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Climate Impacts on Water Resources in India

Environment and Health

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Water Science and Technology Library

Volume 95

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ISSN 0921-092X ISSN 1872-4663 (electronic)
Water Science and Technology Library
ISBN 978-3-030-51426-6 ISBN 978-3-030-51427-3 (eBook)
https://doi.org/10.1007/978-3-030-51427-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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About the Editors

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Professor Pandey also served as Guest Editor for two issues of *Journal of Hydrologic Engineering* (ASCE). He is Editor, *Indian Journal of Soil Conservation*. His laurels include Eminent Engineers Award-2015 given by the Institute of Engineers (India), Uttarakhand State Centre, DAAD scholarship and ASPEE scholarship. He was offered prestigious, JSPS Postdoctoral Fellowship for Foreign Researchers, Japan and BOYSCAST fellowship of DST, GOI. He is a Fellow member of (1). Institution of Engineers (India); (2). Indian Association of Hydrologists (IAH) and (3). Indian Water Resources Society (IWRS).

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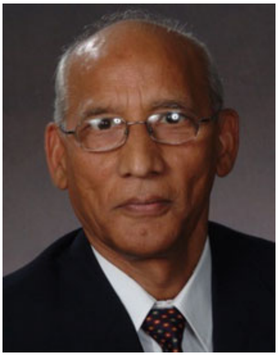
He has research & development experience of more than 40 years in different areas of Hydrology and Water Resources. He has an extensive experience in flood estimation, flood management, drought management, hydrological modeling, environmental impact assessment and climate change & its impact on water resources etc. He has published more than 316 research papers in the reputed International & National Journals, International & National Seminar/Symposia, Workshops, etc. He has received C.B.I.P. Medal, Institution of Engineers Certificate of merit, Union Ministry of Irrigation award and best Scientist award form from NIH, Roorkee. He guided three Ph.D. and 14 M.E. & M.Tech. and one M.Phil. dissertations. He has widely travelled abroad for different assignments.



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Chapter 1
Water and Health

Pramod Pandey and Michelle Soupir

Abstract The linkages between water and health are direct, and one major issue is to determine how extreme weather/climate change could potentially impact our water, and hence public and animal health. Although there are numerous studies indicating increase in transmission of vector-borne diseases due to warmer temperature, how climate change will have long-term effects on water borne pathogen, microbial contamination, and public health is yet known. To understand the possible impact of air temperature and stream flows on pathogen levels in ambient water, this analysis built on a previous study of Pandey (Modeling in-steram *E. coli* concentrations. Iowa State University, Ames, Iowa, 2012), which executed a multiple year study focused on testing pathogen indicator (*E. coli*) in various locations in a river in Iowa. In this watershed-scale study, agriculture land use is the dominant use with limited urban impacts. The results showed the cyclical pattern of pathogen indicator concentrations in the stream water column, which was associated with air temperature patterns in summer and winter seasons. While precise understanding of extreme weather effects on microbial water quality is yet to be known, these results substantiate the fact that an increase in air temperature coincided with the increase in waterborne pathogens in streams, which may increase public and animal health risks through exposure to microbial contamination in water.

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A. Pandey et al. (eds.), *Climate Impacts on Water Resources in India*, Water Science and Technology Library 95, https://doi.org/10.1007/978-3-030-51427-3_1

1.1 Introduction

Microbial contamination of ambient waters such as rivers and lakes are a serious issue (USEPA 2012). Increased pathogen and pathogen indicator concentrations such as *E. coli* in ambient water increases the risk to public and animal health. In the event of increasing frequencies of extreme weather, how water borne pathogen levels will change in ambient water bodies is a matter of a great concern. Due to the fact that many rivers and streams are used for recreational activities as well as for supplying drinking water for humans and animals, any level of increase in the microbial load in ambient water may increase the health risk, and deriving strategies to cope with the increased risk of microbial contamination in water resources requires improving our existing understanding of the possible impacts of global warming/climate change on waterborne pathogens. Previous studies (Vezzulli et al. 2012; Harvell et al. 2002) have shown that there is a possibility that increase in water temperature may accelerate the growth and transmission of bacteria.

Climate, increased temperature, and water contamination have been found to be associated with many previous global outbreaks (Harvell et al. 2002; Daszak et al. 2000; Epstein 1999). An example is the Rift Valley fever outbreaks in East Africa during the years 1950–1998. The rift valley fever is a viral disease, common in domesticated animals in sub-Saharan Africa. The origin of the outbreak was in sub-Saharan Africa, and in 1977, it spread in Egypt through infected livestock trade. Rift Valley fever can also pose potential health risks to humans. The direct and indirect contact with infected animals was the main reason for transmission from livestock to humans (WHO 2018). Multiple studies have been conducted to understand the potential linkages between climate and outbreaks, and in this case, the relationship between temperature and outbreaks was noticeable (Epstein 1999). During warm seasonal weather increased cased of the fever were observed. This pattern of increased fever cases and warm weather continued for many decades.

A similar phenomenon with regards to temperature and the spread of cholera in Bangladesh has also been reported. Cholera-like disease outbreaks became common in Bangladesh for many years, which initially started around 1992. Outbreak of cholera is linked with poor water quality. At the early stages, the outbreak was localized, the epidemic began in the southern part of Bangladesh, however, it spread throughout the country. Each year, more than 100,000 cases and 4500 deaths in Bangladesh are reported due to the cholera-like diseases (Islam et al. 2018). Disease outbreaks such as cholera and diarrheal diseases are mainly due to the microbial contaminated water exposure, unsafe drinking water and lack of basic hygiene (Pandey et al. 2014; Islam et al. 2018). Improving access to safe water has profound impacts on reducing the public health risks. The long-term analysis of weather pattern and cholera outbreaks in Bangladesh signifies the linkages between the outbreaks and warm temperature. Specifically, the increase in Ocean water temperature is linked with cholera outbreaks in Bangladesh (Colwell 1996).

Substantial studies have attempted to use the reported outbreaks and the climate data of an affected area to define the relationships between ambient conditions and disease outbreaks (Vezzulli et al. 2012; Harvell et al. 1999). When establishing the relationship between water quality and the disease outbreaks, often the lack of long-term water quality data is a major challenge. Having an improved knowledge of climate, and water borne contamination can certainly helps in planning and implementation of control measures to reduce the public and animal health risk (Pandey et al. 2014, 2016).

In this work, we attempted to use the data of waterborne pathogens/pathogen indicator, which was measured in streams over many years. In streams, *E. coli* is often used as an indicator organism to assess water quality. We quantified the *E. coli* concentrations in stream water, and retrieved the data of air temperature, stream flow, and precipitation of the study area to understand the linkages between waterborne pathogens and climate conditions.

1.2 Study Area

Figure 1.1 shows Squaw Creek Watershed, streams, and sampling locations. The Squaw Creek Watershed is located in Iowa, USA. University town (Ames) is located downstream of Squaw Creek (Fig. 1.2). Two sampling locations are shown in the figure, which were used for collecting the stream water samples, and monitoring the stream flow. The sampling location near the City of Ames records precipitation, and stream flow continuously. Water quality measurements were carried out between May 2009 and October 2011. In winter, the watershed receives snow, and the weather is cold, thus limiting sample collection during this period. During spring and summer, snow melt and rainfall results in increased stream flow conditions. In the watershed, agricultural land is the dominant use. Details of the watershed are given in Table 1.1. More than 87% of the soil in Iowa is fine sand and clay. Only 8% of the soil is sandy (NRCS 2011). Loamy Wisconsin glacial till and clayey deposits (loam, silt, clay loam) are the major soil type in Squaw Creek Watershed. The watershed data were retrieved from Natural Resources Geographic Information System (NRGIS).

1.3 Sample Collection and *E. coli* Enumeration

Water sampler (Forestry Suppliers Inc., Mississippi, U.S.) was used to collect water samples. Between sampling locations, the sampler was cleaned and rinsed to avoid possible cross contamination. To collect water samples, the sampler was lowered from the bridge to the center of the stream. Each stream sample was collected from the top layer (top 12 cm). After collection of samples, all stream water samples were transported and stored at 4 °C prior to analysis. Samples were analysed within 24 h of sample collections. Standard modified mTEC agar and membrane filtration technique (EPA, method 1603) was used for enumerating *E. coli* (pathogen indicator) concentrations in water (APHA 1999).

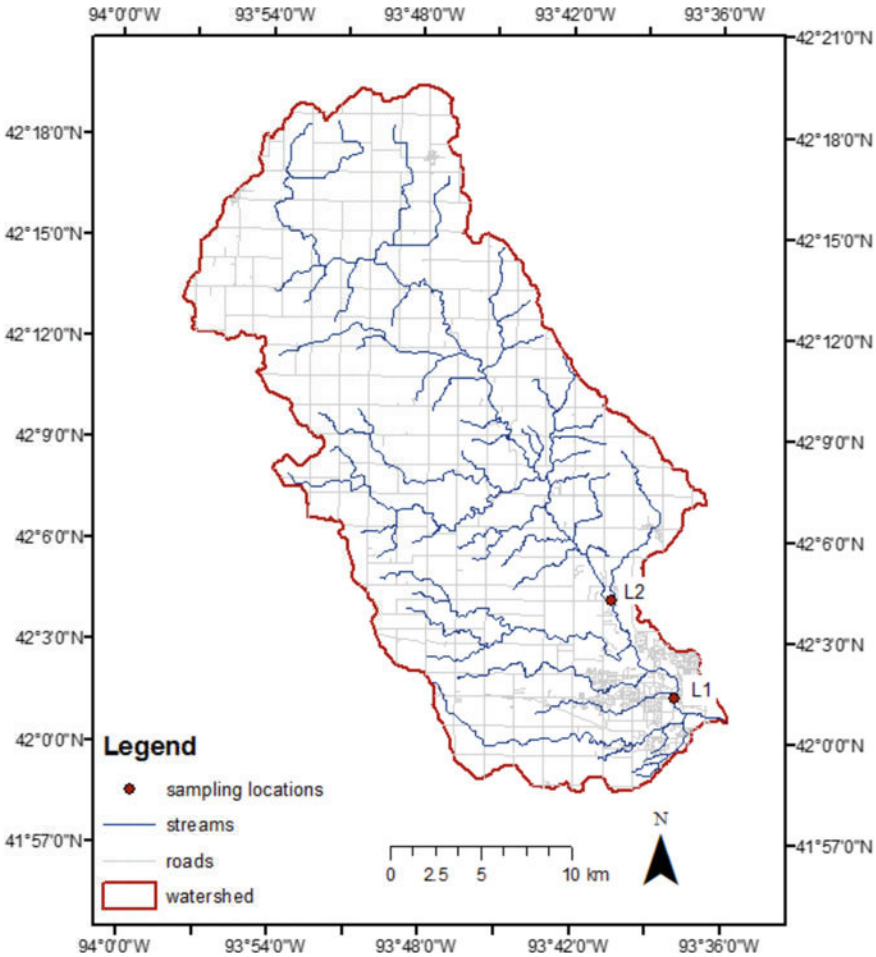

Fig. 1.1 Squaw Creek Watershed, sampling locations, streams and roads. Watershed is upstream of Ames, Iowa. Blue lines indicate stream lines, and light-gray lines indicate road networks. Red dots at the lower end of the watershed indicate sampling location

1.4 Climate Data

Data base of Iowa Environmental Mesonet (IEM Agronomy Department, Iowa State University, was used to obtain the air temperature, and precipitation data. Climate data (air temperature/precipitation) included in the database was recorded using a Campbell HMP 45 instrument, which was mounted on a radiation grill at 2 m height (IEM 2012).

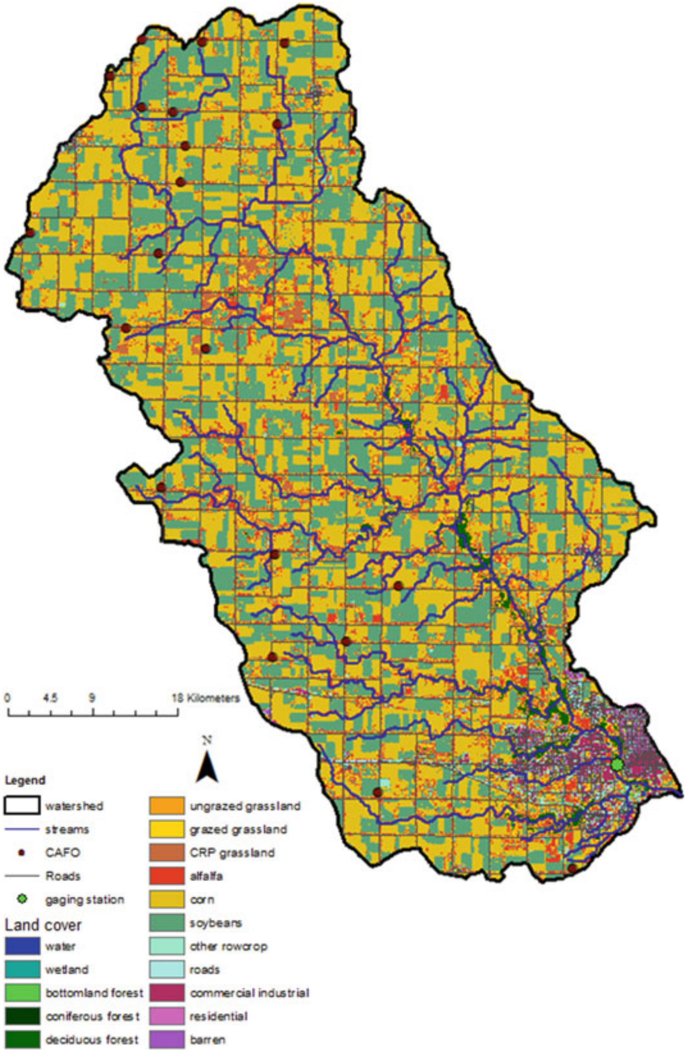

Fig. 1.2 Watershed land cover map of Squaw Creek Watershed, Iowa [green colour indicates soybean crops; yellow colour indicates corn crop (corn and soybean are under crop rotation); dark blue lines indicate streams; and lower end dense area indicate the city of Ames (urban land)]

1.5 Results and Discussion

Stream flow data is shown in Fig. 1.3. Stream flow increased with precipitation (Fig. 1.3) as a result of runoff and direct precipitation on the stream surface. The observations of pathogen indicator are shown in Fig. 1.4. Pathogen indicator (*E. coli*) concentrations at two locations are plotted in figure in time series. Results showed an

Table 1.1 Squaw Creek Watershed characteristics

Description	Values
Watershed area	592.39 km^2
Basin length	43.53 km
Basin perimeter	134.02 km
Land slope	2.01%
Main channel (squaw creek) length	60.46 km
Agricultural land use	74%
Corn and soybean under crop rotation	33 and 41%
Deciduous forest	2.71%
Ungrazed grass	10.87%
Grazed grass	2.52%
CRP grassland	1.70%
Alfalfa	1.84%

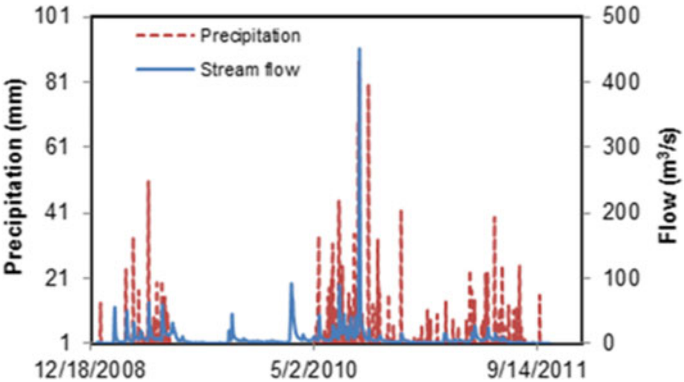

Fig. 1.3 Precipitation and stream flow in sampling locations of the watershed is shown. Red line indicates precipitation, and blue line indicate stream flow measured in sampling locations

increase and peaks of pathogen indicator among three seasons. To understand potential relationships between weather and pathogen indicator concentrations, we plotted pathogen indicator and air temperatures (2009–2011) (Fig. 1.5). The figure shows the variability pattern of the concentrations of pathogen indicator and air temperature. Results indicate that the pattern of waterborne pathogen/indicator organisms in the water column follows the pattern of air temperature (Fig. 1.5).

Relating Fig. 1.3 precipitation and stream flow data with *E. coli* concentrations (Fig. 1.4) in the water column at two locations, it is clear that the increase in *E. coli* concentrations occurs during elevated precipitation, air temperature and streamflow conditions. While relating air temperature data with waterborne pathogen indicator concentrations in the stream (Fig. 1.5), the air temperature peaks match the high pathogen indicator (*E. coli*) concentrations in stream water. When temperatures

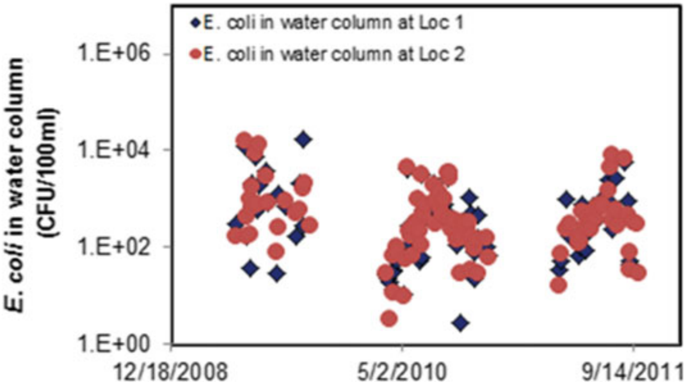

Fig. 1.4 Concentrations of pathogen indicator (*E. coli*) in water column in sampling locations [*E. coli* concentrations was measured at two locations (upstream and downstream and data of both locations are imposed in the plot)]

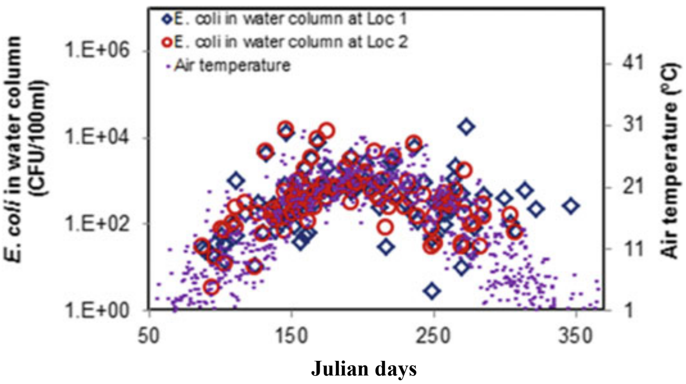

Fig. 1.5 Pattern of air temperature, and pathogen indicator concentrations in stream water

were lower, pathogen indicator concentrations in the water column were reduced. In addition to air temperature, stream flow and surface runoff caused by increase in precipitation resulted in high concentrations of the pathogen indicator in stream water, particularly during the first storm events (first part of the storm hydrograph shown in Fig. 1.3) (Pandey et al. 2016).

Our observations of waterborne pathogen indicator, *E. coli*, in stream water indicates a similar pattern between increasing air temperature and pathogen indicators in stream water. In general, warmer weather provides more conducive conditions for bacteria to grow. From these data of a single location, it can be challenging to understand how long-term increases in temperature/extreme weathers may have long term impacts on waterborne pathogens in streams, nevertheless, these observations suggest that during seasonal increase in temperature, the concentrations of waterborne pathogens are higher in the stream. Further, it can be inferred from these data that increased air temperature during climate warming may provide suitable temperature conditions for microbial populations to grow in ambient waterbodies, which may increase public and animal health risk through exposure to microbially contaminated water.

1.6 Conclusions

In this study, the change in waterborne pathogens over various seasons was analysed. The variability of rainfall, stream flow, and air temperature was studied. The change in stream flow, precipitation, and air temperature was related with the changes in waterbone pathogen concentrations in streams. During the summer seasons, when temperature was elevated, observations showed that waterborne pathogen concentrations increased. During low temperature seasons, waterborne pathogen concentrations were reduced. While additional long term studies from varous geographical locations are needed to understand the relationships between waterborne pathogens and ambient temperature, the findings of this study indicates that the waterborne pathogen concentrations were higher during summer (or higher temepraure conditions) that may increase risks to public and animal heath. This is also the time when humans and animals are more likely to enter waterbodies, and hence it increase the health risks.

Acknowledgement To conduct this research, financial supports were provided by the U.S. Environmental Protection Agency (EPA) Region 7, and the National Science Foundation (NSF). Data presentation and interpretation of this manuscript is of authors and do not reflect the views of the sponsoring agencies.

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Chapter 2
Contamination in Drinking Water Supply: A Case Study of Shimla City, Himachal Pradesh, India

M. K. Sharma, Rajesh Singh, Omkar Singh, and D. G. Durbude

Abstract Shimla city is the capital of the hilly state, Himachal Pradesh. It is situated in the south of river Satluj. The drinking water supply to major portion of the city is met through Ashwani Khad and Dhalli water supply schemes. Ashwani Khad water treatment plant (WTP) receives water from a natural stream, Malyana sewage treatment plant (STP) treated water, and three open drains. During lean period, the treated water is supplemented with bore well water to fulfill the demand and is supplied to consumers after chlorination. Dhalli WTP receives water from Churat Nallah and Sayog catchment, and supplied to consumers after treatment. A mass level jaundice was reported in the Sanjauli-Malyana area of Shimla City during 2006–2007. In view of this, study of contamination in drinking water sources of Shimla City was carried out using hydrological and water quality data analysis. In the present paper, the causes of contamination in drinking water supply and options for ameliorative measures have been identified and discussed.

2.1 Introduction

Article 21 and 47 of the constitution of India prioritized the provision of clean drinking water for the citizens and advises the state governments to provide safe drinking water to improve the public health (Mishra 2018). The central, as well as state governments, has undertaken various schemes for providing safe drinking water

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A. Pandey et al. (eds.), *Climate Impacts on Water Resources in India*, Water Science and Technology Library 95, https://doi.org/10.1007/978-3-030-51427-3_2

to the citizens since independence, however, due to the high population growth, the infrastructure for providing safe water and treatment of effluents to secure the water resources have always been lagging behind requirement. In addition, the average per capita water availability has reduced steadily due to the continuous growth of country's population, and it has been estimated that India will become water stressed country by year 2025 (IDSA Task Force Report 2010).

The health burden on the state exchequer due to poor water quality is enormous. Ingestion of contaminated water with pollutants results in water-borne diseases. Water gets contaminated either at source or while moving through poorly laid and maintained water transmission pipes, or in the homes due to improper storage and unhygienic practices. Mass level Jaundice has been reported due to influx of pollutants/bacteria in the drinking water of Shimla City during 2007. This study was undertaken to identify the sources of contamination and come up with options for avoiding the contaminant ingress into the drinking water sources of Shimla City.

2.2 Study Area

Shimla, the capital city of Himachal Pradesh, is located at 31°6′ North latitude and 77°13′ East longitude (Fig. 2.1) at 2130 m above mean sea level. Shimla City experiences four seasons, stretching almost equally in a year. First quarter (January–March) is snowy and stormy, second quarter (April–June) is dry and sunny, third quarter (July–September) is rainy and damp, and the last quarter (October–December) is bright and clear. Winters are very cold, and the chilly winds from the upper Himalayas make it colder. The city receives snowfall in the last week of December, around Christmas. Temperature of the city varies from 0 to 27 °C. In summers, the weather remains very pleasant with temperature ranging from 15 to 27 °C, and in winters, the temperature remains in the range of 0 to 17 °C. The geology of Shimla region comprises of 0.15 m thin soil layer on the ridges and around 7 m deep soil layer in valleys, an intervening layer of detritus, and hard bedrock. Main drinking water supply is made through Ashwani Khad and Dhalli water supply schemes. Ashwani Khad WTP receives water from Ashwani Khad, a natural stream, and from bore wells to full fill the demand. After different stages of treatment, the treated water is mixed with groundwater during the lean period, and supplied to consumers after chlorination. Dhalli WTP receives water from Churat Nallah and Sayog catchment and supplied to consumers after treatment.

2.3 Methodology

The methodology adopted for identifying the sources of drinking water contamination is described as below:

Fig. 2.1 Location map of Shimla city

(1) Generation of basin characteristics maps using ILWIS GIS/ERDAS, followed by hydrological and basin characterisation.
(2) Monitoring and analysis of drinking water sources, water supply lines, and sewage effluent on quarterly basis.
(3) Analysis of sewage influx in drinking water and efficacy of existing sewerage network in the part of Shimla city (Sanjauli Malyana) using SewerCAD Software (Bentley Systems 2008).
(4) Assessment of possible impact of sewage effluent/toxicants in drinking water sources based on water quality assessment using BIS/WHO standards.

The water samples, from the drinking water resources, natural drains, WTPs, water transmission break points, user points, and STP, were collected in the pre- and post-monsoon season of 2010–2011, and every month in 2011–12. The samples were preserved and analyze as per standard procedures (APHA 1995). All the chemical used during sampling and analysis were Merck make analytical grade.

Fig. 2.2 Drainage map of Shimla city: partly in Satluj (above) and partly in Yamuna Basin (below)

2.4 Results and Implications

2.4.1 Basin Characteristics of Shimla City

The basin characteristics of the Shimla city were evaluated by digitizing the drainage area of Shimla city followed by preparing the digital elevation model (Figs. 2.2 and 2.3). The city lies partly in Satluj river basin and partly in Yamuna river basin, bifurcated by the mall road and the ridge road. The morphometric characteristics of stream (linear, aerial and relief aspect) of study area were analyzed and are presented in Table 2.1 (Tandon 2008). The Sanjali-Malyana region of the city lies in the Yamuna sub-basin with 91.97 km^2 drainage area with fifth order stream and drainage density 3.25.

2.4.2 Application of SewerCAD Software

SewerCAD is an analysis tool for modeling sanitary sewage collection and pumping systems. It is utilized for simulating and computing the sanitary loads during dry and wet-weather sources. The software was used in this study to investigate the efficacy of the existing sewerage system and find out the faults. It was observed from the runs that the existing sewerage network is adequate for designed sewage

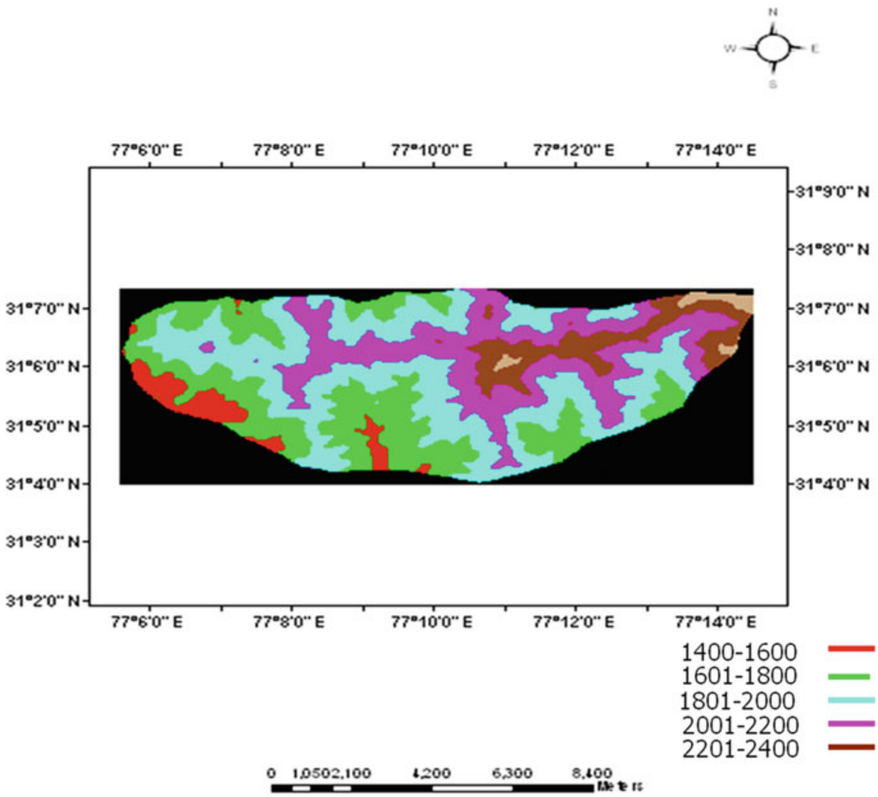

Fig. 2.3 Digital elevation model of Shimla city

Table 2.1 Morphometric characteristics of stream of study watersheds

Parameters	Watershed (Yamuna basin)	Sub-watershed (Sanjauli-Malyana)
Total no. of streams	465	166
Total length of streams (Km)	298.8	80.9
Watershed area (Km^2)	91.97	30
Drainage density (Km/Km^2)	3.25	2.67
Total relief (m)	1000	600

load and the elevation profile indicated smooth flow of sewage. Further, only 25–30% habitation was connected to the sewerage system ruling out any possibility of overflow. However, during field observations it was observed that some manholes were overflowing due to blockage by polybags/jute bags, crisscrossing of sewerage and drinking water lines, leakage in drinking water supply lines, and temporary provisions for arresting the leakages, which may lead to the ingress of polluted water into the drinking water supply.

About 70–75% habitation have primeval septic systems, the overflow from which was discharged directly into the natural streams/drainage. Also, the seepage from the septic tanks into groundwater is identified as one of the reasons for the contamination of groundwater as well as surface water resources, leading to water-borne diseases and more expensive treatment of drinking water.

2.4.3 Sewage Treatment Plant and Open Drains

Sanjauli-Malyana region, where Jaundice cases were reported, receives water from the Ashwani Khad water supply system, commissioned in 1992 for treating the water from a natural stream. However, over the period of time due to the change in the land use pattern in the upper stretches of the stream, the flow reduced and was contaminated with the domestic sewage. The WTP comprises of alum assisted entrapment of suspended solids, followed by sedimentation, filtration, and disinfection. During the lean period and high demand, groundwater is used to supplement the deficit by pumping directly in the treated water tank where it gets chlorinated. The disinfected water is pumped to the Kawalag storage tank and then to the Kusumpti tank where it is re-chlorinated before distribution.

The stream from which the water is pumped to Ashwani Khad WTP receives treated water from Sanjauli-Malyana STP and three natural drains namely housing board colony (Sanjauli) drain (polluted with sewage from the colony), Sanan open drain (polluted with sewage from Nawbhar, Chamyana, and Sanan), and Shivmandir (Malyana) drain (polluted with sewage). Accordingly, the samples were collected and analyzed from these sources to estimate the extent of pollution.

The installed STP is designed to treat 4.4 MLD sewage with 375 mg/l BOD, and produce treated water with BOD and TSS level less than 30 mg/l and 50 mg/l, respectively. It is based on the extended activated sludge process, comprising of bar screen, grit chamber, aeration tank, secondary clarifier, solids contact clarifier, and chlorine contact tank. The solids contact clarifier has been provided for removal of organics by adsorption on chemical sludge escaping from the biological reactor in the winter season when the activity of microorganisms is minimum. It was observed that the treatment units are adequate to treat the designed load, however, the treated water analysis results indicated partial treatment of sewage resulting in pollution of the natural stream. The reduced treatment efficiency of the STP was due to operational issues.

COD and nitrate concentration of open drains were observed in the range 100–400 mg/l and 15–40 mg/l respectively, indicating a substantial amount of sewage/human waste due to open defecation and absence of sewerage lines in the adjoining habitations like Dhingoo, Engine ghar etc. In addition, the kitchen and bathroom drains were not connected to sewerage lines and are discharged directly in the natural drains. It was also observed that the drains were flooded with garbage, which slowly degrades and provides media for microorganisms to flourish and ultimately polluting the stream. Further, despite a full-fledged solid waste management plant, it was observed that the solid wastes were dumped without any treatment near the plant without any engineered structure. It is expected that the leachates from this facility may pollute the water resources.

2.4.4 Water Treatment Plants and User Point

In order to trace the locations and causes of contamination during treatment and supply, samples were collected and analyzed from the inlet and outlet of WTPs, lifting stations, and user points. Dhalli and Ashwani Khad WTPs supply water to the affected areas and hence sampling was done from these two plants.

Dhalli WTP receives around 0.1 MLD water from Sayog catchment and 2 MLD water from Churat Nallah. The Sayog catchment is densely forested without any habitation due to which the water is expected to be pathogen free and without any contaminants, therefore, the water from this catchment is treated through slow sand gravity filters followed by chlorination. The water pumped from Churrat nallah is treated with the aid of alum and lime, flowed by sedimentation, filtration, and chlorination.

Ashwani Khad WTP is designed to treat 10 MLD water sourced from Ashwani Khad, which has six main tributaries namely—Malyana Nallah, Sanan Nallah, Housing Board Nallah, Jagroti Nallah, Koti Nallah, and Bharandi Nallah. Most of these nallah passes through densely populated habitations and one, Malayan Nallah, carries STP treated water. These nallah gets polluted due to the influx of greywater, outflow of numerous domestic septic tanks, and solid waste. The water is treated through flocculator and sedimentation tank, followed by filtration through rapid sand filter, and disinfection by chlorine. During the lean/high demand period, filtered water is blended with groundwater in the filtered/clear water tank. During the design phase, chlorine dosing was planned at inlet which later on shifted to the filter water tank. Based on the field survey and water quality analysis results following conclusions can be inferred:

(1) The input to both the WTPs, except Sayog catchment, is contaminated with organics as well as bacteria. The quality of input to Ashwani Khad deteriorates further in the lean period (summer season) due to the reduction in base flows. The presence of organics and fecal coliform requires continuous operator attention for proper disinfection. The low molecular weight organic compound and nutrients, as a result of chlorination, promote bacterial growth (Saeed et al. 2000),

and therefore, absence of residual chlorine at any moment, from treatment to supply, will lead to disaster.

(2) Dhalli and Ashwani Khad WTPs are designed for the treatment of surface water with practically little contamination and for removal of turbidity, however, the input quality is significantly contaminated, requiring upgradation of the WTPs.

(3) For such type of waters, solids contact clarifier with an option for in built sludge recirculation should be used. The coagulated and flocculated water is filtered through a metal hydroxide sludge blanket in the clarification zone of the clarifier resulting in efficient removal of organics as well as microbes, if operated properly.

(4) Installation of Ultra Filtration (UF) membranes for final polishing of treated water from Ashwani Khad WTP is recommended. UF membranes are a physical barrier for bacteria, viruses, and high molecular weight organic compounds. Reduction of these components will bring down the chlorine demand and also trihalomethanes in the treated water which are carcinogenic compounds. Installation of UF will ensure safe water for the citizens.

(5) Detailed study with ozone for oxidation of organics as well as microbes is suggested. Full scale system should be installed only after six months' field trials.

(6) Due to proper chlorination, in fact high chlorination, the quality of water samples was almost similar at municipal distribution tank and end user tap, free from bacteria.

Three user point samples were collected from each drinking water supply line of the affected area. The analysis of these samples confirmed the presence of free residual chlorine (FRC) and absence of microbial contamination up to the tail end. The treated water from Ashwani Khad WTP was observed to be high chlorine demanding due to the presence of organics in the treated water. The FRC reduced from 25 mg/l at WTP to 1 mg/l at the user point, in spite of re-chlorination at Kusumpti pumping station (Fig. 2.4).

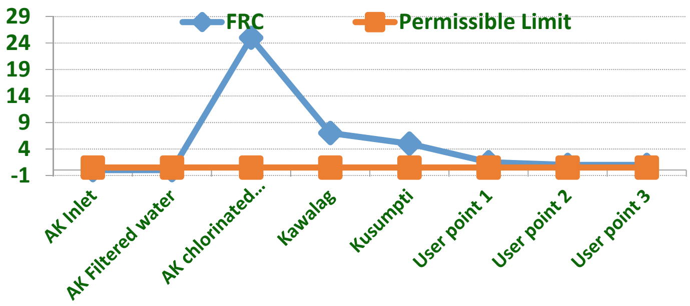

Fig. 2.4 Free residual chlorine profile from WTP to user point