Chapter 13
Integrated Water Resources Management: Perspective for State of Uttarakhand, India

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Abstract Himalayan areas are the water bucket of the world and contribute one of the world's greatest freshwater resources. The Himalayan system provides plentiful services to the downstream towns and population in terms of water for household purposes and ecosystems services, etc. More than 1.4 billion people directly depend on water from the rivers of the Himalaya. So, water resources and its management for providing clean water and sanitation are already a challenge in the Himalayan region. All the mitigation measures adopted under Ganga Action Plan (for cleaning of all tributaries of river Ganga started by ministry of water resource in 14 Jan 1986) focus primarily on the big cities for construction of sewage treatment plants, interceptor sewers, and sewage diversion mechanisms. But always questions are raising about the sustainability, maintenance and cost-efficiency of these mitigation measures, and its effect on water quality of the river. For small areas and towns of Uttarakhand, natural, sustainable, efficient, natural, and long-life mitigation measures are required for reducing the pollution level in the river system.

Keywords Himalaya · IWRM · Uttarakhand · Ganga · Sustainability

Abbreviations

GIS	Geographical information system
S	River meandering sinuosity value
IWRM	Integrated water resources management

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P. Shukla et al. (eds.), *Environmental Processes and Management*, Water Science and Technology Library 120, https://doi.org/10.1007/978-3-031-20208-7_13

RS	Remote sensing
RBF	Riverbank filtration
DEM	Digital elevation model
SOMA	Switch Organic Micro-Pollutant Assessment Tool
STP	Sewage treatment plants
LPCD	Litre per capita per day
MPN	Most probable numbe
MLD	Million litres per day

13.1 Introduction

Freshwater availability in India is 1545 m^3/person/year (according 2011 census), and it will decrease to 1140 m^3/person/year in year 2050 (UNICEF, FAO, and SaciWATERs 2013). It is reported that the water supply and demand gap in 2030 will be 94 billion liters/day (UNICEF, FAO, and SaciWATERs 2013). India will experience water stress in 2050 and will face water shortages when the availability of clean water falls below 1000 m^3/person/year (Ernest and Young 2011).

Water scarcity issue is not just linked to the availability of freshwater because there are places facing water scarcity in spite of abundance of freshwater. Uttarakhand is a Himalayan state situated in Northern India and one of the most rapidly developing states in India. Most part of the state is covered by hilly areas, having a demographic and geographic privilege of high surface water availability; however, the state often faces drinking water scarcity. Being a part of a Himalayan state, it has problems related to floods, earthquakes, and other natural disasters. In the past years, several floods took place in the state; the last being in June 2013 when the Alaknanda River rose up to more than 10 m at some places (Chevuturi and Dimri 2016). As a result, there were severe damages to drinking water schemes, irrigational water structure, buildings, roads, agricultural land, and other infrastructures.

At present, drinking water demand of Uttarakhand is 1035 MLD. It is expected to rise to 1237 MLD in 2021 with increase in the population and reach 1473 MLD in 2031. Drinking water availability in some parts of Uttarakhand is less than 12 LPCD (Kimothi et al. 2012). The primary cause of lower per capita availability is the dependence of water production and supply on rainfall. In monsoon, high flow velocity of the river damages the water abstraction structures frequently. In non-monsoon season, most of the springs go dry. Due to seasonal variation in water availability, currently existing water production systems for agricultural and domestic use are not able to cater the water demand. Constant drinking and irrigation water shortage is also due to the improper techniques of water harvesting and bad practices of water management. The rising population and increasing pollution in the water bodies further exert the pressure on rising water demands. Groundwater availability is limited, and many springs are drying. Additionally, there is a large quantity of surface water and rainwater runoff which is not utilized efficiently for development in these areas.

Riverbanks in the state are densely populated and fulfill the need of agricultural and drinking water of hundreds of towns and thousands of the villages. These river systems also take back all the untreated and treated sewage from these populated areas. In addition to pressures of population, there is lack of proper investment in wastewater treatment and rainwater collection infrastructures. A study conducted under Saph Pani (2013) project shows that one of the Himalayan rivers named Alaknanda River, a tributary of river Ganga at Srinagar, has total coli-form level reached more than 7500 MPN/100 ml. E. coli levels more than 6500 MPN/100 ml, which is greater than the required limit of 5000 MPN/100 ml set by the Central Pollution Control Board of India (CPCB) for usage of source for drinking water. On the basis of this report, it could be inferred that Himalayan river water of the state is not suitable for direct drinking purposes. To overcome these problems, the Indian Ministry of Water Resources came up with the Clean Ganga Mission with the aim to reduce the pollution level in the Himalayan rivers by locating and reducing major sources of wastewater and other point source discharges into the river.

Therefore, a suitable technology and integrated management system is required for these hilly (Himalayan) areas to utilize the water resource to meet the growing drinking and agricultural water demand while coping with these vast geological and climatic variations.

13.1.1 Integrated Water Resources Management

The Integrated Water Resources Management (IWRM) is a method for monitoring water resource and helps to develop, manage water resources in a sustainable and balanced way, taking account of economic, social, and environmental interests. In the Himalayan mountains, glacier melt water and rainfall are the major flow components of the river systems. As discussed in the first chapter, the major riverine towns in the Himalayan areas face frequent occurrence of water scarcity. Thus, there is a critical need for these towns to get an assessment of existing and identification of new potential water bearing zones to cater the population and control the contamination in the river water. In recent years, combination of surface information with subsurface information with the help of groundwater modeling and geographical information system (GIS) is emerging as a potential tool for the sustainable management of water resources (Michl 1996).

The coupling of these two technologies for river management and water resource management can come under the umbrella of IWRM which can form a balance between the environment and human water demands of these towns. The term IWRM emerged in the year 1980, and it is defined by the Global Water Partnership as a "process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

Declining per capita water availability due to consumption patterns, climate change, and water pollution always putting pressure on limited water resources, which come into focus of Integrated Water Resource Management (Gleick 1998; Bonato et al. 2019). Well-prepared and economically viable approaches to implement IWRM in the Himalayan region are not yet widely available (Nischalke 2014). IWRM of the river stretch should contain the following elements: water availability and uses, water demand, water deficits, water quality, and minimum environmental flow from the hydro-electricity generation dam to the downstream.

13.2 Water Issues of Uttarakhand

The availability of water in the Himalayan area and its quantity, quality, and scarcity depend upon the climatic conditions of the area. River water is highly seasonal and varies across the monsoon to non-monsoon. The river discharges are minimum in winters and maximum in rainy season. Changes in seasonal stream-flow have significant impacts on the local populations due to altered water availability patterns and become a main reason of water scarcity in the Himalayan towns. Other reason for non-portability of surface water is turbidity and bacterial populations in it. The growth of human population and human activities near the bank of river are further deteriorating the water quality of the river gradually.

In the recent years, the hilly area of the Uttarakhand state is facing many problems regarding the water supply and sanitation, continuous power supply cuts, collection of water from surface sources which are unsustainable and often far away from habitation and agricultural fields, direct abstraction of surface water for drinking purposes causing filter media chock, drying up of natural water sources, decline in the groundwater level, freezing of water supply pipelines in winter, damages of the pipelines and irrigation canals and damages of natural sources due to landslides, and frequent damages of water abstraction structures due to the high velocity of the river (Patro et al. 2020). Generally, all these problems are grouped into the following categories based on water production and supply for the local water demand.

i. **Low LPCD and bacteriological contamination**: Supply of drinking water is not sufficient (<12 LPCD) and not following the Indian drinking water standard (155 LPCD) in quantity and quality (bacteriological contamination) and becoming the main reason of health problems. Especially Himalayan women are always affected and facing these problems in their daily life, because they often have to carry water containers from a spring to their home.

ii. **High maintenance cost**: The current working conventional water supply methods which meet the local drinking water and agricultural demand are facing functional and operational problems of treatment, failure of pumping stations, huge maintenance cost after every monsoon, etc.

iii. **Increasing pollution and population level**: The pressure from increased urbanization, population growth, and improved standard of living results in a continuous depletion of local water sources and increasing pollution in the river system. People use the river water for cleaning, bathing, household use, rituals, and for funeral.

iv. **Undeveloped wastewater system**: Sustainability with respect to quality and quantity of drinking water is always a billion-dollar question of water supply organization. Water supply and wastewater services in the Himalayan towns are often underdeveloped.

v. **Increasing trends of pilgrims and opening of new education centers**: Due to increasing trends of pilgrims and opening of new education centers in peaceful environment of the Himalayan area, the urban population has increased. This had led to increase in municipal withdrawals of drinking water.

vi. **High variation of discharge in different seasons**: The alteration of water availability in different seasons and growing sewage pollution causes severe problem in direct abstraction from the river, which always become a cause of disturbance of the daily production.

vii. **Changing of river course seasonally**: In dry seasons (non-monsoon), river changes its course and increases the distance between riverbank and the water tapping structures. During the monsoon seasons, high velocity of river often damages these surface waters tapping structures. Most of the irrigation schemes are silted during monsoon, which affects the agricultural water supply.

viii. **Uneven rainfall pattern**: Uneven rainfall is affecting most of the rain-fed agricultural land via water shortage and becoming the main reason of drought in Himalayan areas. In summer (May–July), most of the springs and streams become dry due to a climatic effect, resulting in a shortage of water availability.

ix. **Migration of youth**: In the Himalayan region, many towns and villages are situated on the banks of rivers, but the unavailability of clean drinking water and enough agricultural water due to lack of application of proper technology results in great dissatisfaction of the people. Sometime it becomes a cause of the migration of people from the village area to the city area to access safe water, sanitation, and public service. Most of the migrants are younger and better educated than those who do not move. These non-movers are poor and the most vulnerable to the water scarcity and health problems in this region.

x. **Lack of advanced surface water treatment structures**: Lack of advanced surface water treatment structures causing insufficient filtration adversely impacts the quality of potable water and causes water-borne disease and also affects agricultural surface water pumping stations. The rural poor and urban people who do not have good social conditions and least capacity to adapt available home drinking water purification systems are most likely to be affected by the diseases.

xi. **Disputes in tapping the water sources**: Disputes often arise in tapping the sources of water in the most densely populated areas. Sometime one spring water feeds many villages, towns, or different parts of the towns and their agricultural land.

All these above problems display the link between Himalayan people and their environment in the context of water availability and scarcity, uncertainty in rainfall, climate, hydrology, and river behavior as well as demographics and water use patterns. A catchment or drainage basin is a unit geographical area of landform which drains all the water to a single outlet. Generally, watersheds are formed into many forms and sizes according to its geography and geology (Frissell 1986). The health of a river or lake is a direct indication of how its watershed is treated and handled (Wang et al. 2006). Due to inadequate and inappropriate technological intervention, many of the Himalayan areas have not been able to harness their unique resources.

Floodplains are adjacent to rivers, help maintain the health of the river and are very useful for temporarily storing water, filtering nutrients and contaminants, allow for infiltration, provide habitat to several species, and create recreational opportunities. Floodplains store flood waters and cause a reduction in flow velocity. They also improve water quality with the help of plants within the floodplain which filter sediments and pollutants. Water-related disaster management, including proper risk assessment, should not be considered in isolation, but rather as an essential component of IWRM. Following studies have been conducted on IWRM and its watershed management.

(a) In some parts of the world, land availability is becoming a big issue for urban development. The riverbank space is getting further attention of urban planner to use this space for development. Controlling development in river space is necessary to avoid illegal invasion and to create a better environment to support the river basin community (Patro et al. 2020, 2022).
(b) In planning and management, preservation of ecosystem and satisfaction of human needs must be prioritized. Thus, water resource planning system is always becoming flexible to the change due to the uncertainty issue in developmental framework (Kirby and White 1994).
(c) Riparian buffer maintains healthy aquatic ecosystems and provides a series of other environmental and social benefits. It helps for removing and trapping sediment from runoff and able to stabilize riverbanks. Some activities like construction of impermeable surfaces, mining of riverbed, construction of septic tank, application of pesticides, construction waste disposal sites are not suitable for river floodplain (Seth and Lawrie 2000).
(d) For IWRM, along hydrological boundaries, it is important to involve the local communities more actively in the management, planning, and operation of their water resources. With the help of community's involvement in management of water resources, we can compare the past and present water scenario of the watershed boundary (Amakali and Shixwameni 2003).
(e) Many problems associated to flooding in the river basin can be resolved by making corridor along the river to avoid the encroachment. River corridor defined as a buffer around the river usually based on the width of the river helps to preserve pollution and riverbank stabilization (Lee and Low 2004).
(f) In order to address water demand issues rising from population increase and agricultural pollutions, IWRM approach has been introduced and used. IWRM

includes the coordinated development and management of water resource usage toward environmental conservation, protection, and sustainability. There is a need for studying the holistic coordination of IWRM and GIS technology to mitigate the environmental problems in aquatic ecosystems (Eda and Higa 2010).

(g) With the help of GIS, a dynamic water balance and erosion model were developed for the catchment studied and assessing water demand and usage of water. Different strategies were developed to solve water allocation conflicts. IWRM was a new and modern computer-based toolset which was tested, validated, and sound documented procedures for decision support and implementation of water management strategies (Staudenrausch and Flügel 2001).

13.3 River Morphology and Its Effects

13.3.1 River Morphology

In the Himalayan area, rivers are utilized for the supply of water for drinking and irrigation, hydropower generation, adventure sports like river rafting, habitats furnishing, and cleaning of wastewater from towns by self-purification ability. For these performances of the river, it is essential to identify the functional and environmental situation of a river with its channel pattern. Himalayan rivers are perennial rivers and make an alluvial flood by a different river process, like erosion, transportation, and sedimentation (Bridge 2009). Mostly, erosion occurs in the upper catchment area of drainage due to high slope and weathering of the rocks. V and U-shaped valleys are formed during this erosion and weathering process (Benn and Evans 2014). The eroded materials consist of rock fragments, including mud, silt, and sand. During large floods, the channels often change their course in the floodplain till to next flood (Cook et al. 2014). The formation of channels is explained by river patterns and river configurations and is determined by such factors as discharge, water surface slope, velocity of river, depth and width of the river and river bed materials (Church 1992). The basic forms of mountain river system are braided, meandering, and straight and were categorized by Leopold and Wolman (1957). The river's channel pattern formed under different flow conditions and its boundary condition is based on their sinuosity ratio, given by the channel length by valley length. Sinuosity is depending on the bed load, slope, and velocity of the rivers.

Studies conducted by Xu (1996), Lewin (1984), and Edgar (1984) show that alluvial rivers meandering patterns with channel sinuosity $S = 1.4$–1.6 and try to stable by self-adjustment under different flow boundary condition. An alluvial river has 39% occurrence frequency of $S = 1.4$–1.6, 20.0% of $S = 1.5$–1.6, and remaining 18.8% of $S = 1.4$–1.5. It is resolved that all alluvial rivers have similar intrinsic mechanisms that try to make the similar channel patterns with sinuosity 1.4–1.6. Besides, the field investigation done by Winkley (1982, 1983) shows that the river channel with $S = 1.4$–1.6 has minimum flood profiles and low maintenance cost.

13.3.2 Theoretical Value for Sinuosity

In mountain river system, stream has its maximum power (in terms of flow and velocity) at the origin of the river, and toward downstream, river channel tries to minimize this power to get the dynamic equilibrium for stabilization. That is the main reason of consistent changes in the river slope toward downstream, which is called minimum stream power theory (Yang 1986). According to this theory, an alluvial channel gets the dynamic equilibrium condition when river stream power of the river channel is minimum to its unit length. Let P be the stream power of the channel, then

$$P = Q * S * Y \text{ (for Minimum } P,\ S \to 0) \tag{13.1}$$

where Q = discharge, S = slope, and Y = specific weight of water.

Valley axis of a channel is always perpendicular to contour line. Let us assume that river meander bend is a uniform curve and arc of the circle is a channel centerline (Fig. 13.1). Then, the mean channel slope is

$$S = 2\Delta s/\,\mathrm{Ls} \tag{13.2}$$

where Δs = elevation difference of one meander, Lm = meander wavelength (distance between points A–C), and Ls = meander arc length.

The local channel slope $S(s)$ varies with the position in the bend. It is minimum at valley axis and maximum in farthest point in the valley axis. The minimum value of S is $(s) > 0$. Then,

$$S = 2 * \Delta s/\,\mathrm{Ls} = \text{ minimum 1st condition} \tag{13.3}$$

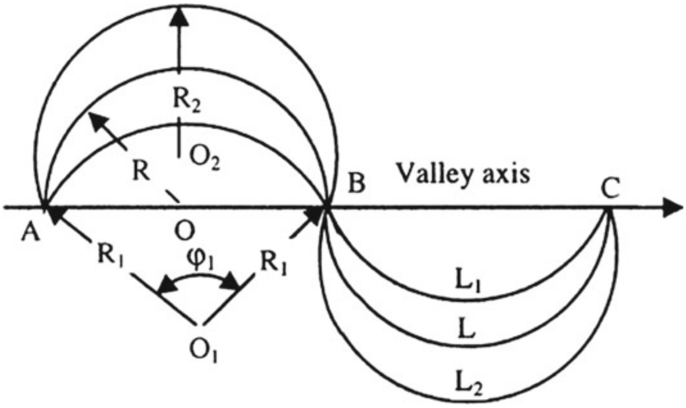

Fig. 13.1 Development of a meander loop (modified and adapted from, Deng and Singh, 2002)

$$S(s) > 0 \text{ 2nd condition} \tag{13.4}$$

$L1$, L, and $L2$ are the three different meander development stages of a river. $L2$ has the longest Ls which satisfy the first condition, but $S(s)$ is maximum and not satisfies the second condition, and $L1$ has minimum $S(s)$ which satisfies the second condition, but Ls are minimum and not satisfy the first condition. Only L is satisfying both conditions of minimum energy. From Fig. 13.1, it is clear that

$$\text{Lm} = 4R,\ \text{Ls} = 2 * \Pi * R \tag{13.5}$$

A field study conducted by Chang (1992) shows that the radius of alluvial river channel curvature is approx. 3 times to the channel width. Let us assume the river width is B and radius of curvature is R. Then from Eq. 13.5, it can be inferred that

$$R = 3 * B \,\&\, \text{Lm} = 12 * B \tag{13.6}$$

And it shows the river sinuosity $S=$ Ls/Lm $= 2\Pi R/4R$ from Eq. 13.6.

$$S = \Pi/2 = 1.57 \tag{13.7}$$

Therefore, on the basis of above calculation, it is clear that the sinuosity S=1.57 range of 1.4–1.6) with meander wavelength Lm $=$ 12*B signifies alluvial rivers optimal channel pattern. For the low cost of maintenance and perfect management of the river channel, $S = 1.4$–1.6 and Lm close to 12*B should be maintained.

13.3.3 Relationship Between Purification Capacity and Sinuosity

It is important to calculate and enhance the self-purification capacity of the riverbank, to lessen the cost of wastewater treatment. Purification capacity depends on the lateral, longitudinal, and vertical mixing ability of river flow as well as filtration capacity of alluvial deposits (Peavy et al. 1985). The dispersion coefficient K, which represents the mixing ability of the river, is higher in longitudinal direction than in other directions (Deng et al. 2001), and the filtration capacity, represented by the hydraulic conductivity k, in the horizontal direction is 10 times greater than the vertical direction. It depends on the depth, area, and type of deposit soil, which plays a main role for adsorption, decomposition, and dilution. To calculate the purification capacity and its influence in river pattern, a study was conducted by Nordin and Sabol (1980) in the USA on 30 streams where 70 longitudinal dispersion coefficients were plotted against the channel sinuosity. On the basis of the results, it is clear that high values of self-purification capacity occur with S ranging from 1.35 to 1.57. Lower sinuosity values make straight rivers which generally made the wide channel with uniform and low velocity gradient which causes a weak self-purification capacity or dispersion coefficient (Fischer 1979).

High sinuosity leads to enhance the river channel resistance and reduced flow velocity of the river, which reduce the self-purification capacity. Consequently, rivers with sinuosity value 1.35–1.57 exhibit the strongest self-purification capacity. The sinuosity of S value 1.4–1.6 with a meander wavelength of twelve times the channel width is perfect for the sound management of alluvial rivers (Deng and Singh 2002). So the aim is to ultimately calculate the purification capacity of alluvial soil with a suitable sinuosity (higher value of S increases the clogging in the river, and lower value of S increases the erosion and decreases the contact time of water and alluvial soil) in the river stretch.

13.3.4 Riverbank Filtration as an Element of IWRM

Watershed area of a river stretch is large, highly sloped, less stable, and newly formed which is the primary reason of the high turbidity in the river water. Due to this watershed area, the river stretches facing the frequent landslides in monsoon season, and landslide mass is fleshed out by the river from upstream to downstream. This landslide mass is deposited in the bank of the river, and after long-time deposition of mass, these riverbanks are now becoming a good water potential zone for the Himalayan area (Fort 2000).

The areas near to the adjacent of rivers, streams, and lakes which are vulnerable to flooding are called floodplains. But in mountain area, floodplains cannot develop due to limit horizontal extent and steep slopes. In plain areas, floodplains can extend >1 mile from the source of water, but in Himalayan areas, riverbanks cannot extend 50 m, except in some parts of the foothill area and less steeps area, like Haridwar, Rishikesh, Dehradun, etc. These riverbanks are usually flooded during the whole monsoon periods. The main reason of the floods is increasing intense rainfall in a large catchment area. But the trend of rainfall is decreasing with increasing intensity in a short time (Basistha et al. 2009). Many surveys have shown that floodplain size is immediately associated with the overall health of a river (Postel and Richter 2003). Floodplains are really useful for temporarily storing water (they reduce the flow speed of the river and suck up and store flood waters), filtering pollutants and contaminants, allow water for infiltration in the soil, purify the river water through alluvial soil, provide the habitat for different type of species, and create recreational opportunities (Postel and Richter 2003).

These floodplains can act as a reservoir of water for these towns. In a floodplain, the recharge comes from both surface water and groundwater. Their water can be easily utilized by the drilling of shallow wells in unconfined aquifers and confined aquifer. In this process, lowering of the water table of unconfined aquifer relative to the adjoining surface water level causes surface water movement through the permeable riverbed into the unconfined aquifers. This water level difference provides a natural path to this subterranean flow, which provides the raw water for drinking purposes.

This process is called riverbank filtration (RBF) (Hiscock and Grischek 2002). These floodplains can become a part of IWRM in the following way:

(a) Floodplains can be used by natural technique RBF, to improve aquifer recharge by constructing the abstraction wells in the vicinity of natural open water bodies and can serve to manage the complete development of groundwater resources for Himalayan areas where groundwater is the limited resource for water supply (Sandhu et al. 2011).
(b) Floodplain acts as a natural filter, mixing the groundwater and bank filtrate water, can dilute the degree of concentration, and biochemically reduces contaminants present through RBF, especially suitable for Himalayan towns which are facing high sewerage pollution, high turbidity in surface water bodies, and high concentration of iron, arsenic, and nitrate in groundwater (Kumar and Mehrotra 2009).
(c) Floodplains can be used for the pre-treatment of surface water (during monsoon) for artificial recharge of groundwater through infiltration basins.
(d) Floodplains have a large capacity to purify the surface water through the alluvial deposition (good hydraulic conductive material) close to the meanders. Floodplains can enhance the sanitation of surface water bodies due to efficient biodegradation and sorption process in hyporheic zone, and it is a sustainable technique for water improvement production and management during the heavy pollution load in the river (Grischek et al. 2011).

13.4 Role of Geographical Information System (GIS) in IWRM

GIS application can play crucial role for the IWRM in the Himalayan region due to unavailability of detailed spatial data and the inaccessibility of many areas. With the help of remote sensing (RS), one can generate valid input data for hydrological models and calculate the water balance. By the combination of different spectral, temporal, and spatial information as well as with land measurements, one can extract valuable information for the IWRM process. GIS can be coupled with any modeling system and serve as a go-data management and pre-processing unit for the hydrological analysis. GIS is also employed as a post-processing component, mixing the various model results and serving as a platform for visualizing them (Michl 1996). Other relevant studies have been carried on GIS, and it is used in IWRM.

a. GIS and RS coupled the eco-hydrological modeling have a significant role in development of a series of indicators of water catchment and its health which is a part of a geographical audit of a river basin (Aspinall and Pearson 2000).
b. GIS and RS data were used for modeling sediment yield by generating and organizing spatial data (Pandey et al. 2007).

c. GIS techniques provide an efficient and useful tool for prediction of future erosion potential and also in understanding the impact of different cropping pattern and conservation support practices (Leidig 2008).
d. Detailed morphological mapping has been done for river shape and size mapping. It integrates with multidisciplinary information which was collected with field survey cartographic map and remote sensing data (Michael et al. 2012).
e. Non-point pollution source co-relates with watershed-scale conditions and its influence in ambient water quality. GIS and RS data evaluate concentration stream and its impacts in the river watershed and could help to optimizing the design of stream monitoring network. So GIS and RS are a promising tool for better management and controlling non-point source pollution (Yang 2010).
f. GIS and RS data help to derived information in terms of natural resources and their spatial distribution for the integration with socio-economic condition. It helps to develop resources action plans which are extremely useful for well-organized and sustainable management of water and natural resources (Shanwad et al. 2012).
g. Remotely sensed multispectral digital image can be conjunct with field data to classify hydro-geomorphic stream at fine scales. GIS is an effective tool for stream order and its concentration if accurate ground controls point was taken for image rectification (Wright et al. 2000).

In recent years, IWRM has been recognized globally as the crucial means in treating with many matters relating to the management of water (Martínez et al. 2014). From that point of view, GIS and RS are really useful to make the goals of the IWRM in the long term.

13.4.1 Use of GIS and RS in Land Suitability Analysis

Use of GIS and RS in land suitability analysis has become an emerging and favorable tool among the scientists, engineers, and managers due to its efficient, reliable, and fast output results, following other studies carried out by researcher for site suitability analysis with the help of GIS and remote sensing.

a. GIS and its analysis tool have been used for optimizing the locations of the sewage treatment plants (STP) and outfalls on the basis of eco-sensitivity areas. The key elements of site selection were encompassing 10 criteria and 15 indices that were established to generate the eco-suitability map and determine possible locations for STP and sewage outfalls (Zhao et al. 2009).
b. For identification of suitable site for solid waste management, a hydro-morpho-geological study was carried on the basis of hydrology, geomorphology, and geology with the help of digital elevation model and LANDSAT-TM satellite imagery. Results show that the site suitability analysis using remote sensing and GIS 17 favorable locations were identified with the help of GIS and RS data which can be used for solid waste management (Sumathi et al. 2008).

c. RS and GIS technologies have been used for study of urban–rural planning land suitability and its comprehensive evaluation. For the suitability analysis, data about limiting factors like terrain, landscapes, traffic, farmland protection, nature reserve and scenic area, and drinking water source protection were acquired from remote sensing techniques and GIS domain. Through analyzing all various factors which impact on land suitability and the distribution of population, the weight of the various factors was determine for evaluation of the land-use suitability (Luo et al. 2008).
d. Proper location of wastewater treatment plant helps to protect the groundwater pollution and soil degradation. Selection and identification of possible sites for the wastewater treatment facilities were assessed using suitability score which depends on land-use pattern, ground slope, and its distance from riverbank and roads. Finally, ideal location for wastewater treatment plant was designated on the basis of weightage value (Benujah and Devi 2009).

In the Himalaya, due to rough terrain, vast, and unapproachable catchment area, examining the drainage network to collect flow data through field visits is difficult. A study conducted by El-Magd et al. (2010) shows that digital elevation models (DEM) are fit for catchment area analysis, and its comparison with existing topographic maps of the area gives good results. DEM data within GIS domain have a potential to extract the drainage network of the river in fastest way, and it can be carried out by using an ASTER DEM data with a 30 × 30 m grid cell size. For the water modeling purposes, evaluation and slope in the streams are needed for starting with the end point of the river stretch. DEM data can delineate automatically streams in the presence of a river as a sink. With this sink, we can calculate the flow direction of the streams. On the basis of flow direction, we can calculate the flow accumulation of the river at any point. After that, stream network is generated within the catchment (Macka 2001).

13.4.2 Groundwater Flow Modeling for Purification Capacity Analysis

River water levels and its interaction with groundwater in the river stretch can be simulated with groundwater flow modeling, e.g., using MODFLOW. Inside the groundwater flow model, building the conceptual model, its design, calibration, and validation/simulation are the usual steps (Anderson and Woessner 1992). For the calculation of filtration capacity of the alluvial aquifer, hydraulic conductivity, river water level, meandering ratio, slope, the width of the alluvial plain, and discharge of the river are the main input parameters. River discharge and levels can be taken from secondary sources, the geo-hydraulic properties from pumping tests at some sites near the river stretch and other remaining parameters can be determined from remote sensing data. By using GIS and remote sensing techniques, the process of conceptualization and the selection of site can be added to make the best results and sites for exploration and purification of the river stretch. For the river stretch, the following methodology was adopted by different researcher: The geo-hydrological data were collected for the site including groundwater observation near the river stretch, discharge measurements of the river are used to calibrate the model, and a digital elevation model (DEM) of 30 × 30 m grid size is used for slope analysis. The purification capacity of the river is calculated with the help of numerical tools. To overcome the issue of water quality and availability and reduce the dependence on groundwater, the alluvial deposits near the riverbanks can play a big role for sustainable water sources and it can be a part of Integrated Water Resources Management of the Himalayan area (Grischek et al. 2011).

13.5 Conclusion

On the basis of literature review, following research gaps are identified for the mountain areas.

I. In India, IWRM approach has been developed only in some part, and only few papers are available on IWRM practices applied in the Himalayas focusing on small towns of Uttarakhand.
II. In 2013 flood in Himalaya, IWRM practices even in small way failed due to the glacier retreats and consequent disasters.
III. Studies on River Ganga have concerned only big cities and did not take into account its main tributary and population.
IV. Limited preliminary works have been done by scientists in development of bank filtration.
V. GIS and RS are used frequently by researchers for land cover analysis and management in India, but in Himalayan mountain area, many parts are untouched by researcher for IWRM with the help of GIS and RS technologies.
VI. Non-point source pollution in the Himalayan rivers has been the focus of several studies conducted by scientists and researchers in many government agencies. Projects have been implemented to correct and prevent related problems. But result shows that there is not much considerable improvement in water quality of the River Ganga.
VII. There has been lack of coordination among organizations and no attention toward integrated resource management in the river basin.
VIII. Few preliminary works have been done by scientists in development of indirect surface water abstraction schemes (bank filtration), which is a sustainable technology in mountain region. These preliminary studies show that mountain regions have a great potential of RBF system for sustainable potable water supply.

These riverbanks of the Himalayan state of India can produce safe and sustainable drinking and agriculture water. Indirect abstractions of surface water through the alluvial medium near the bank of a river can minimize river pollution level. The indirect abstraction of surface water can meet the water demand of the area in a sustainable manner. Thus, the purpose of the management plan should be aimed at a sustainable utilization of these water resources (alluvial plains) as well as of the natural environment. It is need of the present times, to estimate the water availability and demand, to determine suitable sites near a river stretch for drinking water exploration, suitable river meandering sites for calculation of the water purification capacity of the river stretch by inducing recharge, and to calculate the water purification and filtration capacity of these identified sites with the help of groundwater modeling and Switch Organic Micro-Pollutant Assessment Tool (SOMA).

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