVPGC) of the proposal obtained from laboratory and field analyses or published document by the state/central departments or other researcher's secondary data for the period of 2010 to 2016 during the pre-monsoon and post-monsoon. The sample was available for pre and post-monsoon in the years 2010 and 2011 whereas only the pre-mosoon sample was available for the years 2012, 2014 and 2016 under previous research projects. The samples were collected based on random sampling and the number of site selection of the samples was based on the symmetrical distribution for vertical and horizontal representation for the year 2018 and 2019. The data collection was carried on both seasons i.e pre-monsoon and post-monsoon.

All these data were converted in geographical reference data using GPS and GIS technology and plotted in the GIS environment. Each site of a drinking water source studied with water quality issues by their quality index. The detailed temporal dynamics of each quality parameter was evaluated through a geospatial model to find out the temporal change throughout in spatial distribution. This was done to assess the cause and effects of each quality parameter in terms of pattern and dynamics.

The detailed water quality parameters captured either through field or lab investigations and available with PI's group or secondary sources were mapped under the Geospatial environment. These quality parameters were then spatially analyzed through various functions to find out the inter-relations among them and their co-occurrence with hydro-geological investigations.

(b)To identify quality vulnerability study of various sources of drinking water

The basic concept of hydrochemical facies is to diagnose the chemical character of water solutions in hydrologic systems. The facies reflect the effect of chemical processes occurring between the minerals within the lithologic framework and the water (Back, 1960).

Piper diagram consists of three parts: Two trilinear diagrams along the bottom and one diamond-shaped diagram in the middle. The trilinear diagram illustrates the relative concentrations of cations (left diagram) and anions (right diagram) in each sample (Figure 6). For a Piper diagram, the cations are grouped into three major divisions: Sodium (Na^+) plus Potassium (K^+), Calcium (Ca^{++}), and Magnesium (Mg^{++}). The Anions are similarly grouped into three major categories: Bicarbonate (HCO_3^-) plus Carbonate (CO_3^{--}), Sulfate (SO_4^{--}), and Chloride (Cl^-). Each sample will be represented by a point in each trilinear diagram; unique symbols may be selected for each sample and can be referenced in a symbol index at the top of the diagram. Symbols may be accompanied by labels, if desired. The diamond field is designed to show both anion and cation groups. For each sample, a line is projected from its point in the cation and anion trilinear diagrams into the upper region; where the lines intersect, the symbol is plotted (RockWare, 2020). These tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in ore definite terms rather than with other possible plotting methods (Sadashivaiah et al., 2008).

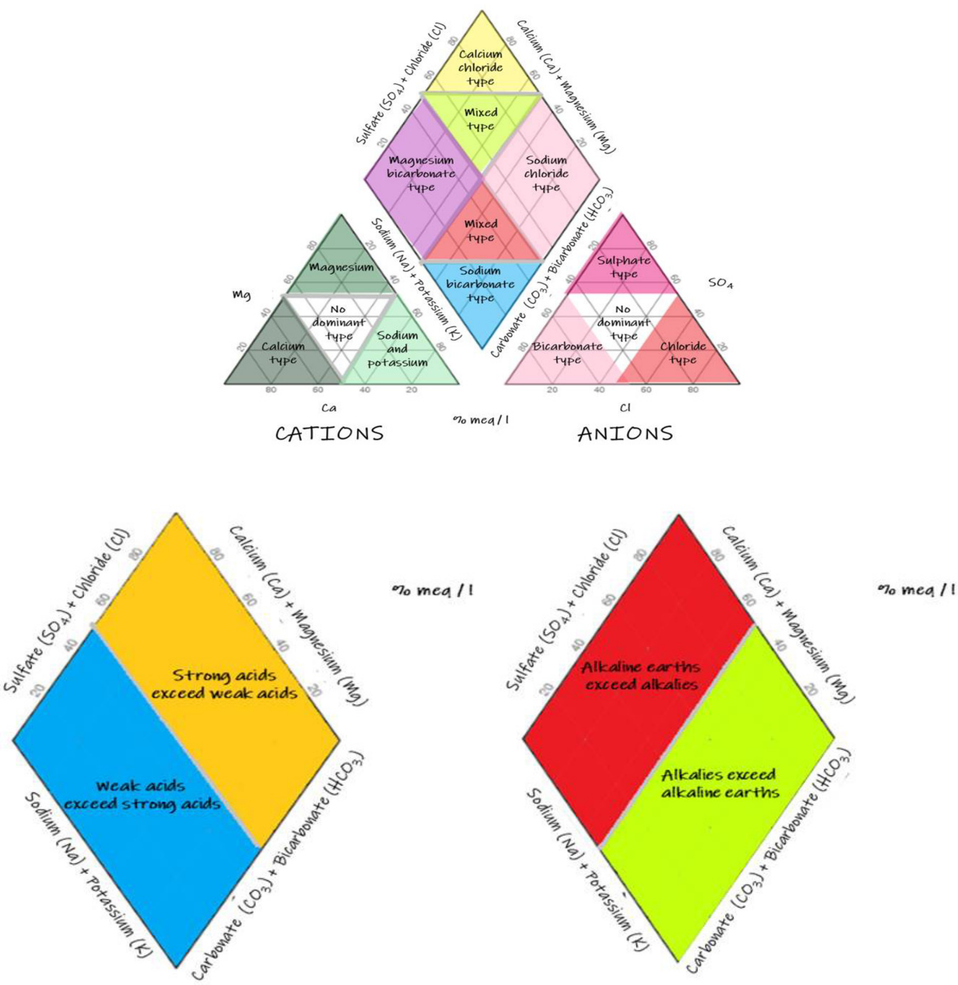


Figure 5: Reference for Piper diagram showing various Hydrochemical facies in the cation-anion triangle and the diamond (HatariLabs, 2018)

The chemical composition of water depends on the geology of the surrounding environment. When the water came in contact with the surface, various chemical processes occur within the geological unit. This process add dissolved constituent into the water and as a result, the chemistry of water gets changed. The composition of water is dominant by the most abundant ions, which are both positively (cations) and negatively charged (anions). Due to the electroneutrality, the cations and anions are present in equilibrium and compass most of the dissolved solids in the water. Calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+1}), and potassium (K^{+1}) are the dominant cations while bicarbonate (HCO_3^{-1}), chloride (Cl^{-1}), and Carbonate (CO_3^{-1}) sulfate (SO_4^{-2}) are the dominant anions into the water. The ionic composition of water is used to classify it into ionic types based on the dominant dissolved cation and anion, expressed in milliequivalents per liter (meq/L). A milliequivalent (meq) is a measurement of the molar concentration of the ion, normalized by the ionic charge of the ion. The dominant dissolved ion must be greater than 50 percent of the total (USGS, 2020).

Another plot has been made for the identification of the hydrochemical process into the natural water named Chaddha diagram. It is a somewhat modified version of the Piper diagram. It can be easily plotted on a spreadsheet by plotting the difference in milliequivalent percentage between alkaline and alkali metals expressed as percentage reacting values on the X-axis and the difference in milliequivalent percentage between weak acidic anions and strong acidic anions on Y-axis (Chadha, 1999). The hydrochemical process explained by the Chaddha diagram can be classified into four quadrants of the graph. These are

- Reverse ion-exchange water (Ca-Mg-Cl type)
- Recharging water (Ca-Mg- HCO_3 type)
- Seawater/end-member waters (NaCl type) and
- Base ion-exchange water (Na- HCO_3 type) (Ravikumar et al., 2017).

Further, Chadha's (1999) plot can be classified into eight fields as given below (Ravikumar et al., 2017)

- Alkaline earth (Ca+Mg) Exceed alkalies (Na+K)
- Alkalies exceeds alkaline earths

- Weak acids (CO_3 + HCO_3) exceed Strong acids (SO_4 +Cl)
- Strong acids exceeds weak acids
- Magnesium/Calcium bicarbonate type (temporary hardness)
- Calcium-chloride Type (permanent hardness)
- Sodium-chloride Type (Saline)
- Sodium-Bicarbonate Type (Alkali carbonate)
- Mixed type (No cation-anion exceed 50%)

(c)To quantify water quality at the regional and local level to provide sufficient quality water

In this study, a weight arithmetic approach has been taken, which is also used by numerous researcher to compute WQI for a diverse range of parameters (Adimalla & Qian, 2019; Kangabam et al., 2017; Kükrer & Mutlu, 2019; Şener et al., 2017; Shah & Joshi, 2017; Solangi et al., 2019; Vishwakarma et al., 2018). The following steps are involved under this approaches.

- To calculate the WQI of spring water, seventeen important parameters were selected. All these parameters were selected based on previous work and literature published on Uttarakhand states on water quality.
- Initially, the weightage of all the water quality parameters have been assigned from 1 to 5 in each category, depending on the relative importance in the case of Uttarkhand, which determines the overall quality of spring water in the study area (Table 2). Next, the relative weight for all the parameters was calculated by the following equation:

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \text{..........................Eq. 1}$$

Wi is relative weight, *wi* is the weight of each parameter and n is the number of parameters.

- The third step of the WQI calculation was to calculate the quality rating scale (qi) for each of the parameters:

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100$$ ....Eq. 2

where, *Ci* is the concentration of each parameter of each sample and *Si* is the BIS standard of each parameter. And at the final step, the WQI was calculated by sub-index (SI) of each chemical parameter by the following equation:

$$SI_i = W_i \times q_i$$ ....Eq. 3

$$\mathrm{WQI} = \sum \mathrm{SI}_{\mathrm{I}}$$ ....Eq. 4

where, SI_i is the sub-index of *i*th parameters.

Table 2: Water quality index calculating of spring water samples

Group	Parameters	Weight (wi)	Relative weight (Wi)	BIS limit
Group 1	pH	4	0.0417	8.5
	Chloride	3	0.0313	1000
	Alakalinity	2	0.0208	600
	Turbidity	2	0.0208	5
	TDS	5	0.0521	2000
	F	4	0.0417	1.5
	SO_4	4	0.0417	400
	TH	2	0.0208	600
	Ca	3	0.0313	200
	Mg	3	0.0313	100
Group 2	Nitrate	3	0.1250	45
	TC	5	0.2083	1
Group 3	As	5	0.0980	0.05
	Cu	3	0.0588	1.5
	Al	3	0.0588	0.2
	Mn	4	0.0784	0.3
	Fe	2	0.0392	1

Finally, the WQI (Table 3) has been classified into five categories (Adimalla & Qian, 2019; Solangi et al., 2019).

Table 3: Value of WQI and Quality of water

Value of WQI	Quality of water
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
>300	Not suitable for drinking

(d)Provide Spatio-temporal water quality dynamics and trend of the future status

To arrive at a more conclusive result, the overall summary of problem water quality parameters with corresponding site numbers having values more than permissible limit for various locations of the Uttarakhand from 2010 to 2019 are geospatial analyzed and mapped under the spatio-temporal domains. The cause of exceeding limit was identified based on land practices and geology of the given area. Finally, the most problematic area was covered under the unit of the watershed to assess the potential use of water resources for those watersheds where water quality parameters are in more than permissible limits.

(e)To prepare an action plan for aquifer augmentation and sustainability of life and livelihoods

Aquifer characteristics analysis was attempted as the next step to replicate the behavior of natural groundwater and hydrologic system by defining the essential features of the system in some physical manner. Modeling thus plays an important role in the management of hydrologic and groundwater systems. The modeling work includes the following framework:

- Creation of the framework for studying system/aquifer dynamics and characteristics and organization of field data.
- Simulation of the model, similar to aquifer conditions and behavior with time.
- Finding out suitable areas for sub-surface (bore well/springs) / rainwater harvesting development in the poor water quality zones.

The aquifer model was created using a conceptual model. The conceptual model was converted into numerical and computer programme. To see the Spatio-temporal dynamics, the model then transformed in the form of space and time domain through geospatial tools. Detailed geological and lithology data analysis was carried out to evaluate the aquifer behaviors of the sub-basin. Aquifer characteristics study has propagated the research towards the identification of sources and sink of pollution sites

Satellite data of high spatial resolution was processed and used for image interpretation for various thematic layers like land use land cover map, soil map and relief map. Further meteorological data from IMD was collected to simulate the aquifer behaviour of vulnerable pockets of the water quality and quantity.

Simulations of aquifer behaviour help to identify the source and sink of water quality in terms of surface and subsurface behavior of waters. Linking with land use practice and geological characteristics of the lithology extend support to anthropogenic and geological evidence of poor water quality.

The regional imbalance mapping was carried out and suggests various water recharge (WR) structures as per the quality stress index. The conjunctive uses and practices of surface and sub-surface (ground) waters provide immense guidance to the water resources experts to implement their WR action plan.

Integrating all the above methodological tools resulted in preparing a model for aquifer augmentation and sustainability of the life of representative selected watershed of Uttarakhand state.

4. Results and Discussion

The overall outcome of the work is expected to be fruitful for tackling the local environment degradation of drinking water resources aiming at better human health in nearby habitat clusters. The study provides scientific solutions for meeting out potable per capita water demand in urban as well as rural areas. A comprehensive understanding of water quality, as a key issue, provide the knowledge and solution to society, water resource engineers, planners, environmentalists and academia essential in development as well as research precision for the drinking water sector in the state.

Feasibility Analysis: To provide a feasible solution of sustainable water availability in hilly terrain conditions of the Himalayan region that amounts to the sustainable practice of water retention in urban and peri-urban surroundings, rural background manifests as a sub-basin model. The proposed geospatial model suggests decentralized inflow of water in the urban areas through various means like rainwater harvesting, perched water harvesting for urban and surrounding rural areas for long retention of water and the long sustainable water cycle, which include the following points:

(i) Water quality vulnerability index, which provides knowledge of regional disparities to any water user for proposing any technology and policy.

(ii) Regional level quantifications of water quality for preparing a water resource action plan at the sub-basin level to reach sufficient quality water at the urban cluster and surrounding rural areas.

(iii) A geospatial model for assessing aquifer and surface water dynamics for potential sites of surface and groundwater recharge for local livelihood.

(iv) The source and track of contamination through geospatial tools.

(v) Action plan for aquifer augmentation and sustainability of life and livelihoods of inhabitants of the studied area.

(a)To undertake modeling of water quality of Uttarakhand by using primary data generated by the Uttarakhand State Council for Science & Technology under different projects using geospatial technologies.

The previous study was carried based on some assumption and similar same direction present study was carried forwarded to the synchronized present and previous water quality data.

- The 13 districts of Uttarakhand were selected for the study of water quality monitoring for 2 consecutive years for 2010 and 2011.
- The effect of seasonal variations has been explored by undertaking the studies during pre-monsoon 2010, post-monsoon 2010, pre-monsoon 2011 and post-monsoon 2011 seasons.
- The effect with regards to raw water (water in natural form) and supply water (water obtained after chemical treatment for supply) has also been studied. The present study selected only raw surface water sources used for domestic supply after treatment. The supply water was excluded from the study. The groundwater sources were not included in this study and are out of the scope of the present study.
- For identification of water sample collection sites, the help of Uttarakhand Jal Sansthan (UJS), Dehradun has been taken and most of the sites are major water supply sources, which cater to the drinking and domestic needs of the population in the respective district. However, the following criteria were used to select the sampling sites:
- Preferably natural raw water sources,
- Sources suspected for natural contaminants
- Sources that cover populated areas, commercial, industrial, agricultural and residential premises, to obtain a good horizontal and vertical representation.
- Total 26 water quality parameters namely colour, odour, taste, pH, alkalinity, turbidity, residual free chlorine, total dissolved solids (TDS), chloride, fluoride, sulphate, nitrate, total hardness, calcium, magnesium, arsenic, copper, aluminium, manganese, iron, phenolic compound, cadmium, lead, zinc, chromium, and coliform

bacteria (i.e. total coliform and fecal coliform) were identified as per BIS 10500 was tested during 2010 and 2011.

- In this study major 18 parameters namely pH, alkalinity, turbidity, total dissolved solids (TDS), chloride, fluoride, sulphate, nitrate, total hardness, calcium, magnesium, arsenic, copper, aluminium, manganese, iron, and coliform bacteria (i.e. total coliform and *E. coli*) were selected as per BIS 10500 (2012) and two additional parameters sodium and potassium capture through the same study from other research work. The rest quality parameter considers out of scope because of the negligible importance found in previous research work at Uttarakhand.

- The rest of the all parameters have been duly analyzed in "State Level Water Quality Analysis Laboratory" (NABL Accredited) at UJS campus, Dehradun.

- The BIS and APHA guidelines have been followed for analytical procedures and methods for carrying out analysis of water quality characteristics.

- 103 raw and supply water sampling sites/sources were analyzed in 2010 and 155 water sampling sites/sources were analyzed in 2011 during pre and post-monsoon seasons. Supply water samples and raw groundwater samples were not included in this study.

- There were 450 water sampling sites/sources were analyzed for raw and supply water in the year 2012 for 29 water quality parameters namely colour, odour, taste, turbidity, pH, total hardness, iron, chloride, residual free chlorine, fluoride, total dissolved solids (TDS), calcium, magnesium, copper, manganese, sulphate, nitrate, phenolic compound, arsenic, cadmium, lead, zinc, chromium, aluminium, alkalinity and coliform bacteria (i.e. total coliform and fecal coliform) as per BIS 10500 along with pesticides, sodium and potassium for each sample of nine districts.

- In the present study, the data was filtered and out of 26 parameters, only 20 parameters namely pH, alkalinity, turbidity, total dissolved solids (TDS), chloride, fluoride, sulphate, nitrate, total hardness, calcium, magnesium, sodium, potassium, arsenic, copper, aluminium, manganese, iron, and coliform bacteria (i.e. total coliform and E coli) were selected as per BIS 10500 (2012) for pre-monsoon seasons of nine districts namely Dehradun, Haridwar, Tehri, Chamoli, Uttarkashi, Nainital, Almora, Champawat and Udhamsingh Nagar of Uttarakhand districts of Uttarakhand. Similar to the previous dataset, raw groundwater sources were not included in this research.

- The location, which crossed above the permissible limit of drinking water during the previous year 2010 to 2012 was re-considered for lab testing in the year 2014 and 2016 in pre-monsoon seasons with the limited locations. The surface sources of these locations were also considered in this study.
- The BIS and APHA specifications have been followed for analytical procedures and methods for carrying out analysis.
- The latitude and longitude of all water sample collection sites, with elevation and temperature, have also been recorded and reported.
- The GPS coordinates (latitude and longitude) from different water sampling sites, which happens to be major drinking water sources for public supply, were collected through field visits by using a GPS system along with elevation above Mean Sea Level (MSL) during 2010, 2011, 2012, 2014 and 2016.
- Further, in 2018 and 2019, all 20 drinking water quality parameters were repeated to evaluate the present condition of the surface source of drinking water quality as per BIS 10500 (2012) standards.

The total number of observations were 433 locations collected from previous research work and the gap area for water quality was assessed on 808 locations in Uttarakhand (Figure 7). The objective is to cover all water quality drinking sources, which are used as feed to local people by Uttarakhand Jal Sansthan through surface sources like stream and Gadhera. The scope of the study is limited to surface sources. The groundwater like bore well and springs directly utilized for drinking water were not included in this study. The overall water quality of groundwater is good as compared to surface sources.

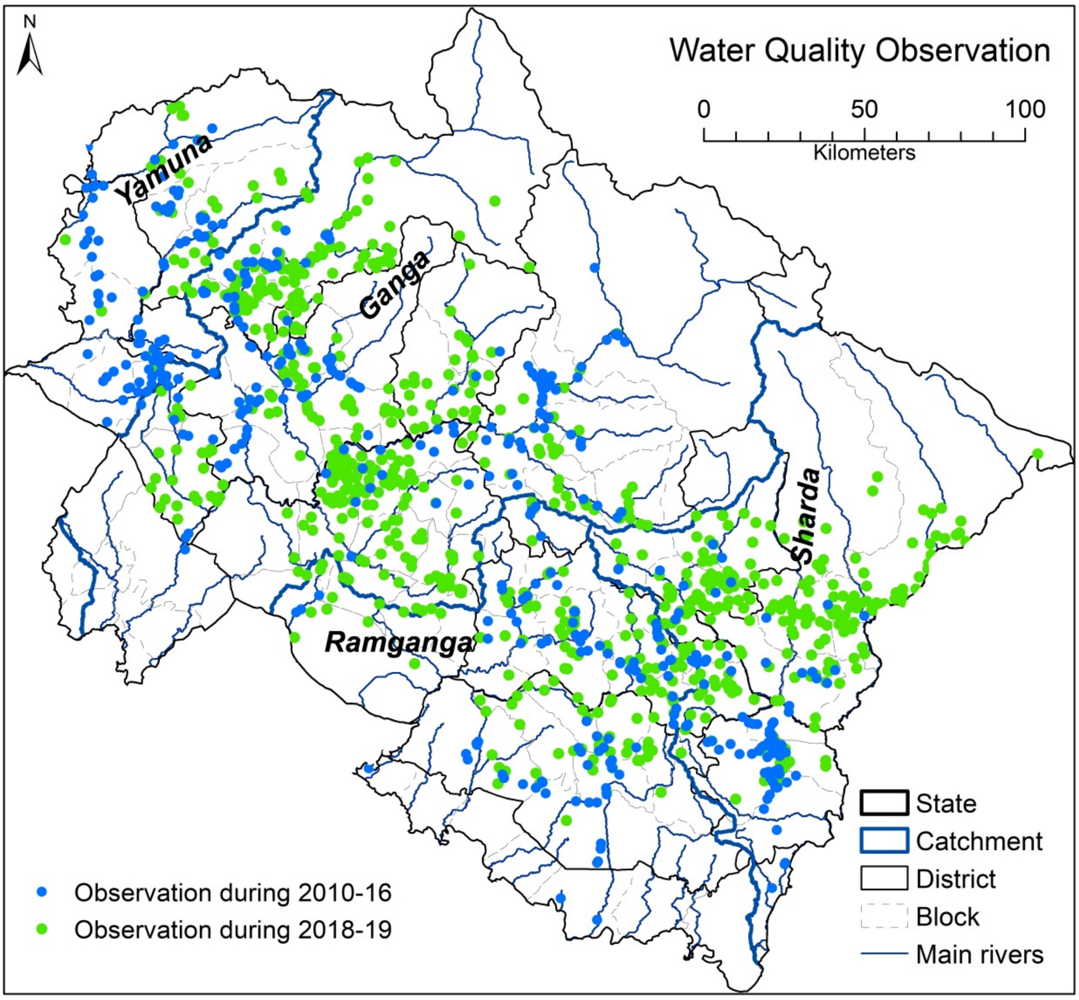
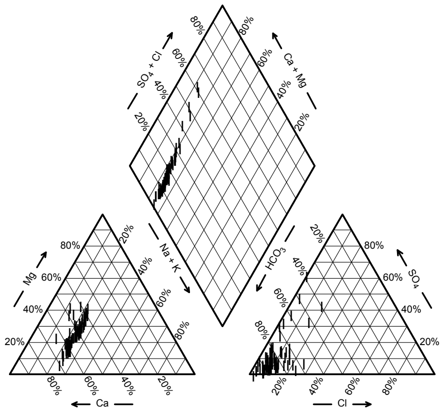


Figure 6: Location of surface water observations

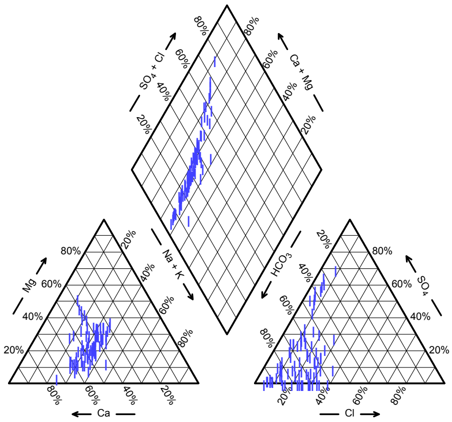
(b)To identify quality vulnerability study of various sources of drinking water

In this study, the Piper Trilinear diagrams (Figure 8) of the year 2010 to 2019 have been prepared to understand the hydrochemical facies of the water samples. This analysis shows that most of the sample in all the years are found in zone 5 which is calcium bicarbonate type of water. This means more than 50 percent of the total cation milliequivalent as Calcium and more than 50 percent of the total anion milliequivalent as bicarbonate.

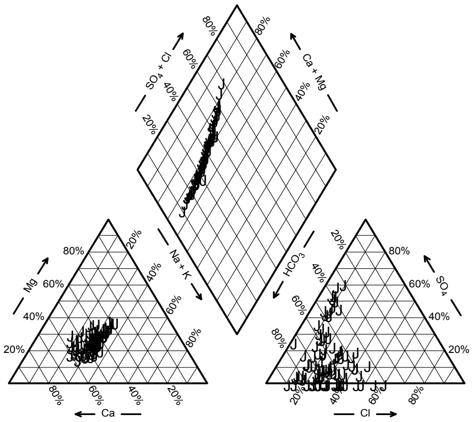
The output of Chadha's plot (Figure 9) is in confirmation with that of the Piper trilinear diagram, where the alkaline earth and weak acidic anions exceed both alkali metals and strong acidic anion, indicated by Ca–Mg–HCO_3 type of water.



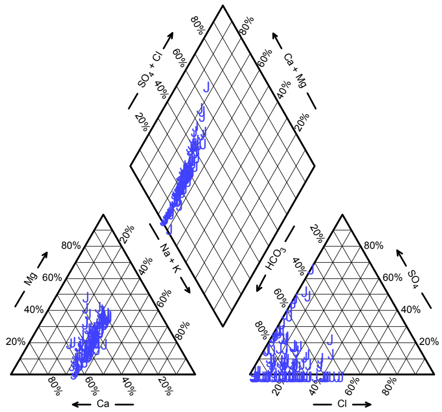
Pre-Monsoon 2010



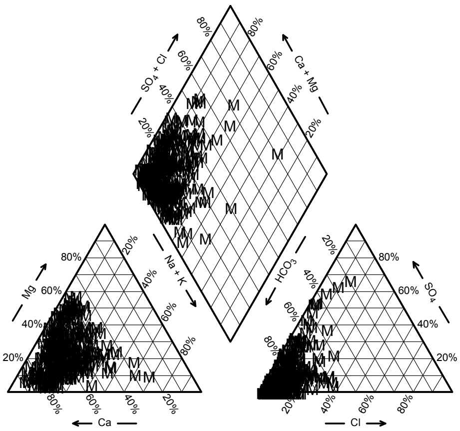
Post-Monsoon 2010



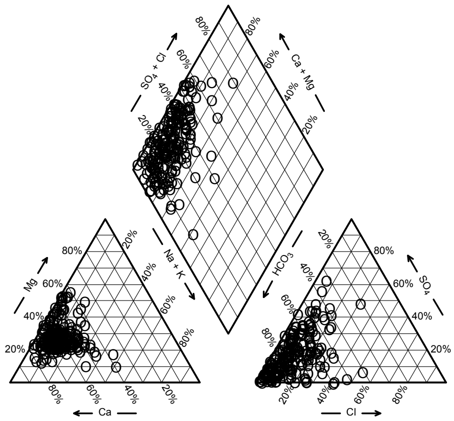
Pre-Monsoon 2011



Post-Monsoon 2011



Pre-Monsoon 2012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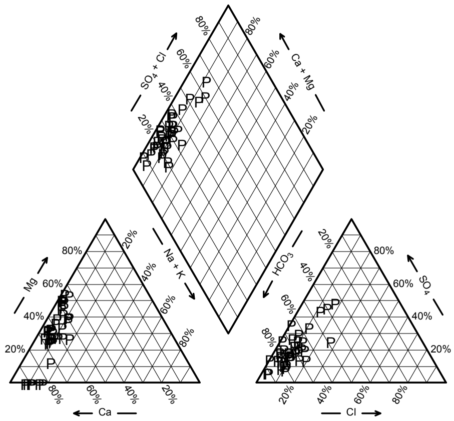
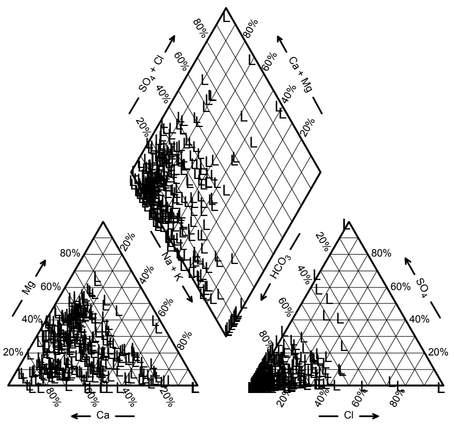
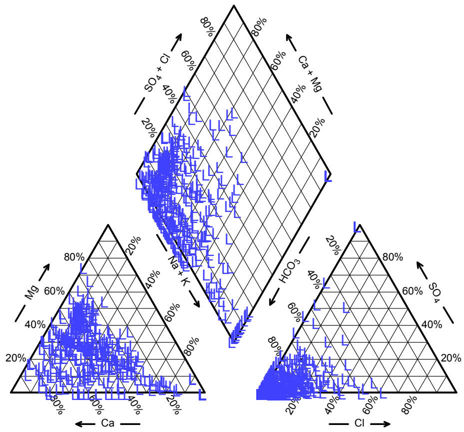
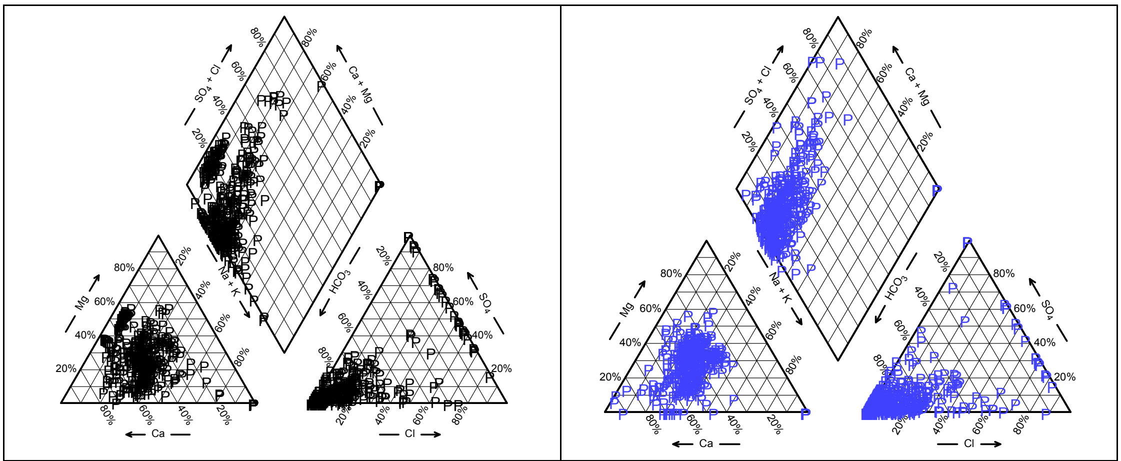
	
Pre-Monsoon 2016	
	
Pre-Monsoon 2018	Post-Monsoon 2018



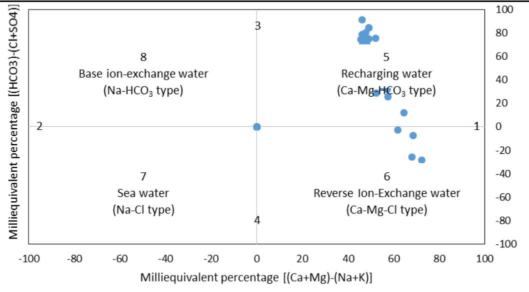
Pre-Monsoon 2019	Post-Monsoon 2019

Figure 7: Piper Trilinear diagram and the percentage of sample lie into particular water types from the year 2010 to 2019

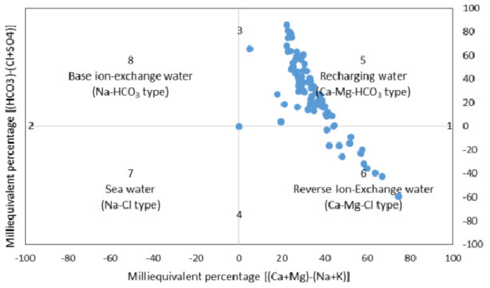
As mentioned above another plot has also been made for the identification of the hydrochemical process into the natural water as Chaddha Diagram. It is a somewhat modified version of the Piper diagram. It can be easily plotted on a spreadsheet by plotting the difference in milliequivalent percentage between alkaline and alkali metals expressed as percentage reacting values on the X-axis and the difference in milliequivalent percentage between weak acidic anions and strong acidic anions on Y-axis (Chadha, 1999). The hydrochemical process explained by the Chaddha diagram can be classified into four quadrants of the graph. These are of the following types:

- Type 1: Reverse ion-exchange water (Ca-Mg-Cl type)
- Type 2: Recharging water (Ca-Mg- HCO_3 type)
- Type 3: Seawater/end-member waters (NaCl type) and
- Type 4: Base ion-exchange water (Na- HCO_3 type)

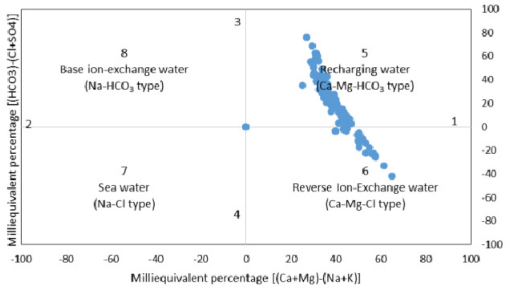
The output of Chadha's plot (Figure 9) is in confirmation with that of the Piper trilinear diagram where the alkaline earth and weak acidic anions exceed both alkali metals and strong acidic anion, indicated by Ca–Mg– HCO_3 type of water.



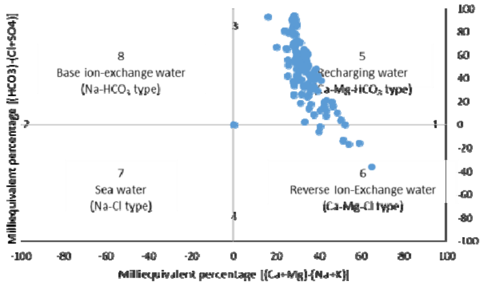
Pre-Monsoon 2010



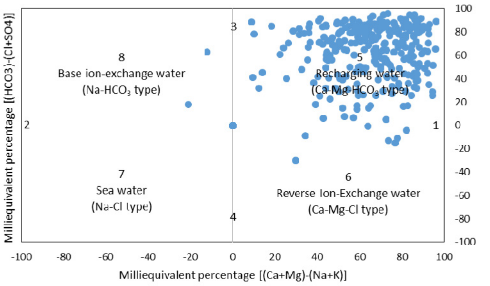
Post-Monsoon 2010



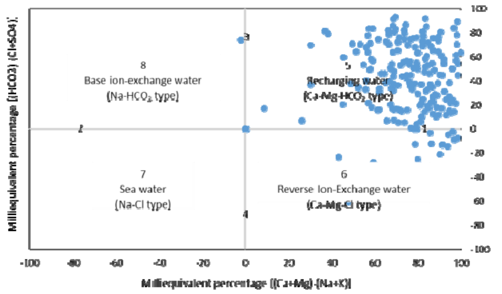
Pre-Monsoon 2011



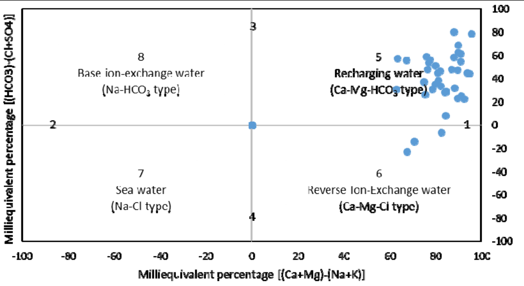
Post-Monsoon 2011



Pre-Monsoon 2012



Pre-Monsoon 2014



Pre-Monsoon 2016

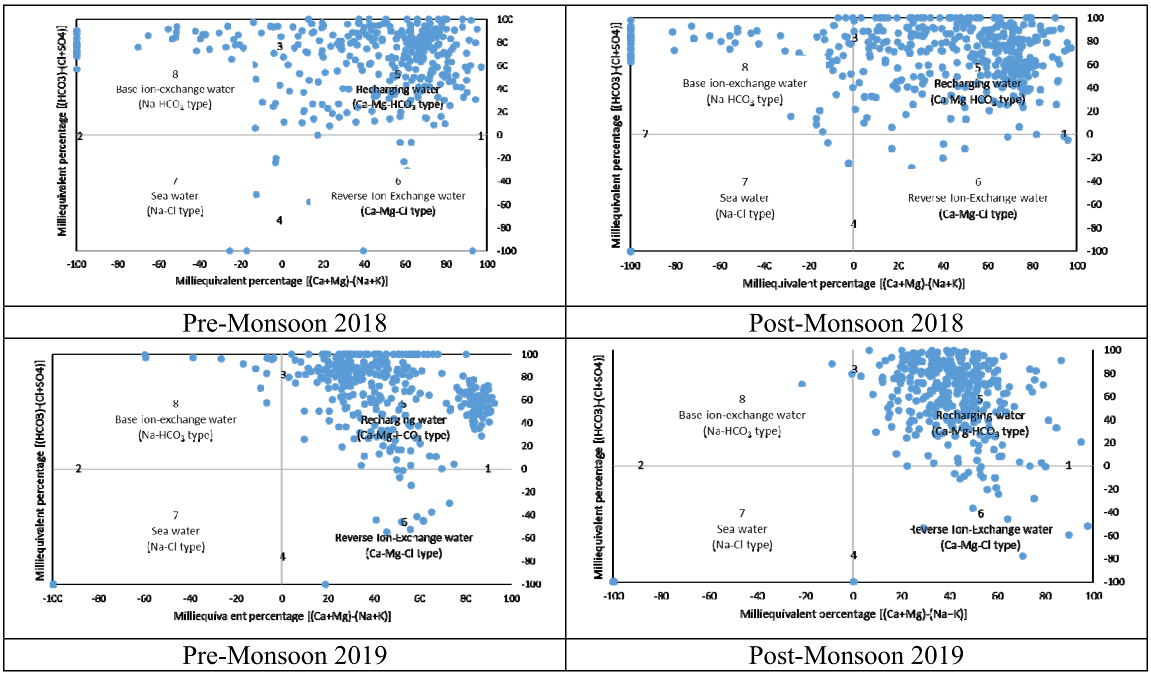


Figure 8: Chaddha's Plot to evaluate the dominant geochemical process in the study area

The position of most of the sample data in Chaddha's plot lies in field 5 (Type 1), which is a Ca-Mg-HCO_3 type of water, which is also depicted as recharging water. Recharging water are formed when water enters into the surface runoff from the surface, it carries dissolved carbonate in the form of HCO_3 and the geochemically mobile Ca, where the carbonate weathering is the dominant process due to the dominance of calcium and magnesium ion into the water.

The Ca-Cl type of water comes into the water system from calcium-bicarbonate type water as a result of cement pollution or dominant geology of limestone (Type -2). Some of the samples also found the NaCl type (Type 3) due to the interaction of water with halite minerals. Another source of chlorine into the water system is fertilizers. The $NaHCO_3$ type of water (Type 4) is formed due to silicate weathering, where the Silicate of sodium, potassium, calcium and magnesium interact with carbonic acid and form various cation into the water system (Table 4). Some of the samples in the study area found $NaHCO_3$ type (Figure 9) which is also supported by a scattered plot diagram.

Table 4: Cause of various types of water in Uttarakhand

Water type	Goegenic source	Anthropogenic source
Recharging water (5) $CaHCO_3$ (type -1)	Calcite, dolomite and limestone Gypsum (Carbonate minerals) (Singh et al., 2015)	
Reverse ion exchange water (6) CaCl (type 2)	Cement material (Gypsum) (Chadha, 1999)	
Saline water (7) NaCl (type-3)	Halite minerals (Joji, 2016)	Fertilizers (Potash) (Molly Hunt, 2012)
Base-exchanged water (8) $NaHCO_3$ (type-4)	Kaolinitic clay, sandstone, shale, limestone, dolomite, phyllite, schist, granite, gneiss, and intrusives. Silt, sand, and clay (Chadha, 1999)	

Table 5 showes that general samples depict as recharging water i.e type 1 (Ca-Mg-HCO_3 type). During the post-monsoon period, Mg-HCO_3 observation value increased due to sedimentation of the surface runoff though out the time series. Another observation of type 2 (Ca-Cl type), which is the dominant geology of limestone, is decreased which indicates reduce in sub-surface water interaction with surface water over the period. During pre-monsoon period, the sub-surface of water contributes comparatively high due to absence of rainfall in the basin. In this case, the pre-monsoon period sub-surface geology contributes substance to dominate the water type, if there is a strong association of surface and sub-surface interaction.

Table 5: Variation in water type in % over the period

Water Types		Pre 2010	Post 2010	Pre 2011	Post 2011	Pre 2012	Pre 2014	Pre 2016	Pre 2018	Post 2018	Pre 2019	Post 2019
Type 1	$CaHCO_3$	88.46	77.65	81.31	76.80	87.34	91.50	76.32	61.77	54.81	62.41	62.32
	$MgHCO_3$	7.69	10.59	7.48	20.00	8.54	6.00	15.79	17.73	23.04	20.65	22.55
Type 2	$CaSO_4$	3.85	5.88	8.41	0.80	1.58	1.00	7.89	1.66	0.45	0.70	0.80
	CaCl	-	-	2.80	0.80	-	0.50	-	-	0.45	1.39	1.06
	$MgSO_4$	-	5.88	-	1.60	0.32	-	-	-	-	-	-
	MgCl	-	-	-	-	-	-	-	-	-	0.23	0.80
Type 3	$NaSO_4$	-	-	-	-	0.32	-	-	-	-	6.96	2.39
	NaCl	-	-	-	-	-	-	-	0.83	1.79	3.25	2.65
Type 4	$NaHCO_3$	-	-	-	-	1.90	1.00	-	18.01	19.46	4.41	7.43

Over the period, it was also observed that the type- 3 (NaCl type) water samples increased. This could be due to agriculture extension and use of fertilizer in the basin. This sample value is high during the pre-monsoon period and less during post-monsoon due to high surface runoff during the post-monsoon period. Time series indicate that there is limited scope to conclude Halite minerals or salt in geology, which is also supported by research with Halite minerals in Himalaya (Gaury, 2018). The $NaHCO_3$ type of water (Type 4) is formed due to silicate weathering indicates that the river system facing a rapid weathering process due to natural extreme rainfall event or rapid construction work in the river basin.

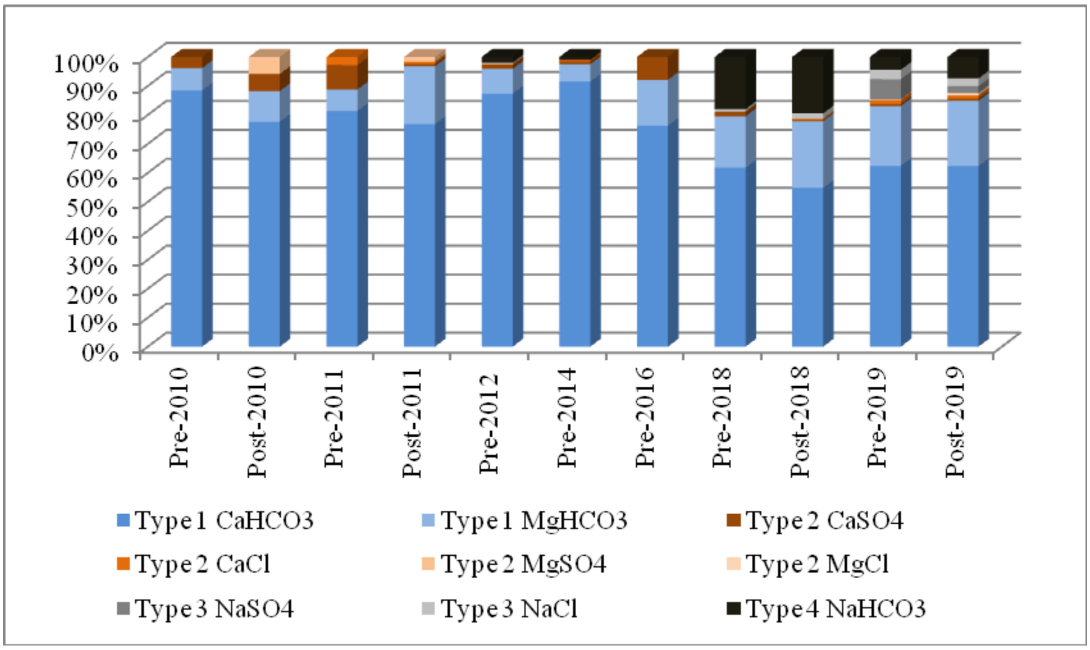
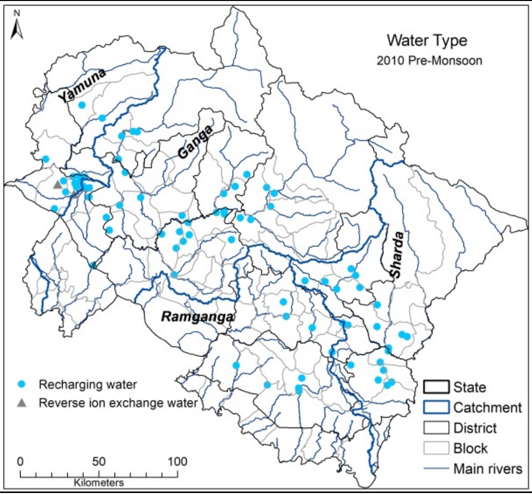
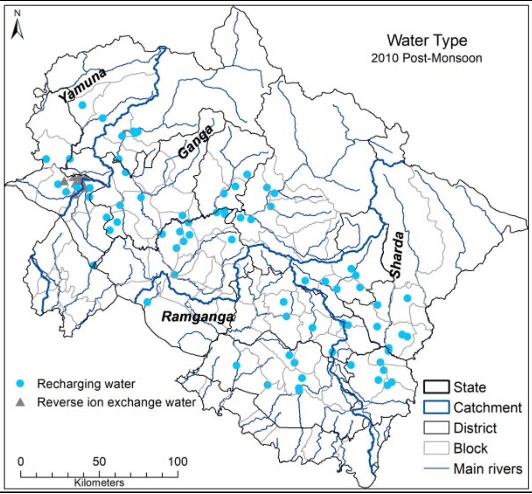


Figure 9: Changing profile of various water types over the period

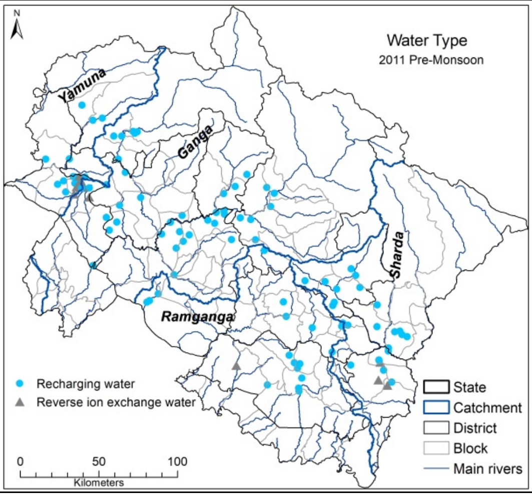
Overall the Uttarakhand sample of water type is sifting towards type-3 and type-4 (Figure 10), which indicated the impact of human and climate change over the basin and need a proper intervention. The entire mapping of various water types was carried over nine years (2010-2019). All location of water sample was classified into four different types and mapped (Figure 11).



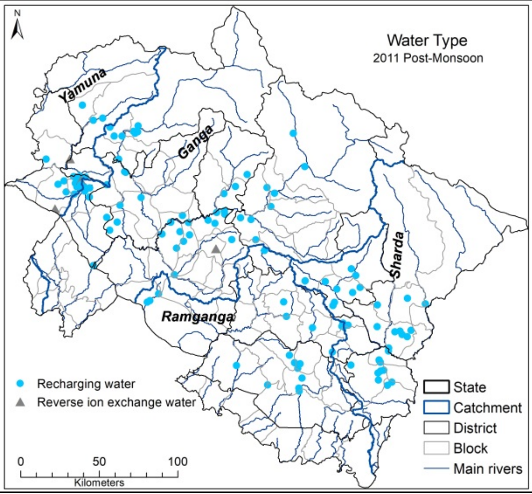
Pre-Monsoon 2010



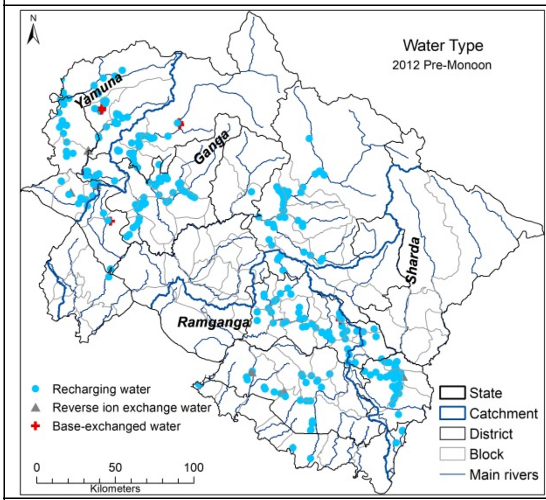
Post-Monsoon 2010



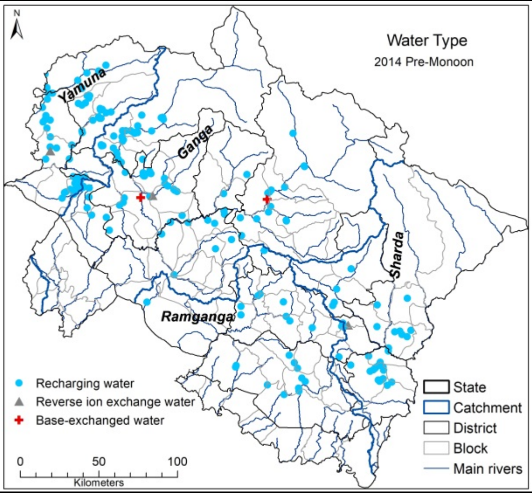
Pre-Monsoon 2011



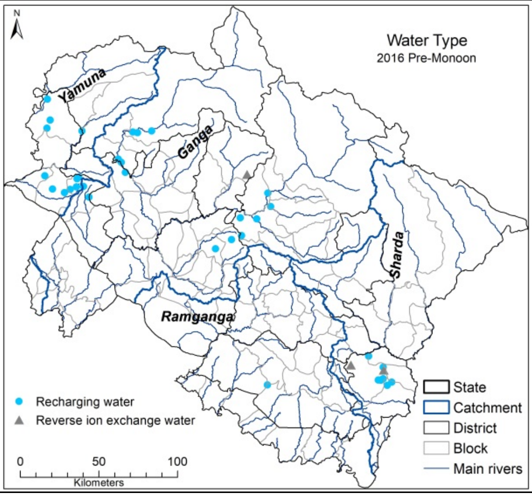
Post-Monsoon 2011



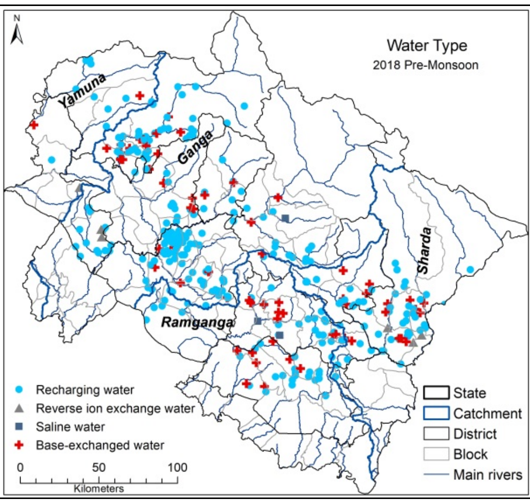
Pre-Monsoon 2012



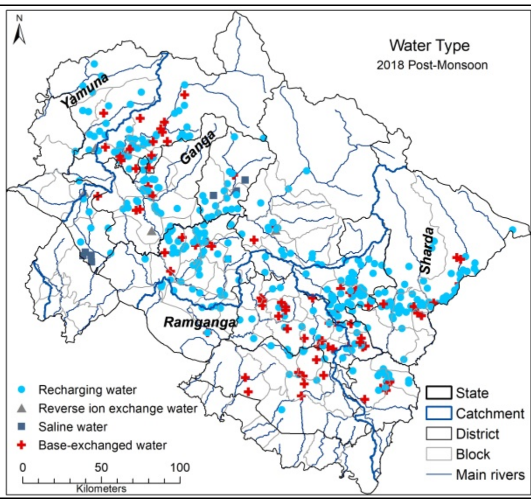
Pre-Monsoon 2014



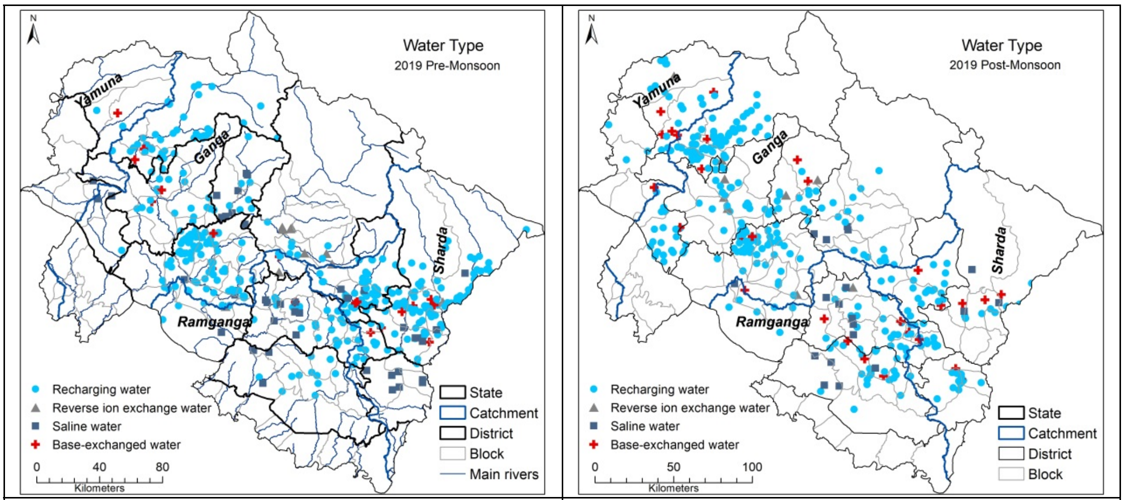
Pre-Monsoon 2016



Pre-Monsoon 2018



Post-Monsoon 2018



Pre-Monsoon 2019	Post-Monsoon 2019

Figure 10: Various water types in Uttarakhand on the temporal domain.

(c)To quantify water quality at the regional and local level to provide sufficient quality water

There are 17 drinking water quality parameters associated to evaluate the water quality index (WQI) of the state.in which 10 parameters are physio-chemical (pH, Chloride, Alakalinity, Turbidity, TDS, Fluoride, Sulphate, Total hardness, Calcium, Magnesium, two biochemical parameters (Nitrate and Total Coliform) and five metals (Arsenic, Copper, Aluminium, Manganese and Iron). The temporal data set of water quality parameters were evaluated on WQI from 2010 to 2019.

Most of the parameters are under the permissible limit, which has less impact on the overall water quality Index but few parameters like Total coliform, Turbidity, Iron, Calcium and Magnesium are major parameter responsible for the poor quality of water.

The sample data for the year 2010 was classified under various range of water quality index and the cause of poor quality was mostly associated with calcium, magnesium, turbidity and total coliform. Not suitable areas are more concentrated near the Raipur block of Dehradun district due to calcium and magnesium (Figure 12) and other locations are is due to pH, turbidity and total coliform. Exceeding value of these parameters is the general characteristics of Himalayan topography and geology, which is one of the major reasons for the poor quality of the water.

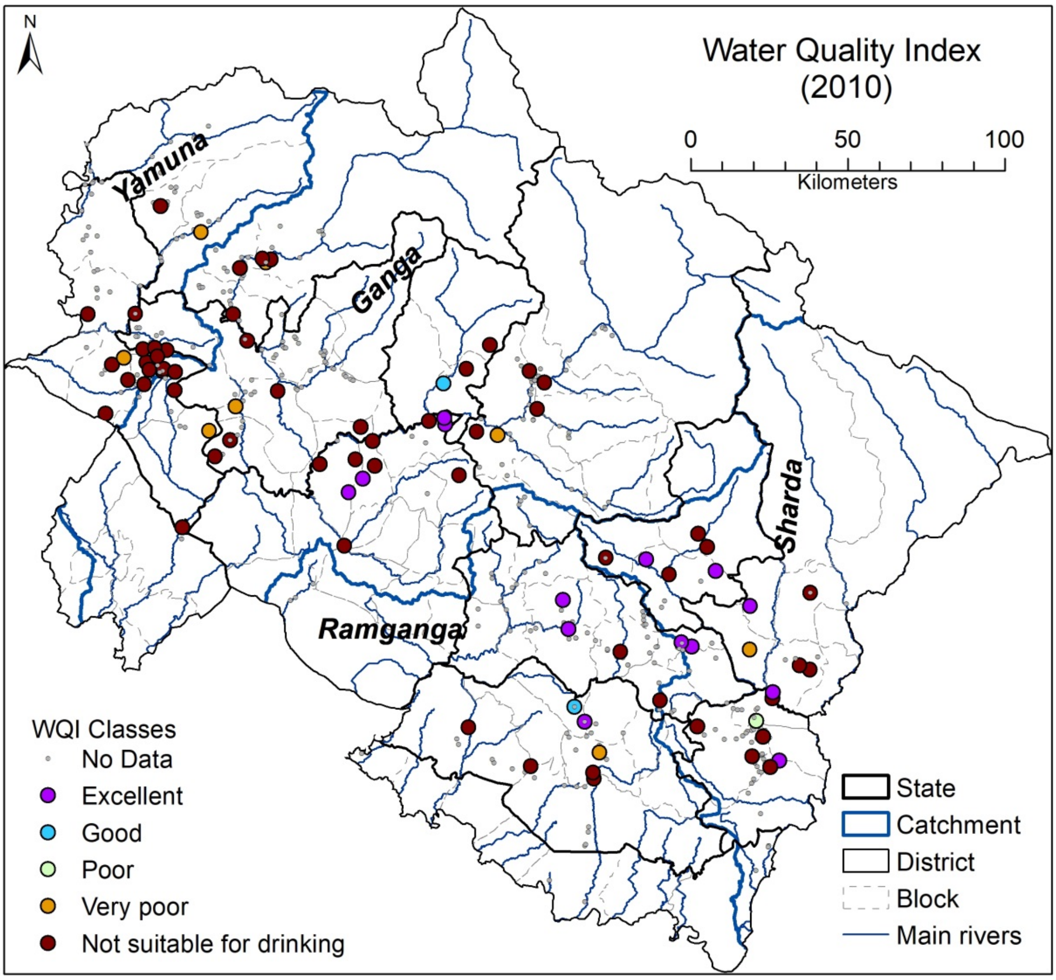


Figure 11: WQI for the year 2010

Similar to 2010, the sample data for the year 2011 was classified under various range of water quality indexes and the cause of poor quality was mostly associated with calcium, magnesium, turbidity and total coliform. Not suitable for drinking areas are more concentrated near the Raipur block of Dehradun due to calcium and magnesium and another locations are again due to pH, turbidity and total coliform. 2010 and 2011as have a similar spatial distribution of the WQI index but it was slightly one scale batter than the previous year (2010) on the WQI index. There are three emerging pockets of poor WQI based on 2010 and 2011data: (1) Raipur block in Dehradun, (2) from Uttarkashi to Tehri dam and (3) from Devprayag to Nandprayag (Figure 13) mostly due to total coliform of sewerage of urban and surface runoff of vegetated cover.

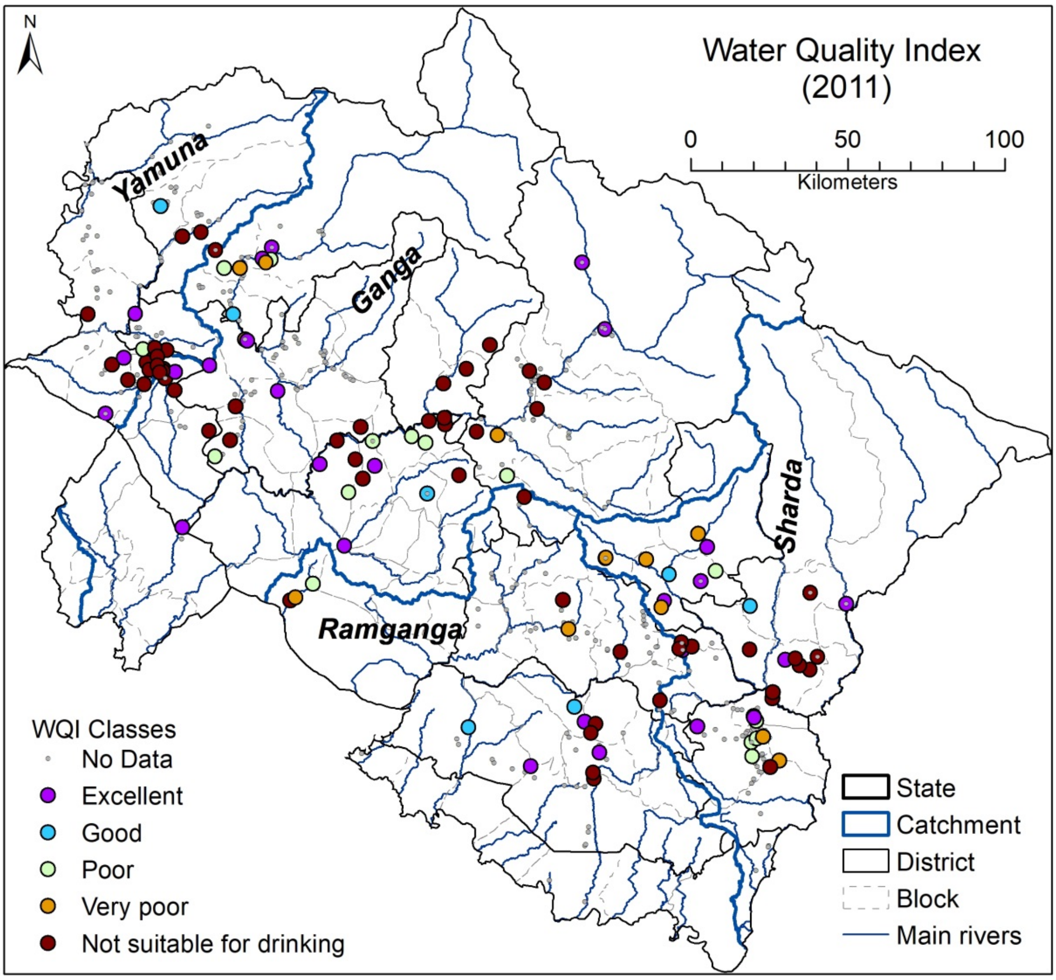


Figure 12: WQI for the year 2011

As per the previous two years, the cause of the poor WQI index in 2012 is due to calcium, magnesium, pH, turbidity and total coliform. The three pockets are continued in this year also first Raipur block in Dehradun due to exceeding permissible limit of calcium, magnesium, pH, turbidity and total coliform value but the second location from Uttarkashi to Tehri dam poor Index is not only due to turbidity and total coliform but also due to the presence of aluminium. The third location from Devprayag to Nandprayag (Figure 14) is mostly due to the total coliform of sewerage of urban and surface runoff of vegetated cover. Other than this, a new region was also identified near Pati and Lohaghat of Champawat district area due to excess of aluminium and fluoride.

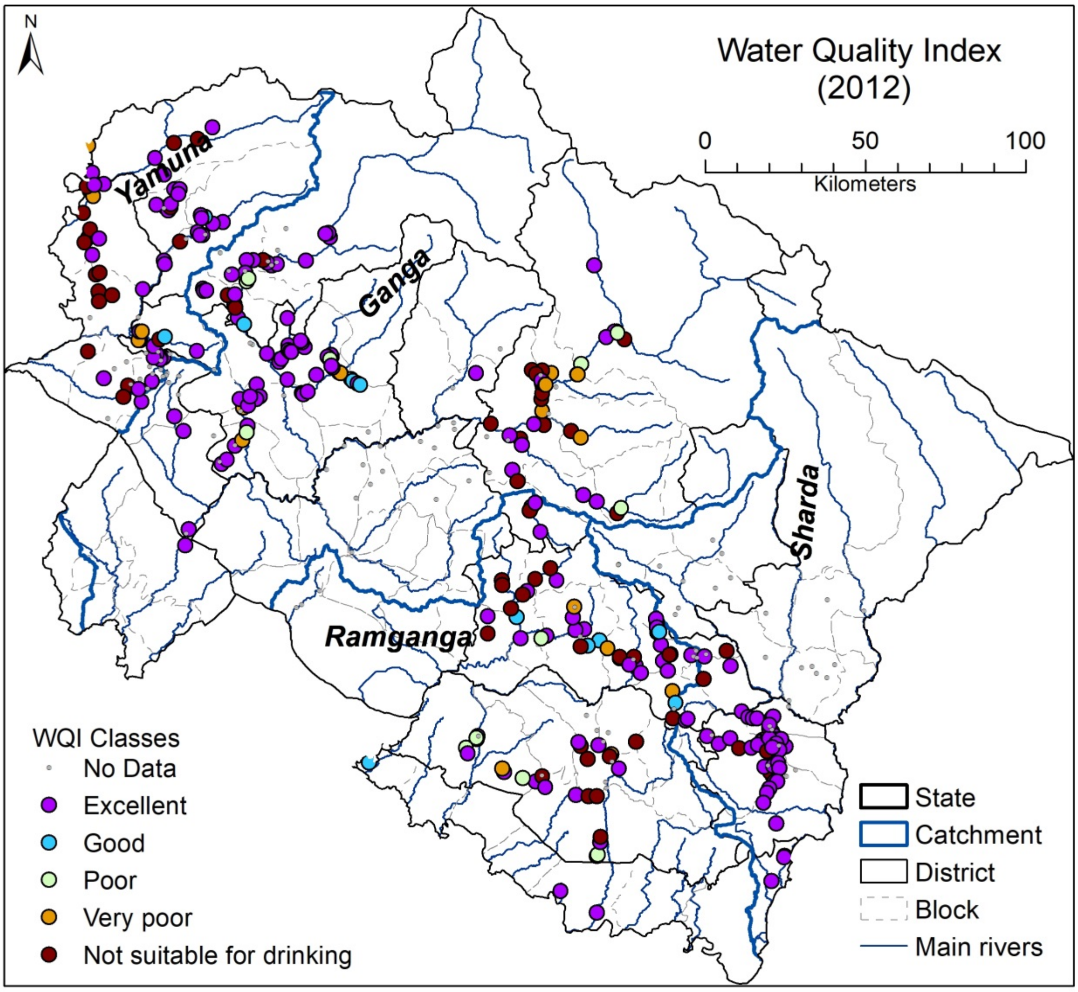


Figure 13: WQI for the year 2012

Poor WQI index in 2014 is due to turbidity and total coliform. The three pockets are continued this year, first Raipur block in Dehradun, second from Uttarkashi to Tehri dam and the third location from Devprayag to Nandprayag (Figure 15) are mostly due to total coliform of sewerage of urban and surface runoff of vegetated cover. There is an additional one region at Chakrata in Dehradun district of the Yamuna basin in the Uttarakhand which was also confirmed in the previous 2012 and next year 2016 sampling but not confirmed in 2010 and 2011. This location is also recognized as the fifth poor water quality zone due to turbidity and total coliform. This location recognized high aluminium concentration during 2012.

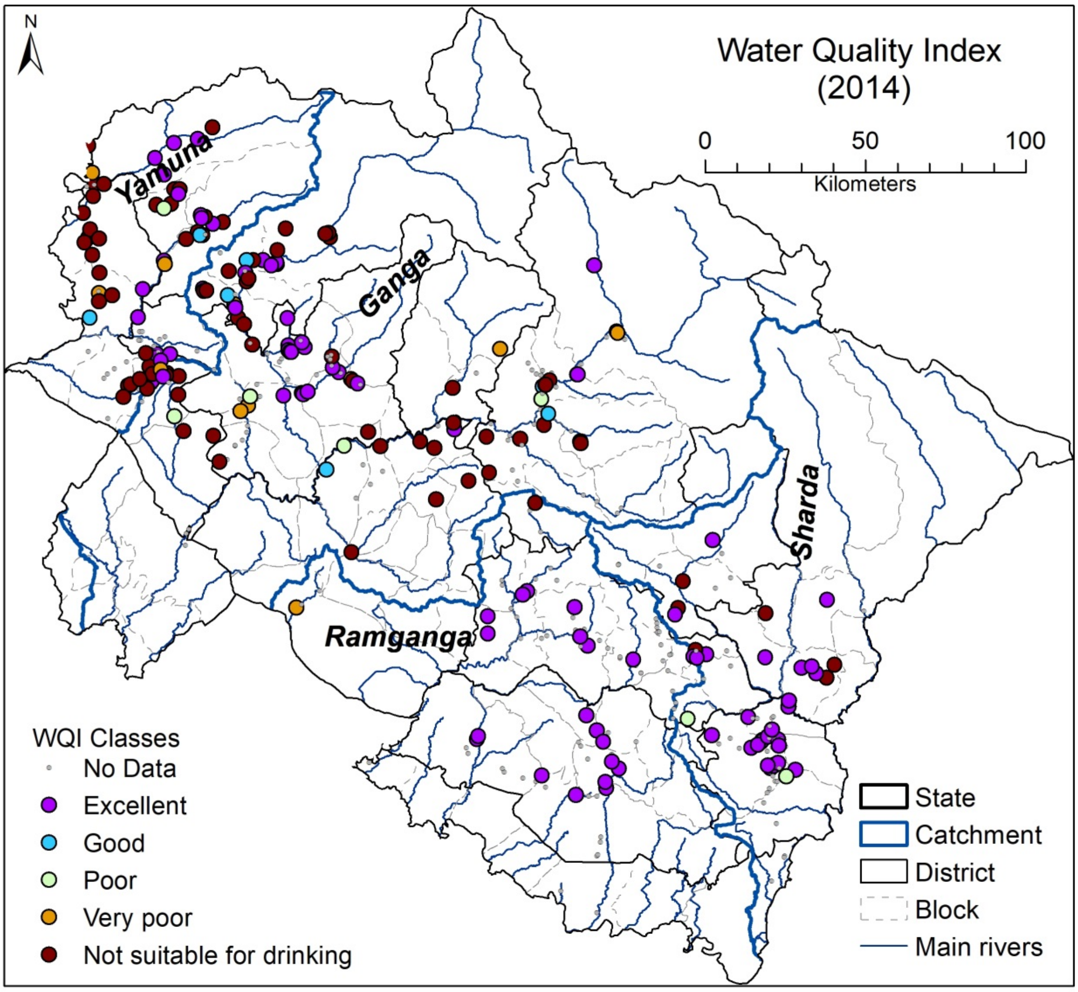


Figure 14: WQI for the year 2014

A random sample was collected during 2016 at those locations, where water quality exceeded above the permissible limit before 2010 to 2014 in any of the parameters associated with drinking water quality. The WQI confirmed all five pockets of poor quality in 2016. Raipur and Chakrata of Dehradun district in the Yamuna basin; Uttarkashi to Terhri dam in Bhagirathi basin; Nandprayag to Rudraprayag in Alaknanda basin and Lohaghat of Champawat district in the small tributaries of Kali river basin (Figure 16). Based on the previous data analysis the five pockets were further confirmed by the recent years 2018 and 2019 through primary field survey using the WQI index.

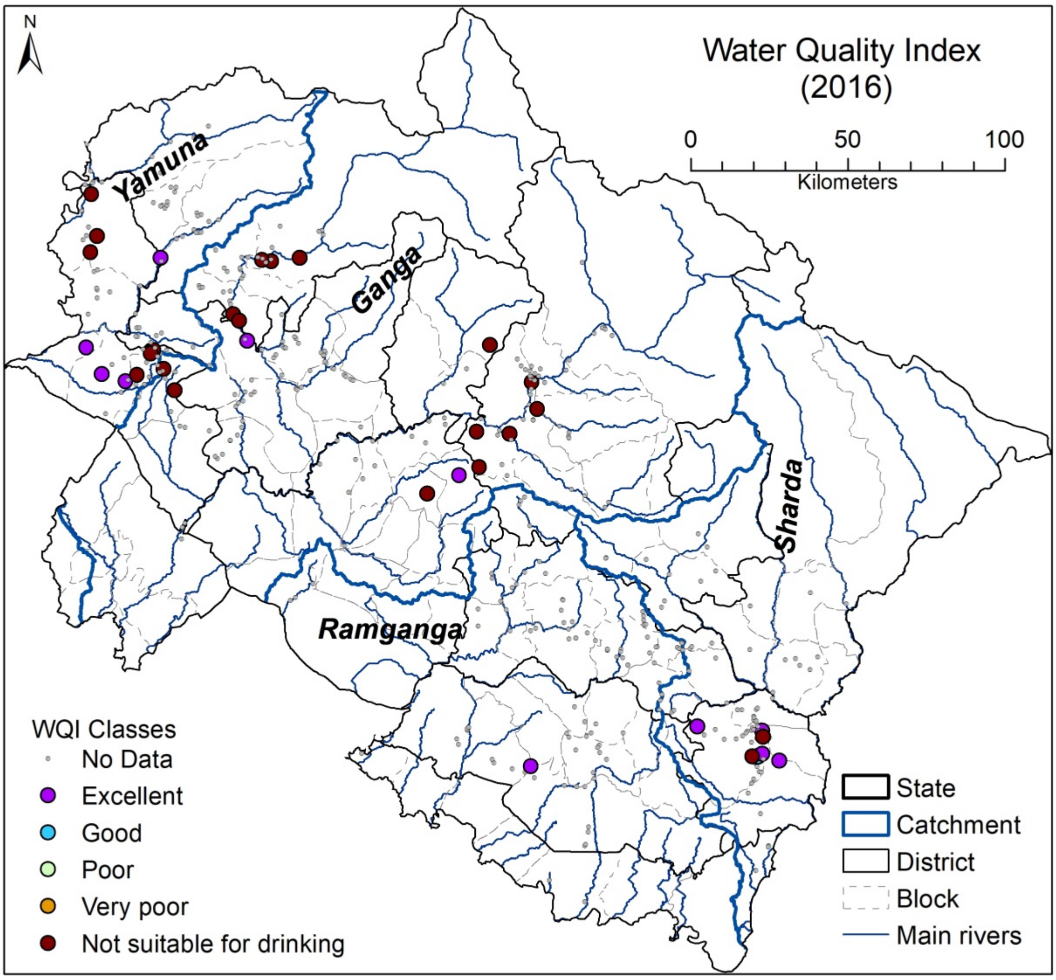


Figure 15: WQI for the year 2016

The last two consecutive (2018-19) years based on the primary survey, it was observed that the poor WQI is confined in two stretches first from Uttarkashi to Tehri dam and second from was Nandprayag to Devprayag (Figures 17&18). In both the year WQI is poor due to total coliform and turbidity. Additional parameter *E.coli* was tested in these two years to confirm the basic reason for the poor water quality index. The presence of *E.coli* is an indicator of pathogenic organisms in the water bodies. There can be various possible sources of *E.coli* that contaminate surface water includes septic leachate, municipal wastewater discharge, agricultural or storm runoff, wildlife populations or nonpoint sources of human and animal waste. This area is developing very fast due to tourism activities and Char Dham yatra, which causes major reasons for septic leachate, municipal wastewater discharge due to the poor sewerage system and high runoff in hills. Further, the change in land use and land cover especially the extension of agriculture has been explained in the next section which includes hydrological analysis of the basin.

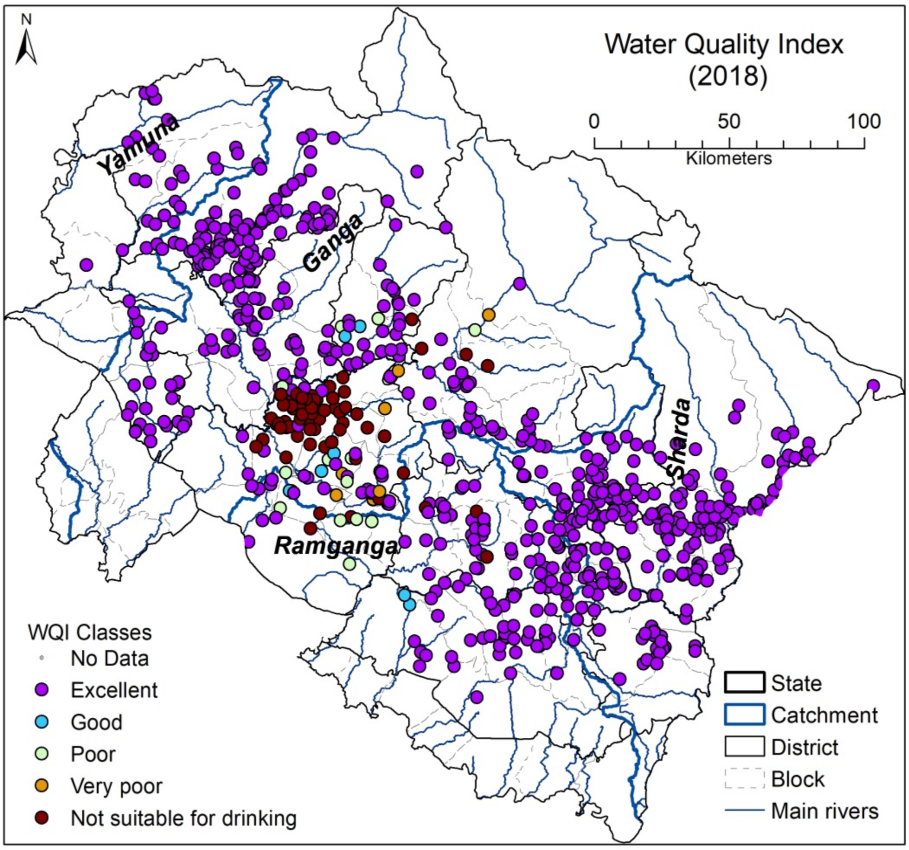


Figure 16: WQI for the year 2018

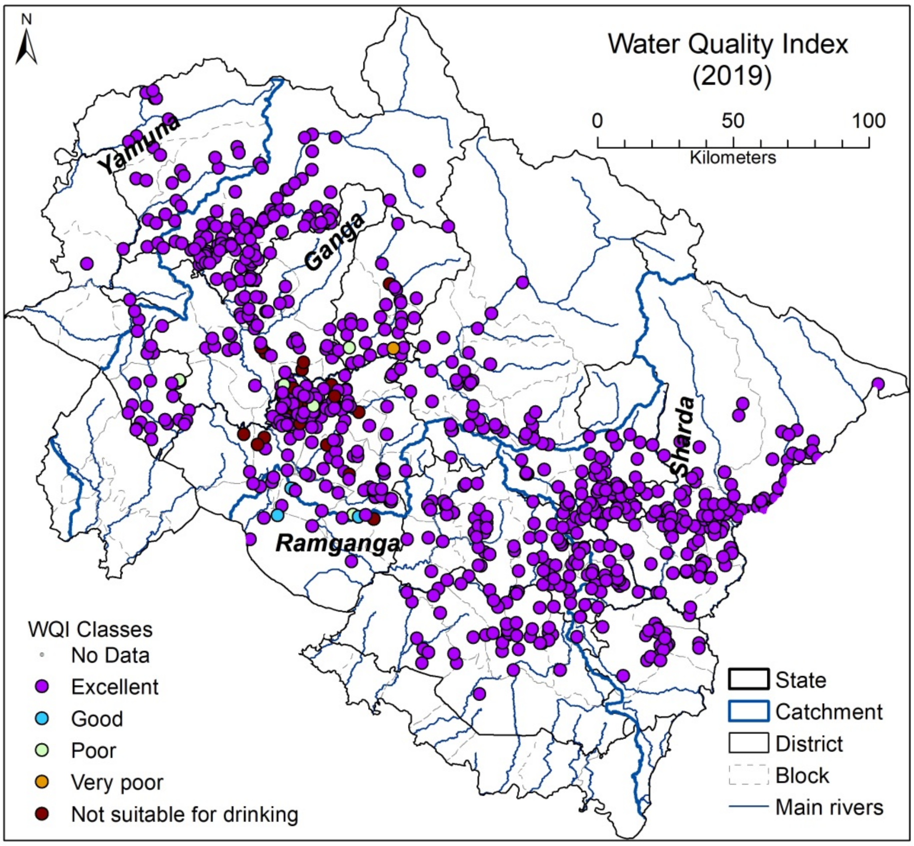


Figure 17: WQI for the year 2019

Total coliform is due to surface runoff from the vegetated area, poor sewerage system of the urbanized hilly area with the rapid development process under tourism observed. Turbidity is also associated with high surface runoff. Iron, Calcium and Magnesium are associated with the local geological factors of the area. In these parameters, total coliform is a major parameter that makes entire Uttarakhand under poor water quality index. The exceeding value of these parameters is the general characteristics of Himalayan topography and geology. which is one of the major reasons for the poor quality of the water. The concentration becomes high during the lean period of rainfall (pre-monsoon) but after the rainy season or post-monsoon period, the same location was reclassified under the better order of WQI value throughout the study period from 2010 to 2019.

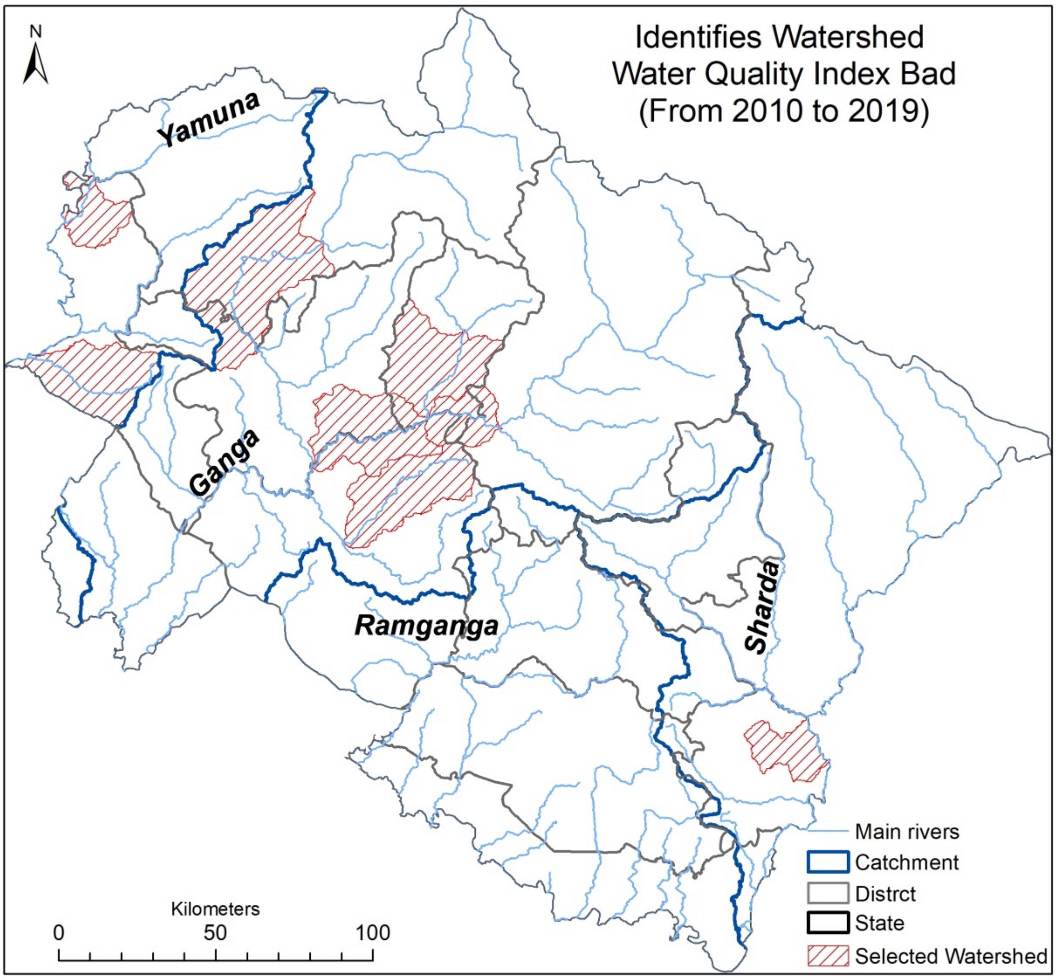


Figure 18: WQI for the years 2010-2019

Overall five sites are identified based on the WQI index, which fall under eight sub-basins (Figure 19). These sub-basins are further analyzed for a hydrological basis to prepare an action plan for aquifer augmentation.

(d)Provide Spatio-temporal water quality dynamics and trend of the future status

A total of 20 water quality parameters were selected for Spatio-temporal quality dynamics from 2010 to 2019. Few quality parameters exceed the drinking permissible limit. The study evaluated each of the parameters, which exceeded above the permissible limit under the spatio-temporal domain.

The first parameter was pH, which is exceeding the limit above 8.5 was identified at various locations (Figure 20). The most dominant districts are Champawat and Dehradun (Table 6) have been categorically observed in the study for the same.

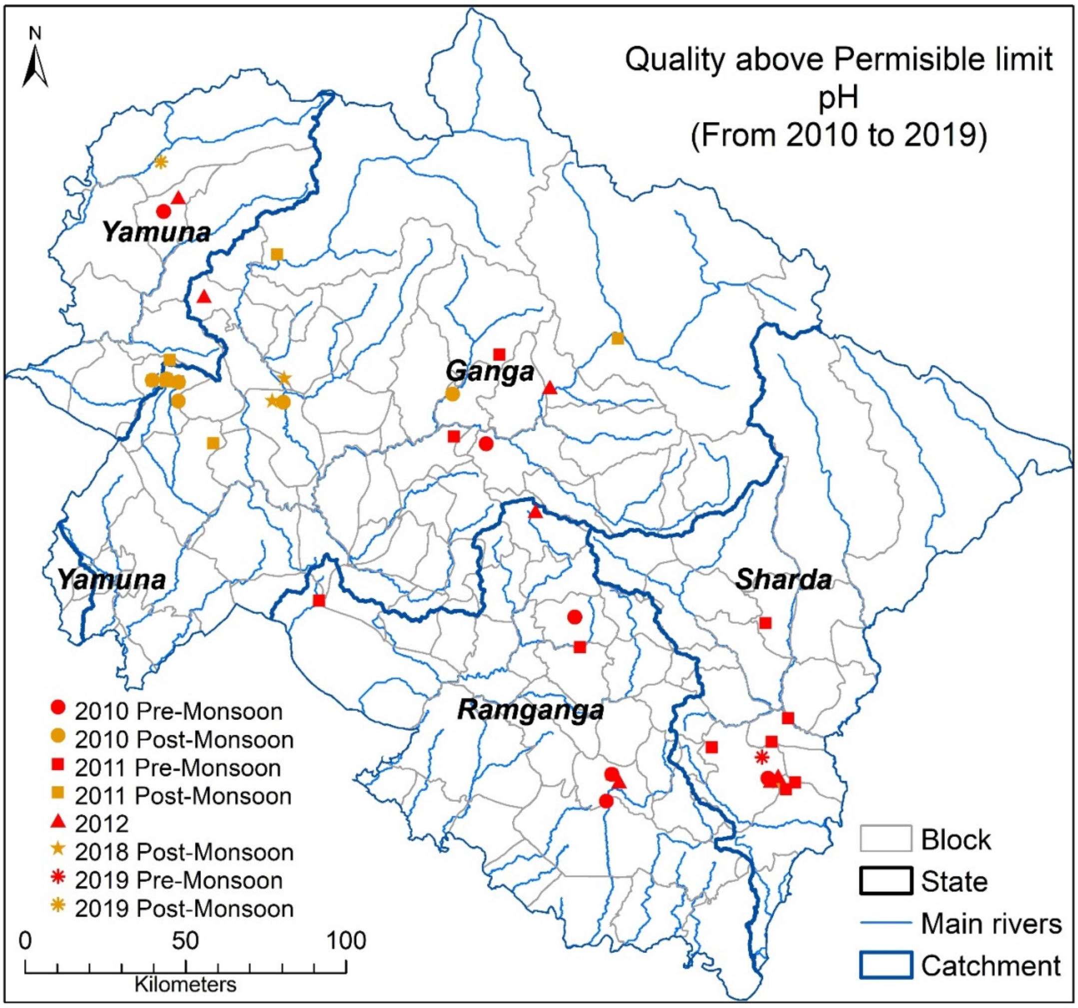


Figure 19: Location of water sources exceeding pH above the permissible limit

Table 6: Sites above the permissible limit of pH

Sl No	Sites	Major Location	Year	Seasons
1	Dwarhat (Kheron Gadhera)	Almora	2010	Pre
2	Dwarhat (Kheron Gadhera)	Almora	2010	Post
3	Ranikheit (Tadikhat (Gagas)	Almora	2011	Pre
4	Firalu	Barkot	2019	Post
5	Gairsain (Gwaad Gadhera)	Chamoli	2012	Pre
6	Gaucher (Ghaghragaad)	Chamoli	2010	Pre
7	Gopeshwar Polytechnic	Chamoli	2012	Pre
8	Joshimath (Nawganga)	Chamoli	2011	Post
9	Barakot (Chhadkhola)	Champawat	2011	Pre
10	Champawat (Churakhad)	Champawat	2010	Pre
11	Champawat Nagar Phase I	Champawat	2012	Pre
12	Dota	Champawat	2019	Pre
13	Fungar (Dudhadhari Kola)	Champawat	2011	Pre
14	Kherkkarki (Chhidapani khola)	Champawat	2011	Pre
15	Kimad (Kedarnath khola)	Champawat	2011	Pre
16	Kimad (Kedarnath khola)	Champawat	2011	Post
17	Madli Tank	Champawat	2012	Pre
18	matika khola	Champawat	2018	Post
19	Bhogpur (Aamgarh Khala)	Dehradun	2011	Post
20	Danda Lakhaud (Karligaad)	Dehradun	2010	Post
21	Danda Lakhaud (Karligaad)	Dehradun	2011	Post
22	Dehradun City (Bandal)	Dehradun	2010	Post
23	Dehradun City (Bhitarli)	Dehradun	2010	Post
24	Dehradun City (Bhitarli)	Dehradun	2011	Post
25	Dehradun City (Massifall)	Dehradun	2010	Post
26	Dehradun City (Massifall)	Dehradun	2011	Post
27	Gujrada (Karligaad)	Dehradun	2010	Post
28	Gujrada (Karligaad)	Dehradun	2011	Post
29	Kirsali (Telagaad)	Dehradun	2011	Post
30	Mussoorie (Kolti)	Dehradun	2011	Post
31	Bhimtal (Bhimtal Lake)	Nainital	2010	Pre
32	Bhimtal (Bhimtal Lake)	Nainital	2010	Post
33	Bhimtal (Bhimtal Lake)	Nainital	2011	Pre
34	Haldwani (Gola River)	Nainital	2010	Pre
35	Naukuchiyatal Bhimtal	Nainital	2012	Pre
36	Dugadda (Khoh River)	Pauri	2011	Pre
37	Dugadda (Khoh River)	Pauri	2011	Post
38	Berinaag (Ghurghatiya)	Pithoragarh	2011	Pre
39	Pithoragarh (Ramganga River)	Pithoragarh	2011	Pre
40	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2010	Post
41	Tiladi (Bhunak Gadhera)	Rudraprayag	2011	Pre
42	Ukimath (Pighala Pani)	Rudraprayag	2011	Pre
43	Kapdagarh Source Nam Tok	Tehri	2018	Post

Sl No	Sites	Major Location	Year	Seasons
44	Khemda Source Nam Tok	Tehri	2018	Post
45	New Tehri (Bhagirathi River)	Tehri	2010	Post
46	Dandagaon Chinyalisour	Uttarkashi	2012	Pre
47	Gangori (Singoti khala)	Uttarkashi	2011	Post
48	Naag Jhala Pathari Khud Purola	Uttarkashi	2012	Pre
49	Purola (Kufara Khaad)	Uttarkashi	2010	Pre

The turbidity in water may cause due to the presence of suspended and colloidal matter such as classified silt, clay, finely divided organic and inorganic matter and plankton and other microscopic organisms. The correlation between turbidity and the concentration or weight of the suspended matters is difficult to determine because the size, shape and refractive index of the particles affect the light-scattering properties of the suspension (Baird et al., 2017).

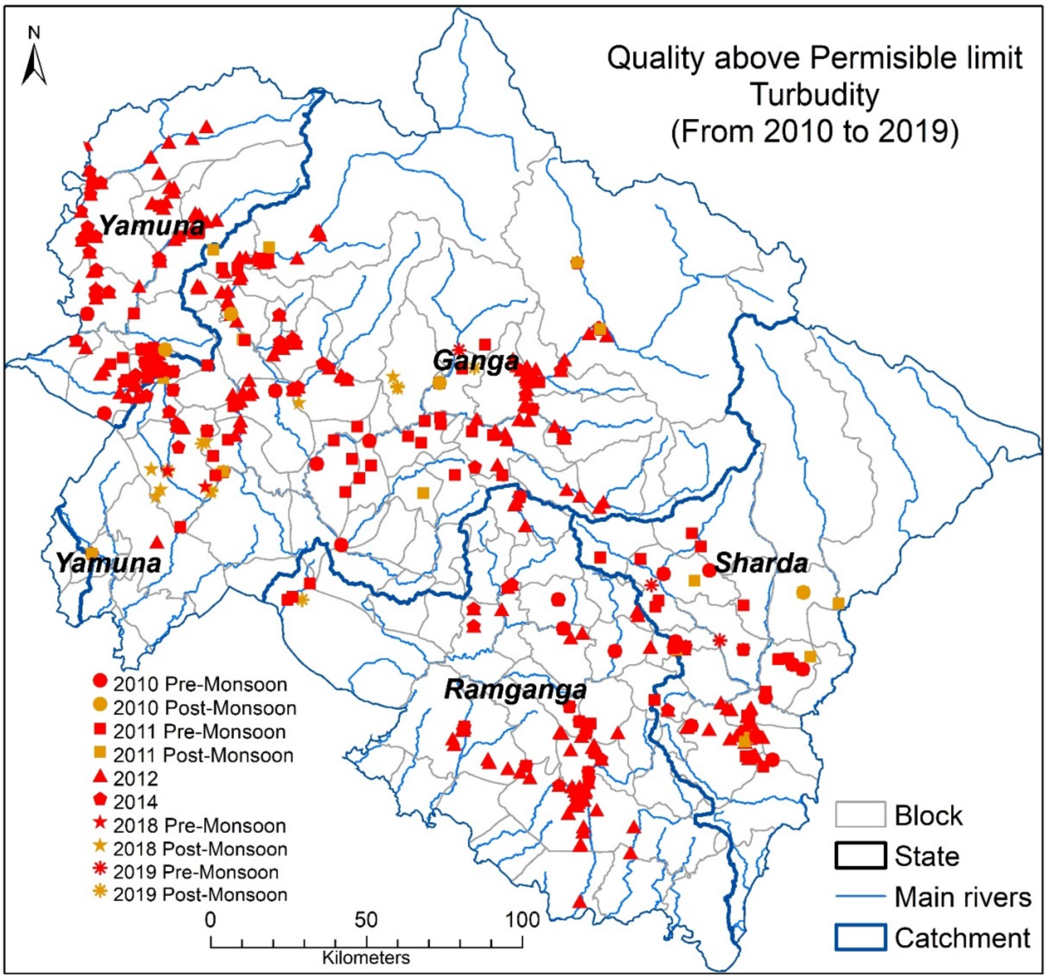


Figure 20: Location of water sources exceeding turbidity above the permissible limit

Figure 21 shows the turbidity is a major issue in Uttarakhand. This is due to the high sediment load of organic and inorganic matter due to hilly topography. The same has been reduced in the plain area (Table 7).

Table 7: Sites above the permissible limit of turbidity

Sl No	Sites	Major Location	Year	Seasons
1	Almora (Kosi Nadi)	Almora	2010	Pre
2	Almora (Kosi Nadi)	Almora	2011	Post
3	Artola (Gandhak Gadhera)	Almora	2011	Post
4	Artola (Gandhak Gadhera)	Almora	2014	Pre
5	Beena Samuhik Yojana	Almora	2012	Pre
6	Dhari Supai Yojana	Almora	2012	Pre
7	Dwarhat (Kheron Gadhera)	Almora	2010	Pre
8	Dwarhat (Kheron Gadhera)	Almora	2011	Post
9	Dwarhat (Kheron Gadhera)	Almora	2014	Pre
10	Jageshwar (Erawatgupha Gadhera)	Almora	2011	Post
11	Jageshwar (Erawatgupha Gadhera)	Almora	2014	Pre
12	Jageshwar Market Phlai, Jageshwar	Almora	2012	Pre
13	Jaiti Yojana	Almora	2012	Pre
14	Jaiti Yojana	Almora	2014	Pre
15	Jhimaar Gram Sabha Yojana, Jhimaar Gaon, Sult	Almora	2012	Pre
16	Jhimaar Gram Sabha Yojana, Jhimaar Gaon, Sult	Almora	2014	Pre
17	Kalika Tok Pumping Yojana	Almora	2012	Pre
18	Karget Yojana, Kaligaon Market, Sult	Almora	2012	Pre
19	Karget Yojana, Kaligaon Market, Sult	Almora	2014	Pre
20	Khaspad (Gyari Gaad Gadhera)	Almora	2011	Post
21	Lamgara (Bharat Khali)	Almora	2011	Post
22	Majhkhali	Almora	2012	Pre
23	Mohana Malla Peyjal Yojna	Almora	2012	Pre
24	Mohana Malla Peyjal Yojna	Almora	2014	Pre
25	Naithana Devi Pumping Jojna	Almora	2012	Pre
26	Naithana Devi Pumping Jojna	Almora	2014	Pre
27	Naula-Jainel Yojna	Almora	2012	Pre
28	Panava Naula (Paneth Gadhera)	Almora	2010	Pre
29	Panava Naula (Paneth Gadhera)	Almora	2011	Post
30	Quarali (Gyari Gaad Gadhera)	Almora	2011	Post
31	Quarali (Gyari Gaad Gadhera)	Almora	2014	Pre
32	Ranikheit (Tadikhat (Gagas)	Almora	2010	Pre
33	Ranikheit (Tadikhat (Gagas)	Almora	2011	Post
34	Ranikheit (Tadikhat (Gagas)	Almora	2014	Pre
35	Thapala	Almora	2012	Pre
36	Anna-Bmna zone-II (Garud Ganga)	Bageshwar	2011	Post
37	Bageshwar (Salani source river)	Bageshwar	2011	Post
38	Bageshwar (Saryu river)	Bageshwar	2010	Pre
39	Bageshwar (Saryu river)	Bageshwar	2010	Post
40	Bageshwar (Saryu river)	Bageshwar	2011	Post
41	Bamantana	Bageshwar	2019	Pre
42	Bhayon (Gadera Gadhera)	Bageshwar	2011	Post
43	Bijori Jhal (Dhikra Gadhera)	Bageshwar	2011	Post
44	Gadera (Group Nala)	Bageshwar	2010	Pre
45	Gadera (Group Nala)	Bageshwar	2010	Post
46	Gadera (Group Nala)	Bageshwar	2011	Post
47	Kafkot (Balen Gadhera)	Bageshwar	2011	Post
48	Karala Gaon (Kathpuria Sprig)	Bageshwar	2011	Pre
49	Karala Gaon (Kathpuria Sprig)	Bageshwar	2011	Post
50	Loov (Bhanarigan Gadhera)	Bageshwar	2011	Post

Sl No	Sites	Major Location	Year	Seasons
51	Narayangunth (Laksuro Spring)	Bageshwar	2011	Post
52	Badrinath (Charan Paduka)	Chamoli	2011	Post
53	Badrinath (Charan Paduka)	Chamoli	2014	Pre
54	Bairagna Dasholi	Chamoli	2012	Pre
55	Bhanak Gopeshwar Gopeshwar	Chamoli	2012	Pre
56	Chamoli (Khanduri Gadhera)	Chamoli	2011	Post
57	Chamoli Alaknanda Ghat	Chamoli	2012	Pre
58	Chamoli Alaknanda Ghat	Chamoli	2014	Pre
59	Chamoli Chamoli Market	Chamoli	2012	Pre
60	Deval Bazar Deval	Chamoli	2012	Pre
61	Deval Dev Dasholi	Chamoli	2012	Pre
62	Devradi Tharali Tharali Bazar	Chamoli	2012	Pre
63	Dhartalla Kothinand Kesari	Chamoli	2012	Pre
64	Dimmar Karanprayag	Chamoli	2012	Pre
65	Fahli Ghaat	Chamoli	2012	Pre
66	Fahli Ghaat	Chamoli	2014	Pre
67	Gairsain (Gwaad Gadhera)	Chamoli	2011	Post
68	Gairsain (Gwaad Gadhera)	Chamoli	2014	Pre
69	Gairsain (Gyonhat Gadhere)	Chamoli	2011	Post
70	Gairsain Bazar Gairsain	Chamoli	2012	Pre
71	Gauchar Karanprayag	Chamoli	2012	Pre
72	Gaucher (Ghaghragaad)	Chamoli	2011	Post
73	Ghigram Dasholi	Chamoli	2012	Pre
74	Gopeshwar	Chamoli	2012	Pre
75	Gopeshwar Boitarini Kund	Chamoli	2012	Pre
76	Gopeshwar Jal Sansthan	Chamoli	2012	Pre
77	Gopeshwar Polytechnic	Chamoli	2012	Pre
78	Gopeshwar Temple Gopeshwar	Chamoli	2012	Pre
79	Jirkot Gaisain Mehalchori	Chamoli	2012	Pre
80	Joshimath (Nawganga)	Chamoli	2011	Post
81	Joshimath (Nawganga)	Chamoli	2014	Pre
82	Julgadh Payjal Yojana, Gaisain Adibadri	Chamoli	2012	Pre
83	Kandora Hindoli Karanprayag	Chamoli	2012	Pre
84	Karanprayag (Ghatgaad Gadhera)	Chamoli	2011	Post
85	Karanprayag Market Karanprayag	Chamoli	2012	Pre
86	Kuhed Dasholi	Chamoli	2012	Pre
87	Kulsari Dasholi	Chamoli	2012	Pre
88	Maithana Dasholi	Chamoli	2012	Pre
89	Maithana Dasholi	Chamoli	2014	Pre
90	Mallakheit Karanprayag	Chamoli	2012	Pre
91	Mandal Bazar Dasholi	Chamoli	2012	Pre
92	Nandaprayag (Bridge) Karanprayag	Chamoli	2012	Pre
93	Nandaprayag (Zaithagaad)	Chamoli	2011	Post
94	Nandaprayag (Zaithagaad)	Chamoli	2014	Pre
95	Nandaprayag Karanprayag	Chamoli	2012	Pre
96	Nandprayag (Sangam)	Chamoli	2014	Pre
97	Naurakh Runargathan, Dasholi	Chamoli	2012	Pre
98	Naurakh Runargathan, Dasholi	Chamoli	2014	Pre
99	Pakhi Joshimath	Chamoli	2012	Pre
100	Parsari Joshimath	Chamoli	2012	Pre
101	Pipalkoti (Mangerigaad)	Chamoli	2011	Post
102	Pipalkoti Dasholi	Chamoli	2012	Pre
103	Pipalkoti Dasholi	Chamoli	2014	Pre
104	Rampura Natural Source Dasholi	Chamoli	2012	Pre
105	Rampura Natural Source Dasholi	Chamoli	2014	Pre
106	Ravigram I Joshimath Nagar Palika	Chamoli	2012	Pre
107	Ravigram I Joshimath Nagar Palika	Chamoli	2014	Pre
108	Ravigram II Joshimath	Chamoli	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
109	Sagar/Gwaad Dasholi	Chamoli	2012	Pre
110	Saiti (NS) Ghat	Chamoli	2012	Pre
111	Saiti (NS) Ghat	Chamoli	2014	Pre
112	Sclang Joshimath	Chamoli	2012	Pre
113	Sera (Ghat)	Chamoli	2012	Pre
114	Serani Ghat	Chamoli	2012	Pre
115	Sonyana Silangi Dhunaghat	Chamoli	2012	Pre
116	Sunii	Chamoli	2012	Pre
117	Sunoli Karanprayag Sunoli	Chamoli	2012	Pre
118	Tatasu Majhaydi Karanprayag	Chamoli	2012	Pre
119	Baira Ghirkunj Yojana	Champawat	2012	Pre
120	Bairakot I	Champawat	2012	Pre
121	Bairakot II	Champawat	2012	Pre
122	Barakot (Chhadkhola)	Champawat	2011	Post
123	Chamoula	Champawat	2012	Pre
124	Champawat (Churakhad)	Champawat	2011	Post
125	Champwat Shant Bazar	Champawat	2012	Pre
126	Chilniya Semalkhet	Champawat	2012	Pre
127	Circuit House Tank Champwat	Champawat	2012	Pre
128	Devidhara	Champawat	2012	Pre
129	Dhayarkhola Yojana	Champawat	2012	Pre
130	Dungri Fartyaal	Champawat	2012	Pre
131	Edakot	Champawat	2012	Pre
132	Forti (Tanki Ka Khola)	Champawat	2011	Post
133	Forti (Tanki Ka Khola)	Champawat	2012	Pre
134	Fungar (Dudhadhari Kola)	Champawat	2010	Pre
135	Fungar (Dudhadhari Kola)	Champawat	2011	Post
136	Galchourasui	Champawat	2012	Pre
137	Karnakaryati	Champawat	2012	Pre
138	Kherkkarki (Chhidapani khola)	Champawat	2011	Post
139	Khetikhan	Champawat	2012	Pre
140	Kimad (Kedarnath khola)	Champawat	2010	Pre
141	Kimad (Kedarnath khola)	Champawat	2011	Post
142	Kolidhek (Mayawati Gadhera)	Champawat	2011	Post
143	Kolidhek (Mayawati Gadhera)	Champawat	2012	Pre
144	Lohaghat (Lohawati River)	Champawat	2010	Pre
145	Lohaghat (Lohawati River)	Champawat	2010	Post
146	Lohaghat (Lohawati River)	Champawat	2011	Post
147	Lohaghat Souru Churi Pump House	Champawat	2012	Pre
148	Nagar Palika Chauraya Tank	Champawat	2012	Pre
149	Pathimarket	Champawat	2012	Pre
150	Punaie (Larag Gadhera)	Champawat	2011	Post
151	Punaie (Larag Gadhera)	Champawat	2012	Pre
152	Raigaon	Champawat	2012	Pre
153	Raighanw Nigeligan	Champawat	2011	Pre
154	Raighanw Nigeligan	Champawat	2011	Post
155	Rainagar Chauri	Champawat	2012	Pre
156	Risheswar Tubewel	Champawat	2012	Pre
157	Sui Peyjal Yojana	Champawat	2012	Pre
158	Aam Source (Madusidha)	Dehradun	2010	Pre
159	Aam Source (Madusidha)	Dehradun	2011	Post
160	Aambadi	Dehradun	2012	Pre
161	Aambadi	Dehradun	2014	Pre
162	Aamwala Guchka Gadera (Nuniyas gaon)	Dehradun	2014	Pre
163	Adersh Nagar	Dehradun	2014	Pre
164	BadasiGrant Raipur, Deukhala	Dehradun	2012	Pre
165	BadasiGrant Raipur, Deukhala	Dehradun	2014	Pre
166	Bhagwanpur (Aglikhala)	Dehradun	2011	Post

Sl No	Sites	Major Location	Year	Seasons
167	Bharatwala (Bhitarligaad)	Dehradun	2011	Post
168	Bharatwala (Bhitarligaad)	Dehradun	2014	Pre
169	Bharatwala (Bisht Gaon/Shaspur)	Dehradun	2012	Pre
170	Bharatwala (Bisht Gaon/Shaspur)	Dehradun	2014	Pre
171	Bhauwala (Maldunga)	Dehradun	2011	Post
172	Bhauwala Rampur, Rajawala	Dehradun	2012	Pre
173	Bhauwala Rampur, Ramsawal	Dehradun	2012	Pre
174	Bhogpur (Aamgarh Khala)	Dehradun	2011	Post
175	Bhogpur (Aamgarh Khala)	Dehradun	2014	Pre
176	Bhopalpani, Kadaikhala Sodikhal, Raipur	Dehradun	2012	Pre
177	Bhopalpani, Kadaikhala Sodikhal, Raipur	Dehradun	2014	Pre
178	Danda Lakhaud (Karligaad)	Dehradun	2011	Post
179	Danda Lakhaud (Karligaad)	Dehradun	2014	Pre
180	Dehradun City (Bandal)	Dehradun	2011	Post
181	Dehradun City (Bandal)	Dehradun	2014	Pre
182	Dehradun City (Bhitarli)	Dehradun	2011	Post
183	Dehradun City (Bhitarli)	Dehradun	2014	Pre
184	Dehradun City (Massifall)	Dehradun	2010	Pre
185	Dehradun City (Massifall)	Dehradun	2011	Post
186	Dehradun City (Massifall)	Dehradun	2014	Pre
187	Dhauran (Talanighat)	Dehradun	2011	Post
188	Dhauran (Talanighat)	Dehradun	2014	Pre
189	Dhobighat, Mussoorie	Dehradun	2012	Pre
190	Ghanghoda Hariyawala, Shaspur	Dehradun	2012	Pre
191	Gujrada (Karligaad)	Dehradun	2011	Post
192	Gujrada (Karligaad)	Dehradun	2014	Pre
193	Gujrada (Nagal Hatnala MTW)	Dehradun	2011	Post
194	Jaadi Chakrata	Dehradun	2012	Pre
195	Jaadi Chakrata	Dehradun	2014	Pre
196	Jhajhra Panditwadi Sudhowala	Dehradun	2012	Pre
197	Jinsi, Mussoorie	Dehradun	2012	Pre
198	Kalsi (Jhajhreda)	Dehradun	2010	Pre
199	Kalsi (Jhajhreda)	Dehradun	2011	Post
200	Kalsi (Jhajhreda)	Dehradun	2014	Pre
201	Kalsi Bazar Kalsi, Amlaw	Dehradun	2012	Pre
202	Kandli Vilaspur, Shaspur	Dehradun	2012	Pre
203	Kirsali (Telagaad)	Dehradun	2011	Post
204	Kirsali (Telagaad)	Dehradun	2014	Pre
205	Kohlupani (Aamwala) Shaspur	Dehradun	2012	Pre
206	Kolti, Mussoorie	Dehradun	2012	Pre
207	Kolukhet (Chandroti)	Dehradun	2011	Post
208	Kolukhet (Chandroti)	Dehradun	2014	Pre
209	Kotala Santure (Madusidh Khala)	Dehradun	2011	Post
210	Kwarana Mangraul Sunaua	Dehradun	2012	Pre
211	Kwarana Mangraul Sunaua	Dehradun	2014	Pre
212	Makhi Pokhau Sawaiklaad	Dehradun	2012	Pre
213	Makhi Pokhau Sawaiklaad	Dehradun	2014	Pre
214	Malsi (Kaligaad)	Dehradun	2011	Post
215	Mangrouli, Sujunaklaad	Dehradun	2012	Pre
216	Mussoorie (Bhiladu)	Dehradun	2011	Post
217	Mussoorie (Bhiladu)	Dehradun	2012	Pre
218	Mussoorie (Bhiladu)	Dehradun	2014	Pre
219	Mussoorie (Dhobighat)	Dehradun	2011	Post
220	Mussoorie (Dhobighat)	Dehradun	2014	Pre
221	Mussoorie (Jinsi)	Dehradun	2011	Post
222	Mussoorie (Kandighat)	Dehradun	2011	Post
223	Mussoorie (Kandighat)	Dehradun	2014	Pre
224	Mussoorie (Kolti)	Dehradun	2010	Post

Sl No	Sites	Major Location	Year	Seasons
225	Mussoorie (Kolti)	Dehradun	2011	Post
226	Mussoorie (Kolti)	Dehradun	2014	Pre
227	Mussoorie (Macnan)	Dehradun	2011	Post
228	Mussoorie (Macnan)	Dehradun	2012	Pre
229	Mussoorie (Macnan)	Dehradun	2014	Pre
230	Mussorie Kandighat + Mare	Dehradun	2012	Pre
231	Naudi Tyutaad,	Dehradun	2012	Pre
232	Panditwari Mil-Mil Chowki	Dehradun	2012	Pre
233	Paula Soda Badari, Raipur	Dehradun	2012	Pre
234	Paundha Aamwala	Dehradun	2012	Pre
235	Paundha Aamwala	Dehradun	2014	Pre
236	Penwa (Penwa) Chunakhaad	Dehradun	2012	Pre
237	Penwa (Penwa) Chunakhaad	Dehradun	2014	Pre
238	Purtaad (Chatra) Dhanarti Klaad	Dehradun	2012	Pre
239	Purtaad (Chatra) Dhanarti Klaad	Dehradun	2014	Pre
240	Raygi Shediya Chhumra Paniklaad	Dehradun	2012	Pre
241	Raygi Shediya Chhumra Paniklaad	Dehradun	2014	Pre
242	Retaad (Kunen) Durani	Dehradun	2012	Pre
243	Retaad (Kunen) Durani	Dehradun	2014	Pre
244	Rishikesh (Pump No.6)	Dehradun	2011	Post
245	Saahiya Nebi Sarlaklaad	Dehradun	2012	Pre
246	Saahiya Nebi Sarlaklaad	Dehradun	2014	Pre
247	Samuha Tok, Nithala, Nichloklaad	Dehradun	2012	Pre
248	Sauda (Penva) Bharunuwa	Dehradun	2012	Pre
249	Sauda (Penva) Bharunuwa	Dehradun	2014	Pre
250	Soda Saroli, Chuowala, Raipur	Dehradun	2012	Pre
251	Soda Saroli, Chuowala, Raipur	Dehradun	2014	Pre
252	Sukhaad (Birnaad) Sukhaiki	Dehradun	2012	Pre
253	Sukhaad (Birnaad) Sukhaiki	Dehradun	2014	Pre
254	Sunbagh (Anu) Daglikhaad	Dehradun	2012	Pre
255	Sunbagh (Anu) Daglikhaad	Dehradun	2014	Pre
256	Tyuna Mangtaad Saraswati Khaad	Dehradun	2012	Pre
257	Tyuna Mangtaad Saraswati Khaad	Dehradun	2014	Pre
258	Tyuni (Raygi) Bamrikhaad	Dehradun	2012	Pre
259	Tyuni (Raygi) Bamrikhaad	Dehradun	2014	Pre
260	Vinau-Bantau Uprolikhida Koli	Dehradun	2012	Pre
261	Vinau-Bantau Uprolikhida Koli	Dehradun	2014	Pre
262	Bajeligdoli	Didihat	2019	Pre
263	Gadhera	Dwarikhal	2019	Post
264	Haridwar, Pantdeep, RBF (Pump No.18)	Haridwar	2011	Post
265	Roorkee (Padao)	Haridwar	2011	Post
266	Roorkee (Padao)	Haridwar	2014	Pre
267	Bailpadow Kaladhungi	Nainital	2012	Pre
268	Bandarajuda Kaladhungi	Nainital	2012	Pre
269	Bhimtal (Bhimtal Lake)	Nainital	2011	Post
270	Bhimtal (Bhimtal Lake)	Nainital	2014	Pre
271	Bhimtal Market (Diggi Gadhera)	Nainital	2012	Pre
272	Bhimtal, Songaon	Nainital	2012	Pre
273	Damura Dunga Haldwani	Nainital	2012	Pre
274	Devalchore Bandobasti Haldwani	Nainital	2012	Pre
275	Devendrapuri Badi Mukhani Haldwani	Nainital	2012	Pre
276	Dhari Bhimtal (Tank)	Nainital	2012	Pre
277	Dhobhighat Indiranagar Haldwani	Nainital	2012	Pre
278	Dungarpur Panchayat Ghar Lalkuan	Nainital	2012	Pre
279	Fatehpur Haldwani	Nainital	2012	Pre
280	Fatehpur Haldwani	Nainital	2014	Pre
281	Foot Kuan Haldwani	Nainital	2012	Pre
282	Garampani (Dopakhi) (kanwadi Spring)	Nainital	2011	Post

Sl No	Sites	Major Location	Year	Seasons
283	Garampani (Dopakhi) (kanwadi Spring)	Nainital	2014	Pre
284	Guijarpur Banki Kotibagh	Nainital	2012	Pre
285	Haldwani (Gola River)	Nainital	2011	Post
286	Haldwani (Gola River)	Nainital	2014	Pre
287	Himatpur Lalkuan	Nainital	2012	Pre
288	Jagtpur Lalkuan	Nainital	2012	Pre
289	Jalsansthan Bhawali, Nainital	Nainital	2012	Pre
290	Jalsansthan Tikoniya Haldwani	Nainital	2012	Pre
291	Jyolikoat Bhimtal Nainital	Nainital	2012	Pre
292	Kainchi (Kainchi Gadhera)	Nainital	2011	Post
293	Kainchi (Kainchi Gadhera)	Nainital	2014	Pre
294	Kaladungi (Bijpur)	Nainital	2011	Post
295	Kaladungi (Bijpur)	Nainital	2014	Pre
296	Kaniya Chilkiya Lakhanpur Ramnagar	Nainital	2012	Pre
297	Kathgodam (Sheetalahat)	Nainital	2011	Post
298	Kathgodam (Sheetalahat)	Nainital	2014	Pre
299	Kuleti (Kuleti Gadhera)	Nainital	2011	Pre
300	Kuleti (Kuleti Gadhera)	Nainital	2011	Post
301	Lakhan Mandi Haldwani Chorgaliyan	Nainital	2012	Pre
302	Lalkuan Market	Nainital	2012	Pre
303	Mahila Degree College Haldwani	Nainital	2012	Pre
304	Mahila Degree College Haldwani	Nainital	2014	Pre
305	Main Pump House Nainital	Nainital	2012	Pre
306	Mandiaya Tanda Chilkiya Ramnagar	Nainital	2012	Pre
307	Manpur Paschim Devalchore Haldwani	Nainital	2012	Pre
308	Milanchal Colony Dehriya Haldwani	Nainital	2012	Pre
309	Nandpur Chilkiya, Ramngar	Nainital	2012	Pre
310	Naukuchiyatal Bhimtal	Nainital	2012	Pre
311	Naukuchiyatal Bhimtal	Nainital	2014	Pre
312	Nayagaon Kaladhungi	Nainital	2012	Pre
313	Paniyali Haldwani	Nainital	2012	Pre
314	Rajeev Nagar Bengali Colony Lalkuan	Nainital	2012	Pre
315	Ramnagar (Kosi River)	Nainital	2011	Post
316	Ramnagar (Kosi River)	Nainital	2014	Pre
317	Ramnagar Jal Sansthan Baldiya Padow	Nainital	2012	Pre
318	Ramnagar Market	Nainital	2012	Pre
319	Ramnagar Market	Nainital	2014	Pre
320	Shishmahal Plant T.W. No. 3 Kathgodam	Nainital	2012	Pre
321	Shubhash Nagar Avas Vikas Haldwani	Nainital	2012	Pre
322	Sukhatal T.W. Nainital	Nainital	2012	Pre
323	Syamkhet (Kahalauira Gadhera)	Nainital	2011	Pre
324	Syamkhet (Kahalauira Gadhera)	Nainital	2011	Post
325	Syamkhet (Kahalauira Gadhera)	Nainital	2014	Pre
326	Transport Nagar Devalchore, Haldwani	Nainital	2012	Pre
327	Unchapool Haldwani	Nainital	2012	Pre
328	Vijaypur Dhamala	Nainital	2012	Pre
329	Buganio (Gadoli Gadhera)	Pauri	2011	Post
330	Dugadda (Khoh River)	Pauri	2011	Post
331	Ghodikhal (Kevru Gadhera)	Pauri	2011	Post
332	Kanskheit (Adwani Gadhera)	Pauri	2011	Post
333	Kotdwar (Khoh River)	Pauri	2011	Post
334	Kotdwar (Khoh River) 5Km Pump House	Pauri	2011	Post
335	Maithana Gaon (Gazald Gadhera)	Pauri	2011	Post
336	Nautha-Burni (Nautha- Gadhera)	Pauri	2011	Post
337	Satpuli (Madhuganga River)	Pauri	2010	Pre
338	Satpuli (Madhuganga River)	Pauri	2011	Post
339	Srinagar (Alaknada River)	Pauri	2010	Pre
340	Srinagar (Alaknada River)	Pauri	2011	Post

Sl No	Sites	Major Location	Year	Seasons
341	Srinagar (Alaknada River)	Pauri	2014	Pre
342	Swargashram (Infiltration Well)	Pauri	2011	Post
343	Swargashram (Infiltration Well)	Pauri	2014	Pre
344	Berinaag (Ghurghatiya)	Pithoragarh	2011	Post
345	Chhera (Maila)	Pithoragarh	2011	Pre
346	Chhera (Maila)	Pithoragarh	2011	Post
347	Didihat (Bhanara)	Pithoragarh	2010	Post
348	Didihat (Bhanara)	Pithoragarh	2011	Post
349	Gangolihaat (Kaliya Patal)	Pithoragarh	2011	Post
350	Gangolihaat (Kaliya Patal)	Pithoragarh	2014	Pre
351	Hyunpani (Ghatyurigar)	Pithoragarh	2011	Pre
352	Hyunpani (Ghatyurigar)	Pithoragarh	2011	Post
353	Joljiwi Tanapani	Pithoragarh	2011	Post
354	Nanipatal (Nanipatal Gadhera)	Pithoragarh	2011	Post
355	Pithoragarh (Raigaad)	Pithoragarh	2010	Pre
356	Pithoragarh (Raigaad)	Pithoragarh	2011	Post
357	Pithoragarh (Ramganga River)	Pithoragarh	2010	Pre
358	Pithoragarh (Ramganga River)	Pithoragarh	2011	Post
359	Pithoragarh (Thalika Gadhera)	Pithoragarh	2011	Post
360	Pithoragarh (Thuligaad)	Pithoragarh	2010	Pre
361	Pithoragarh (Thuligaad)	Pithoragarh	2011	Post
362	Aamsari	Rishikesh	2018	Post
363	Amsari	Rishikesh	2018	Pre
364	Amsari	Rishikesh	2019	Post
365	Bhuunukhala	Rishikesh	2018	Post
366	Dundapani	Rishikesh	2018	Post
367	GramPnchyat	Rishikesh	2018	Pre
368	GramPnchyat	Rishikesh	2019	Post
369	Killu pani	Rishikesh	2018	Post
370	Killu pani	Rishikesh	2019	Post
371	Kssu pani	Rishikesh	2019	Post
372	Kusrani	Rishikesh	2018	Post
373	Ayadgaad	Rudraprayag	2018	Post
374	Ayadgaad	Rudraprayag	2019	Post
375	Helaigaad	Rudraprayag	2018	Post
376	Jamargad	Rudraprayag	2019	Pre
377	Neilgad	Rudraprayag	2019	Post
378	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2010	Post
379	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2011	Post
380	Kandadhar Jamsali (Kulagaad)	Rudraprayag	2011	Post
381	Khakhara Peyjal Yojana (Fatehpur Tok Spring)	Rudraprayag	2011	Post
382	Koteshwar Ashram	Rudraprayag	2014	Pre
383	Nagrasu (Dharimangra)	Rudraprayag	2011	Post
384	Rudraprayag (Punad Gadhera)	Rudraprayag	2011	Post
385	Sumairpur (Lugai Gadhera)	Rudraprayag	2011	Post
386	Tiladi (Bhunak Gadhera)	Rudraprayag	2011	Post
387	Ukimath (Pighala Pani)	Rudraprayag	2011	Post
388	Agrakhal (Vasuwakhal)	Tehri	2011	Post
389	Banali Yojana	Tehri	2012	Pre
390	Baunsadi Yojana	Tehri	2012	Pre
391	Baunsadi Yojana	Tehri	2014	Pre
392	Bhatusain Yojana	Tehri	2012	Pre
393	Bhedlamiyali Peyjal	Tehri	2012	Pre
394	Chamba (Nagni Gadhera)	Tehri	2011	Post
395	Chamba Pumping	Tehri	2012	Pre
396	Dangi Yojana	Tehri	2012	Pre
397	Dangi Yojana	Tehri	2014	Pre
398	Deval Yojana	Tehri	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
399	Deval Yojana	Tehri	2014	Pre
400	Devprayag (Diwanigaad)	Tehri	2010	Pre
401	Devprayag (Diwanigaad)	Tehri	2011	Post
402	Dhanaulty (Chandukhil)	Tehri	2011	Post
403	Dharkot Dikhot	Tehri	2012	Pre
404	Ghansali Jal Sansthan Yojana/Bhilangana	Tehri	2012	Pre
405	Ghansali Jal Sansthan Yojana/Bhilangana	Tehri	2014	Pre
406	Hindolakhal (Alaknanda River)	Tehri	2011	Post
407	Jaddhar Yojna	Tehri	2012	Pre
408	Jajal Khadi	Tehri	2012	Pre
409	Jakhadi Yojana	Tehri	2012	Pre
410	Jakhadi Yojana	Tehri	2014	Pre
411	Jhakhnyali (I) Yojana	Tehri	2012	Pre
412	Jhakhnyali (II) Yojana	Tehri	2012	Pre
413	Kandisaud (Khamoli Gadhera)	Tehri	2011	Post
414	Kandisaud (Sannu Gadhera)	Tehri	2011	Post
415	Khitta Yojana	Tehri	2012	Pre
416	Khitta Yojana	Tehri	2014	Pre
417	Kirtinagar (Dang Gadhera)	Tehri	2011	Post
418	Likhuwar Yojana	Tehri	2012	Pre
419	Likhuwar Yojana	Tehri	2014	Pre
420	Muyal Yojana	Tehri	2012	Pre
421	Muyal Yojana	Tehri	2014	Pre
422	Nainbagh (Bareda khadd)	Tehri	2011	Post
423	Nand Gaon Yojana	Tehri	2012	Pre
424	Nand Gaon Yojana	Tehri	2014	Pre
425	Narendranagar (Chanderbhaga River)	Tehri	2011	Post
426	New Tehri (Bhagirathi River)	Tehri	2010	Pre
427	New Tehri (Bhagirathi River)	Tehri	2010	Post
428	New Tehri (Bhagirathi River)	Tehri	2011	Post
429	Palas/Swati Yojana	Tehri	2012	Pre
430	Palas/Swati Yojana	Tehri	2014	Pre
431	Pata Jangleth	Tehri	2012	Pre
432	Pursole Gaon	Tehri	2012	Pre
433	Ramol Gaon Yojana	Tehri	2012	Pre
434	Ramol Gaon Yojana	Tehri	2014	Pre
435	Rani Chouri Chamba	Tehri	2012	Pre
436	Silyara Yojana	Tehri	2014	Pre
437	Soud Kudi Yojana	Tehri	2012	Pre
438	Suda Peyjal Yojana	Tehri	2012	Pre
439	Swadi Yojana	Tehri	2012	Pre
440	Swadi Yojana	Tehri	2014	Pre
441	Nalai MBR	Udham Singh Nagar	2012	Pre
442	Anol Naragaad Chinyalisour	Uttarkashi	2012	Pre
443	Arakoat Mori	Uttarkashi	2012	Pre
444	Badathi Chungi Silora, Dunda	Uttarkashi	2012	Pre
445	Badethi Badethikhad Chinyalisaur	Uttarkashi	2012	Pre
446	Badkot (Bhotukhaad)	Uttarkashi	2011	Post
447	Badkot Bhotukhudd Naugaon	Uttarkashi	2012	Pre
448	Bhatwari, Bhatwari gaad Bhatwari	Uttarkashi	2012	Pre
449	Birpur Ghatukhal Dunda	Uttarkashi	2012	Pre
450	Brahmakhal (Silkyara Gadhera)	Uttarkashi	2011	Post
451	Brahmakhal (Siyalnakhadd)	Uttarkashi	2011	Post
452	Burnigaad Naugaon	Uttarkashi	2012	Pre
453	Burnigaad Naugaon	Uttarkashi	2014	Pre
454	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2010	Post
455	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2011	Post
456	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
457	Damta Naugaon	Uttarkashi	2012	Pre
458	Dandagaon Chinyalisour	Uttarkashi	2012	Pre
459	Dharasu Gadhera Chinyalisaur	Uttarkashi	2012	Pre
460	Dharkot Nagungaad Chinyalisour	Uttarkashi	2012	Pre
461	Dunda (Ginwala Gaad)	Uttarkashi	2011	Post
462	Dundagram Dunda	Uttarkashi	2012	Pre
463	Gainchawan gaon, Mori	Uttarkashi	2012	Pre
464	Gangori (Singoti khala)	Uttarkashi	2011	Post
465	Gendala Bhramkhal Sartaligadhera Dunda	Uttarkashi	2012	Pre
466	Gundiyal Gaon Chanika Purola	Uttarkashi	2012	Pre
467	Gyansu (Varuna Gaad)	Uttarkashi	2011	Post
468	Gyansu Bhatwari	Uttarkashi	2012	Pre
469	Hitanu Kaidigaad Dunda	Uttarkashi	2012	Pre
470	Jakhol Saruktaal Mori	Uttarkashi	2012	Pre
471	Jaspur Tioth Kidyar Bhatwari	Uttarkashi	2012	Pre
472	JoshiYada (Indrawati river)	Uttarkashi	2011	Post
473	Joshiyara Indrawati Bhatwari	Uttarkashi	2012	Pre
474	Khadara Jakhnikhad Chinyalisaur	Uttarkashi	2012	Pre
475	Kharadi Bhetipani Naugaon	Uttarkashi	2012	Pre
476	Kharsadi Mori	Uttarkashi	2012	Pre
477	Koti Bakhreti Dwara, Rawanikhal Naugaon	Uttarkashi	2012	Pre
478	Koti Yojana Purola	Uttarkashi	2012	Pre
479	Kunwa Naugaon	Uttarkashi	2012	Pre
480	Kunwa Naugaon	Uttarkashi	2014	Pre
481	Kyark Bandrani, Bhatwari Gaad Bhatwari	Uttarkashi	2012	Pre
482	Mairana yojana Purola	Uttarkashi	2012	Pre
483	Makhana Matikhudd Purola	Uttarkashi	2012	Pre
484	Manari Shilkur Gaad Bhatwari	Uttarkashi	2012	Pre
485	Matali Lingwana Dunda	Uttarkashi	2012	Pre
486	Mori Market, Mori Block	Uttarkashi	2012	Pre
487	Naag Jhala Pathari Khud Purola	Uttarkashi	2012	Pre
488	Naugaon (Kesarikhadd)	Uttarkashi	2011	Post
489	Naugaon, Naugaon Block	Uttarkashi	2012	Pre
490	Patara Nigaru Dunda	Uttarkashi	2012	Pre
491	Ponti Kameela Naugaon	Uttarkashi	2012	Pre
492	Pouri Saradi yojana Saradi Gaon	Uttarkashi	2012	Pre
493	Purola (Kufara Khaad)	Uttarkashi	2011	Post
494	Purola yojana Malagaad Purola	Uttarkashi	2012	Pre
495	Raithal Bhatwari Gaad Bhatwari	Uttarkashi	2012	Pre
496	Rajgari Chedi Naugaon	Uttarkashi	2012	Pre
497	Rama Spring Purola	Uttarkashi	2012	Pre
498	Saakri Market, Guimagaad Mori	Uttarkashi	2012	Pre
499	Shrikoat Padiyar chowk Chinyalisour	Uttarkashi	2012	Pre
500	Thanki Bhanki Naugaon	Uttarkashi	2012	Pre
501	Udalka Shivani Dunda	Uttarkashi	2012	Pre
502	Upradi Muralthu Navgaon	Uttarkashi	2012	Pre
503	Uttarkashi (Assi ganga)	Uttarkashi	2011	Post

The alkalinity of the water is also known as its acid-neutralizing capacity. Alkalinity is a very important parameter in many uses and treatments of natural waters and wastewaters. The alkalinity of surface water is mainly the function of carbonate, bicarbonate and hydroxide content, which is the indication of the concentration of these constituents. The excess of alkaline earth metals play a significant role in the determination of alkalinity, which is suitable for the determination of irrigation suitability (Baird et al., 2017)

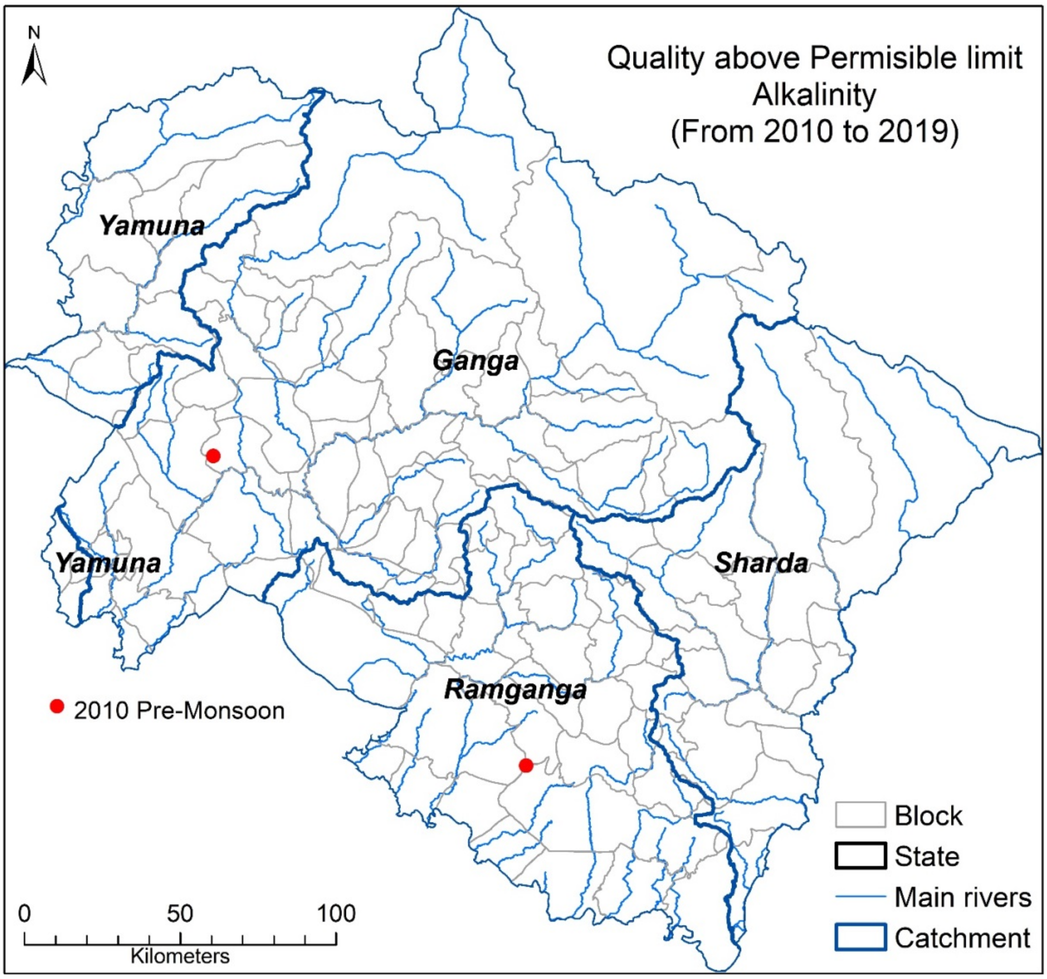


Figure 21: Location of water sources exceeding alkalinity above the permissible limit

Only two locations (Figure 22) have been observed where the alkalinity exceeded above the permissible limits. There is the past experience (2010) of such poor quality but presently there is no such issue in water quality (Table 8).

Table 8: Sites above the permissible limit of alkalinity

Sl No	Sites	Major Location	Year	Seasons
1	Kaladungi (Bijpur)	Nanital	2010	Pre
2	Narendranagar (Chanderbhaga River)	Tehri	2010	Pre

The most common forms of calcium are calcium carbonate (calcite) and calcium magnesium carbonate (dolomite). Pharmaceuticals, photography, de-icing salts, lime, pigments, fertilizers and plasters are widely used as calcium compounds. The solubility of calcium carbonate is controled by pH and dissolved CO_2. The equilibrium between CO_2, HCO_3 and CO_3 is the major buffering mechanism in freshwaters. The calcium and magnesium salts determine the hardness of water which is often used as a measure of potable water quality. The interaction between water and surface deposits of limestone, dolomite, gypsum and gypsiferous shale is responsible for calcium in the water.

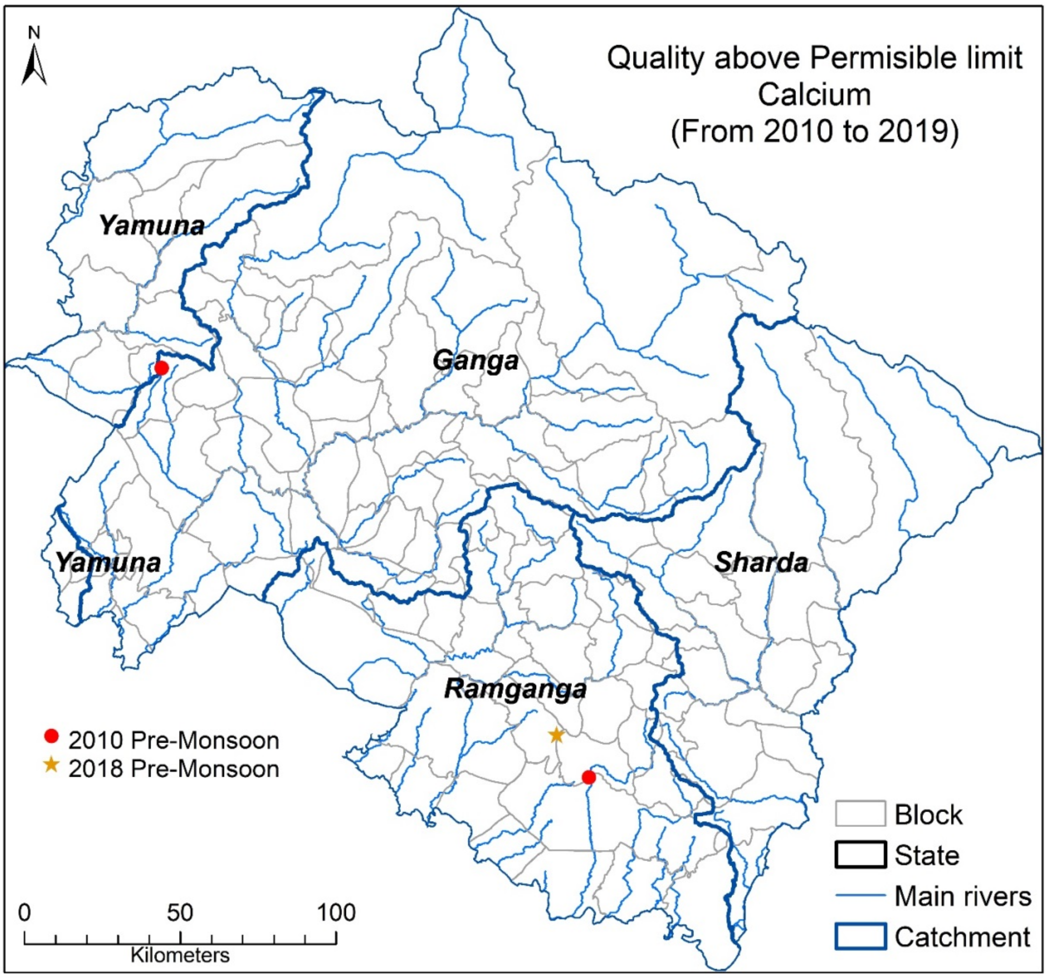


Figure 22: Location of water sources exceeding calcium above the permissible limit

This indicates that these locations (Figure 23) have interaction between water and surface deposits of limestone, dolomite, gypsum and gypsiferous shale. The lists of the locations are given in Table 9.

Table 9: Sites above the permissible limit of calcium

Sl No	Sites	Major Location	Year	Seasons
1	Dehradun City (Massifall)	Dehradun	2010	Pre
2	Chaphi Laggakun	Nainital	2018	Pre
3	Haldwani (Gola River)	Nainital	2010	Pre

The sources of calcium and magnesium are mostly common in the water system. It is used in alloys, pyrotechnics, flash photography, drying agents, fertilizers, pharmaceuticals and foods. It is an important contributor of hardness in water and the magnesium salts break down, when heated and form scale in boilers. There are various processes, which use for the reduction of magnesium and its associate hardness to accepted levels such as chemical softening, reverse osmosis or ion exchanges.

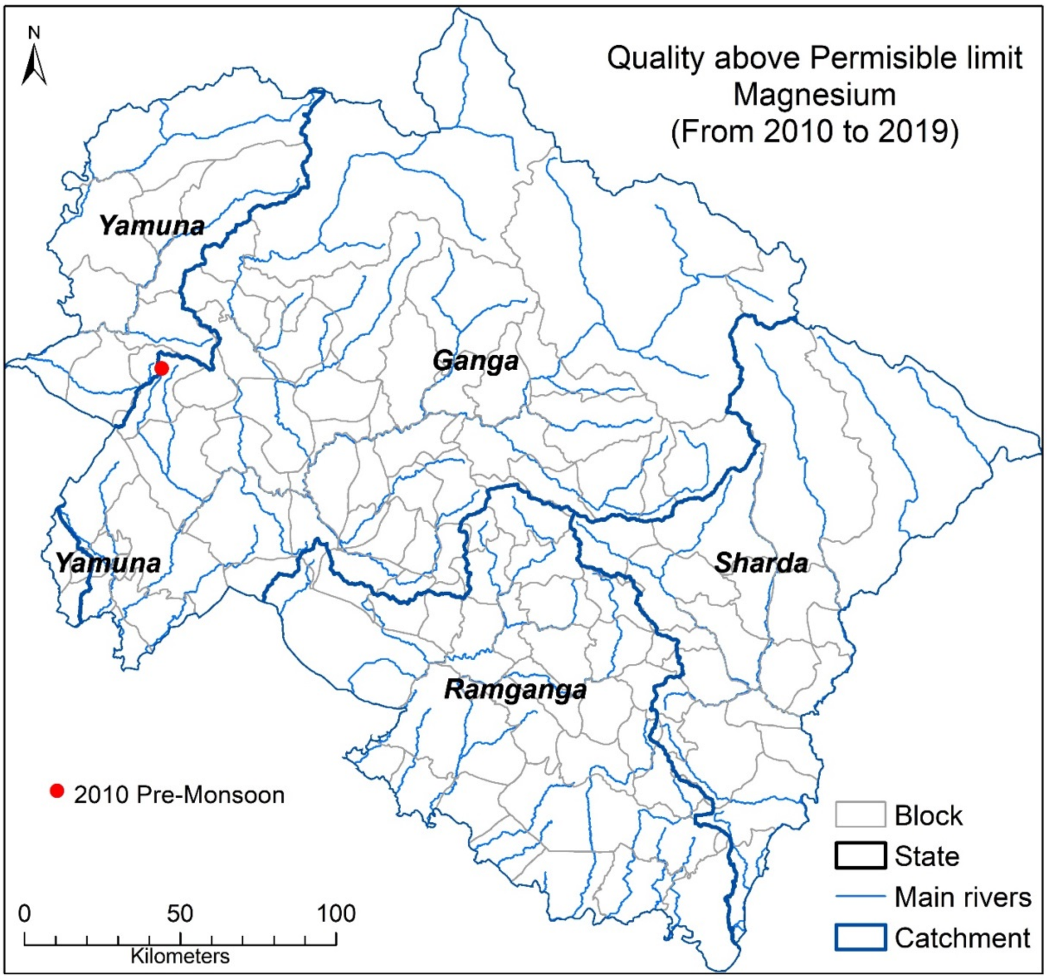


Figure 23: Location of water source exceeding magnesium above the permissible limit

Magnesite and dolomite minerals are a common source of magnesium in this location and exceed the magnesium (Figure 24) in the same location as calcium with same time duration. This indicates the magnesite and dolomite minerals introduce in a particular time that could be high sedimentation during that time but later such parameter did not exceed the limit (Table 10).

Table 10: Site above the permissible limit of magnesium

Sl No	Sites	Major Location	Year	Seasons
1	Dehradun City (Massifall)	Dehradun	2010	Pre

The sum of Nitrate and Nitrite are treated as total oxidized nitrogen. Nitrate is generally found in trace amounts in surface water but it may attain high levels in some groundwater. The wastewater and sewerage are the major sources of nitrate in surface water. Away from this source, fertilizers and atmospheric deposition are also the sources of nitrate in water (Vrzel et al., 2016). The excessive amount of nitrate can cause an illness known as methemoglobinemia in infants.

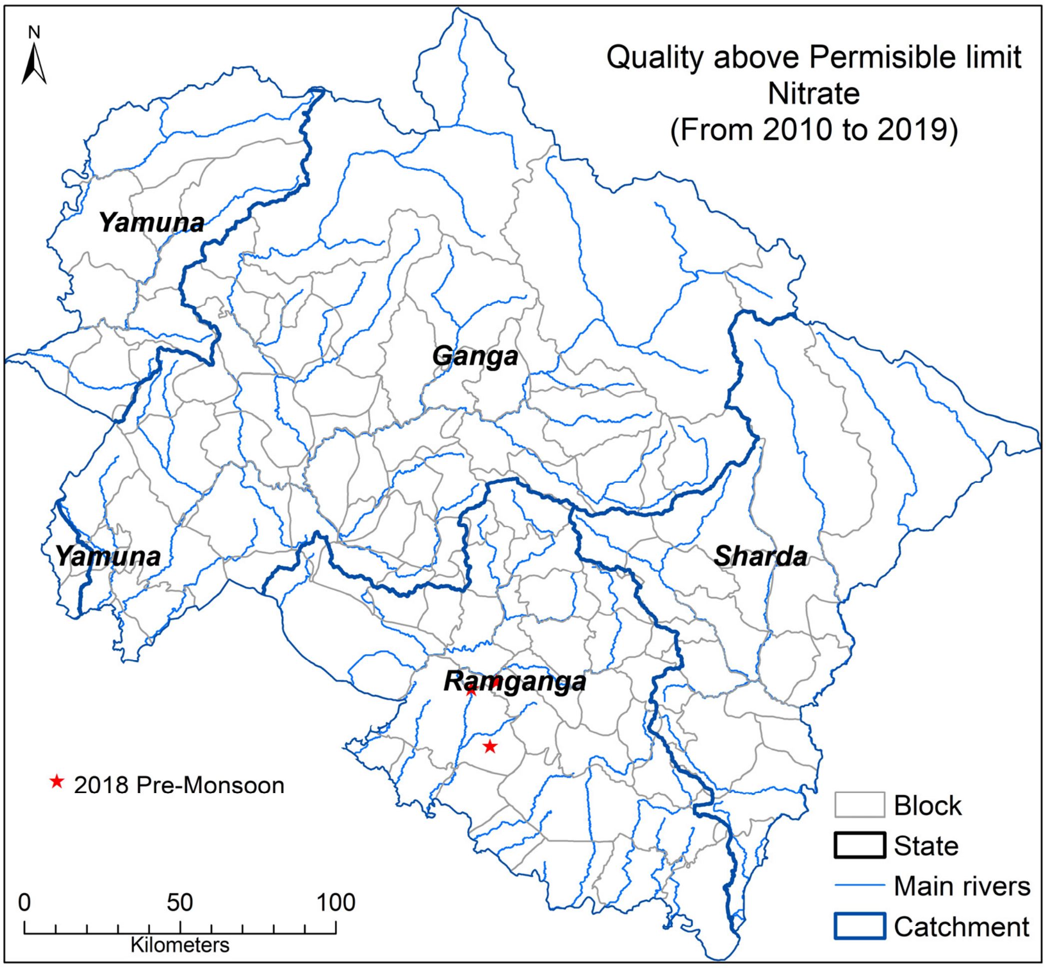


Figure 24: Location of water source exceeding magnesium above the permissible limit

This area is dominantly by intensive use of agriculture practices (Figure 25) and due to use fertilizer use the limit of nitrate has been exceeding in the present time (Table 11).

Table 11: Site above the permissible limit of magnesium

Sl No	Sites	Major Location	Year	Seasons
1	Ramnagar	Nainital	2018	Pre

Hardness is the measurement of the capacity of water to precipitate soap. Soap is majorly precipitated by the calcium and magnesium present in water. Whereas some other cations also precipitate soap but their contribution is very minimal and difficult to define.

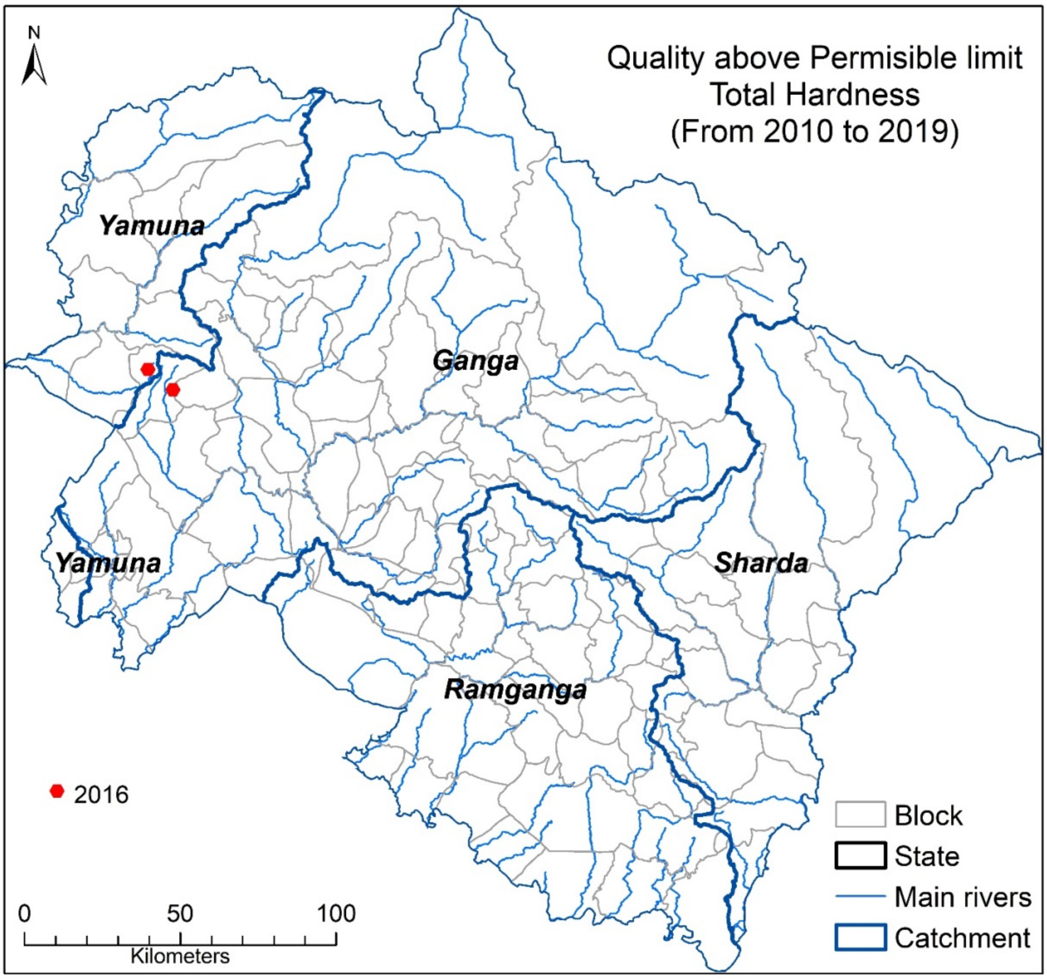


Figure 25: Location of water sources exceeding total hardness above the permissible limit

Therefore, the total hardness is defined as the sum of the calcium and magnesium concentration, both expressed as calcium carbonate in milligrams per liter. Numerically, when the hardness is greater than the sum of carbonate and bicarbonate alkalinity that amount of hardness is equivalent to the total alkalinity is called "carbonate hardness" and the amount of hardness more than this is called "noncarbonated hardness." If the hardness is numerically less than the sum of carbonate and bicarbonate alkalinity, all hardness is known as carbonate hardness and noncarbonated hardness is absent.

The geology of the area is significantly contributing to the total hardness in this area (Figure 26). The magnesium and calcium are also high in this area (Table 12).

Table 12: Sites above the permissible limit of total hardness

Sl No	Sites	Major Location	Year	Seasons
1	Dehradun City (Bandal)	Dehradun	2016	Pre
2	Dehradun City (Bhitarli)	Dehradun	2016	Pre

Fluoride ion may occur naturally in water or it may be added in controlled amounts. Naturally, fluoride reaches into the water system from fluoride associated igneous and metamorphic rocks such as granite and gneisses. Fluoride has also some anthropogenic sources such as agro-chemicals and brick industries. The leaching of fluoride from soil and clay sediments takes place in alkaline conditions and high bicarbonate concentration in water. This is enhanced when the calcite precipitation takes place under alkaline conditions. The low level of fluoride (<0.1 mg/l) may cause dental decay, whereas high fluoride concentration in drinking water has adverse health effects (Singh et al., 2018).

In Uttarkhand fluoride is geo-genic due to metamorphic rocks. There are selected pockets of hills where fluoride is exceeding above the permissible limit (Figure 27). There is no Spatio-temporal trend (Table 13) to specify the dominant fluoride area but it will enhance when calcite precipitation takes place under alkaline condition.

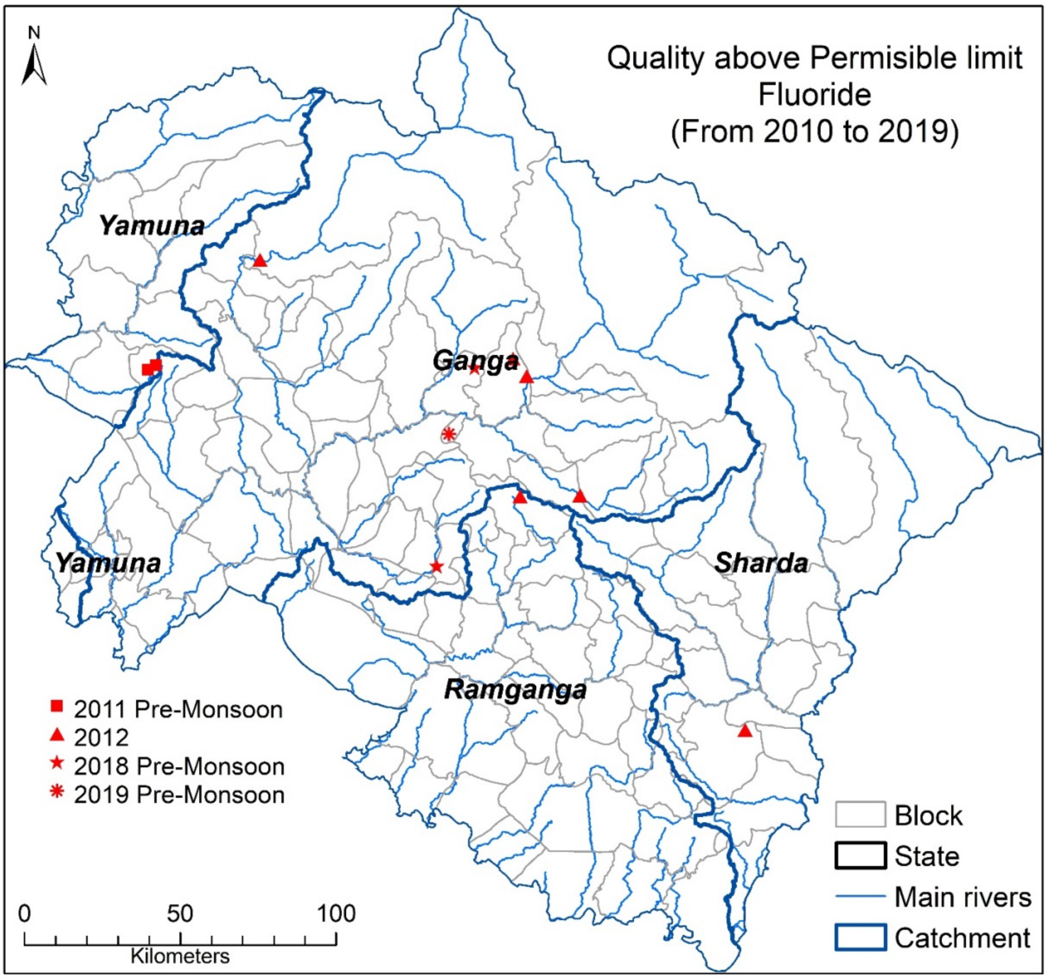


Figure 26: Location of water sources exceeding Fluoride above the permissible limit

Table 13: Sites above the permissible limit of fluoride

Sl No	Sites	Major Location	Year	Seasons
1	Devradi Tharali Tharali Bazar	Chamoli	2012	Pre
2	Gairsain (Gwaad Gadhera)	Chamoli	2012	Pre
3	Gopeshwar Jal Sansthan	Chamoli	2012	Pre
4	Mandal Bazar Dasholi	Chamoli	2012	Pre
5	Bandesa Dhek	Champawat	2012	Pre
6	Dehradun City (Bhitarli)	Dehradun	2011	Pre
7	Kolukhet (Chandroti)	Dehradun	2011	Pre
8	Maskar	Rudraprayag	2019	Pre
9	Neilgad	Rudraprayag	2018	Pre
10	Patal rolla	Satpuli	2018	Pre
11	Gyansu Bhatwari	Uttarkashi	2012	Pre

The aluminum occurs in the earth's crust in combination with silicon and oxygen to form feldspars, micas and clay minerals. Bauxite and corundum are the most important minerals of aluminum, which is used as an abrasive. The aluminum potassium sulfate (alum) is used for the water treatment process to flocculate suspended particles but it may leave some residue of aluminum in treated water. The aluminum is nonessential for plants and animals. Above permissible limit of aluminum in drinking water, it may cause Alzheimer's disease.

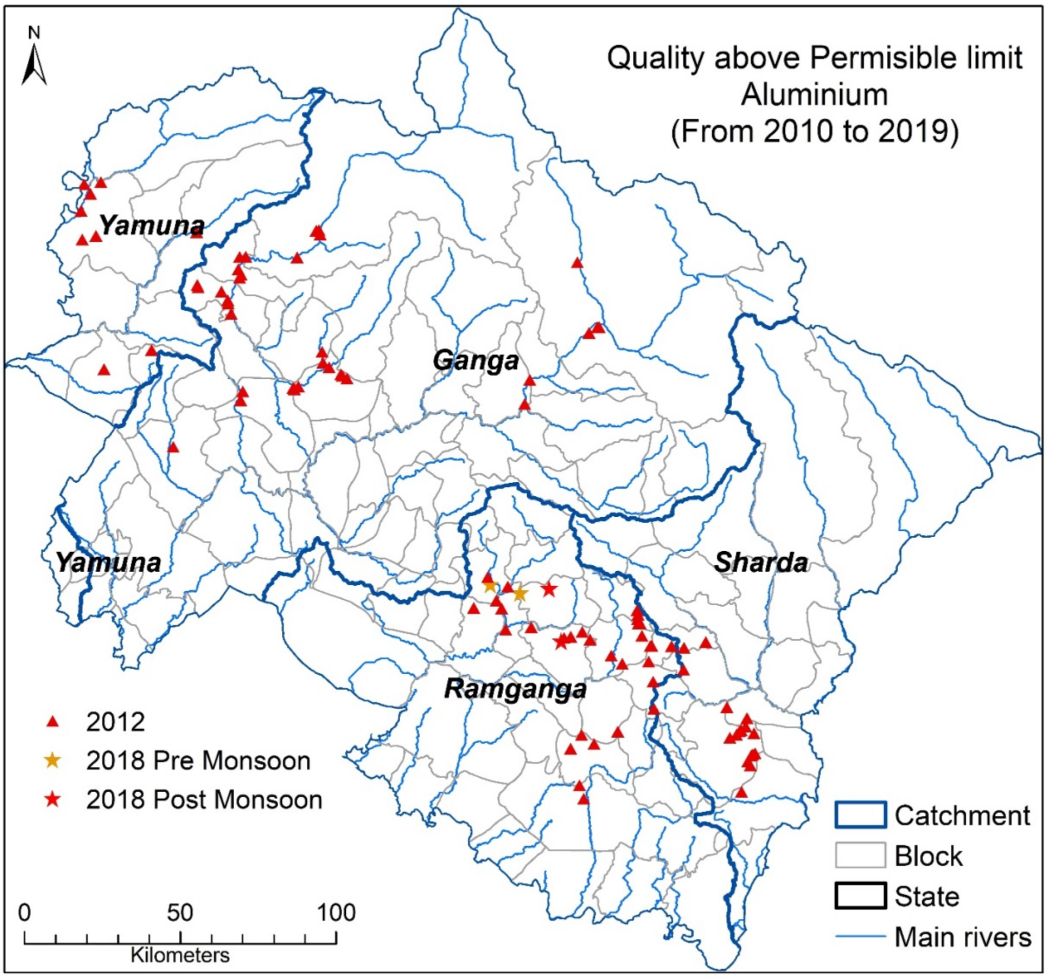


Figure 27: Location of water sources exceeding aluminum above the permissible limit

The upper basin of Yamuna, Bhagirathi, Alaknanda, Most of the area of upper Ranganga and lower Saryu River (Figure 28) is identified the presence of aluminium with the above permissible limit. Especially, Almora, Uttarkashi and Champawat districts (Table 14) are under high risk.

Table 14: Sites above the permissible limit of aluminum

Sl No	Sites	Major Location	Year	Seasons
1	Airadi Rajwar Peyjal Jojna	Almora	2012	Pre
2	Beena Samuhik Yojana	Almora	2012	Pre
3	Bhaisadi Yojana	Almora	2012	Pre
4	Bhawani Devi Pumping Yojna	Almora	2012	Pre
5	Chalthilagga Khatiyola	Almora	2012	Pre
6	Dahal, Ranikhet	Almora	2018	Post
7	Dhari Supai Yojana	Almora	2012	Pre
8	Dotiyal Gaon	Almora	2012	Pre
9	Dwarson Swajal	Almora	2012	Pre
10	Jageshwar Market Phlai, Jageshwar	Almora	2012	Pre
11	Jaksoda Ayar Pani	Almora	2012	Pre
12	Jhimaar Gram Sabha Yojana, Jhimaar Gaon, Sult	Almora	2012	Pre
13	Kaafli Yojana	Almora	2012	Pre
14	Kalika Tok Peyjal Yojana	Almora	2012	Pre
15	Kalika Tok Pumping Yojana	Almora	2012	Pre
16	Khoont Yojana	Almora	2012	Pre
17	Kosi Maatela Almora	Almora	2012	Pre
18	Lamgada	Almora	2012	Pre
19	Loukot, Ranikhet	Almora	2018	Pre
20	Majhkhali	Almora	2012	Pre
21	Maliyal Gaon, Ranikhet	Almora	2018	Post
22	Mohana Malla Peyjal Yojna	Almora	2012	Pre
23	Nailpad Pokhri	Almora	2012	Pre
24	Namkaran Gadhera Yojana Palau Badechinna	Almora	2012	Pre
25	Naula-Jainel Yojna	Almora	2012	Pre
26	Panuwaanaula Gram Yojana	Almora	2012	Pre
27	Patharkhola, Ranikhet	Almora	2018	Pre
28	Ranikhet Tadikhet Yojana	Almora	2012	Pre
29	Sagneti Peyjal Yojana	Almora	2012	Pre
30	Shahar Fatak Yojana	Almora	2012	Pre
31	Shayi Devi Yojana	Almora	2012	Pre
32	Sunouli	Almora	2012	Pre
33	Thapala	Almora	2012	Pre
34	Timli Chachroti Peyjal Yojana	Almora	2012	Pre
35	Badrinath (Charan Paduka)	Chamoli	2012	Pre
36	Chamoli Alaknanda Ghat	Chamoli	2012	Pre
37	Nandaprayag Karanprayag	Chamoli	2012	Pre
38	Ravigram I Joshimath Nagar Palika	Chamoli	2012	Pre
39	Sclang Joshimath	Chamoli	2012	Pre
40	Sunii	Chamoli	2012	Pre
41	Amori Yojana	Champawat	2012	Pre
42	Chamoula	Champawat	2012	Pre
43	Champwat Shant Bazar	Champawat	2012	Pre
44	Circuit House Tank Champwat	Champawat	2012	Pre
45	Dungri Fartyaal	Champawat	2012	Pre
46	Gallagaon	Champawat	2012	Pre
47	Karnakaryati	Champawat	2012	Pre
48	Khetikhan	Champawat	2012	Pre
49	Kiskot Yojana	Champawat	2012	Pre
50	Nagar Palika Chauraya Tank	Champawat	2012	Pre
51	Nauli Yojana	Champawat	2012	Pre
52	Raigaon	Champawat	2012	Pre
53	Risheswar Tubewel	Champawat	2012	Pre
54	Sui Peyjal Yojana	Champawat	2012	Pre
55	Bandowala Adenesh Nagar MTW	Dehradun	2012	Pre
56	Bhauwala Rampur, Ramsawal	Dehradun	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
57	Mussorie Kandighat + Mare	Dehradun	2012	Pre
58	Penwa (Penwa) Chunakhaad	Dehradun	2012	Pre
59	Purtaad (Chatra) Dhanarti Klaad	Dehradun	2012	Pre
60	Pyunal (Mundhri) Gaalti	Dehradun	2012	Pre
61	Retaad (Kunen) Durani	Dehradun	2012	Pre
62	Sukhaad (Birnaad) Sukhaiki	Dehradun	2012	Pre
63	Sunbagh (Anu) Daglikhaad	Dehradun	2012	Pre
64	Bhimtal, Songaon	Nainital	2012	Pre
65	Damura Dunga Haldwani	Nainital	2012	Pre
66	Dhari Bhimtal (Tank)	Nainital	2012	Pre
67	Dhobhighat Indiranagar Haldwani	Nainital	2012	Pre
68	Jalsansthan Bhawali, Nainital	Nainital	2012	Pre
69	Jyolikoat Bhimtal Nainital	Nainital	2012	Pre
70	Bhatusain Yojana	Tehri	2012	Pre
71	Ghansali Jal Sansthan Yojana/Bhilangana	Tehri	2012	Pre
72	Jhakhnyali (I) Yojana	Tehri	2012	Pre
73	Jhakhnyali (II) Yojana	Tehri	2012	Pre
74	Kikot Peyjal Yojana	Tehri	2012	Pre
75	Muyal Yojana	Tehri	2012	Pre
76	Nand Gaon Yojana	Tehri	2012	Pre
77	Palas/Swati Yojana	Tehri	2012	Pre
78	Silyara Yojana	Tehri	2012	Pre
79	Suda Peyjal Yojana	Tehri	2012	Pre
80	Swadi Yojana	Tehri	2012	Pre
81	Badethi Badethikhad Chinyalisaur	Uttarkashi	2012	Pre
82	Bhatwari, Bhatwari gaad Bhatwari	Uttarkashi	2012	Pre
83	Birpur Ghatukhal Dunda	Uttarkashi	2012	Pre
84	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2012	Pre
85	Dandagaon Chinyalisour	Uttarkashi	2012	Pre
86	Dharasu Gadhera Chinyalisaur	Uttarkashi	2012	Pre
87	Dundagram Dunda	Uttarkashi	2012	Pre
88	Hitanu Kaidigaad Dunda	Uttarkashi	2012	Pre
89	Khadara Jakhnikhad Chinyalisaur	Uttarkashi	2012	Pre
90	Kyark Bandrani, Bhatwari Gaad Bhatwari	Uttarkashi	2012	Pre
91	Manari Shilkur Gaad Bhatwari	Uttarkashi	2012	Pre
92	Matali Lingwana Dunda	Uttarkashi	2012	Pre
93	Raithal Bhatwari Gaad Bhatwari	Uttarkashi	2012	Pre
94	Shrikoat Padiyar chowk Chinyalisour	Uttarkashi	2012	Pre
95	Udalka Shivani Dunda	Uttarkashi	2012	Pre
96	Upradi Muralthu Navgaon	Uttarkashi	2012	Pre

Iron found in the hematite, magnetite, taconite and pyrite minerals. The groundwater is often anoxic and the iron in groundwater is found in the soluble form, which is known as the ferrous state. The solubility of ferrous ion is controlled by the carbonate concentration. The increase in iron concentration in water can cause stains in plumbing, cooking utensils and laundry and create objectionable tastes and colour to foods.

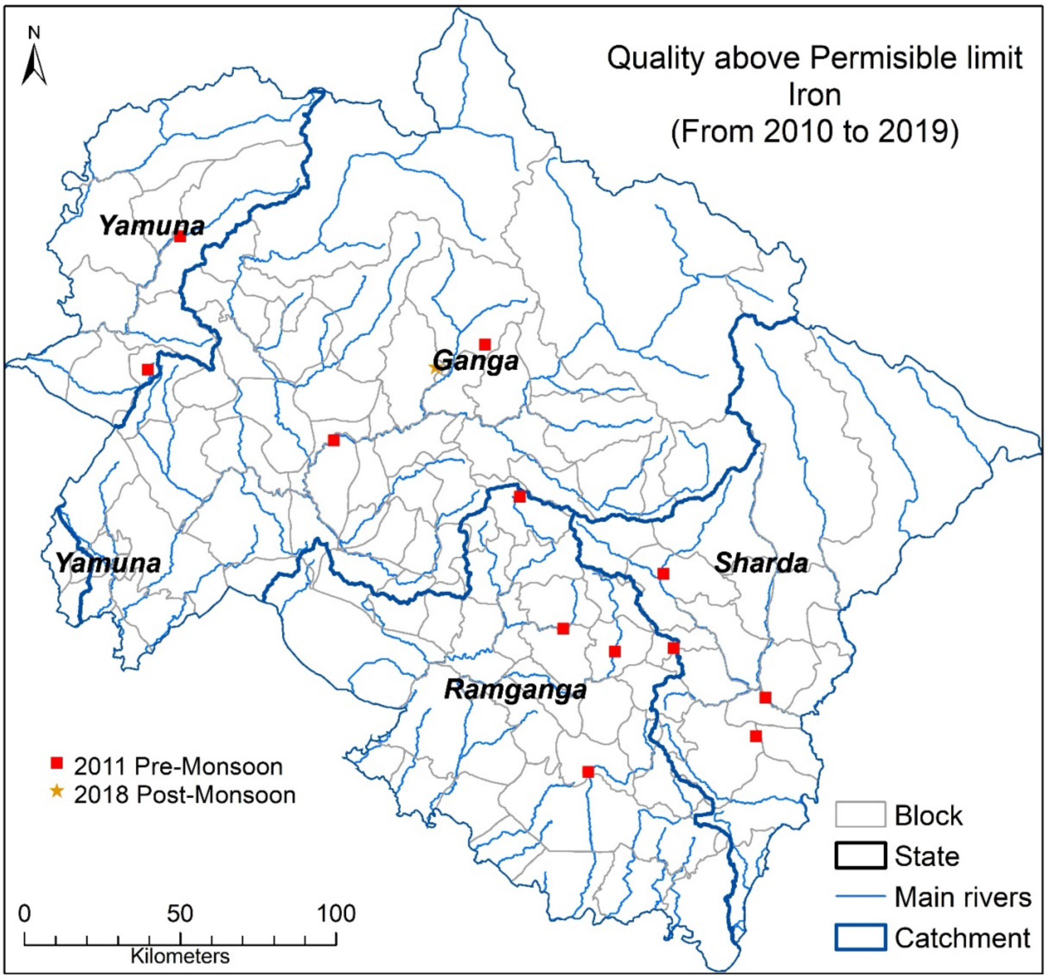


Figure 28: Location of water sources exceeding aluminum above the permissible limit

Table 15: Sites above the permissible limit of aluminum

Sl No	Sites	Major Location	Year	Seasons
1	Almora (Kosi Nadi)	Almora	2011	Pre
2	Quarali (Gyari Gaad Gadhera)	Almora	2011	Pre
3	Ranikheit (Tadikhat (Gagas)	Almora	2011	Pre
4	Bageshwar (Saryu river)	Bageshwar	2011	Pre
5	Gairsain (Gwaad Gadhera)	Chamoli	2011	Pre
6	Lohaghat (Lohawati River)	Champawat	2011	Pre
7	Dehradun City (Bhitarli)	Dehradun	2011	Pre
8	Kathgodam (Sheetalahat)	Nainital	2011	Pre
9	Pithoragarh (Ramganga River)	Pithoragarh	2011	Pre
10	Yata	Rudraprayag	2018	Post
11	Ukimath (Pighala Pani)	Rudraprayag	2011	Pre
12	Hindolakhal (Alaknanda River)	Tehri	2011	Pre
13	Naugaon (Kesarikhadd)	Uttarkashi	2011	Pre

Most of the location was observed during 2011 and only one location in 2018 was identified as the above permissible limit of Iron (Figure 29). There is no spatial-temporal trend identified but the presence in the above threshold limit is due to geological characterizes of structure hills (Table 15).

Microbial contamination is linked with the fecal indicator bacteria (FIB), which is largely used as a proxy of microbiological quality of water. The total coliform (TC) are a commonly used FIB group that can indicate fecal contamination. It is found that many common waterborne coliform bacteria (e.g. Klebsiella, Enterobacter, Citrobacter) are not necessarily of fecal origin (Xue et al., 2018). Total coliforms include species that may inhabit the intestines of warm-blooded animals or occur naturally in soil, vegetation, and water. They are usually found in fecally-polluted water and are often associated with disease outbreaks. Although they are not usually pathogenic themselves, their presence in drinking water indicates the possible presence of pathogens. *E. coli*, one species of the coliform group, is always found in feces and is, therefore, a more direct indicator of fecal contamination and the possible presence of enteric pathogens (Oshiro, 2002).

This very common problem in the water quality of Himalaya due to the high surface runoff and presence of vegetated soil covers. Most of the surface sources are highly vulnerable due to total coliform (Figure 30) and Table 16.

Spatiotemporal mapping identifies this is a very common problem in this area, it was observed throughout the temporal period and common characteristics of the surface source of Uttarakhand.

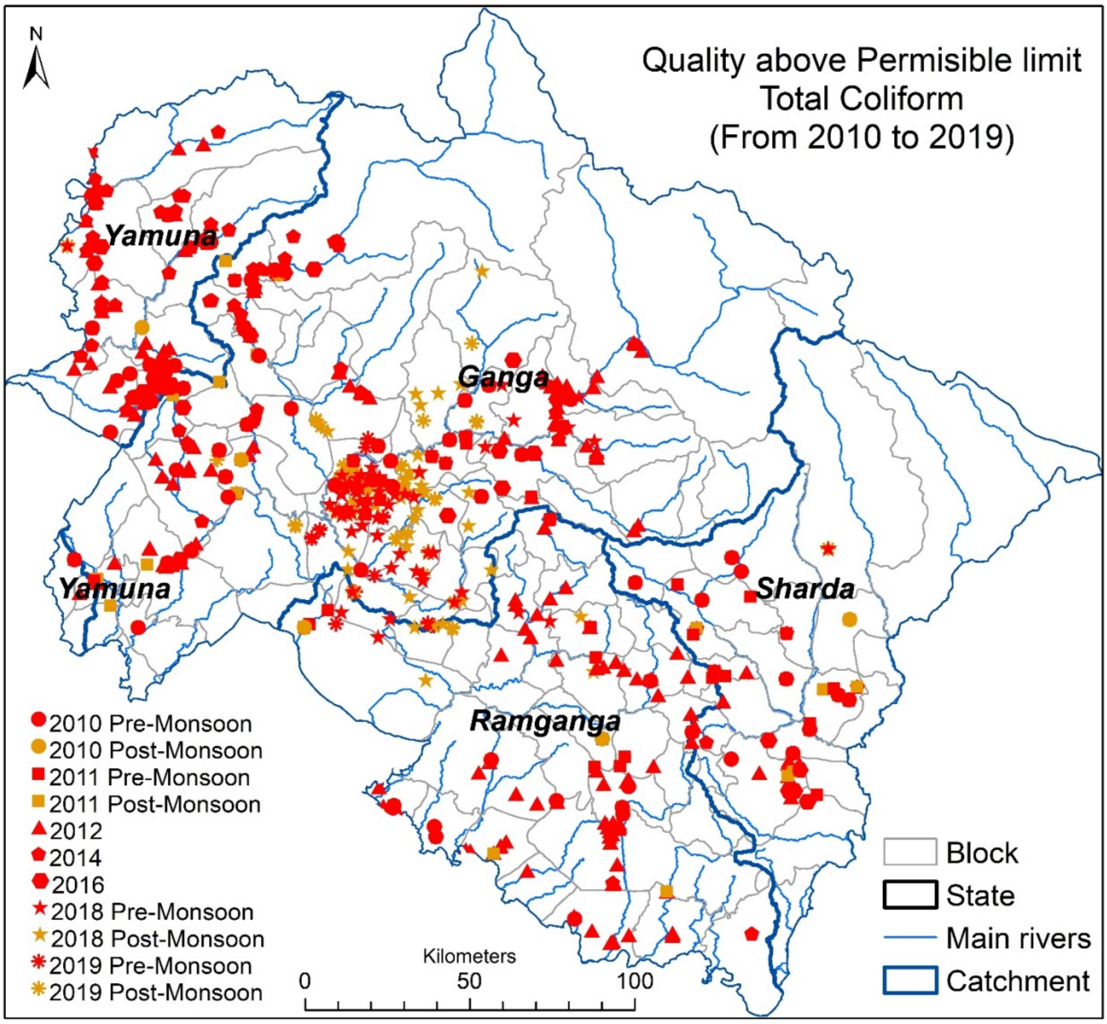


Figure 29: Location of water sources exceeding total coliform above the permissible limit

Table 16: Sites above the permissible limit of total coliform

Sl No	Sites	Major Location	Year	Seasons
1	Gram Samuh Yojna	Almora	2012	Pre
2	Airadi Rajwar Peyjal Jojna	Almora	2012	Pre
3	Almora (Kosi Nadi)	Almora	2010	Pre
4	Almora (Kosi Nadi)	Almora	2010	Post
5	Almora (Kosi Nadi)	Almora	2011	Pre
6	Almora (Kosi Nadi)	Almora	2011	Post
7	Bakhali Pumping House	Almora	2012	Pre
8	Chaugaon Peyjal Yojana	Almora	2012	Pre
9	Dhari Supai Yojana	Almora	2012	Pre
10	Dwarahaat Pumping Yojana	Almora	2012	Pre
11	Dwarhat (Kheron Gadhera)	Almora	2011	Pre
12	Dwarhat (Kheron Gadhera)	Almora	2011	Post
13	Dwarson Swajal	Almora	2012	Pre
14	Jageshwar (Erawatgupha Gadhera)	Almora	2011	Pre

Sl No	Sites	Major Location	Year	Seasons
15	Jageshwar (Erawatgupha Gadhera)	Almora	2011	Post
16	Jaiti Yojana	Almora	2014	Pre
17	Kaafli Yojana	Almora	2012	Pre
18	Kalika Tok Pumping Yojana	Almora	2012	Pre
19	Kaneli Yojna	Almora	2012	Pre
20	Kanera Peyjal Yojana	Almora	2012	Pre
21	Karget Yojana, Kaligaon Market, Sult	Almora	2012	Pre
22	Khaspad (Gyari Gaad Gadhera)	Almora	2011	Pre
23	Kosi Maatela Almora	Almora	2012	Pre
24	Lamgada	Almora	2012	Pre
25	Lamgara (Bharat Khali)	Almora	2010	Pre
26	Lamgara (Bharat Khali)	Almora	2011	Pre
27	Line Bagicha	Almora	2012	Pre
28	Majhkhali	Almora	2012	Pre
29	Manyagar (Paneth Gadhera)	Almora	2011	Post
30	Mohana Malla Peyjal Yojna	Almora	2012	Pre
31	Nailpad Pokhri	Almora	2012	Pre
32	Naula-Jainel Yojna	Almora	2012	Pre
33	Panava Naula (Paneth Gadhera)	Almora	2011	Pre
34	Panava Naula (Paneth Gadhera)	Almora	2011	Post
35	Panava Naula (Paneth Gadhera)	Almora	2014	Pre
36	Ranikheit (Tadikhat (Gagas)	Almora	2011	Pre
37	Ranikheit (Tadikhat (Gagas)	Almora	2011	Post
38	Ranikhet Tadikhet Yojana	Almora	2012	Pre
39	Shahar Fatak Yojana	Almora	2012	Pre
40	Sunouli	Almora	2012	Pre
41	Timli Chachroti Peyjal Yojana	Almora	2012	Pre
42	Udaipur Yojana, Udaipur Gaon, Syalde	Almora	2012	Pre
43	Anna-Bmna zone-II (Garud Ganga)	Bageshwar	2010	Pre
44	Anna-Bmna zone-II (Garud Ganga)	Bageshwar	2010	Post
45	Anna-Bmna zone-II (Garud Ganga)	Bageshwar	2011	Pre
46	Bageshwar (Saryu river)	Bageshwar	2010	Pre
47	Bageshwar (Saryu river)	Bageshwar	2010	Post
48	Bageshwar (Saryu river)	Bageshwar	2011	Post
49	Bageshwar (Saryu river)	Bageshwar	2014	Pre
50	Bhayon (Gadera Gadhera)	Bageshwar	2010	Pre
51	Bhayon (Gadera Gadhera)	Bageshwar	2010	Post
52	Bijori Jhal (Dhikra Gadhera)	Bageshwar	2011	Pre
53	Gadera (Group Nala)	Bageshwar	2011	Pre
54	Kafkot (Balen Gadhera)	Bageshwar	2010	Pre
55	Kafkot (Balen Gadhera)	Bageshwar	2010	Post
56	Kafkot (Balen Gadhera)	Bageshwar	2011	Pre
57	Karala Gaon (Kathpuria Sprig)	Bageshwar	2011	Pre
58	Karala Gaon (Kathpuria Sprig)	Bageshwar	2011	Post
59	Loov (Bhanarigan Gadhera)	Bageshwar	2011	Post
60	Loov (Bhanarigan Gadhera)	Bageshwar	2014	Pre
61	Kaneri	Chamoli	2018	Pre
62	Kothgeed	Chamoli	2018	Pre
63	Nauri	Chamoli	2018	Pre
64	Vaatok	Chamoli	2018	Pre
65	Bairagna Dasholi	Chamoli	2012	Pre
66	Bhanak Gopeshwar Gopeshwar	Chamoli	2012	Pre
67	Chamoli (Khanduri Gadhera)	Chamoli	2010	Pre
68	Chamoli (Khanduri Gadhera)	Chamoli	2010	Post
69	Chamoli (Khanduri Gadhera)	Chamoli	2011	Pre
70	Chamoli (Khanduri Gadhera)	Chamoli	2011	Post
71	Chamoli Alaknanda Ghat	Chamoli	2012	Pre
72	Chamoli Alaknanda Ghat	Chamoli	2014	Pre

Sl No	Sites	Major Location	Year	Seasons
73	Chamoli Chamoli Market	Chamoli	2012	Pre
74	Chamoli Chamoli Market	Chamoli	2014	Pre
75	Deval Bazar Deval	Chamoli	2012	Pre
76	Deval Dev Dasholi	Chamoli	2012	Pre
77	Dhartalla Kothinand Kesari	Chamoli	2012	Pre
78	Dimmar Karanprayag	Chamoli	2012	Pre
79	Dimmar Karanprayag	Chamoli	2014	Pre
80	Dimmar Karanprayag	Chamoli	2016	Pre
81	Fahli Ghaat	Chamoli	2012	Pre
82	Gairsain (Gwaad Gadhera)	Chamoli	2011	Pre
83	Gairsain (Gwaad Gadhera)	Chamoli	2014	Pre
84	Gairsain (Gyonhat Gadhere)	Chamoli	2011	Pre
85	Gairsain (Gyonhat Gadhere)	Chamoli	2012	Pre
86	Gauchar Karanprayag	Chamoli	2012	Pre
87	Gaucher (Ghaghragaad)	Chamoli	2010	Pre
88	Gaucher (Ghaghragaad)	Chamoli	2010	Post
89	Gaucher (Ghaghragaad)	Chamoli	2011	Pre
90	Gaucher (Ghaghragaad)	Chamoli	2014	Pre
91	Gaucher (Ghaghragaad)	Chamoli	2016	Pre
92	Ghigram Dasholi	Chamoli	2012	Pre
93	Gopeshwar	Chamoli	2012	Pre
94	Gopeshwar (Bhanak Gadhera)	Chamoli	2010	Pre
95	Gopeshwar (Bhanak Gadhera)	Chamoli	2010	Post
96	Gopeshwar (Bhanak Gadhera)	Chamoli	2011	Pre
97	Gopeshwar (Bhanak Gadhera)	Chamoli	2011	Post
98	Gopeshwar Boitarini Kund	Chamoli	2012	Pre
99	Gopeshwar Polytechnic	Chamoli	2012	Pre
100	Gopeshwar Polytechnic	Chamoli	2014	Pre
101	Joshimath (Nawganga)	Chamoli	2012	Pre
102	Joshimath (Nawganga)	Chamoli	2014	Pre
103	Kandora Hindoli Karanprayag	Chamoli	2012	Pre
104	Karanprayag (Ghatgaad Gadhera)	Chamoli	2010	Pre
105	Karanprayag (Ghatgaad Gadhera)	Chamoli	2010	Post
106	Karanprayag (Ghatgaad Gadhera)	Chamoli	2011	Pre
107	Kuhed Dasholi	Chamoli	2012	Pre
108	Maithana Dasholi	Chamoli	2012	Pre
109	Maithana Dasholi	Chamoli	2014	Pre
110	Mandal Bazar Dasholi	Chamoli	2012	Pre
111	Nandaprayag (Bridge) Karanprayag	Chamoli	2012	Pre
112	Nandaprayag (Zaithagaad)	Chamoli	2010	Pre
113	Nandaprayag (Zaithagaad)	Chamoli	2011	Pre
114	Nandaprayag (Zaithagaad)	Chamoli	2014	Pre
115	Nandaprayag (Zaithagaad)	Chamoli	2016	Pre
116	Nandaprayag Karanprayag	Chamoli	2012	Pre
117	Nandprayag (Sangam)	Chamoli	2014	Pre
118	Nandprayag (Sangam)	Chamoli	2016	Pre
119	Naurakh Runargathan, Dasholi	Chamoli	2012	Pre
120	Pakhi Joshimath	Chamoli	2012	Pre
121	Parsari Joshimath	Chamoli	2012	Pre
122	Pipalkoti (Mangerigaad)	Chamoli	2010	Pre
123	Pipalkoti (Mangerigaad)	Chamoli	2010	Post
124	Pipalkoti (Mangerigaad)	Chamoli	2011	Pre
125	Pipalkoti (Mangerigaad)	Chamoli	2011	Post
126	Pipalkoti Dasholi	Chamoli	2012	Pre
127	Rampura Natural Source Dasholi	Chamoli	2014	Pre
128	Rampura Natural Source Dasholi	Chamoli	2016	Pre
129	Ravigram I Joshimath Nagar Palika	Chamoli	2012	Pre
130	Ravigram II Joshimath	Chamoli	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
131	Sagar/Gwaad Dasholi	Chamoli	2012	Pre
132	Saiti (NS) Ghat	Chamoli	2012	Pre
133	Saiti (NS) Ghat	Chamoli	2014	Pre
134	Sera (Ghat)	Chamoli	2012	Pre
135	Serani Ghat	Chamoli	2012	Pre
136	Sonyana Silangi Dhunaghat	Chamoli	2012	Pre
137	Sunoli Karanprayag Sunoli	Chamoli	2012	Pre
138	Sunoli Karanprayag Sunoli	Chamoli	2014	Pre
139	Bandesa Dhek	Champawat	2012	Pre
140	Barakot (Chhadkhola)	Champawat	2010	Pre
141	Barakot (Chhadkhola)	Champawat	2010	Post
142	Barakot (Chhadkhola)	Champawat	2011	Pre
143	Champawat (Churakhad)	Champawat	2010	Pre
144	Champawat (Churakhad)	Champawat	2010	Post
145	Champawat (Churakhad)	Champawat	2011	Pre
146	Champawat (Churakhad)	Champawat	2016	Pre
147	Circuit House Tank Champwat	Champawat	2016	Pre
148	Dhunaghat	Champawat	2012	Pre
149	Forti (Tanki Ka Khola)	Champawat	2011	Post
150	Fungar (Dudhadhari Kola)	Champawat	2011	Pre
151	Kherkkarki (Chhidapani khola)	Champawat	2010	Pre
152	Kherkkarki (Chhidapani khola)	Champawat	2010	Post
153	Kherkkarki (Chhidapani khola)	Champawat	2011	Pre
154	Kherkkarki (Chhidapani khola)	Champawat	2011	Post
155	Kherkkarki (Chhidapani khola)	Champawat	2014	Pre
156	Kherkkarki (Chhidapani khola)	Champawat	2016	Pre
157	Kimad (Kedarnath khola)	Champawat	2010	Pre
158	Kimad (Kedarnath khola)	Champawat	2010	Post
159	Kolidhek (Mayawati Gadhera)	Champawat	2011	Post
160	Kolidhek (Mayawati Gadhera)	Champawat	2012	Pre
161	Lohaghat (Lohawati River)	Champawat	2010	Pre
162	Lohaghat (Lohawati River)	Champawat	2010	Post
163	Lohaghat (Lohawati River)	Champawat	2011	Pre
164	Lohaghat (Lohawati River)	Champawat	2016	Pre
165	Lohaghat Souru Churi Pump House	Champawat	2012	Pre
166	Nauli Yojana	Champawat	2012	Pre
167	Raigaon	Champawat	2016	Pre
168	Sui Peyjal Yojana	Champawat	2012	Pre
169	Aam Source (Madusidha)	Dehradun	2010	Pre
170	Aambadi	Dehradun	2012	Pre
171	Aambadi	Dehradun	2014	Pre
172	Aamwala Guchka Gadera (Nuniyas gaon)	Dehradun	2014	Pre
173	Aamwala Guchka Gadera (Nuniyas gaon)	Dehradun	2016	Pre
174	Adersh Nagar	Dehradun	2012	Pre
175	BadasiGrant Raipur, Deukhala	Dehradun	2014	Pre
176	Bhagwanpur (Aglikhala)	Dehradun	2010	Pre
177	Bhagwanpur (Aglikhala)	Dehradun	2011	Pre
178	Bhagwanpur (Aglikhala)	Dehradun	2011	Post
179	Bharatwala (Bhitarligaad)	Dehradun	2010	Pre
180	Bharatwala (Bhitarligaad)	Dehradun	2010	Post
181	Bharatwala (Bhitarligaad)	Dehradun	2011	Pre
182	Bharatwala (Bhitarligaad)	Dehradun	2011	Post
183	Bharatwala (Bhitarligaad)	Dehradun	2014	Pre
184	Bhauwala (Maldunga)	Dehradun	2010	Pre
185	Bhauwala (Maldunga)	Dehradun	2010	Post
186	Bhauwala (Maldunga)	Dehradun	2011	Post
187	Bhauwala Rampur, Ramsawal	Dehradun	2012	Pre
188	Bhogpur (Aamgarh Khala)	Dehradun	2010	Pre

Sl No	Sites	Major Location	Year	Seasons
189	Bhogpur (Aamgarh Khala)	Dehradun	2010	Post
190	Bhogpur (Aamgarh Khala)	Dehradun	2011	Pre
191	Bhogpur (Aamgarh Khala)	Dehradun	2014	Pre
192	Bhopalpani, Kadaikhala Sodikhal, Raipur	Dehradun	2014	Pre
193	Danda Lakhaud (Karligaad)	Dehradun	2010	Pre
194	Danda Lakhaud (Karligaad)	Dehradun	2010	Post
195	Danda Lakhaud (Karligaad)	Dehradun	2014	Pre
196	Dehradun City (Bandal)	Dehradun	2010	Pre
197	Dehradun City (Bandal)	Dehradun	2010	Post
198	Dehradun City (Bandal)	Dehradun	2011	Pre
199	Dehradun City (Bandal)	Dehradun	2011	Post
200	Dehradun City (Bandal)	Dehradun	2014	Pre
201	Dehradun City (Bandal)	Dehradun	2016	Pre
202	Dehradun City (Bhitarli)	Dehradun	2010	Pre
203	Dehradun City (Bhitarli)	Dehradun	2011	Pre
204	Dehradun City (Bhitarli)	Dehradun	2011	Post
205	Dehradun City (Bhitarli)	Dehradun	2014	Pre
206	Dehradun City (Bhitarli)	Dehradun	2016	Pre
207	Dehradun City (Bijapur)	Dehradun	2010	Pre
208	Dehradun City (Bijapur)	Dehradun	2011	Pre
209	Dehradun City (Bijapur)	Dehradun	2011	Post
210	Dehradun City (Bijapur)	Dehradun	2014	Pre
211	Dehradun City (Massifall)	Dehradun	2010	Pre
212	Dehradun City (Massifall)	Dehradun	2010	Post
213	Dehradun City (Massifall)	Dehradun	2011	Pre
214	Dehradun City (Massifall)	Dehradun	2011	Post
215	Dehradun City (Massifall)	Dehradun	2014	Pre
216	Dehradun City (Massifall)	Dehradun	2016	Pre
217	Dhauran (Talanighat)	Dehradun	2010	Pre
218	Dhauran (Talanighat)	Dehradun	2010	Post
219	Dhauran (Talanighat)	Dehradun	2011	Pre
220	Dhauran (Talanighat)	Dehradun	2011	Post
221	Dhauran (Talanighat)	Dehradun	2014	Pre
222	Doiwala, Kheta MTW	Dehradun	2012	Pre
223	Ghanghoda Hariyawala, Shaspur	Dehradun	2012	Pre
224	Gujrada (Karligaad)	Dehradun	2010	Pre
225	Gujrada (Karligaad)	Dehradun	2010	Post
226	Gujrada (Karligaad)	Dehradun	2014	Pre
227	Gujrada (Nagal Hatnala MTW)	Dehradun	2011	Post
228	Jaadi Chakrata	Dehradun	2014	Pre
229	Jaadi Chakrata	Dehradun	2016	Pre
230	Jhajhra Panditwadi Sudhowala	Dehradun	2012	Pre
231	Kalsi (Jhajhreda)	Dehradun	2010	Pre
232	Kalsi (Jhajhreda)	Dehradun	2010	Post
233	Kalsi (Jhajhreda)	Dehradun	2011	Pre
234	Kalsi (Jhajhreda)	Dehradun	2011	Post
235	Kalsi (Jhajhreda)	Dehradun	2014	Pre
236	Kalsi Bazar Kalsi, Amlaw	Dehradun	2012	Pre
237	Kirsali (Telagaad)	Dehradun	2010	Post
238	Kirsali (Telagaad)	Dehradun	2011	Pre
239	Kirsali (Telagaad)	Dehradun	2014	Pre
240	Kohlupani (Aamwala) Shaspur	Dehradun	2012	Pre
241	Kohlupani (Aamwala) Shaspur	Dehradun	2014	Pre
242	Kolukhet (Chandroti)	Dehradun	2011	Pre
243	Kolukhet (Chandroti)	Dehradun	2011	Post
244	Kolukhet (Chandroti)	Dehradun	2014	Pre
245	Kotala Santure (Madusidh Khala)	Dehradun	2010	Pre
246	Kotala Santure (Madusidh Khala)	Dehradun	2010	Post

Sl No	Sites	Major Location	Year	Seasons
247	Kotala Santure (Madusidh Khala)	Dehradun	2011	Pre
248	Kotala Santure (Madusidh Khala)	Dehradun	2014	Pre
249	Kwarana Mangraul Sunaua	Dehradun	2012	Pre
250	Kwarana Mangraul Sunaua	Dehradun	2014	Pre
251	Makhi Pokhau Sawaiklaad	Dehradun	2012	Pre
252	Makhi Pokhau Sawaiklaad	Dehradun	2014	Pre
253	Malsi (Kaligaad)	Dehradun	2011	Pre
254	Malsi (Kaligaad)	Dehradun	2011	Post
255	Mangrouli, Sujunaklaad	Dehradun	2012	Pre
256	Mussoorie (Bhiladu)	Dehradun	2011	Post
257	Mussoorie (Bhiladu)	Dehradun	2016	Pre
258	Mussoorie (Dhobighat)	Dehradun	2010	Pre
259	Mussoorie (Dhobighat)	Dehradun	2010	Post
260	Mussoorie (Dhobighat)	Dehradun	2011	Pre
261	Mussoorie (Dhobighat)	Dehradun	2011	Post
262	Mussoorie (Jinsi)	Dehradun	2010	Pre
263	Mussoorie (Jinsi)	Dehradun	2010	Post
264	Mussoorie (Jinsi)	Dehradun	2011	Pre
265	Mussoorie (Kandighat)	Dehradun	2010	Pre
266	Mussoorie (Kandighat)	Dehradun	2011	Pre
267	Mussoorie (Kandighat)	Dehradun	2011	Post
268	Mussoorie (Kandighat)	Dehradun	2014	Pre
269	Mussoorie (Kolti)	Dehradun	2010	Pre
270	Mussoorie (Kolti)	Dehradun	2010	Post
271	Mussoorie (Kolti)	Dehradun	2011	Pre
272	Mussoorie (Macnan)	Dehradun	2011	Pre
273	Mussoorie (Macnan)	Dehradun	2011	Post
274	Mussoorie (Macnan)	Dehradun	2016	Pre
275	Paula Soda Badari, Raipur	Dehradun	2012	Pre
276	Paundha Aamwala	Dehradun	2012	Pre
277	Paundha Aamwala	Dehradun	2014	Pre
278	Penwa (Penwa) Chunakhaad	Dehradun	2012	Pre
279	Penwa (Penwa) Chunakhaad	Dehradun	2014	Pre
280	Purtaad (Chatra) Dhanarti Klaad	Dehradun	2014	Pre
281	Pyunal (Mundhri) Gaalti	Dehradun	2012	Pre
282	Raiwala (Infiltration Well)	Dehradun	2014	Pre
283	Raygi Shediya Chhumra Paniklaad	Dehradun	2014	Pre
284	Retaad (Kunen) Durani	Dehradun	2014	Pre
285	Retaad (Kunen) Durani	Dehradun	2016	Pre
286	Rishikesh (Pump No.6)	Dehradun	2010	Pre
287	Saahiya Nebi Sarlaklaad	Dehradun	2012	Pre
288	Saahiya Nebi Sarlaklaad	Dehradun	2014	Pre
289	Samuha Tok, Nithala, Nichloklaad	Dehradun	2012	Pre
290	Sauda (Penva) Bharunuwa	Dehradun	2012	Pre
291	Sauda (Penva) Bharunuwa	Dehradun	2014	Pre
292	Soda Saroli, Chuowala, Raipur	Dehradun	2014	Pre
293	Sukhaad (Birnaad) Sukhaiki	Dehradun	2012	Pre
294	Sukhaad (Birnaad) Sukhaiki	Dehradun	2014	Pre
295	Sukhaad (Birnaad) Sukhaiki	Dehradun	2016	Pre
296	Sunbagh (Anu) Daglikhaad	Dehradun	2012	Pre
297	Sunbagh (Anu) Daglikhaad	Dehradun	2014	Pre
298	Tyuna Mangtaad Saraswati Khaad	Dehradun	2012	Pre
299	Tyuna Mangtaad Saraswati Khaad	Dehradun	2014	Pre
300	Tyuni (Raygi) Bamrikhaad	Dehradun	2014	Pre
301	Vinau-Bantau Uprolikhida Koli	Dehradun	2012	Pre
302	Vinau-Bantau Uprolikhida Koli	Dehradun	2014	Pre
303	Borgaon Source Scheme	Devprayag	2019	Post
304	Juyalgarh Source Scheme	Devprayag	2019	Pre

Sl No	Sites	Major Location	Year	Seasons
305	Koti Tyunsa Source Scheme	Devprayag	2018	Post
306	Maletha Source Scheme	Devprayag	2019	Pre
307	Ratoli Source Scheme	Devprayag	2019	Post
308	Sondhar Hand Pump Scheme	Devprayag	2019	Post
309	Khadrasi Scheme	Dwarikhal	2018	Post
310	Kochiyar Scheme	Dwarikhal	2018	Post
311	Mandul Scheme	Dwarikhal	2018	Post
312	Mandul Scheme	Dwarikhal	2019	Pre
313	Math gaun Scheme	Dwarikhal	2018	Pre
314	Math gaun Scheme	Dwarikhal	2019	Post
315	MatyaliMaletha Scheme	Dwarikhal	2018	Pre
316	MatyaliMaletha Scheme	Dwarikhal	2019	Pre
317	PaliGaun Nayedi Scheme	Dwarikhal	2018	Post
318	Prinda Scheme	Dwarikhal	2018	Pre
319	Prinda Scheme	Dwarikhal	2019	Pre
320	Haridwar (Chakalan pump No.34)	Haridwar	2010	Post
321	Haridwar, Pantdeep, RBF (Pump No.18)	Haridwar	2010	Post
322	Haridwar, Pantdeep, RBF (Pump No.18)	Haridwar	2011	Post
323	Balli	Kotdwara	2018	Pre
324	Byella Talla sheme	Kotdwara	2019	Pre
325	Kochiyar Scheme	Kotdwara	2019	Post
326	PaliGaun Nayedi Scheme	Kotdwara	2019	Pre
327	Bailpadow Kaladhungi	Nainital	2012	Pre
328	Bhimtal (Bhimtal Lake)	Nainital	2010	Pre
329	Bhimtal (Bhimtal Lake)	Nainital	2010	Post
330	Bhimtal Market (Diggi Gadhera)	Nainital	2012	Pre
331	Bhimtal, Songaon	Nainital	2012	Pre
332	Chhoti Haldwani Kaladhungi	Nainital	2012	Pre
333	Damura Dunga Haldwani	Nainital	2012	Pre
334	Devendrapuri Badi Mukhani Haldwani	Nainital	2012	Pre
335	Dhari Bhimtal (Tank)	Nainital	2012	Pre
336	Fasital Gadhera Pump House Nainital	Nainital	2012	Pre
337	Garampani (Dopakhi) (kanwadi Spring)	Nainital	2010	Post
338	Garampani (Dopakhi) (kanwadi Spring)	Nainital	2011	Pre
339	Haldwani (Gola River)	Nainital	2010	Pre
340	Haldwani (Gola River)	Nainital	2010	Post
341	Haldwani (Gola River)	Nainital	2011	Pre
342	Haldwani (Gola River)	Nainital	2011	Post
343	Himatpur Lalkuan	Nainital	2012	Pre
344	ITI Dehriya, Haldwani	Nainital	2012	Pre
345	Jal Sansthan Khandelwal Park Haldwani	Nainital	2012	Pre
346	Jalsansthan Tikoniya Haldwani	Nainital	2012	Pre
347	Jyolikoat Bhimtal Nainital	Nainital	2012	Pre
348	Kaladungi (Bijpur)	Nainital	2010	Pre
349	Kaladungi (Bijpur)	Nainital	2010	Post
350	Kaniya Chilkiya Lakhanpur Ramnagar	Nainital	2012	Pre
351	Kathgodam (Sheetalahat)	Nainital	2010	Pre
352	Kathgodam (Sheetalahat)	Nainital	2010	Post
353	Kathgodam (Sheetalahat)	Nainital	2011	Pre
354	Kathgodam (Sheetalahat)	Nainital	2011	Post
355	Kuleti (Kuleti Gadhera)	Nainital	2011	Pre
356	Lalkuan Market	Nainital	2012	Pre
357	Mahila Degree College Haldwani	Nainital	2012	Pre
358	Manpur Paschim Devalchore Haldwani	Nainital	2012	Pre
359	Milanchal Colony Dehriya Haldwani	Nainital	2012	Pre
360	Nandpur Chilkiya, Ramngar	Nainital	2012	Pre
361	Nanital (Tube Well5&8)	Nainital	2011	Pre
362	Paniyali Haldwani	Nainital	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
363	Rajeev Nagar Bengali Colony Lalkuan	Nainital	2012	Pre
364	Ramnagar (Kosi River)	Nainital	2010	Pre
365	Ramnagar (Kosi River)	Nainital	2010	Post
366	Ramnagar (Kosi River)	Nainital	2011	Post
367	Shubhash Nagar Avas Vikas Haldwani	Nainital	2012	Pre
368	Syamkhet (Kahalauira Gadhera)	Nainital	2011	Pre
369	Syamkhet (Kahalauira Gadhera)	Nainital	2011	Post
370	Unchapool Haldwani	Nainital	2012	Pre
371	Vijaypur Dhamala	Nainital	2012	Pre
372	Buganio (Gadoli Gadhera)	Pauri	2010	Pre
373	Buganio (Gadoli Gadhera)	Pauri	2010	Post
374	Dugadda (Khoh River)	Pauri	2011	Pre
375	Dugadda (Khoh River)	Pauri	2011	Post
376	Ghodikhal (Kevru Gadhera)	Pauri	2011	Pre
377	Kanskheit (Adwani Gadhera)	Pauri	2011	Pre
378	Kotdwar (Khoh River)	Pauri	2010	Post
379	Kotdwar (Khoh River)	Pauri	2011	Pre
380	Kotdwar (Khoh River)	Pauri	2011	Post
381	Kotdwar (Khoh River)	Pauri	2014	Pre
382	Kotdwar (Khoh River) 5Km Pump House	Pauri	2011	Pre
383	Kotdwar (Khoh River) 5Km Pump House	Pauri	2011	Post
384	Maithana Gaon (Gazald Gadhera)	Pauri	2010	Pre
385	Maithana Gaon (Gazald Gadhera)	Pauri	2010	Post
386	Maithana Gaon (Gazald Gadhera)	Pauri	2011	Pre
387	Nautha-Burni (Nautha- Gadhera)	Pauri	2014	Pre
388	Nautha-Burni (Nautha- Gadhera)	Pauri	2016	Pre
389	Satpuli (Madhuganga River)	Pauri	2010	Pre
390	Satpuli (Madhuganga River)	Pauri	2014	Pre
391	Srinagar (Alaknada River)	Pauri	2010	Pre
392	Srinagar (Alaknada River)	Pauri	2010	Post
393	Srinagar (Alaknada River)	Pauri	2011	Post
394	Srinagar (Alaknada River)	Pauri	2014	Pre
395	Swargashram (Infiltration Well)	Pauri	2011	Post
396	Swargashram (Infiltration Well)	Pauri	2014	Pre
397	Berinaag (Ghurghatiya)	Pithoragarh	2011	Pre
398	Berinaag (Ghurghatiya)	Pithoragarh	2011	Post
399	Berinaag (Ghurghatiya)	Pithoragarh	2014	Pre
400	Chhera (Maila)	Pithoragarh	2011	Pre
401	Chhera (Maila)	Pithoragarh	2011	Post
402	Didihat (Bhanara)	Pithoragarh	2010	Post
403	Didihat (Bhanara)	Pithoragarh	2011	Post
404	Gangolihaat (Kaliya Patal)	Pithoragarh	2010	Pre
405	Gangolihaat (Kaliya Patal)	Pithoragarh	2010	Post
406	Gangolihaat (Kaliya Patal)	Pithoragarh	2011	Pre
407	Hyunpani (Ghatyurigar)	Pithoragarh	2011	Post
408	Naini Bnar	Pithoragarh	2018	Pre
409	Naini Bnar	Pithoragarh	2019	Post
410	Nanipatal (Nanipatal Gadhera)	Pithoragarh	2011	Post
411	Nanipatal (Nanipatal Gadhera)	Pithoragarh	2014	Pre
412	Pithoragarh (Raigaad)	Pithoragarh	2010	Pre
413	Pithoragarh (Raigaad)	Pithoragarh	2010	Post
414	Pithoragarh (Raigaad)	Pithoragarh	2011	Pre
415	Pithoragarh (Raigaad)	Pithoragarh	2011	Post
416	Pithoragarh (Ramganga River)	Pithoragarh	2010	Pre
417	Pithoragarh (Ramganga River)	Pithoragarh	2011	Pre
418	Pithoragarh (Ramganga River)	Pithoragarh	2011	Post
419	Pithoragarh (Thalika Gadhera)	Pithoragarh	2011	Pre
420	Pithoragarh (Thalika Gadhera)	Pithoragarh	2011	Post

Sl No	Sites	Major Location	Year	Seasons
421	Pithoragarh (Thuligaad)	Pithoragarh	2010	Pre
422	Pithoragarh (Thuligaad)	Pithoragarh	2010	Post
423	Pithoragarh (Thuligaad)	Pithoragarh	2011	Pre
424	Pithoragarh (Thuligaad)	Pithoragarh	2011	Post
425	Pithoragarh (Thuligaad)	Pithoragarh	2014	Pre
426	Dahal	Ranikhet	2018	Post
427	Loukot	Ranikhet	2018	Pre
428	Maliyal Gaon	Ranikhet	2018	Post
429	Patharkhola	Ranikhet	2018	Pre
430	Palli	Rishikesh	2019	Post
431	Ayadgaad	Rudraprayag	2018	Post
432	bhelgad	Rudraprayag	2018	Post
433	bhelgad	Rudraprayag	2019	Post
434	Dolapani	Rudraprayag	2019	Post
435	Gholtir	Rudraprayag	2018	Pre
436	Helaigaad	Rudraprayag	2018	Post
437	Helaigaad	Rudraprayag	2018	Post
438	Neilgad	Rudraprayag	2018	Pre
439	ritwapani	Rudraprayag	2019	Post
440	Safe	Rudraprayag	2018	Post
441	Yata	Rudraprayag	2018	Post
442	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2010	Pre
443	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2011	Pre
444	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2011	Post
445	Augustmuni (Bhorgaad Gadhera)	Rudraprayag	2014	Pre
446	Kandadhar Jamsali (Kulagaad)	Rudraprayag	2011	Pre
447	Kandadhar Jamsali (Kulagaad)	Rudraprayag	2014	Pre
448	Khakhara Peyjal Yojana (Fatehpur Tok Spring)	Rudraprayag	2011	Pre
449	Khakhara Peyjal Yojana (Fatehpur Tok Spring)	Rudraprayag	2011	Post
450	Khakhara Peyjal Yojana (Fatehpur Tok Spring)	Rudraprayag	2014	Pre
451	Nagrasu (Dharimangra)	Rudraprayag	2010	Pre
452	Nagrasu (Dharimangra)	Rudraprayag	2010	Post
453	Nagrasu (Dharimangra)	Rudraprayag	2011	Pre
454	Nagrasu (Dharimangra)	Rudraprayag	2014	Pre
455	Rudraprayag (Punad Gadhera)	Rudraprayag	2010	Pre
456	Rudraprayag (Punad Gadhera)	Rudraprayag	2010	Post
457	Rudraprayag (Punad Gadhera)	Rudraprayag	2011	Pre
458	Sumairpur (Lugai Gadhera)	Rudraprayag	2011	Pre
459	Sumairpur (Lugai Gadhera)	Rudraprayag	2011	Post
460	Sumairpur (Lugai Gadhera)	Rudraprayag	2014	Pre
461	Tiladi (Bhunak Gadhera)	Rudraprayag	2011	Pre
462	Ukimath (Pighala Pani)	Rudraprayag	2010	Pre
463	Ukimath (Pighala Pani)	Rudraprayag	2010	Post
464	Ukimath (Pighala Pani)	Rudraprayag	2011	Pre
465	Ukimath (Pighala Pani)	Rudraprayag	2011	Post
466	Ukimath (Pighala Pani)	Rudraprayag	2014	Pre
467	Ukimath (Pighala Pani)	Rudraprayag	2016	Pre
468	Aagroda	Satpuli	2018	Pre
469	Aagroda	Satpuli	2019	Post
470	Aandkhil	Satpuli	2019	Pre
471	Aasgadh	Satpuli	2018	Pre
472	Badsu	Satpuli	2018	Pre
473	Baluni	Satpuli	2018	Pre
474	Bijoli	Satpuli	2019	Post
475	Bilkhet	Satpuli	2018	Pre
476	Bunga	Satpuli	2018	Pre
477	Chiloli	Satpuli	2018	Pre
478	Chora	Satpuli	2018	Post

Sl No	Sites	Major Location	Year	Seasons
479	Deval	Satpuli	2018	Pre
480	Ghandiyal	Satpuli	2018	Pre
481	Ghandiyal	Satpuli	2019	Post
482	Ghodiyan	Satpuli	2018	Post
483	Ghodiyan	Satpuli	2019	Post
484	Gothinda	Satpuli	2018	Pre
485	Gwaalli	Satpuli	2018	Post
486	Jakhola	Satpuli	2018	Post
487	Jakhola	Satpuli	2019	Post
488	Jaspur	Satpuli	2018	Post
489	Khandda malla	Satpuli	2018	Pre
490	Kilwas	Satpuli	2018	Post
491	Kolinda	Satpuli	2018	Post
492	Kota	Satpuli	2018	Post
493	Liwitha	Satpuli	2018	Pre
494	Lodhli	Satpuli	2018	Post
495	Majkot	Satpuli	2018	Pre
496	Molthi Bichli	Satpuli	2018	Post
497	Patal gunth	Satpuli	2018	Pre
498	Pinkot	Satpuli	2018	Post
499	Pokhra	Satpuli	2018	Pre
500	Pokhri	Satpuli	2018	Post
501	Rolli	Satpuli	2018	Post
502	Sanglakoti Market	Satpuli	2019	Pre
503	Suralgaun	Satpuli	2018	Pre
504	Takulsari	Satpuli	2018	Post
505	Athul Badul	Srinagar	2018	Post
506	Athul Talla	Srinagar	2018	Post
507	Athul Talla	Srinagar	2019	Post
508	Baherakhal	Srinagar	2018	Post
509	Baherakhal	Srinagar	2019	Post
510	Barsila	Srinagar	2018	Pre
511	Barsudi	Srinagar	2018	Post
512	Bhati Gaun	Srinagar	2018	Post
513	Bhatkot	Srinagar	2018	Pre
514	Bhawan	Srinagar	2018	Pre
515	Bisald	Srinagar	2018	Pre
516	Buransi	Srinagar	2018	Post
517	Buransi	Srinagar	2019	Post
518	Charakot	Srinagar	2018	Pre
519	Charakot	Srinagar	2019	Post
520	Chaupadiyo Pakha	Srinagar	2018	Post
521	Chawath	Srinagar	2018	Pre
522	Chawath	Srinagar	2019	Post
523	Chetud	Srinagar	2018	Pre
524	Chetud	Srinagar	2019	Post
525	Dalmi	Srinagar	2019	Post
526	Dhanau Talla	Srinagar	2018	Pre
527	Dhancaura	Srinagar	2018	Pre
528	Dhari Gaun	Srinagar	2018	Post
529	Dhari Gaun	Srinagar	2019	Post
530	Dobalya	Srinagar	2018	Pre
531	Dobh Srikot	Srinagar	2018	Pre
532	Falswadi	Srinagar	2018	Pre
533	Falswadi	Srinagar	2019	Pre
534	Farasu	Srinagar	2018	Post
535	Gadoli	Srinagar	2018	Pre
536	Gahad lagga Bhutoli	Srinagar	2018	Post

Sl No	Sites	Major Location	Year	Seasons
537	Gahath Nakot	Srinagar	2018	Pre
538	Ghindabagi	Srinagar	2018	Pre
539	Ghodikhal	Srinagar	2018	Post
540	Girgaun	Srinagar	2018	Pre
541	Gostu	Srinagar	2018	Post
542	Gwadigaad	Srinagar	2018	Post
543	Jamsali	Srinagar	2018	Post
544	Jitoli Maroda	Srinagar	2018	Post
545	Kaleshwar	Srinagar	2018	Pre
546	Kandayi	Srinagar	2018	Post
547	Kandayi	Srinagar	2019	Post
548	Kandayi Talli	Srinagar	2018	Post
549	Kandola	Srinagar	2018	Post
550	Kandola	Srinagar	2019	Post
551	Kewars	Srinagar	2018	Post
552	Khadet Talla	Srinagar	2018	Pre
553	Koltha	Srinagar	2018	Post
554	Kot	Srinagar	2018	Pre
555	Kot	Srinagar	2019	Pre
556	Kothar	Srinagar	2018	Pre
557	Kothar	Srinagar	2019	Post
558	Kotsada	Srinagar	2018	Pre
559	Kulasu	Srinagar	2018	Post
560	Kulasu	Srinagar	2019	Post
561	Kushli Singori	Srinagar	2018	Post
562	Lasera	Srinagar	2018	Post
563	Lwali	Srinagar	2019	Post
564	Maletha	Srinagar	2018	Post
565	Molan	Srinagar	2018	Pre
566	Muchayali	Srinagar	2018	Post
567	Musoli	Srinagar	2018	Post
568	Nagoli	Srinagar	2018	Pre
569	Naugaun	Srinagar	2018	Post
570	Nayi	Srinagar	2018	Pre
571	Nishani	Srinagar	2018	Post
572	Niwada	Srinagar	2018	Pre
573	Notha	Srinagar	2018	Post
574	Paligaun	Srinagar	2018	Pre
575	Palkot	Srinagar	2018	Post
576	Panchur	Srinagar	2019	Post
577	Paniya	Srinagar	2018	Post
578	Pasina	Srinagar	2018	Post
579	Pedul	Srinagar	2018	Pre
580	Pedul	Srinagar	2018	Pre
581	Pedul	Srinagar	2019	Pre
582	Pipali	Srinagar	2018	Post
583	Pokhari masan Gaun	Srinagar	2018	Pre
584	Purmesi	Srinagar	2018	Pre
585	Ranakot	Srinagar	2018	Pre
586	Ratkoti	Srinagar	2018	Post
587	Revdi Talli	Srinagar	2018	Pre
588	Rigud	Srinagar	2018	Post
589	Rigud	Srinagar	2019	Post
590	Rigud	Srinagar	2019	Post
591	Sabdarkhal	Srinagar	2018	Post
592	Sarana	Srinagar	2018	Pre
593	Saud Maroda	Srinagar	2018	Pre
594	Seim	Srinagar	2018	Post

Sl No	Sites	Major Location	Year	Seasons
595	Silsu Kota	Srinagar	2018	Pre
596	Sindi Jaskot	Srinagar	2018	Pre
597	Sirala	Srinagar	2018	Pre
598	Sumadi	Srinagar	2018	Post
599	Sumadi	Srinagar	2019	Post
600	Tamlag	Srinagar	2018	Pre
601	Tapradi	Srinagar	2018	Post
602	Tapradi	Srinagar	2019	Post
603	Tedi	Srinagar	2018	Pre
604	Thapliyal Gaun	Srinagar	2018	Pre
605	Thapliyal Gaun	Srinagar	2019	Post
606	Uttarasu	Srinagar	2018	Pre
607	Vajali	Srinagar	2018	Post
608	Viadgaun	Srinagar	2018	Pre
609	Vijay Nagar	Srinagar	2018	Pre
610	Agrakhal (Vasuwakhal)	Tehri	2010	Post
611	Agrakhal (Vasuwakhal)	Tehri	2011	Pre
612	Bahedi Yojana	Tehri	2012	Pre
613	Bhatoli Yojana	Tehri	2012	Pre
614	Bhatusain Yojana	Tehri	2014	Pre
615	Bhedlamiyali Peyjal	Tehri	2012	Pre
616	Chamba (Nagni Gadhera)	Tehri	2010	Pre
617	Chamba (Nagni Gadhera)	Tehri	2010	Post
618	Chamba (Nagni Gadhera)	Tehri	2011	Pre
619	Chamba (Nagni Gadhera)	Tehri	2014	Pre
620	Devprayag (Diwanigaad)	Tehri	2010	Pre
621	Devprayag (Diwanigaad)	Tehri	2011	Post
622	Devprayag (Diwanigaad)	Tehri	2014	Pre
623	Dhanaulty (Chandukhil)	Tehri	2011	Post
624	Gaid Yojana	Tehri	2012	Pre
625	Ghansali Yojana	Tehri	2012	Pre
626	Hindolakhal (Alaknanda River)	Tehri	2011	Pre
627	Hindolakhal (Alaknanda River)	Tehri	2011	Post
628	Hindolakhal (Alaknanda River)	Tehri	2014	Pre
629	Jhakhnyali (I) Yojana	Tehri	2012	Pre
630	Jhakhnyali (I) Yojana	Tehri	2014	Pre
631	Jhakhnyali (II) Yojana	Tehri	2012	Pre
632	Jhakhnyali (II) Yojana	Tehri	2014	Pre
633	Kandisaud (Khamoli Gadhera)	Tehri	2010	Pre
634	Kandisaud (Khamoli Gadhera)	Tehri	2010	Post
635	Kandisaud (Khamoli Gadhera)	Tehri	2014	Pre
636	Kandisaud (Sannu Gadhera)	Tehri	2011	Post
637	Kikot Peyjal Yojana	Tehri	2014	Pre
638	Kirtinagar (Dang Gadhera)	Tehri	2010	Pre
639	Kirtinagar (Dang Gadhera)	Tehri	2011	Pre
640	Kirtinagar (Dang Gadhera)	Tehri	2014	Pre
641	Nainbagh (Bareda khadd)	Tehri	2010	Post
642	Narendranagar (Chanderbhaga River)	Tehri	2010	Pre
643	Narendranagar (Chanderbhaga River)	Tehri	2010	Post
644	Narendranagar (Chanderbhaga River)	Tehri	2011	Pre
645	Narendranagar (Chanderbhaga River)	Tehri	2014	Pre
646	New Tehri (Bhagirathi River)	Tehri	2010	Pre
647	New Tehri (Bhagirathi River)	Tehri	2010	Post
648	New Tehri (Bhagirathi River)	Tehri	2011	Post
649	Pata Jangleth	Tehri	2012	Pre
650	Rani Chouri Chamba	Tehri	2012	Pre
651	Sadab Yojana	Tehri	2012	Pre
652	Sajnu ka Gaon Yojana	Tehri	2012	Pre

Sl No	Sites	Major Location	Year	Seasons
653	Suda Peyjal Yojana	Tehri	2014	Pre
654	Suransh Sankari	Tehri	2012	Pre
655	Takarna Yojana	Tehri	2012	Pre
656	Anol Naragaad Chinyalisour	Uttarkashi	2012	Pre
657	Anol Naragaad Chinyalisour	Uttarkashi	2014	Pre
658	Anol Naragaad Chinyalisour	Uttarkashi	2016	Pre
659	Arakoat Mori	Uttarkashi	2012	Pre
660	Arakoat Mori	Uttarkashi	2014	Pre
661	Badathi Chungi Silora, Dunda	Uttarkashi	2012	Pre
662	Badethi Badethikhad Chinyalisaur	Uttarkashi	2012	Pre
663	Badkot (Bhotukhaad)	Uttarkashi	2010	Pre
664	Badkot (Bhotukhaad)	Uttarkashi	2010	Post
665	Badkot (Bhotukhaad)	Uttarkashi	2011	Pre
666	Badkot Bhotukhudd Naugaon	Uttarkashi	2014	Pre
667	Bhatwari, Bhatwari gaad Bhatwari	Uttarkashi	2014	Pre
668	Birpur Ghatukhal Dunda	Uttarkashi	2014	Pre
669	Brahmakhal (Silkyara Gadhera)	Uttarkashi	2011	Post
670	Brahmakhal (Siyalnakhadd)	Uttarkashi	2011	Pre
671	Brahmakhal (Siyalnakhadd)	Uttarkashi	2014	Pre
672	Burnigaad Naugaon	Uttarkashi	2014	Pre
673	Chibala yojana Purola	Uttarkashi	2012	Pre
674	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2010	Pre
675	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2010	Post
676	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2011	Pre
677	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2011	Post
678	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2014	Pre
679	Chinyalisaud (Nagud Gadhera)	Uttarkashi	2016	Pre
680	Chinyalisaur Nagungaad	Uttarkashi	2014	Pre
681	Dandagaon Chinyalisour	Uttarkashi	2014	Pre
682	Dharasu Gadhera Chinyalisaur	Uttarkashi	2014	Pre
683	Dharkot Nagungaad Chinyalisour	Uttarkashi	2014	Pre
684	Dunda (Ginwala Gaad)	Uttarkashi	2010	Pre
685	Dunda (Ginwala Gaad)	Uttarkashi	2010	Post
686	Dunda (Ginwala Gaad)	Uttarkashi	2011	Pre
687	Dunda (Ginwala Gaad)	Uttarkashi	2011	Post
688	Gainchawan gaon, Mori	Uttarkashi	2012	Pre
689	Gangori (Singoti khala)	Uttarkashi	2014	Pre
690	Gundiyal Gaon Chanika Purola	Uttarkashi	2014	Pre
691	Gyansu (Varuna Gaad)	Uttarkashi	2010	Pre
692	Gyansu (Varuna Gaad)	Uttarkashi	2010	Post
693	Gyansu (Varuna Gaad)	Uttarkashi	2011	Post
694	Gyansu Bhatwari	Uttarkashi	2014	Pre
695	Gyansu Bhatwari	Uttarkashi	2016	Pre
696	Hitanu Kaidigaad Dunda	Uttarkashi	2012	Pre
697	Hitanu Kaidigaad Dunda	Uttarkashi	2014	Pre
698	Jakhol Saruktaal Mori	Uttarkashi	2014	Pre
699	Jaspur Tioth Kidyar Bhatwari	Uttarkashi	2014	Pre
700	Jaspur Tioth Kidyar Bhatwari	Uttarkashi	2016	Pre
701	JoshiYada (Indrawati river)	Uttarkashi	2010	Post
702	JoshiYada (Indrawati river)	Uttarkashi	2011	Pre
703	Joshiyara Indrawati Bhatwari	Uttarkashi	2014	Pre
704	Kharadi Bhetipani Naugaon	Uttarkashi	2014	Pre
705	Koti Yojana Purola	Uttarkashi	2014	Pre
706	Kyark Bandrani, Bhatwari Gaad Bhatwari	Uttarkashi	2014	Pre
707	Ladari Yojana Bidu Spring Bhatwari	Uttarkashi	2012	Pre
708	Mairana yojana Purola	Uttarkashi	2014	Pre
709	Manari Shilkur Gaad Bhatwari	Uttarkashi	2014	Pre
710	Manari Shilkur Gaad Bhatwari	Uttarkashi	2016	Pre

Sl No	Sites	Major Location	Year	Seasons
711	Matali Lingwana Dunda	Uttarkashi	2014	Pre
712	Naugaon (Kesarikhadd)	Uttarkashi	2011	Pre
713	Naugaon (Kesarikhadd)	Uttarkashi	2011	Post
714	Naugaon (Kesarikhadd)	Uttarkashi	2014	Pre
715	Naugaon, Naugaon Block	Uttarkashi	2012	Pre
716	Ponti Kameela Naugaon	Uttarkashi	2014	Pre
717	Purola (Kufara Khaad)	Uttarkashi	2010	Pre
718	Purola (Kufara Khaad)	Uttarkashi	2011	Pre
719	Purola (Kufara Khaad)	Uttarkashi	2011	Post
720	Purola (Kufara Khaad)	Uttarkashi	2014	Pre
721	Purola yojana Malagaad Purola	Uttarkashi	2012	Pre
722	Raithal Bhatwari Gaad Bhatwari	Uttarkashi	2014	Pre
723	Rama Spring Purola	Uttarkashi	2014	Pre
724	Saakri Market, Guimagaad Mori	Uttarkashi	2012	Pre
725	Shrikoat Padiyar chowk Chinyalisour	Uttarkashi	2012	Pre
726	Shrikoat Padiyar chowk Chinyalisour	Uttarkashi	2014	Pre
727	Thanki Bhanki Naugaon	Uttarkashi	2012	Pre
728	Thanki Bhanki Naugaon	Uttarkashi	2014	Pre
729	Udalka Shivani Dunda	Uttarkashi	2012	Pre
730	Udalka Shivani Dunda	Uttarkashi	2014	Pre
731	Upradi Muralthu Navgaon	Uttarkashi	2014	Pre
732	Uttarkashi (Assi ganga)	Uttarkashi	2010	Pre
733	Uttarkashi (Assi ganga)	Uttarkashi	2010	Post
734	Uttarkashi (Assi ganga)	Uttarkashi	2011	Pre
735	Uttarkashi (Assi ganga)	Uttarkashi	2011	Post
736	Bayla	Vikasnagar	2018	Pre
737	Bayla	Vikasnagar	2019	Post

Escherichia coli (*E. coli*) is the most common bacteria of fecal coliform members and it is found in the intestinal tract of humans or other warm-blooded animals. The presence of *E.coli* is also an indicator of pathogenic organisms in the water bodies. There can be various possible sources of *E.coli* that contaminate surface water includes septic leachate, municipal wastewater discharge, agricultural or storm runoff, wildlife populations or nonpoint sources of human and animal waste (An et al., 2002).

The major concentration of *E. coli* was observed in a few specific pockets of Uttrakhand during 2018-2019. It is mostly located in the river basin along the Devprayag to Rudraprayag (Figure 31). This area is developing very fast due to tourism activities and this causes major reasons for septic leachate, municipal wastewater discharge in this area. Spatiotemporal mapping identifies this is a common problem in this specific area and is listed in Table 17.

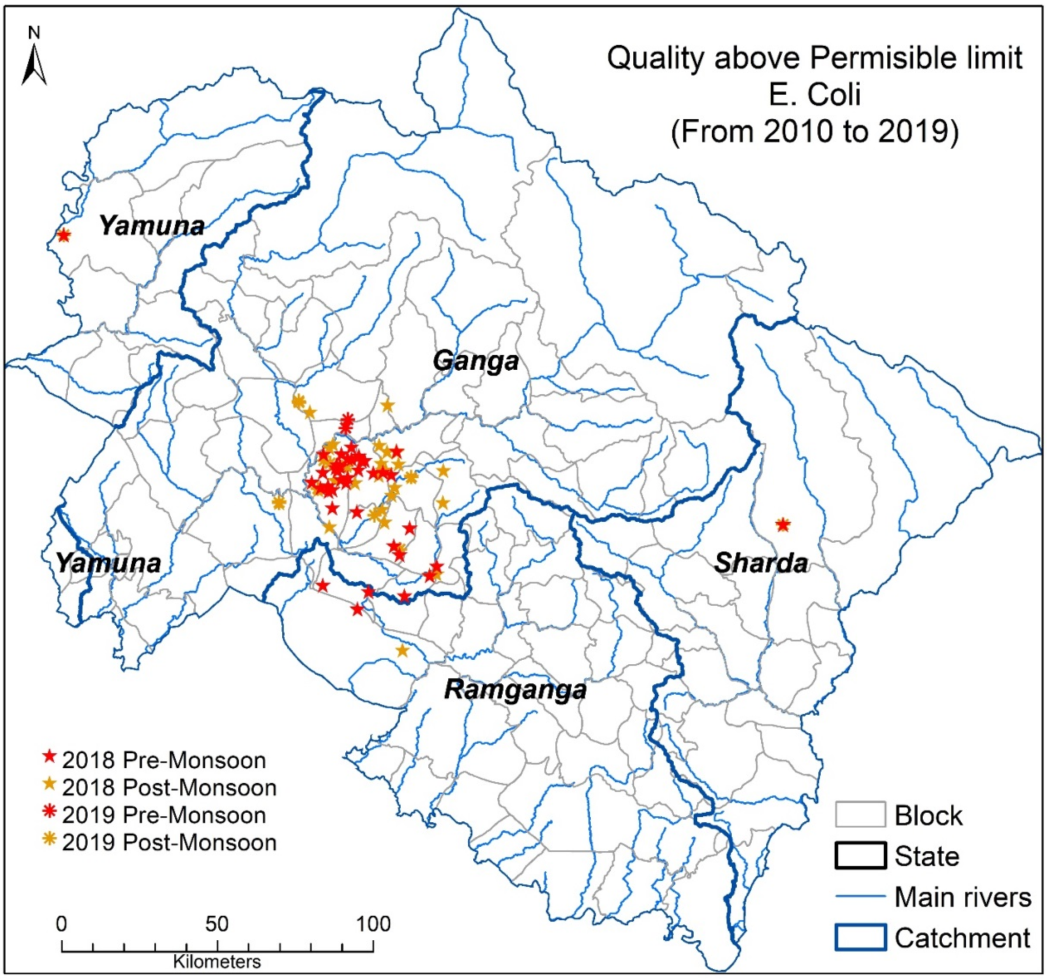


Figure 30: Location of water sources exceeding total coliform above the permissible limit

Table 17: Sites above the permissible limit of *E. coli*

Sl No	Sites	Major Location	Year	Seasons
1	Chauki Garh Source Nam Tok	Devprayag	2019	Pre
2	Chiledi Gram Punchayat Source Scheme	Devprayag	2018	Post
3	Dugadda Garh Source Nam Tok	Devprayag	2019	Pre
4	Koti Tyunsa Source Scheme	Devprayag	2018	Post
5	Ratoli Source Scheme	Devprayag	2019	Post
6	Sondhar Hand Pump Scheme	Devprayag	2019	Post
7	Byella Talla sheme	Kotdwara	2018	Pre
8	Naini Bnar	Pithoragarh	2019	Post
9	Aagroda	Satpuli	2018	Pre
10	Aasgadh	Satpuli	2018	Pre
11	Bilkhet	Satpuli	2018	Pre
12	Chora	Satpuli	2018	Post
13	Deval	Satpuli	2018	Pre
14	Ghandiyal	Satpuli	2019	Post
15	Ghodiyan	Satpuli	2019	Post
16	Jakhola	Satpuli	2018	Post
17	Jakhola	Satpuli	2019	Post
18	Jaspur	Satpuli	2018	Post
19	Khandda malla	Satpuli	2018	Pre
20	Kota	Satpuli	2018	Post
21	Lodhli	Satpuli	2018	Post
22	Majkot	Satpuli	2018	Pre

Sl No	Sites	Major Location	Year	Seasons
23	Molthi Bichli	Satpuli	2018	Post
24	Patal gunth	Satpuli	2018	Pre
25	Pinkot	Satpuli	2018	Post
26	Pokhra	Satpuli	2018	Pre
27	Rolli	Satpuli	2018	Post
28	Suralgaun	Satpuli	2018	Pre
29	Athul Talla	Srinagar	2018	Post
30	Baherakhal	Srinagar	2018	Post
31	Barsila	Srinagar	2018	Pre
32	Bhati Gaun	Srinagar	2018	Post
33	Bhawan	Srinagar	2018	Pre
34	Bisald	Srinagar	2018	Pre
35	Charakot	Srinagar	2019	Post
36	Chaupadiyo Pakha	Srinagar	2018	Post
37	Chetud	Srinagar	2019	Post
38	Dhancaura	Srinagar	2018	Pre
39	Dhari Gaun	Srinagar	2018	Post
40	Dobh Srikot	Srinagar	2018	Pre
41	Falswadi	Srinagar	2018	Pre
42	Gadoli	Srinagar	2018	Pre
43	Gahad lagga Bhutoli	Srinagar	2018	Post
44	Gahath Nakot	Srinagar	2018	Pre
45	Ghindabagi	Srinagar	2018	Pre
46	Girgaun	Srinagar	2018	Pre
47	Gobaniyon	Srinagar	2019	Pre
48	Gostu	Srinagar	2018	Post
49	Gwadigaad	Srinagar	2018	Post
50	Jamsali	Srinagar	2018	Post
51	Jitoli Maroda	Srinagar	2018	Post
52	Kandayi	Srinagar	2018	Post
53	Kandayi	Srinagar	2019	Post
54	Kandayi Talli	Srinagar	2018	Post
55	Kandola	Srinagar	2019	Post
56	Koltha	Srinagar	2018	Post
57	Kot	Srinagar	2018	Pre
58	Kotsada	Srinagar	2018	Pre
59	Kushli Singori	Srinagar	2018	Post
60	Molan	Srinagar	2018	Pre
61	Muchayali	Srinagar	2018	Post
62	Musoli	Srinagar	2018	Post
63	Nagoli	Srinagar	2018	Pre
64	Naugaun	Srinagar	2018	Post
65	Nishani	Srinagar	2018	Post
66	Niwada	Srinagar	2018	Pre
67	Palkot	Srinagar	2018	Post
68	Paniya	Srinagar	2018	Post
69	Pokhari masan Gaun	Srinagar	2018	Pre
70	Purmesi	Srinagar	2018	Pre
71	Revdi Talli	Srinagar	2018	Pre
72	Rigud	Srinagar	2018	Post
73	Rigud	Srinagar	2019	Post
74	Sarana	Srinagar	2018	Pre
75	Saud Maroda	Srinagar	2018	Pre
76	Seim	Srinagar	2018	Post
77	Sindi Jaskot	Srinagar	2018	Pre
78	Sirala	Srinagar	2018	Pre
79	Tamlag	Srinagar	2018	Pre
80	Thapliyal Gaun	Srinagar	2018	Pre

Sl No	Sites	Major Location	Year	Seasons
81	Uttarasu	Srinagar	2018	Pre
82	Viadgaun	Srinagar	2018	Pre
83	Vijay Nagar	Srinagar	2018	Pre
84	Bayla	Vikasnagar	2018	Pre
85	Bayla	Vikasnagar	2019	Post

The parameters above the permissible limits are identified in all four major basins Yamuna, Ganga, Ramgamga and Sarda in which there are fifteen sub-basins identified, where water quality parameters have exceeded in any of the years from 2010 to 2019. It varies from two to four parameters, which exceeded above permissible limits. 12 out of 15 sub-basins were identified with the presence of total coliform, whereas 6 out of 15 identified the presence of *E.coli*. Similarly, the permissible limit of Iron exceeded in 6 out of 15 sub-basins. Fluoride and Aluminium are also major parameters in the Uttarakhand, which exceeded above the permissible limit of drinking water in these sub-basins.

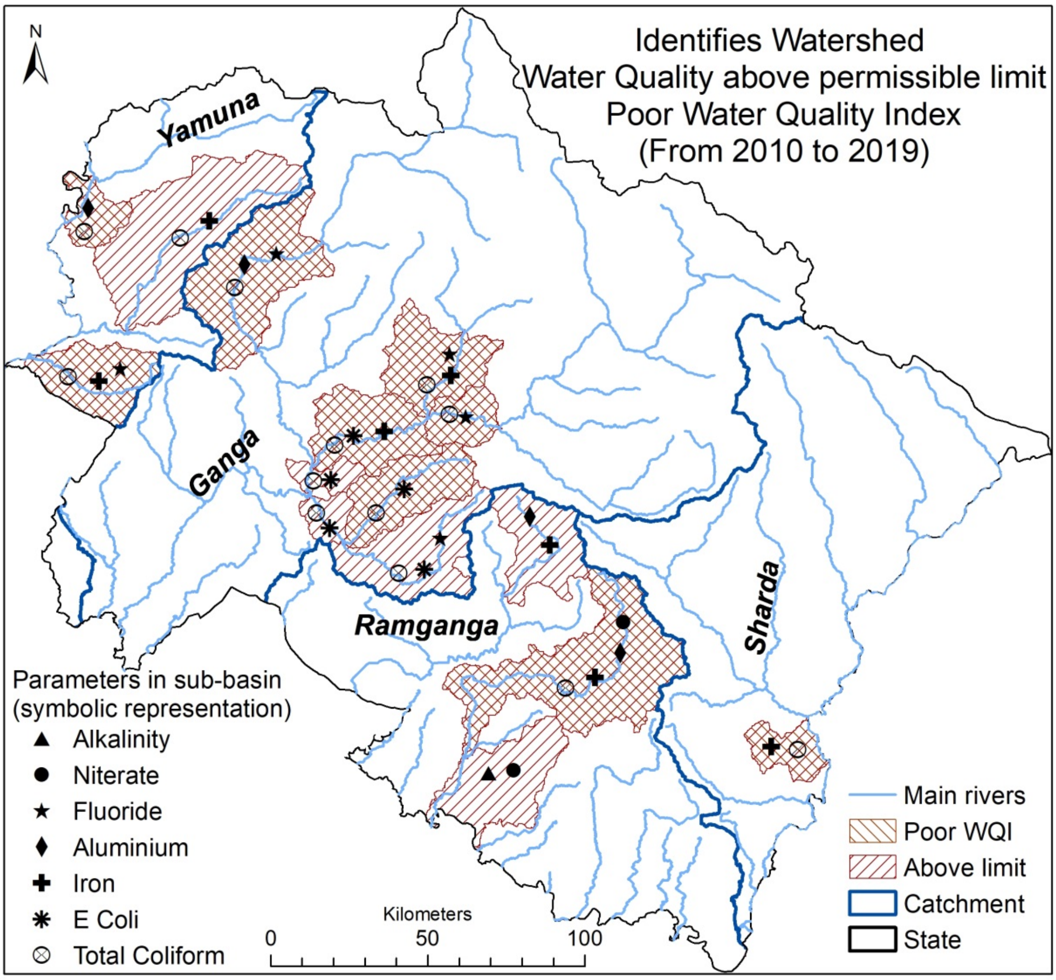


Figure 31: Identified sub-basins based on WQI and above the permissible limit

Finally, the eight sub-basins were selected based on a combination of WQI and parameters exceeding above the permissible limit of drinking water (Figure 32). One sub-basin consider based on only exceeding above the permissible limit of drinking water for aquifer augmentation for the sustainability of life. These nine sub-basins are hydrological and geological analyzed in the spatio-temporal domain.

(e)To prepare an action plan for aquifer augmentation and sustainability of life and livelihoods

Based on the behavioral aspect of types of water, WQI and parameters above the permissible limit nine sub-basins are hydrologically investigated using Mike21 and SWAT tool under the Graphical User Interface environment of GIS.

The precipitation and hydrological behavior over the study period (2010- 2019) and land cover change dynamics were captured in this section and finally concluded towards the aquifer augmentation and sustainability of life.

Land Use and Land Cover change dynamics

The land use land cover was prepared for two time periods 2010 (Figure 33) and 2019 (Figure 34) to evaluate the process in the change of land practices. 12 major classes were identified using visual classification and major classes like agriculture, forest, snow/ glacial area were validated with NRSC and FSI data sets.

Table 18: Various land use and land cover areas of Uttarakhand.

Sl No	Classes	Total Geographical area (in %)		
		2010	2019	Change (%)
1	Built-up	0.56	0.72	0.16
2	Cropped area	13.30	14.07	0.77
3	Fallow land	5.80	6.30	0.49
4	Forest land	45.80	45.44	-0.36
5	Forest blank	0.32	0.43	0.11
6	Alpine grassland	4.82	6.15	1.33
7	Scrubland	7.69	10.00	2.31
8	Barren land	6.87	1.51	-5.36
9	Sandy area	0.01	0.00	-0.01
10	Snow /Glacial area	13.38	13.83	0.45
11	Lake/ Reservoir	0.31	0.34	0.03
12	River	1.13	1.21	0.08
	Total	100.00	100.00	

There is an increase of built-up, agriculture and snow cover area from 2010 to 2019 and a decrease in forest land and barren area in the state (Table 18). Further, a matrix was prepared to evaluate the process of changes among the classes from 2010 to 2019.

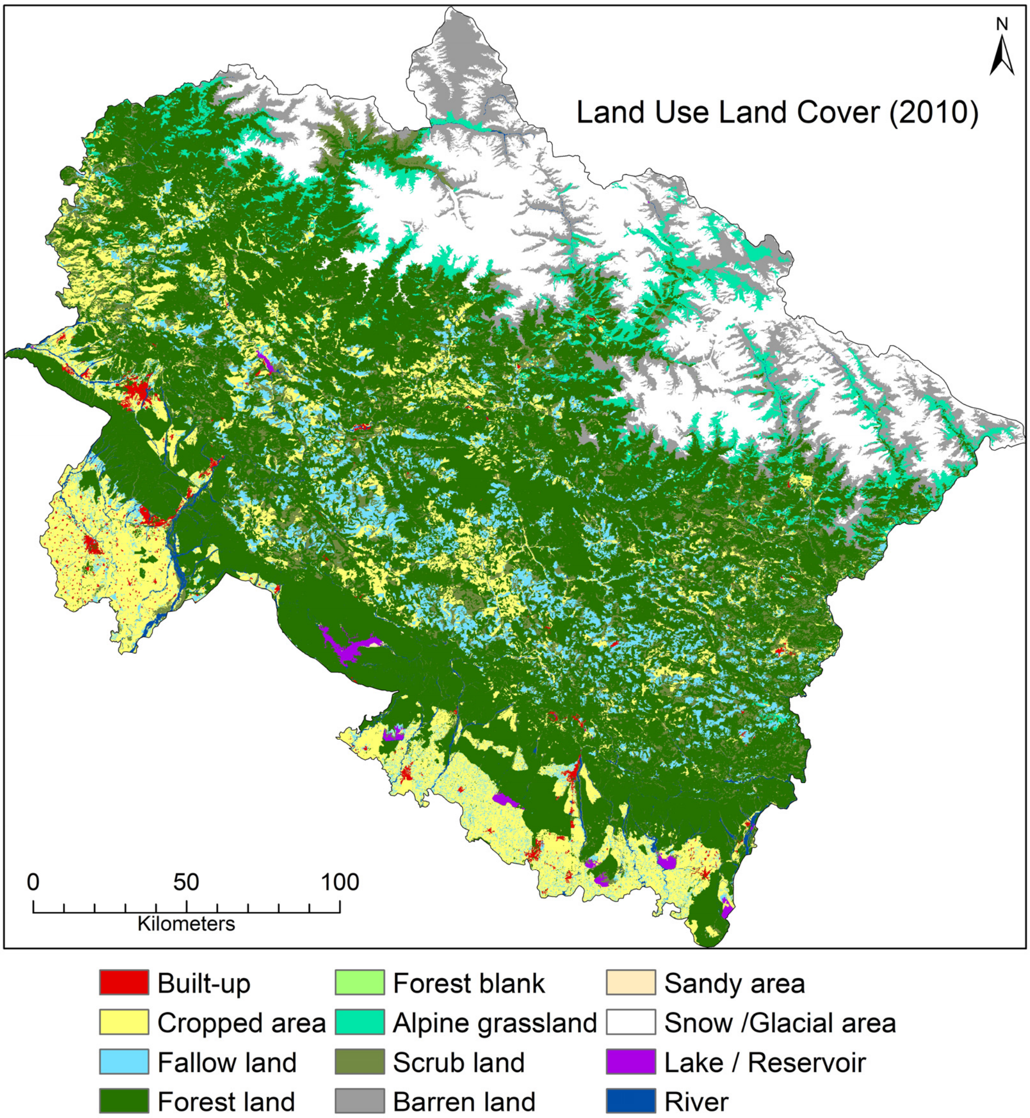


Figure 32: Land use land cover of 2010

It was observed that the agriculture, forest, scrubland, barren land, alpine grasses and snow cover area are highly dynamic within two periods of time from 2010 to 2019 (Table 19). Agriculture land was highly dynamic with fallow land, which is a very common phenomenon associated with agriculture practices and vice versa with fallow land. A few pockets of fallow land were converted to built-up land from 2010 to 2019. Forest land converted to forest blank and scrubland which is well documented by the Forest Survey of India. There is an increase in the forest blank which introduce in high surface runoff in hydrology. The alpine grasses have a natural exchange with snow cover area but in some of the area it was observed that alpine grasses are converted into manmade activities like agriculture and the built-up area which indicated the change in soil hydrological process and quality of the water altered by human activities, it could be due to tourism activities in the alpine region.

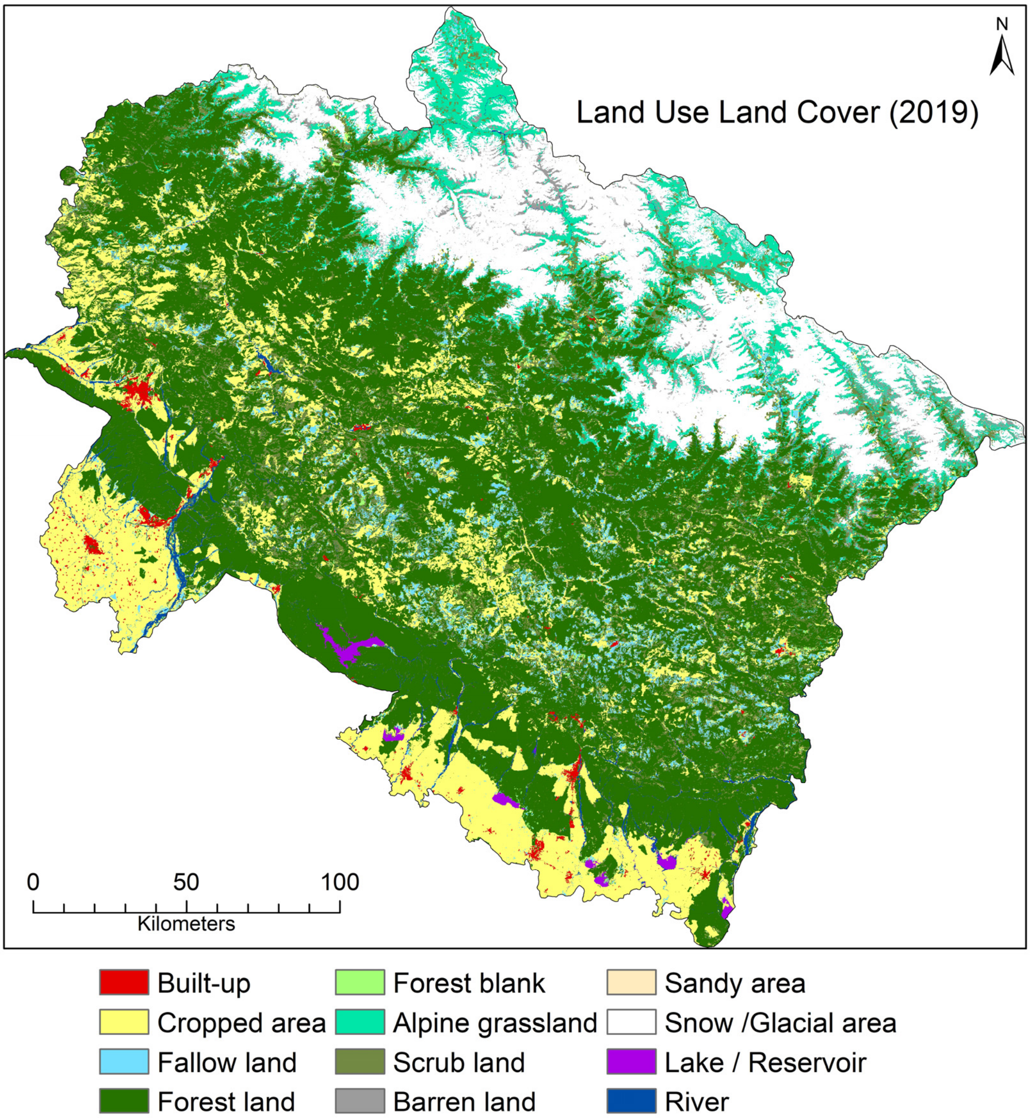


Figure 33: Land use land cover of 2010

Conversion of alpine grasses to scrubland reduces the surface runoff and during water quality analysis, less total coliform and turbidity was observed in those areas, where such dynamics occur from 2010 to 2019. Barren land was converted to the vegetated surface like agriculture, alpine grasses, scrubland, forest cover, which also reduce the surface runoff in those areas. This impact increases sub-surface and groundwater storage in the area. It also reduces the impact of high turbidity.

Table 19: Change in dynamics from 2010 to 2019

	Classes	2019 Built-up	Cropped area	Fallow land	Forest land	Forest blank	Alpine grass	Scrub land	Barren land	Sandy area	Snow / Glacial	Lake/ Reservoir	River	Total	Total (%)
2010	Built-up	298.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	298.7	0.6
	Cropped area	50.0	6355.9	676.9	0.0	0.0	11.7	0.0	0.2	0.0	0.1	2.2	26.9	7123.8	13.3
	Fallow land	22.8	759.8	2308.4	0.0	0.0	3.7	1.7	5.1	0.0	0.0	0.7	6.9	3109.2	5.8
	Forest land	0.0	0.0	0.0	22481.9	54.2	1.5	1811.2	9.6	0.4	14.1	9.0	157.5	24539.3	45.8
	Forest blank	0.0	0.0	0.0	0.0	172.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	172.6	0.3
	Alpine grass	0.1	112.5	140.6	218.0	0.6	817.1	802.8	26.4	0.0	462.0	0.0	2.7	2582.8	4.8
	Scrub land	3.7	163.7	104.1	1528.0	0.0	142.9	2083.8	1.3	0.1	50.8	8.0	33.7	4120.2	7.7
	Barren land	0.0	79.9	117.1	48.8	0.2	2024.2	511.6	608.9	0.0	289.3	0.0	2.9	3682.8	6.9
	Sandy area	0.0	0.5	0.9	0.5	0.0	0.0	1.4	0.0	1.0	0.0	2.6	0.1	6.9	0.0
	Snow /Glacial	0.0	13.7	9.6	17.9	0.4	288.3	90.1	157.9	0.0	6592.5	0.0	0.2	7170.4	13.4
	Lake/ Reservoir	0.2	1.3	1.3	5.5	0.1	0.0	0.8	0.0	0.0	0.1	145.6	12.1	167.0	0.3
	River	9.2	50.5	14.8	45.8	1.4	5.5	56.0	0.5	0.0	0.6	14.7	406.6	605.6	1.1
	Total	384.0	7537.7	3373.7	24346.4	229.5	3294.9	5359.5	809.8	1.4	7409.4	182.7	650.2	53579.3	100.0
	Total (%)	0.7	14.1	6.3	45.4	0.4	6.1	10.0	1.5	0.0	13.8	0.3	1.2	100.0	

Hydrological analysis

Base on previous section nine sub-basins (Figure 35) analyses under the hydrological process where water quality index is poor and parameters exceeded above the permissible limit of drinking water.

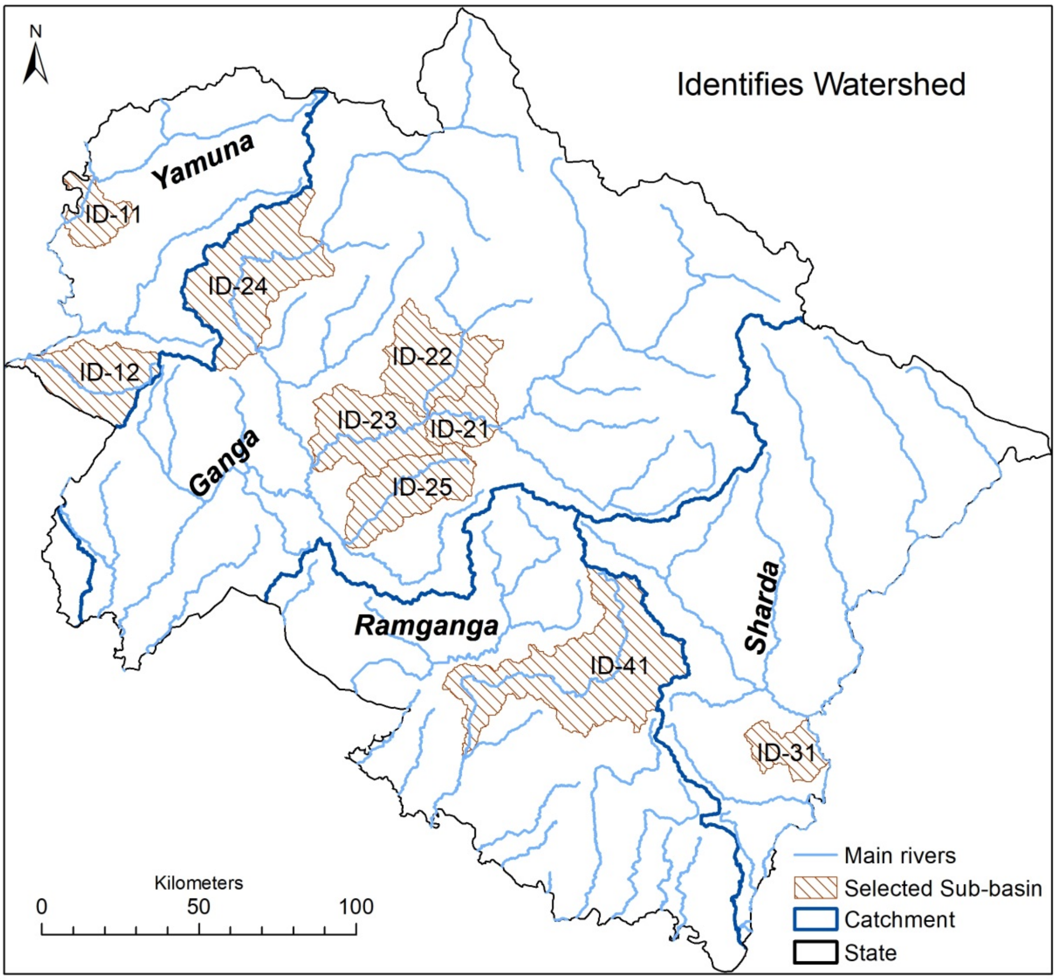


Figure 34: Selected sub-basins for hydrological assessment

In this section, the rainfall-runoff model was carried and the potential sub-surface and groundwater storage was identified for aquifer augmentation and sustainability of life in the future. The Mike-NAM model was used for total water balance and aquifer augmentation. Two sub-basin of the Yamuna basin, five sub-basin of the Ganga basin, one from the Sarda basin and one from the Ramganga basin was selected (Table 20). The average annual discharge (2009-18) of the sub-basin is ranging from 19 to 555 Cusec. The sub-basin 21, 23, 24 and 31 has a high discharge rate and this sub-basin was observed high turbidity and total coliform high. Sub-basin 41 was considered for high concentrations of aluminum and iron due to the geological characteristics of the area.

Table 20: Description of selected sub-basin

Sl No	Sub-Basin ID	Sub-basin	Basin	Outlet Location	Area (Sq Km)	Annual average Discharge (Cusec)
1	Sub-11	Tons	Yamuna	Sriya	309.83	95.53
2	Sub-12	Asan	Yamuna	Assan	713.48	33.79
3	Sub-21	Alaknanda	Ganga	Rudraprayag	340.04	345.55
4	Sub-22	Mandakini	Ganga	Rudraprayag	756.04	67.50
5	Sub-23	Alaknanda	Ganga	Devaprayag	778.16	436.46
6	Sub-24	Bhagirathi	Ganga	Jogiyara	1322.56	197.57
7	Sub-25	Nayar	Ganga	Mallethi	748.92	19.17
8	Sub-31	Part of Kali	Sarda	Naag	315.49	554.41
9	Sub-41	Ramganga	Ramganga	Ramnagar	1876.16	51.66

In the Yamuna basin, the Tons River has high discharge compared to the Asan River. The water quality of the Asan is poor due to the high concentration of pH, calcium, magnesium, iron and fluoride whereas turbidity and total coliform were the dominant factor of poor water quality in Tons River.

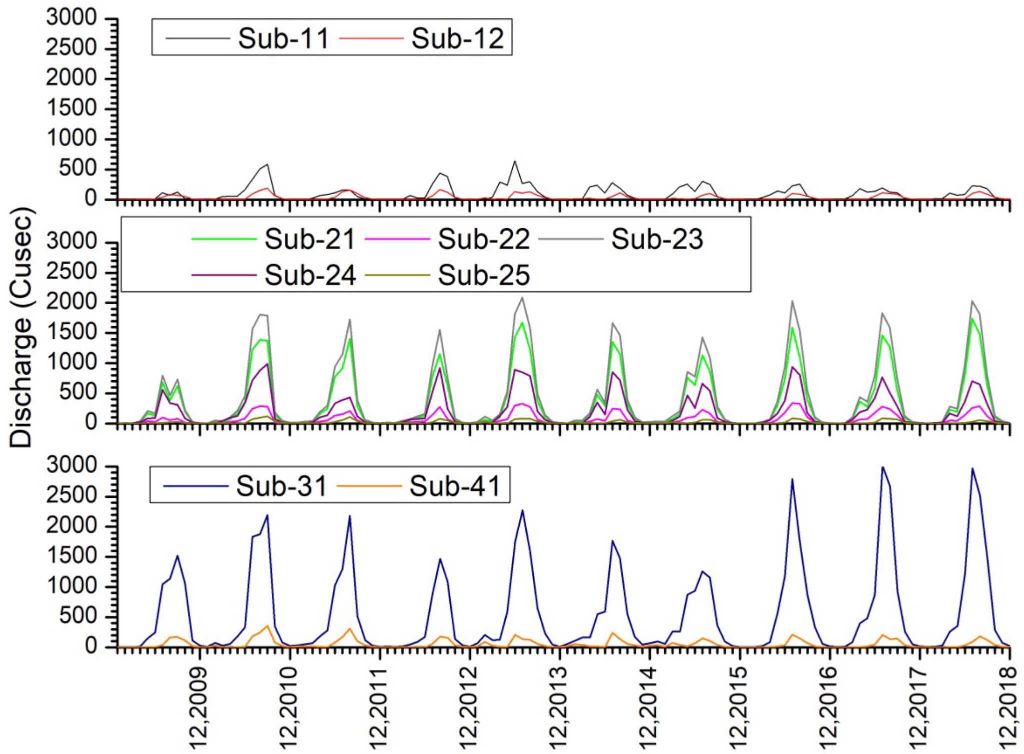


Figure 35: Temporal variations of discharge rate of selected sub-basins.

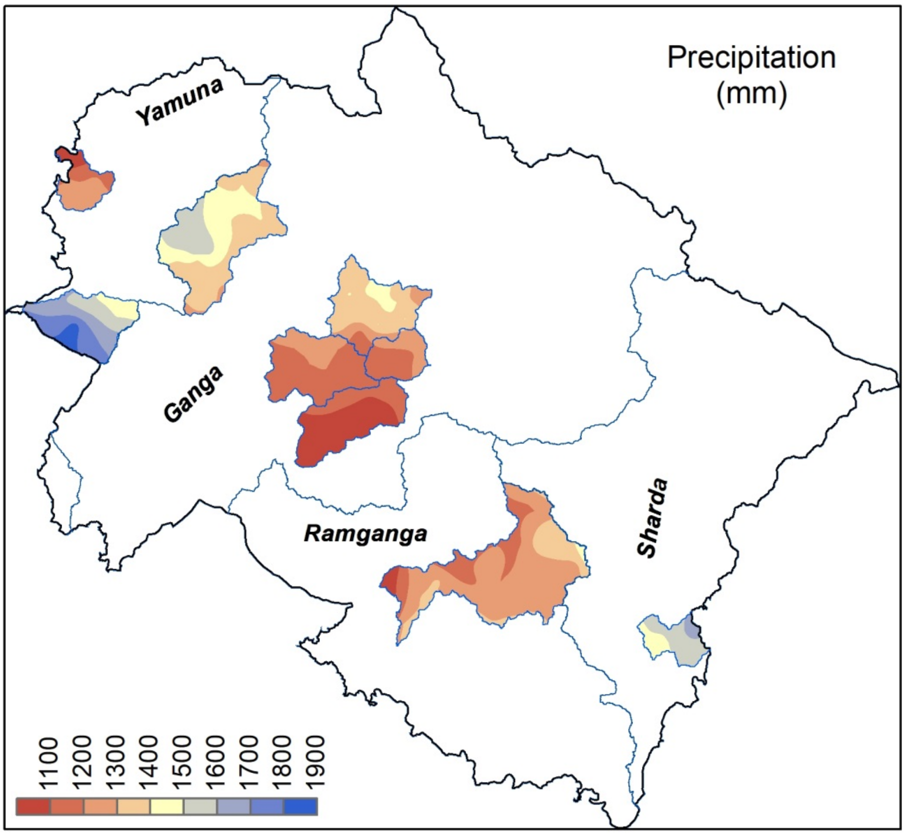
The total coliform and turbidity were high in 2012 and the same year's average discharge was also observed high in the Tons River (Figure 36) whereas the Asan River has fewer changes in their discharge rate.

Five sub-basins in the Ganga River were simulated under the rainfall-runoff model from 2009 to 2018 (Figure 36). In all the basin discharge rate was high in 2012 and 2018-19. During this period the total coliform and turbidity were high in quality of water. The second aspect from land use and land cover change dynamics, it was observed that area is the witness of the high level of land change dynamics. The large area was converted into agriculture and built-up from 2010 to 2019. This could be another reason for the high surface region. Due to urban growth and tourism activities in this region, the *E.coli* increased very high in the water system.

In the Ramganga River sub-basin the there is less variation of discharge over the period. This river system is poor water quality due to geological reasons. The various geo-genic induced materials the area is having element above the permissible limit. Iron and Aluminium are dominant in the local geology.

The discharge rate was high observed in the Kali River (Lohaghat) during 2012 and 2018-19. The total coliform and turbidity were also observed high in the same year (Figure 36). There is less urban development and tourism growth in this basin and *E.coli* was not detected in this sub-basin. The basin is also having poor quality of water due to Aluminium, Fluoride and Iron due to local geology.

Though maximum rainfall observed in the Asan river basin maximum runoff is observed in Alaknanda, Kali, Nayar and Bhagirathi (Figure 37) due to surface roughness and leading presence of a high concentration of total coliform. On the other side due to tourism activities, Alaknanda is highly contaminated with *E.coli*, whereas the presence of *E.coli* is negligible in Kali (Lohaghat section). This indicated that the physical and human processes together impacting the quality of the water in Uttarakhand. The physical process does not only cause poor water quality in the sub-basin but also affects other characterstics.



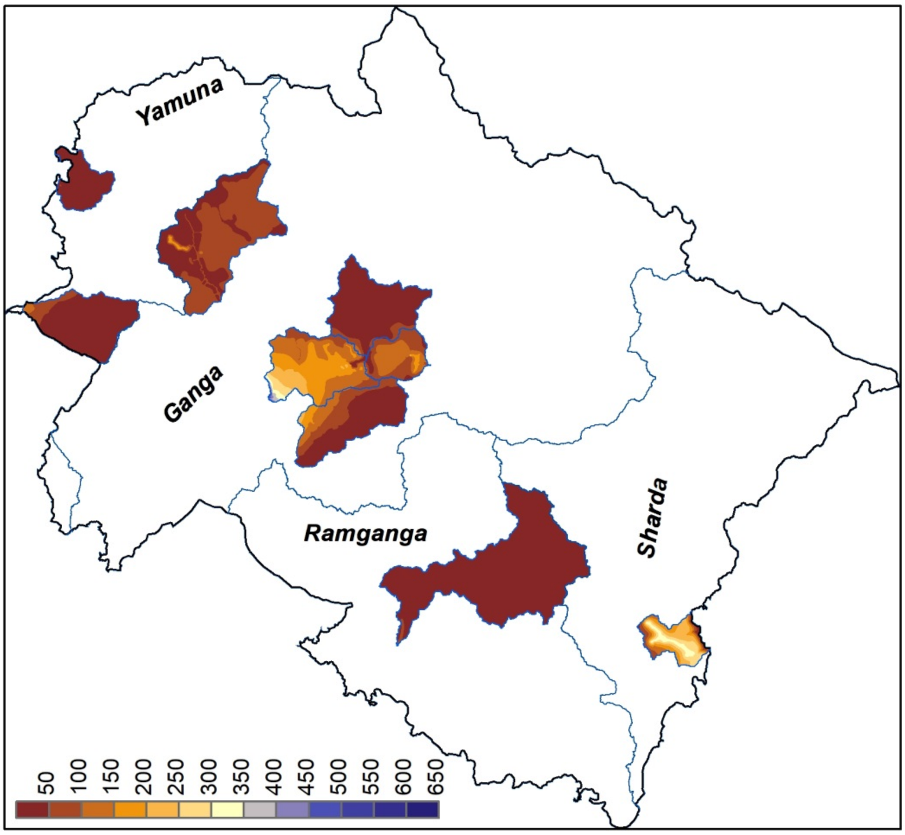


Figure 36: Spatial variations of rainfall and runoff of selected sub-basins

Aquifer augmentation

After the rainfall-runoff model, the study was conducted to evaluate the potential source of sub-surface and groundwater storage in the problematic sub-basin. Each sub-basin was divided into multiple small micro basins by a semi-distributed hydrological model. Each micro basin was evaluated with a hydrological response unit (HRU). The hydrological response unit is a function of three major parameters land cover practices, soil characteristics and slope in addition to meteorological behavior of the sub-basin.

Based on the Thiessen polygon approach, the entire sub-basin was grided into 100x100 meters of spatial resolution to generate outcomes of aquifer behaviours of the water cycle at three levels i.e surface, sub-surface (below the root zone) and groundwater. Surface water budget provides the available water over the surface in the form of runoff, lake and rivers; sub-surface level estimate the amount of water in the saturated and semi-saturated aquifer in the form of dug well / bore well or springs and last third layer provide the available water budget of groundwater aquifer in the form of deep bore well/tube well or fracture/fault springs.

The total amount of rainfall at each grid (100x100 n) was calculated to provide the available precipitation ranges in Cubic meter (CuM) of each sub-basin. The amount of water running over the surface; percolated to sub-surface and move to groundwater was estimated based on the hydrological response of the micro basin.

The highest precipitation amount observed Asan followed by Bhagirathi and Kali (Lohaghat section) sub-basin while the maximum surface water balance observed in Bhagirathi followed by Mandakini, Asan and Kali sub-basin (Figure 38).

Overall sub-surface and groundwater storage is highest in Asan followed by Kali, Ramganga and part of Bhagirathi sub-basin. This is providing the information on conjunctive use of surface and sub-surface sources for drinking purposes.

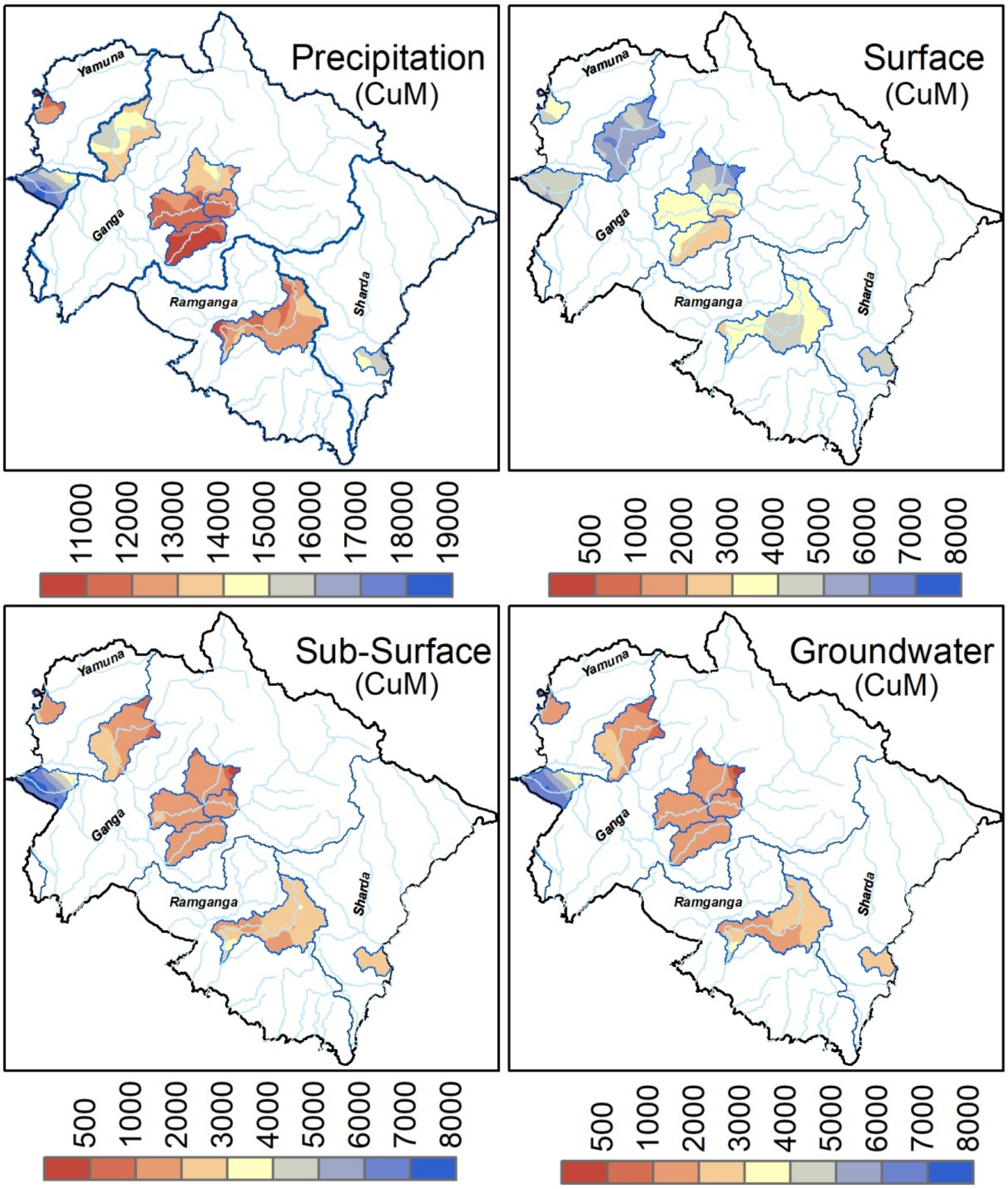


Figure 37: Water budget of the selected basins.

The total precipitation amount of water was stored at three vertical i.e surface layer, subsurface and groundwater about 22 to 56% (Figure 39) of total precipitation run over the surface with spatial variation depends on the hydrological response of the micro basins. There is the potential of sub-surface storage under the unsaturated zone below the root zone of the soil. This amount varies 2 to 48% of total precipitation and nearly the same amount can also move to groundwater for storage to aquifer system.

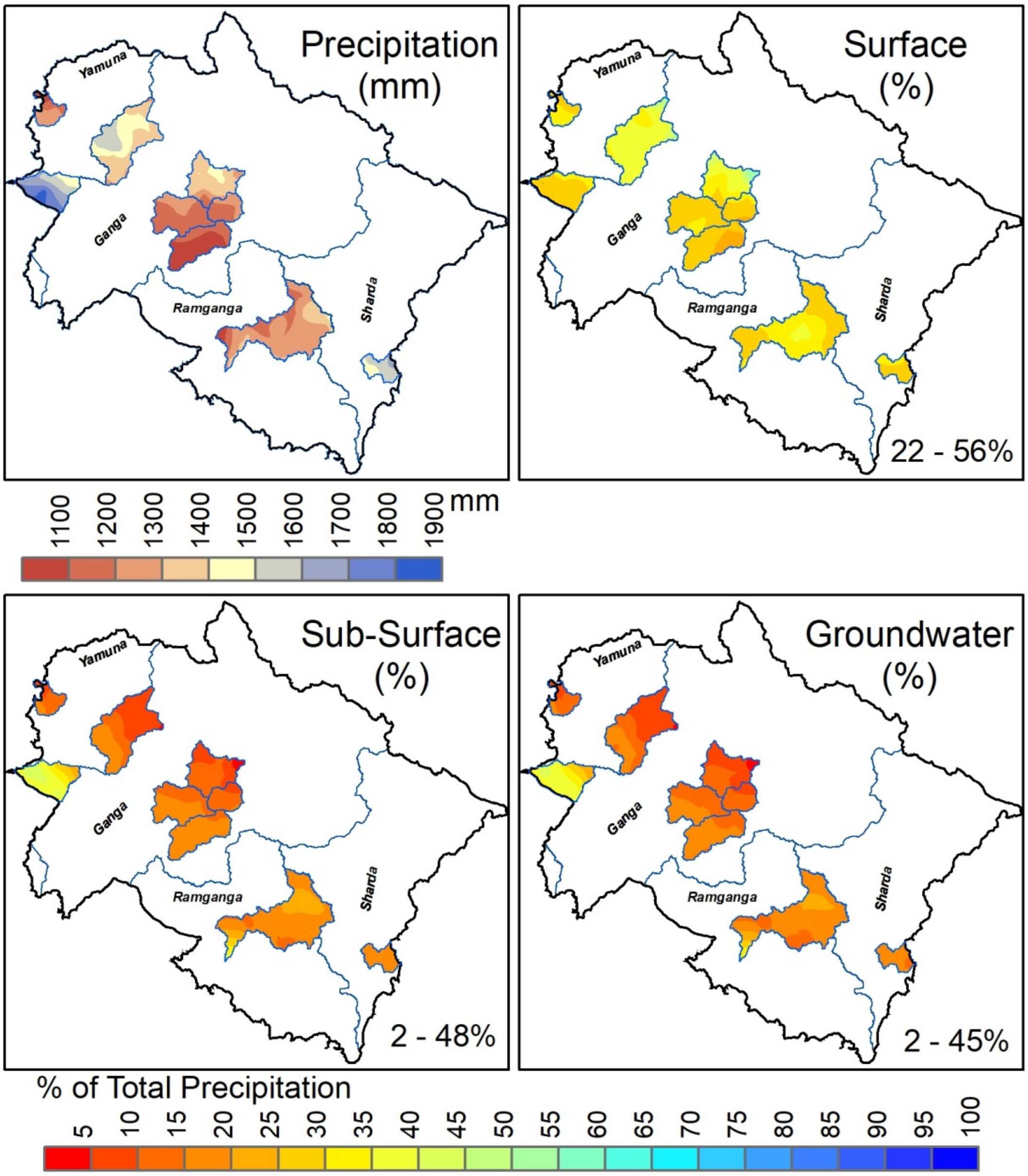
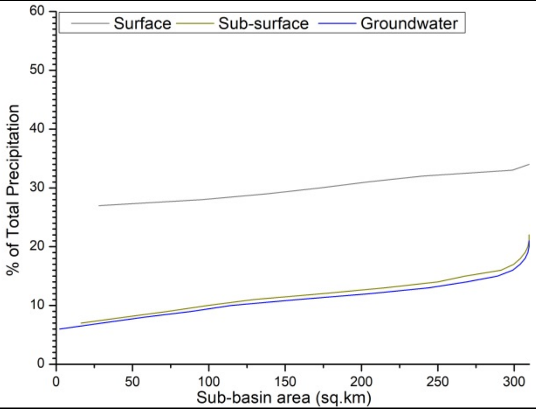


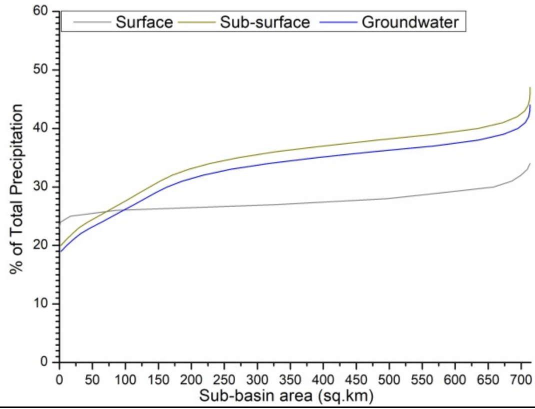
Figure 38: Contribution of water budget under three vertical layer in selected sub-basins

A hypsometric curve was created for each sub-basin to explore the potential area of groundwater recharge and taping the sub-surface aquifer at a local scale or sub-basin scale. The Tons rivers sub-basin (Sub-11) 100 sq.km area has the potential to store groundwater less than 10% of the precipitation and the remaining 209 sq. km area has the potential to store 10-20% of the total precipitation in the aquifer.

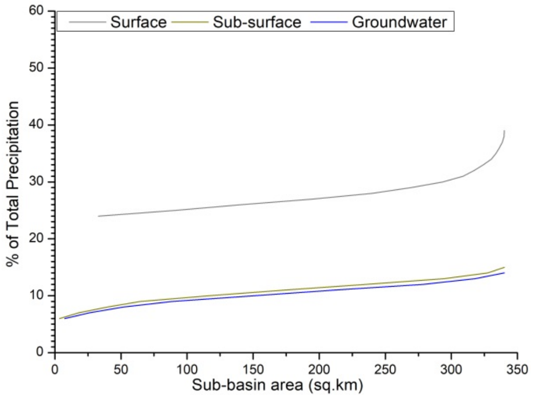
The Asan River sub-basin (Sub-12) has a very high potential of groundwater storage nearly 150 sq.km areas have a potential of 30% of total precipitation storage and nearly 550 sq km has a potential of 30 – 40% of total precipitation storage. Nearly 13 sq.km areas have above 40% precipitation storage in the basin.



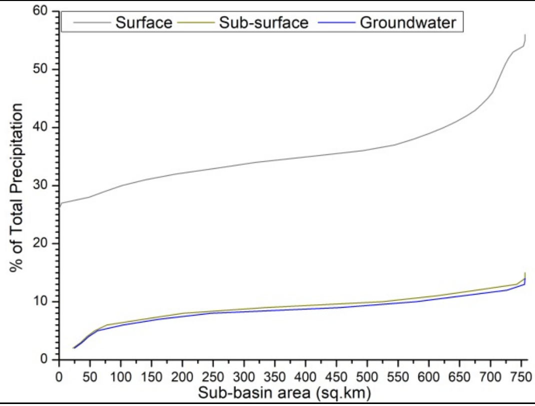
Tons (Sub-11)



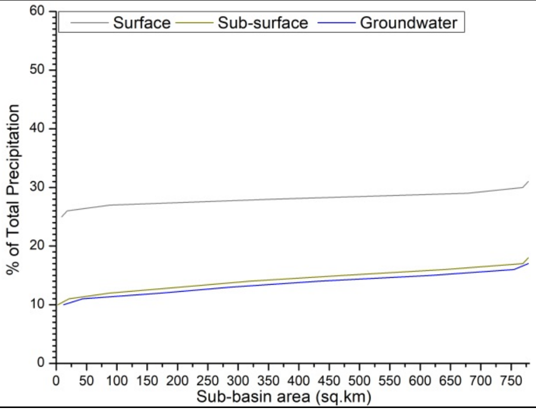
Asan (Sub-12)



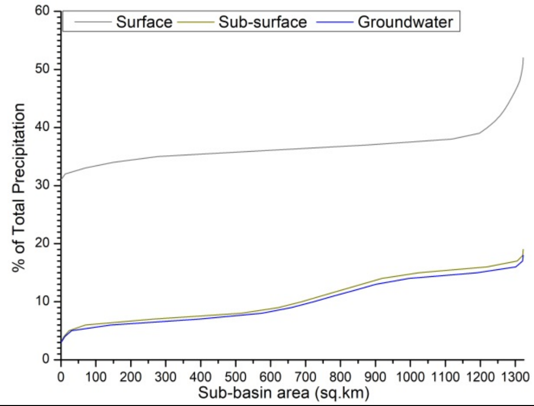
Alaknanda (Sub-21), at Rudraprayag



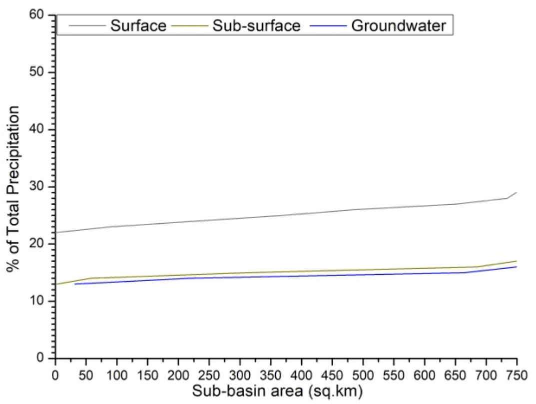
Mandakini (Sub-22) at Rudraprayag



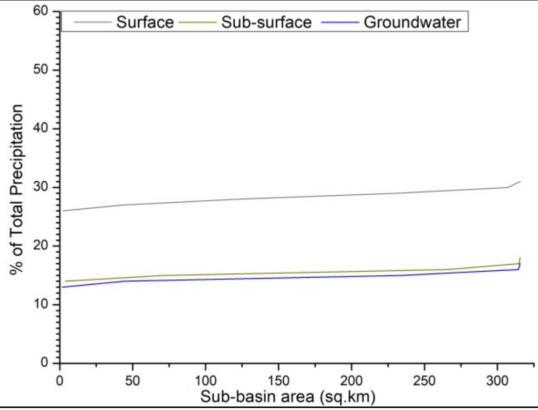
Alaknanda (Sub-23) at Devaprayag



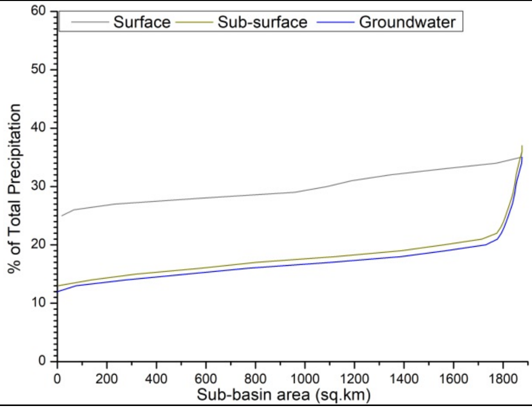
Bhagirathi (Sub-24) before Tehri dam



Nayar (Sub-25)



Part of Kali (Sub-31) for Lohaghat



Ramganga (Sub-41)

Figure 39: Aquifer augmentation of selected sub-basins

Asan sub-basin is highly contaminated by surface sources of drinking water due there local geology and the hydrological process concluded that this sub-basin can be replaced by groundwater sources of drinking water.

Alaknanda river sub-basin up to Rudraprayag (Sub-21) is cover 345 sq.km area. The 150 sq. km area has the potential to recharge up to 10% of total precipitation whereas the remaining 195 sq. km recharge with 10-15% of total precipitation. Alaknanda from Rudraprayag to Devprayag (Sub-23) covers 778 sq. km area and the entire area has the potential to recharge groundwater 10-16% of the total local precipitation.

Mandakini sub-basin (Sub-22) can be recharge with up to 10% of total precipitation covers a total geographical area of 575 sq. km and the remaining 181 sq. km have the potential to recharge 10-15% of the total precipitation.

Bhagirathi river sub-basin (Sub-25) before the Tehri dam is covered 1323 sq. km area. Nearly 750 sq. km area has the potential to recharge groundwater with 10% of the total precipitation and remaining have the potential to recharge the aquifer with 10-18% of the precipitation.

The entire Nayar river sub-basin (Sub-25) has the potential to recharge 13-16% of total precipitation, which covers 749 sq. km area. Similar in the case of the Lohaghat (Champawat) sub-basin which is part of the Kali river sub-basin (Sub-31), has the potential to store water in the aquifer with 13-16% of the total precipitation.

Ramganaga river sub-basin (Sub-41) has 1700 sq km area to recharge with 12-20% total precipitation and the remaining 176 sq km, is a very good aquifer, which has the potential to recharge 20-35% of total precipitation.

5. Conclusion

The utilization of advanced tools and techniques such as spatial models, geospatial tools, high-resolution remote sensing data and numerical hydrological model, the work on water quality issues of the Himalayan state of Uttarakhand is expected to serve the society sustainably living along the river basins. The study was ensuring the availability of sufficient quality drinking water to the communities in the representative selected sub-basin of the Uttarakhand the environmental aspects and human health.

The study carried 20 parameters of drinking water quality of surface sources namely pH, alkalinity, turbidity, total dissolved solids (TDS), chloride, fluoride, sulphate, nitrate, total hardness, calcium, magnesium, arsenic, copper, aluminium, manganese, iron, and coliform bacteria (i.e. total coliform and E coli) as per BIS 10500 (2012) as well as sodium and Potassium as per WHO.

The total numbers of 433 locations of the surface source of drinking water were collected from previous studies from 2010 to 2016 and then the gap area was assessed. Further 808 locations of the Uttarakhand water quality sampling surveyed were carried out during 2018 and 2019. All these sources were surface sources of drinking water. Uttarakhand Jal Sansthan provides drinking water through Gadhera, Spring, Nalkoop and Nadi from the states. In which more than 60% of drinking water is either Gadhera (streams) or Nadi (Rivers). This study focused on the surface source of drinking water and its quality issues. The study was conducted from 2010 to 2019 and two seasons pre and post-monsoon were considered.

Most of the sample depicts recharging water i.e Ca-Mg-HCO_3 type (type-1) and their sample value increase during the post-monsoon period, whereas Mg-HCO_3 samples increased due to sedimentation of the surface runoff though out the time series. The local geology caused Ca-Cl type (type-2), which is the dominant geology of limestone but has a seasonal impact on their occurrences.

Due to agriculture extension and use of fertilizer in the present time (2018 and 2019), NaCl type (type- 3) water increased in recent times, which is earlier not detected. This type of water increased during the pre-monsoon period and decrease during post-monsoon due to the impact of high surface runoff. The $NaHCO_3$ (type-4) of water is due to the rapid weathering process either extreme rainfall event or high construction activities along the river course.

Overall the Uttarakhand water type is sifting towards type-3 and type-4, which indicated a high impact of human activities and the effect of climate change on water quality for 10 years. The concluding remarks are that there should be intensive water resources planning on those areas, where water type is either NaCl or $NaHCO_3$. These areas are highly vulnerable to the cost of human health. These selected pockets or locations can be treated separately.

Water Quality Index (WQI) was prepared using 17 drinking water quality parameters in which 10 parameters were physio-chemical, two were based on biological driven and five were heavy metals. Total coliform is a major parameter that makes entire Uttarakhand under poor water quality index. The turbidity and pH are the two most important variables for poor water quality index. Rest other parameters do not impact greatly over the water quality index, *E.Coli* in those areas, where human interface is high, makes water quality poor. The concentration becomes high during the lean period of rainfall (pre-monsoon) but after the rainy season or post-monsoon period, the same location was reclassified under the better order of WQI value throughout the study period from 2010 to 2019. Eight sub-basins were identified under very poor and bad water quality index due above mentioned parameters.

The parameters above permissible limits were analyzed throughout the state, under four major basin Yamuna, Ganga, Ramgamga and Sarda with fifteen sub-basins identified, where water quality parameters are exceeded during any of the years from 2010 to 2019. It varies from two to four parameters, which exceeded the above permissible limit. The presence of total coliform, presence of *E.coli*, Fluoride, Iron and Aluminium are major parameters in the Uttarakhand, which exceeded above the permissible limits of drinking water. The total coliform is a major parameter that makes entire Uttarakhand under poor water quality index. The concentration becomes high during the lean period of rainfall (pre-monsoon) but after the rainy season or post-monsoon period, the same location was reclassified under the better order of WQI value throughout the study period from 2010 to 2019. A total of fifteen sub-basins are identified, where the drinking water quality parameters exceeded the above permissible limit.

Land use land cover dynamics explained and concluded that due to the increase of agriculture land and built-up area with the development of tourism activities is increasing the total coliform and *E.coli* in the surface water. Change from alpine grass to scrubland reduces the surface runoff and while water quality analysis, it was observed that due to this conversion less total coliform and turbidity was observed in those areas from 2010 to 2019. Conversion of Barren land to the vegetated surface like agriculture, alpine grasses, scrubland, forest cover reduces the surface runoff as well as increases sub-surface and groundwater storage in the area. It also reduces the impact of high turbidity. There should be a proper sewerage system in those pockets, where tourism developed is high to reduce the *E.coli* and total coliform.

This hydrological rainfall-runoff modeling in the Spatio-temporal domain concluded with the following decision:

- Higher the discharge rate introduces high turbidity in the water quality on temporal scale analysis.
- Total coliform increase with the increase of discharge rate in water quality and their amount varies at the temporal scale of discharge rate.
- E.coli is associated with total coliform but it is more associated with urban and tourism development in the hills and directly link with poor sewerage systems in tourism location.
- Most important the local geological characteristics is a major governing factor in some of the sub-basin that requires a different action plan for the sustainability of life

Aquifer augmentation analysis concluded that there is a possibility of conjunctive use of surface and sub-surface sources of water for drinking purposes. The 2 to 48% of total precipitation can be stored and harvested though springs recharge and use for drinking water. This is a good source for potable water for local communities. A detailed plan to be implemented o those areas where the sub-surface source can be tapped through springs rejuvenation, The poor water quality due to turbidity, total coliform and *E.coli* can be removed through the natural source of water recharge. Those areas where natural recharge is possible in the root zone can be tapped through either bore well or springs.

These are also a possibility of 2 to 45% of water to recharge groundwater at a local scale. In this area deep bore well and fracture/fault springs can be used for drinking water. There is limited scope for harvesting deep groundwater at a large scale but local scale based on geological condition deep aquifer can also be utilized. The minimum precipitation of the state is runoff (nearly 40-60%) from the state. It is important to tap water in terms of recharging of sub-surface and groundwater aquifers.

Hypsometric analysis of the aquifer potential of each basin concluded that there is great potential to harvest and recharge the ground for rural and urban drinking water for long term sustainability. Asan river sub-basin has very high potential as aquifer augmentation followed by the Ramganga river basin. The Tons rivers sub-basin and Bhagirathi river sub-basin have slightly low potential as compared to Asan and Ranganga River.

Nayar river sub-basin and Kali river sub-basin have the potential to recharge 13-16% of the precipitation whereas the least potential was identified in the Alaknanda river sub-basin and Mandakini river sub-basin to recharge groundwater with 10-15% of total precipitation.

The surface source of drinking water is already monitored and maintained by Uttarakhand Jal Sansthan and evaluated periodically through the NABL accredited lab. Small commands areas need to be developed based on topographic constrain to store surface water for the local level in remote villages, where accessibility is a major issue.

The findings of the water quality modeling studies, to be presented in the form of technical guidelines especially for hilly terrain conditions, are likely to help in finding solutions to the identified problems either directly or indirectly. The work is linked with various basic and applied sciences, including space technology, hydrology, chemistry, environment and human health that would surely provide a platform to disseminate the knowledge to various departments/agencies, and ministries linked with water resources.

Moreover, experts/ researchers/ engineers/ water managers/ academicians/ policy planners/ young scientists working in this area will be benefitted from the results of the study. The following respective departments/ stakeholders of Uttarakhand would surely take a decision based on the outcomes presented in the study:

- Department of Public and Health
- Department of Water Resources,
- Uttarakhand Jal Sansthan
- Department of Environment and Forest
- Department of Science and Technology (state level)

6. Meetings and Trainings

Milestones achieved of the project

a. ***Initial phase (1st year):*** All milestones for first year as described in the project proposal were achieved.

b. ***Middle phase-(2nd year):*** All milestones for second year as described in the project proposal were achieved.

c. ***Final Phase (3rd year):*** All milestones for third year as described in the project proposal were achieved. Further, the following were conducted:

Evaluation and monitoring of progress:

Regular workshops & meetings were held between the collaborating parties of the project
Intermediate project report was submitted, yearly.
The project fellow participated in the 2nd Himachal Pradesh Science Congress from 20 to 21st November, 2017. An oral presentation on the topic entitled "**Utilization of geospatial technologies to assess and enhance water quality in Uttarakhand**" and one poster presentation on the topic entitled "**Seasonal assessment of drinking water quality in schools of Kumaon region of Himalayan State of Uttarakhand**" were presented.
The review meeting with all collaborating partners of projects was held on 30th January, 2018 at UCOST, Dehradun. Dr. D. P. Uniyal (Principal Investigator of the Project) UCOST, had given an overview of the project and put up the agenda before the board, consisting of the following:

(a) Project progress presentation by PI and Co PI's.

(b) To discuss the future action plan for field work and Knowledge sharing of the project between UCOST, TERI university, DAV (PG) College Dehradun and Uttarakhand Jal Sansthan, Dehradun.

(c) To discuss the capacity building training of project staff on Remote Sensing and Geographical Information System at lab of TERI University, future action plan, field work, gap areas and knowledge sharing of the project between all three centers. In this review meeting all PI, Co PI's and project fellows discussed the progress of the projects and brief knowledge on data base type used in the project, GIS and remote sensing technology.

After detail discussion, the following points were decided:-

Dr. D. P. Uniyal, suggested revisiting gap and re evaluation of water quality in gap areas which will be identified through secondary data. The mutual capacity building of research fellows with Dr. Vinay Sinha, which included training programme and provision of soft copies of training manuals, was also discussed. He also proposed a stakeholders meeting to be organized in the month of March. The beneficiaries were identified and the objectives of the meeting were discussed. The objectives included impact of the project on the beneficiaries, correlation of water quality with livelihood and generation of performa on socio economic basis.

Dr. Vinay Shankar Prasad Sinha, Associate Professor, TERI University discussed his objectives of the project and also focused on type of database required and brain stormed on the type of equipment used in project. Discussion on water quality data assimilation and processing, creation of basin and drainage network and transect map, model setup and calibration. Identification of gap areas and state action plan on climate changes of Uttarakhand, through secondary research was required. He suggested to be carried out semi-annual meetings and give opportunity to have awareness on the GIS and RS at lab of TERI University.

Dr. Prashant Singh, Co- PI DAV (PG) College, Dehradun assured to provide previous project's data which were needed by TERI University to assist better in the modeling of the hydrological data. He also discussed kit training, field testing kit training programs held in Tehri and Lacchiwala region as well and said through previous project studies find gap identification, state action plan of rainfall and climate change. After his entire requirement we will have a data on gap areas as secondary data.

Dr. Prasoon Joshi, Associate Fellow, TERI University, New Delhi, an expert on water resource management and geo-spatial and remote sensing techniques gave us brief introduction on remote sensing technology. He gave a workshop on writing research papers and citation index.

Indian Institute of Remote Sensing Indian Space Research Organization Department of Space, Government of India 4, Kalidas Road, Dehradun -248001 announced a one day IIRS meet on 27/02/2018. Project fellow participated in the meet on "IIRS USER INTERACTION MEET' with the theme 'IIRS-Academia Partnership for Geospatial Applications'.

The main objectives of the meet were:

Interface with Academic institute for enhancing the geospatial applications in the country vis-à-vis the role of IIRS. Interaction with partners of IIRS distance learning programme for further strengthening the programme.

Understand and explore new opportunities with user organization in government, non-government and private sectors on the capacity building requirements.

Appraise the user ministers/stakeholders departments and geospatial community on recent advances in geospatial technologies and applications vis-a-vis IIRS role in capacity building and research.

Interaction with geospatial industry on the current and future requirements and explore the placement opportunities for IIRS students and collaborative research.

The meet provided a platform to share the experiences of user ministers/stakeholders, geospatial community, and the IIRS faculty and to explore the potential areas for capacity building and joint research. The IUIM-2018 focused on ‘IIRS- Academia Partnership for Geospatial Applications”.

The programme included deliberations on recent advances in geospatial technologies and their applications, requirements of user organizations (government, non- government and private sectors), issues of capacity building, industry requirements, placement opportunities and feedback on IIRS capacity building and research programme and trends in geospatial technologies and applications and presentation given by IIRS/ISRO, academia, industry, user organization and focused interaction. IUIM included plenary sessions and lectures.

After the entire presentation panel discussed remarks by panelists and open discussion were also held. An exhibition was also organized during the meet for the benefit of user/stakeholders, academia, students etc. to showcase training and education opportunities at IIRS and current research initiatives and output of IIRS faculty and students.

A meeting was held on 30th January 2018, at Vigyan Dham, Uttarakhand State Council for Science and Technology. All PI and Co PI’s decided a hand on training for junior research fellows and had the hands on training at Water Analysis Laboratory (Uttarakhand Jal Sansthan (UJS) Dehradun) to have knowledge to understand the water testing techniques.

The training period was from 16th March 2018 to 26th March 2018 in which research fellow visited Uttrakhand Jal Sansthan Laboratory under the supervision of Dr. Prashant Singh, Dr. Vikas Kandari, Dr. Ravinder Aswal and Mrs. Snigdha. It is NABL accredited lab for water quality testing. APHA and BIS 10500 2012 are used as standards for the water quality parameters. Total of 19 water quality physico-chemical and microbial parameters were being tested there.

A manual was provided to study the summary of the water quality parameters, selection of methods to be used in their analysis, collection of samples and the procedures undertaken to test these parameters. Principles behind the instruments used were elaborated by the supervisors. Procedures learnt during the training period for chemical analysis were digital titration method, electrometric method, spectro-photometric method, and colorimetric method and HACH methods.

A total of 11 samples were tested for their water quality. Out of which 7 samples were tested for fluoride, nitrate and sulphate, 2 samples were tested for total hardness, pH, total dissolved solids and turbidity. Digestion of remaining water samples was done and they were tested for copper, iron, aluminium and manganese metals.

Various library consultations were also attended by the junior research fellows at various esteemed institutions like Wildlife Institute of India (Dehradun), Forest Research Institute (Dehradun), Indian Institute of Remote Sensing (Dehradun) and Uttarakhand State Council for Science and Technology (Dehradun), which will benefit them at a broader spectrum.

The project fellow participated in three days workshop which was organized at hotel Pearl Avenue, Dehradun “Training on Water Safety and Security of the Village Water Sanitation Committee (VWSC) Members “from 15th -17th March 2019.

The chief specialist Professor A. Majumdar, School of Water Resource engineering, Jadavpur University, Er. S. K. Sharma, Chief General Manager UJS, Dr. Vinay Sinha, TERI University New Delhi and Professor Prashant Singh, DAV PG College, Dehradun addressed the first day of workshop.

They discussed the condition and capacities of the water resources of the two selected gram panchayats (Ghena) District Tehri Garhwal and Gram Panchayat (Lachchiwala) District Dehradun.

On the second and the third day of workshop, field inspection along with the testing of water sample was conducted at the respective Gram Panchayat.

All the villagers were given training over the testing of various water quality parameters using field testing kit. A field testing kit was provided to each Gram Panchayat so that they could conduct a regular and periodic check over various catchments at committee level.

It was a capacity building workshop on water safety and security under Development of Water Quality Monitoring and Surveillance Mode in Selected areas of Uttarakhand.

A scheduled meeting was held on 18th March 2019 at UCOST. All the PI, CO-PI’s and project staff members have attended the meeting. Dr. D. P. Uniyal Senior Joint Director /Project Investigator of the project, UCOST had given an overview of the project and put up the agenda before the board consisting of following –

Project progress presentation by PI and co-PI, to discuss the future action plan for field work and to discuss the capacity building training of project staff on GIS and RS at lab of TERI University.

Dr .Prashant Singh Co-PI D.A.V.PG College after wards discuss the work progress reports and his future propose action plans.

Dr. Vinay Shankar Prasad Sinha, Associate Professor TERI University discussed his objectives of project. Time series analysis of quality of water for the entries state of Uttarakhand, Comparative analysis of the water quality of surface as well as ground water for different basin and to forecast the change or concentration of water of different water quality parameter.

7. Glimpses' of the Project Activity

8. Publication of the Project

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Preliminary Study on Geospatial Techniques to assess and enhance water Quality of Uttarakhand, India

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Abstract

Uttarakhand being a mountainous state having maximum area under forest cover, about 65% and provides large amount of freshwater river for Ganga basin where habitation and agriculture are dominant. The rising demand of drinking water due to population growth also leads to the water scarcity in the terms of availability of quality drinking water. Contamination mentioned by Central Pollution Control Board (CPCB), 2009 and low per capita availability of quality drinking water reported by Department of Science and Technology (Government of India), 2010-2015, are the key issues of the state. To understand the availability of safe drinking water it is necessary to understand the overall hydrology of the basin in a spatial domain. The utilization of advance tools and techniques such as spatial models, geo statistical tools, high resolution remote sensing data and numerical hydrological model in the present study will enhance and ensure the water quality issue of Himalayan state of Uttarakhand which is expected to serve the society living along the river basin as well as in mountainous systems. The study will ensure the availability of sufficient quality drinking water to the communities in the selected watershed of each districts, considering the environmental aspects and human health while assessing 26 water quality parameters like color, odour,taste, turbidity, pH, total hardness, iron, chloride, chlorine, fluoride, total dissolved solids, calcium, magnesium, copper ,manganese, sulphate, nitrate, phenolic compound, arsenic, cadmium, lead, zinc, chromium, alkalinity and coliform bacteria etc. and also provide feasible solution of sustainable availability of water. Geospatial water quality and quantity model help to find out the spatio-temporal analysis of contamination and particles movement in the watersheds. Modern geo statistical simulation algorithms can produce multiple subsurface realizations that are in agreement with the conceptual geological models. The quality modeling and monitoring will help in providing portable surface and ground waters to the citizens.

Keywords: ***Hydrology, Water quality, Geospatial models***

Introduction

Over exploitation of our water resources resulting in the use of poor quality and quantity of water for drinking especially in water stressed zones, which through food cycle enters in to human and animals, causing increased risk of various diseases as per as low per capita availability in rural and urban areas. Moreover, direct surface, subsurface and ground waters are still the main source of drinking water in rural areas and few cities of India. Over extraction and inadequate recharge is quite a common problem. Of course poor people have tended to suffer the greatest health burden from inadequate and poor quality water supplies (Chiang and Kinzelbach,1998) and as a result of poor health, have been unable to escape from the cycle of poverty and waterborne diseases. The key characteristic of the freshwater resources is their uneven distribution and variability with respect to time and space. The challenges being faced by water resource managers for any given location are a unique combination of mainly physical, cultural and engineering factors. It seems rationalized that effective mitigation measures are needed to cope up with climate change along with an adaptive strategy. Innovations in institutional arrangements and management structures are a necessary precondition for tackling the problems of management of supply of good quality and adequate quantity of water for its citizens. Waste

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and inadequate management of water are the main culprits behind growing problems, particularly in poverty-ridden regions.

To understand the availability of safe drinking water it is necessary to understand the overall hydrology of the basin in a spatial domain (Brown and Matlock, 2011).With the rising demand of drinking water due to population growth leads to the water scarcity on terms of availability of safe drinking water. The magnitude of the water deficit must be returned into the system in order to sustain the balance between available water and water demand. Water resource supplies using the Water Stress Indicator recognizes environmental water requirements as an important parameter of available freshwater (Asheesh and Mohamed. 2003; Brown and Matlock, 2011). Over the years, rising population, growing industrialization and expanding agriculture have pushed up the demand for water. Water quality (Carr and Neary, 2010) decides the extent to which it can be used for the purpose. Thus, quality and quantity aspects of water need to be evaluated thoroughly to meet the ever increasing needs of water for different uses especially for drinking as well as agricultural uses.

Uttarakhand provides large amount of fresh river water for major part of the Ganga basin where habitation and agriculture are dominant. Contamination mentioned (CPCB, 2009) by Central Pollution Control Board (CPCB) and low per capita water availability (DST, 2015) reported by Department of Science and Technology, Delhi is the two key issues of this state. Contamination of water resources has become a major threat to human security particularly in developing countries like India. In fact, water quality problems are caused by pollution and over-exploitation. Both human and natural activities can changes the physical, chemical, and biological characteristics of water and will have specific ramifications for health of humans and ecosystems. It is the need of the hour to understand surface and groundwater resource potential in respect to aquifers through Geospatial techniques. Geospatial water quality and quantity models help to find out the spatio-temporal analysis of contamination and particle movement in the watershed. Modern geo-statistical simulation algorithms can produce multiple subsurface realizations that are in agreement with conceptual geological models and statistical rock physics can be used to map these realizations into physical properties that are sensed by the geophysical or hydro-geological data (Linde *et al.,* 2015). The quality modeling and monitoring help in providing potable surface and ground waters to the citizens, there should be comprehensive study of natural environment, human dimension and management practices under upstream downstream linkage. These linkages will be possible in a very effective manner if planning and action plan are based on geospatial environment. The geospatial environment will study the entire components of linkages with geographical coordinate location and their spatial association. This project is the extension of earlier projects funded by the Department of Science and Technology (Government of India), in which all 13 districts water quality primary data was generated. In the present study, under the project "Modelling for Enhancing Water Quality in Uttarakhand using Geospatial Technology" funded by the Department of Science and Technology (Government of India), the primary data in the previous projects and in the gap areas, may be incorporated in Remote Sensing and Geographical Information System platform to develop a model.

Materials and Methods

Present study was initiated in the month of July 2017 with an objective to create a Hydro-geo spatial model of Uttarakhand using geospatial tools and techniques to target hot spot zones and take a decision to resolve the problems of water quality in various districts in collaboration with Uttarakhand Council for Science and Technology, Dehradun.The. The Energy and Resources Institute, Delhi and Dayananda Anglo Vedic (PG) College, Dehradun.The. The present paper is hypothesis of study for improving drinking water quality and quantity by the utilization of remote sensing and geographical information system techniques. The primary data was already generated in all 13 districts viz; Dehradun, Haridwar, Pauri, Tehri, Chamoli, Uttarkashi, Rudraprayag, Nainital, Almora, Pithoragarh, Bageshwar, Champawat and Udham Singh Nagar under the project of water surveillance.

In the present study, Geo-spatial techniques and tools were selected for the modeling of water

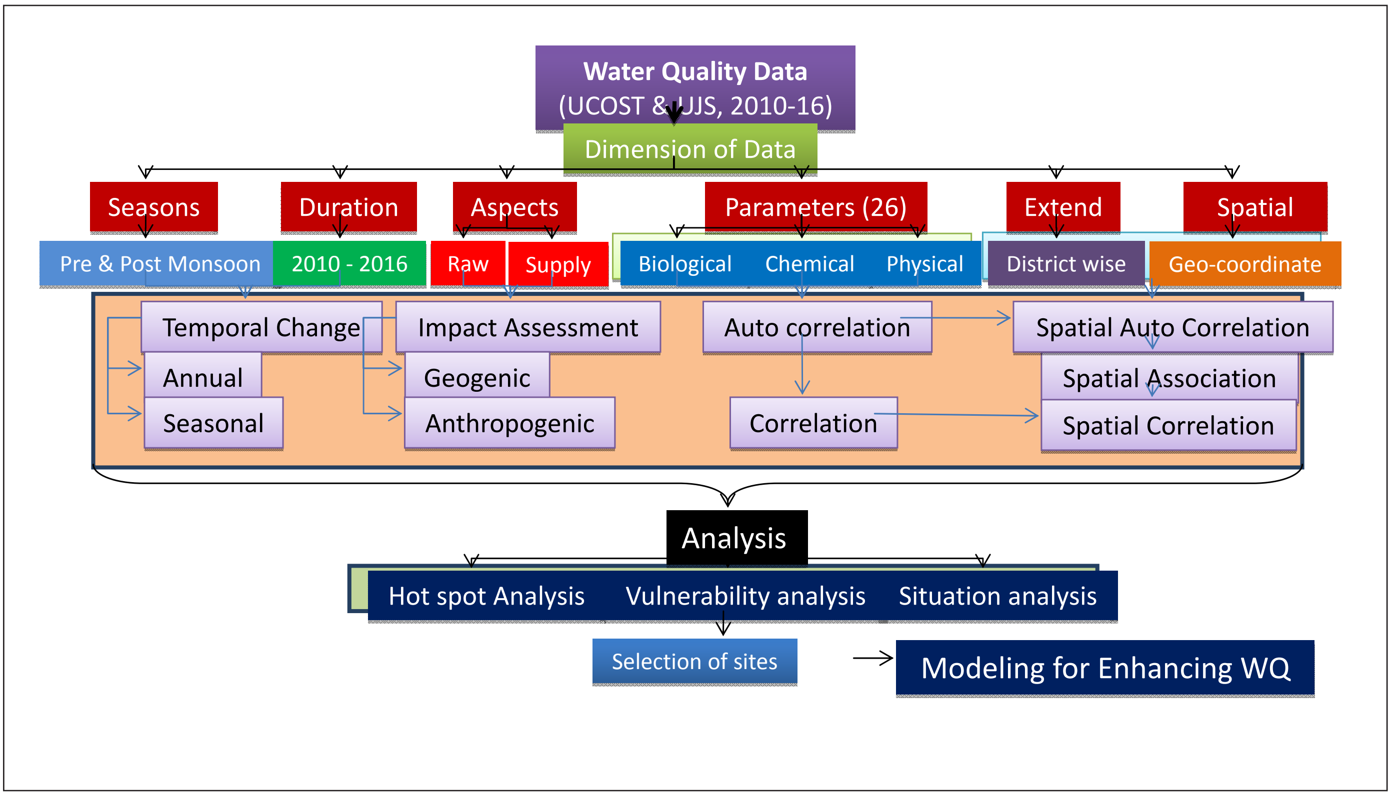

Fig.1 Method adopted to develop a hydro-geological model

quality in all 13 Districts of the state. The Geo-spatial techniques will centralized to target the hot spot zone and take a decision to resolve the problems of water quality stress in the Uttarakhand with Sustainability of environment. The parameters viz., Water quality assessment, Water quality index, Stress index, Social issues, Geo-statistical analysis of poor water quality, aquifer dynamics were selected for the development of water atlas of the Uttarakhand state. To study the water level at various hydro-geo morphological units of the watershed during pre-monsoon and post monsoon seasons, the water level indicator was selected to measure from the various open wells / tube wells using. It was also cleared in the present study, the samples will be collected based on stratified random sampling and number of sites selected based on area of micro watersheds.

It was also cleared in the approach and methodology of study that, the collected water samples will assessed to determine the water quality, its vulnerability index and stress index. GALDIT' methodology was selected to determine the Groundwater vulnerability index. In GALDIT methodology, it is a ranking system, consists three main parts: weights, ranges and rating used to map the groundwater vulnerability index using GIS. Each GALDIT parameter has been assigned a relative weight ranging from 1 to 4 based on standardized method. Groundwater vulnerability index is computed by multiplying the value attributed to each parameter (rating) with its relative GALDIT weight and then adding all six products. Higher the GALDIT score more the aquifer is vulnerable (http://www.aprh).

G- Groundwater occurrence (aquifer type: unconfined, confined or leaky confined)

A- Aquifer hydraulic conductivity

L- Height of groundwater level above mean sea level

D- Distance from shore (distance inland, perpendicular from shoreline)

I- Impact of existing status of seawater intrusion in area

T- Thickness of aquifer being mapped

Groundwater Vulnerability Index = $1\times G + 3\times A + 4\times L + 2\times D + 1\times I + 2\times T$

Each sites of water quality will be tested through vulnerability index and will see how society is affected by their score. A detailed temporal dynamics of each quality parameters will be evaluated through geo-spatial model to find out the temporal change throughout in spatial distribution. This help to assess the causes and affect of each quality parameters in terms of pattern and dynamics. A depth field investigation survey was also selected out in different part of towns and surrounding rural area depending on the various water sources to determine the Social and economic response of people and different sectors in regard to poor water quality. The approaches were selected in this study will helpful to develop the sustainable spatial water to remove poor water quality availability in hilly areas especially in Himalayan state Uttarakhand.

Results and Discussion

A comprehensive understanding of water quality, as a key issue, will provide the knowledge and solution to society, water resource engineers, planners, environmentalist, agriculturist and academia essential in precision agriculture and drinking purpose. Modeling of natural drinking water resources of Uttarakhand through Geospatial techniques will provide a feasible solution of sustainable water availability in hilly terrain conditions of Himalayan region that amounts to sustainable practice of water retention in an urban and peri urban surroundings, rural background that manifests as watershed model, satellite data of high spatial resolution is required for image interpretation for various thematic layers LULC, soil map, geomorphology, geology, hydro-geomorphology and drainage mapping. This high spatial resolution data is used to prepare a geospatial model which will suggest decentralized inflow of water in the urban areas through various means like rainwater harvesting, perched water harvesting for urban and surrounding rural areas for long retention of water and long sustainable water cycle. To understand the availability of safe drinking water it is necessary to understand the overall hydrology of the basin in a spatial domain.

The utilization of advance tools and techniques such as spatial models, geo statistical tools, high resolution remote sensing data and numerical hydrological model in the present study will enhance and ensure the water quality issue of Himalayan state of Uttarakhand which is expected to serve the society living along the river basin as well as in mountainous systems. The study will ensure the availability of sufficient quality drinking water to the communities in the selected watershed of each districts, considering the environmental aspects and human health while assessing 26 water quality parameters like color, odour,taste, turbidity, pH, total hardness, iron, chloride, chlorine, fluoride, total dissolved solids, calcium, magnesium, copper ,manganese, sulphate, nitrate, phenolic compound, arsenic, cadmium, lead, zinc, chromium, alkalinity and coliform bacteria etc. and also provide feasible solution of sustainable availability of water.

Geospatial water quality and quantity model help to find out the spatio-temporal analysis of contamination and particles movement in the watersheds. Modern geo statistical simulation algorithms can produce multiple subsurface realizations that are in agreement with the conceptual geological models. The quality modeling and monitoring will help in providing portable surface and ground waters. Evapo-transpiration and percolation can be accessed through spatial model tool like Soil and Water Assessment Tools (SWAT) and used for simulating the impact of land cover practices on the peizometer wells in the area.Few hydro-geological characteristics like hydraulic conductivity, transmissivity, storage parameters and effective porosity will be quantified with observed lithology and geology data. Once the water quality study is completed the geospatial mapping of water quality and stress index will be performed using GIS environment. Water quality vulnerability index will provide knowledge of regional disparities to any water user for proposing any technology and policies. Several other solution methods are available to solve the solute transport equation and they can be categorized as particle-based methods, finite-difference methods and a total-variation-diminishing (TVD) method. Briefly, the particle-based methods, Method of Characteristics (MOC), Modified Method of Characteristics (MMOC) and Hybrid Method of Characteristics (HMOC), solve the advection term using conventional particle tracking based on a mixed Eulerian–Lagrangian approach and solve the dispersion and source/sink mixing terms using finite difference (Zheng and Wang, 1999; Zheng, 1999). Regional level quantifications of water quality for preparing a water resource action plan at watershed level, to reach sufficient quality water at urban cluster and surrounding rural areas. A geospatial model is prepared for assessing aquifer and surface water dynamics for potential sites of surface water percolation (infiltration) in soil profiles and ground water recharge for local livelihood. It will assist in finding out the source and keep track of contamination through geospatial tools. An action plan is prepared for aquifer augmentation and sustainability of life and livelihoods of inhabitants of the studied area. The model which will be developed in this study can be replicated in other parts of the country those having same topography.

Conclusion

The overall outcome of the present study is expected to be fruitful for tackling the local environment degradation of water aiming at better human health and improved agricultural demand nearby urban cluster. The present study not only impart, the mapping of water sources, it will also provide the scientific solution to avail a potable per capita water demand in urban as well as rural area.\

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