Chapter 2
Recharge Potential Mapping in Complex Hydrological System of Kosi Basin in the Mid-Himalayan Region

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Abstract Increasing water use and climatic variability threaten thousands of springs and spring-fed watersheds in the mid-Himalayan region. The decline in spring discharge resulted in shrinking cropland, out migration and is adversely affecting the economy of the region. Shallow aquifer and short retention time emphasize on need of disposition of site suitable artificial measures to recharge groundwater. Complex geological and tectonic formations and lithological and chronological variations on one hand and impact of undulated terrain and land use pattern on the other put obstruction in finding suitable recharge sites in Himalaya. In this study, a GIS-based weighted sum analysis approach was used to identify suitable sites for artificial recharge of groundwater in Upper Kosi basin of Indian Himalayan region. The tools of GIS facilitate study relief and structural aspect of basin, quantify the influence of one factor on the other and provide precise and quick information on suitable recharge sites for rejuvenation of springs and hydrological sustainability of watershed. The results indicated that 19.6% area lies under good to excellent while 46.9% area having fait to poor potential of groundwater recharge. Area under good to excellent recharge potential can be further considered for implementation of site suitable groundwater augmentation measures for sustained specific yield of an aquifer.

Keywords Spring rejuvenation · Recharges potential site · Mid-Himalayan region · Groundwater augmentation

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P. Kumar et al. (eds.), *Applications and Challenges of Geospatial Technology*,
https://doi.org/10.1007/978-3-319-99882-4_2

2.1 Introduction

Surface water and groundwater are complementary in the hydrological system and interact through various physiographic and diversified climatic landscapes. The dissimilarity of topographical characteristics with regard to soil, lithology, geomorphology, stratigraphy and variation in precipitation over time and space led to an unequal allocation of groundwater resource in different regions of the country (Jaiswal et al. 2003). Kumaun Himalaya, with respect to global climate change and rainfall variability, is among the world's most vulnerable regions in terms of water stress, specifically in the spring-fed river regime (Mishra 2014). The economy, demography, biodiversity, ecology and landscape of Kumaun are controlled by five watersheds of the region namely Ramganga, Kosi, Gaula, Saryu and Gagas. Kosi watershed which is a spring fed system, due to its dependence on precipitation and spring resurgence, is under critical water stress. Water availability is a function of runoff, groundwater flow and net storage. Drying up of perennial streams, evidence of died springs and diminishing discharge and rapid declining of summer flows in Kosi River are threatening not only human sustainability but also the biodiversity of this region. The major reasons suggested by researcher are rainfall variability (Negi and Joshi 2004) and complex hydrogeological behaviour of springs. Spring water in Kumaun is stored in the form of unconfined aquifers in most of the cases where the water comes out under the action of gravity, and therefore, rainfall variability and pattern affect spring water discharge. Secondly, the increasing water demand with increasing population and decreasing water discharge of spring widens gaps in water demand and supply. Rawat (2014) indicated that the perennial streams in Kosi watershed are disappearing inch by inch every year, and the total length of perennial streams has decreased from 225.89 km (a situation across 40 years back) to 41.57 km in 2014. Because of transformation process of perennial to seasonal streams in Kosi watershed, discharge of the Kosi River in summers has decreased very fast. The minimum summer discharge (i.e. the base flow) of the Kosi River was recorded 790 l/s in 1992 which drastically declined up to 80 l/s in 2013. Another research conducted by G.B. Pant National Institute of Himalayan Environment & Sustainable Development (GBPNIHESD) indicated that demand for water in Kosi watershed has increased from 8836 Cu m/day (2001) to 10,910 cu.m/day (2011) for human and 6110 cu.m/day (2007) to 7393 cu.m/day (2014) for livestock and predicted rise in water demand from 45 to 85% in the next 18 years for different socio-economic scenarios. With climatic changes and declining precipitation, drying springs are unable to feed future water demand of increasing population. Peculiar hydrological characteristics of a watershed, geology, slope, aspect and climate (Jaturon et al. 2014; Kumar and Shankar 2014) and is reflected in terms of land use practice, occupational structure and social, cultural, floral and faunal biodiversity. Therefore, the study of a watershed needs to be conducted in systematic approach considering one and each component affecting or affected by the different parameters acting in watershed.

Researches on discharge of Kosi River indicated that future of Kosi River is depressing. The diminishing discharge of springs in Himalaya continuously reported by various researchers (Valdiya and Bartarya 1989, 1991; Negi and Joshi 2004; Joshi and Kothyari 2003) indicated that these traditional sources of water have become unsustainable to fulfil future water demand. In view of perturbed hydraulic situations and increasing water demand, the need of the hour is to formulate mechanical and biological treatment for rejuvenation of spring-fed rivers. Geomorphologic features combined with structures such as joints/fractures and lithology controls not only the flow and occurrence but also quality of groundwater. Generally, the conventional methods of investigation like field-based hydrogeological and geophysical resistivity survey are costly (Singh and Prakash 2003) and do not always consider the varied factors that control the groundwater movement and occurrence in aquifer (Oh et al. 2011). Results are therefore not as consistent as they may perhaps be in case of complex terrain using these traditional techniques of groundwater exploration (Murthy 2000). In view of above constraints of conventional techniques, groundwater potential investigation required a cumulative approach which can count each factor responsible for peculiar hydrological characteristics of a watershed. Recent advancement in techniques of remote sensing has proved indispensable for environmental monitoring, geographical and geomorphologic mapping, climatic condition, hazard mapping, resource estimation and management, urban planning and many more applications (Chowdhury et al. 2009). Hence, in search for groundwater potential mapping, it offers the current spatial character of general information on landforms, geology, soils, LULC, drainage and slope very quickly and reliably, even with less expenditure and labour than traditional techniques (Gumma and Pavelic 2013). Various researches have been carried out to delineate groundwater recharge potential throughout the world by utilizing remote sensing and GIS-based methods. Researchers established that GIS provide spatial autocorrelations between governing factors in complex hydrogeological system by incorporating spatial data with database of water resources and present more realistic and extensive view of complete watershed (Fortes et al. 2005; Chenini et al. 2010). Various studies have been conducted in various regions of the globe in order to identify and delineate groundwater recharge potential zones using advanced remote sensing and GIS-based techniques (Krishnamurthy et al. 2000; Shaban et al. 2006; Solomon and Quiel 2006; Tweed et al. 2007; Riad et al. 2011). During the past few decades, researchers found multi-criteria decision analysis (MCDA) as an effective method that provides a framework for water resource management and planning (Pietersen 2006; Jha et al. 2010).

Widening gap between increasing water demand due to increasing population and decreasing supply due to diminishing discharge of springs and streams in Kosi basin needs implementation of an appropriate water management system that has capacity to cope with the situation. Groundwater recharge is the only remaining solution with planners and resource managers to preserve existing water resources and restraint depleting groundwater levels. Identification of site suitable groundwater recharging structures is a prerequisite in this effort. Integrating thematic layers of controlling factors such as LULC, lithology, geomorphology, structure, slope, drainage density, and soil with expert knowledge and knowledge-driven factor analysis provides a way to look into complexities that arises due to different factors and assessing the overall recharge capacity. In view of depleting water sources and to augment groundwater, the present study is an effort to delineate groundwater recharge potentiality in the complex hydrogeological mountainous watershed for identification of sites for groundwater augmentation as the necessity to revitalize dying spring and streams of Kosi basin.

2.2 Materials and Method

2.2.1 Characteristics of Study Area

The Upper Kosi watershed lies in Kumaun region of Kumaun Himalaya; fed by numerous tiny springs and rainfall, river Kosi is said to be the backbone of economy, basis of biodiversity and habitat sustainability. Hydrology of Kosi watershed is controlled by different landscapes (tectonically and fluvial), soil and geology and modified by various landforms (dissected valley, terraces, ridge), microclimate and demography (Fig. 2.1).

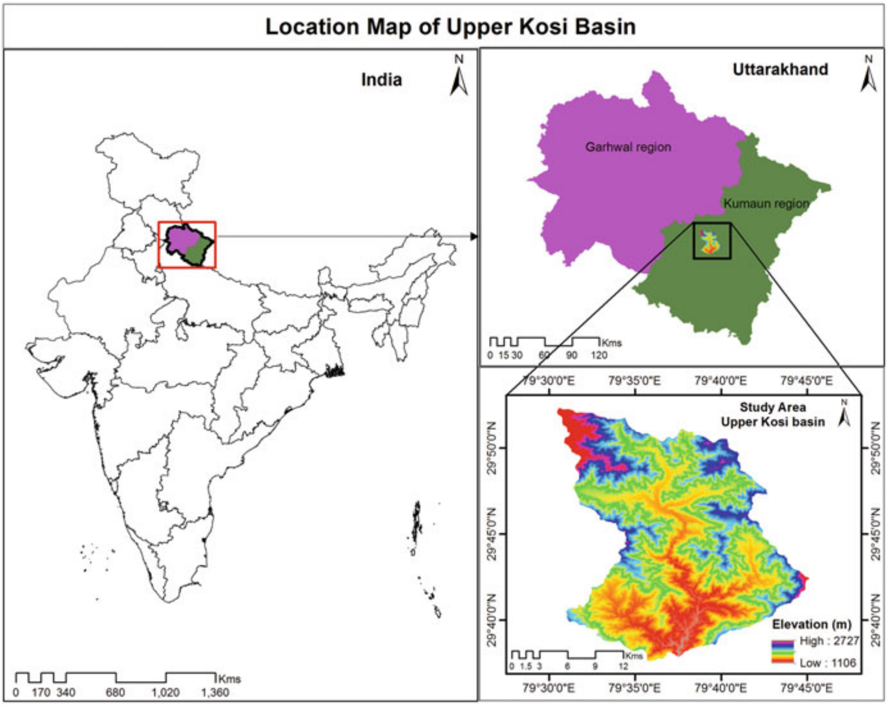

Fig. 2.1 Location of study area

The Kosi River originates from its northernmost point at Pinath (near Kausani, Almora district), which flows downward and joins Ramganga in Ramnagar as its major tributary. Geographically, the catchment of Upper Kosi River (the northernmost sub-watershed of Kosi River basin) has its spatial extent between 29° 37′ 30″ N to 29° 52′ 20″ N and 79° 31′ 00″ E to 79° 45′ 00″ E which covers an area of about 462 sq.km. The absolute relief of the catchment ranges between 1106 m and 2758 m above mean sea level.

The climate of the watershed is temperate with summer, rainy and winter as three distinct seasons. As climate is regarded a controlling factor for land use, complexities of the landscape promote variations in microclimatic phenomena and influence the soil and vegetation. The watershed represents diverse agricultural land (irrigated to rain-fed, less fertile terraces to highly productive valley, food grains (wheat, paddy), vegetables, etc.) but highly dependent upon water supply from Kosi River. The wide and open valley and bench terraces containing thick layer of alluvium and suitable climate condition were prime factors that encouraged the settlements of human population in the region. The ultimate storehouse of water in Kumaun region is the mountain groundwater in the form of spring water (locally known as 'naula', 'dhara' and 'gadhera') at up/middle/down slopes. Most of the people residing in rural (64,202, Census 2011) places heavily depend on these resources for drinking and all other uses. The undulating topography, diverse microclimatic conditions, etc. also pose some difficulty in the efficient distribution of natural water resources. Springs in the Kosi watershed are now under stress due to climatic variation, increasing population/water demand and poor management of water resources. Water stress and drying spring are raising question on the sustainability of Kosi watershed. Water conservation and proper management are the only solution left for hydrological sustainability of the watershed.

2.2.2 Data Collection and Preprocessing

Watershed boundary was delineated from integrated use of Survey of India (SOI) topographical map and CartoSat-2 Digital Elevation Model (DEM) acquired from NRSC-Bhuvan. Slope of the area was generated with contour interval of 10 m using DEM. SOI maps were first scanned and converted into digital format and geo-referenced (projection-UTM, spheroid and datum-WGS 84, Zone 44 North). Geo-rectified satellite data of IRS Resourcesat-2 (LISS-IV sensor) was utilized for preparing land use/land cover map (1:10000 scales) after performing radiometric enhancement for better analysis and identification of features. For assimilating information on soil and geology, soil map was procured from National Bureau of Soil Survey and Land Utilisation Planning (NBSS&LUP), Nagpur, and geology map procured from Geological Survey of India (GSI) on 1:50,000 scale. The secondary information acquired on lineaments, geomorphology and lithology was collected and co-registered using high-resolution LISS-IV sensor (5 m). All these maps were rectified using ERDAS Imagine 2013 and put into geo-database for further processing in ArcGIS-10.3 software.

2.2.3 *Multi-criteria Decision and Weightage Sum Analysis*

The major challenge faced by hydrogeologist is the quantification of controlling factors and proportional influence of one factor for controlling GW recharge and discharge over the others. Multi-criteria decision analysis (MCDA) evaluates multiple conflicting criteria in decision-making where conflicting criteria are typical in valuing options. GIS-based multi-criteria decision analysis provides good functionality for mapping potential of groundwater revival (Chenini et al. 2010). In case of complex hydrogeology and formations, multiple factors influence the recharge potential of a region but in different proportion. In multi-criteria evaluation technique, experts have liberty and judgment on relative weights of controlling factors for assessment of recharge potential (Kaliraj et al. 2014). The judgment lies in the assigning appropriate weightage to these factors. Principal geomorphologic and hydrogeological controlling factors on groundwater flow systems in groundwater–surface water interactions have been identified, and weightage has been assigned based on their relative impact (Magesh et al. 2012). Integration of these controlling factors and their potential weights has been calculated using weighted sum analysis method in ArcGIS.

2.3 Results and Discussion

2.3.1 *Relief Aspect and Recharge Potentiality of Basin*

Upper Kosi River is a seventh-order stream, elevation between 1150 m and 2700 m asl, following dendritic to sub-dendritic pattern at major scale as major tributaries join main streams at angle less than 90°. This type of pattern develops in a region underlain by homogeneous material. It indicated that the subsurface geology has a similar resistance to weathering throughout the catchment, and there is no apparent control over the direction of river. But at minor scale, the first- and second-order streams join higher-order stream at sharp angle at many places showing trellis pattern. Trellis pattern at local level indicated the development of folded topography. Rectangular pattern at some place indicated the impact of joint and fractures at local scale. Drainage density is dominant factor for identification of potential recharge sites. Drainage density is termed as the closeness of spacing the drainage channels and computed by dividing the total length of the stream by total basin area (Singh et al. 2014).The occurrence of a natural drainage system is an indirect sign of high porosity and permeability due to its direct relationship with surface runoff (Krishnamurthy et al. 2000). A region with low drainage density causes more

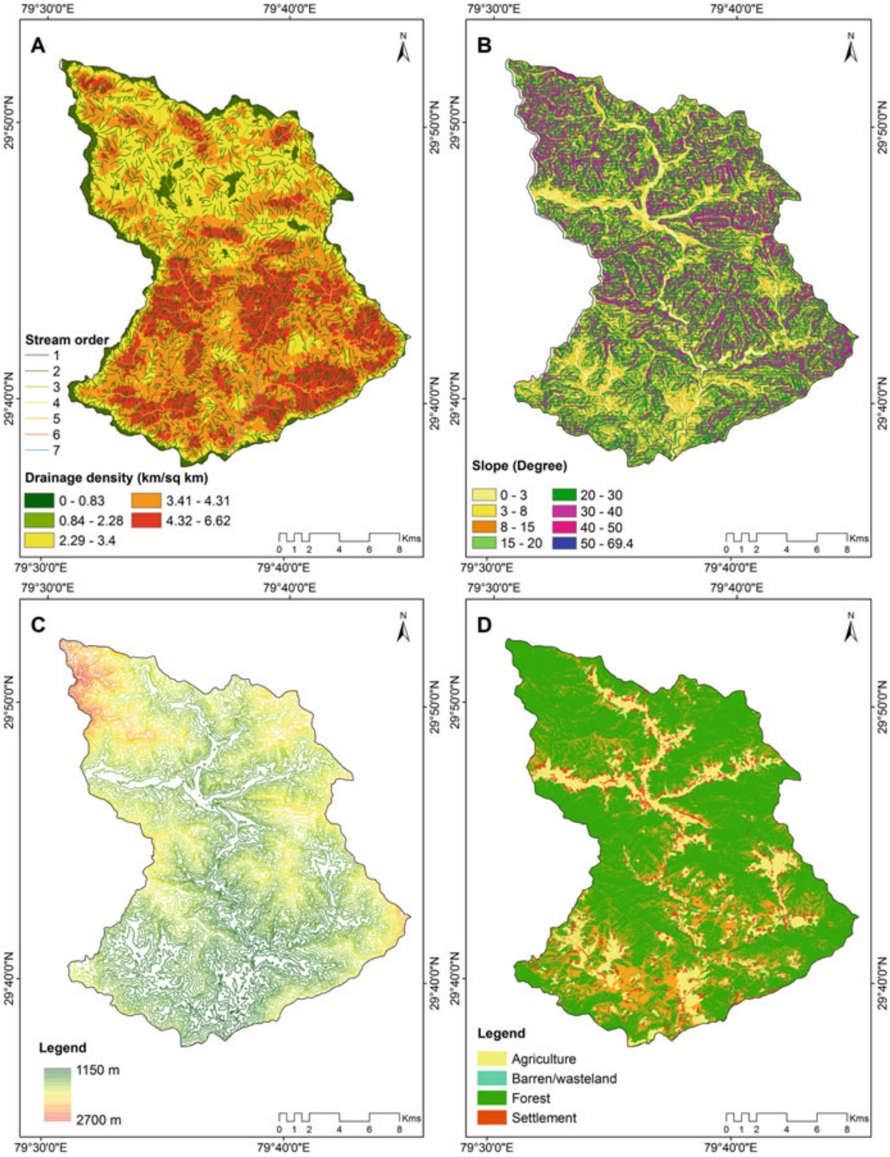

Fig. 2.2 Relief aspects of basin controlling hydrological behaviours of the region. (**a**) Stream order and density, (**b**) slope angel, (**c**) contours and (**d**) land use and land cover

infiltration and lowered runoff. It means that areas having high drainage density have lower potential of groundwater recharge and not suitable for implementation of groundwater augmentation measures (Dinesh Kumar et al. 2007). Drainage density of the basin lies between 0 and 6.6 km/km^2 indicating various degrees for recharging groundwater (Fig. 2.2a).

Degree of slope also influences the surface water infiltration directly. Steep slope enhances velocity of surface runoff, therefore reducing percolation (i.e. infiltration is inversely proportional to the slope) thus adversely affecting the process of groundwater recharge (Adiat et al. 2012). Steep slopes have less potential of recharging as it allows water to flow downwards providing inadequate time to permeate. Alternatively, flat terrain escalates the process of groundwater recharge by storing rainwater and by providing restrained evaporation environment. Out of total catchment area of watershed, 3.6% is under <3° and considered as flat surface with comparatively high recharging capacity, but at the same time, 90% of this area is under river channel which is again not good for recharging groundwater due to saturated soil and thus low infiltration capacity. Therefore, this area has been masked while preparing potential recharge zone map. 52.6% area is having >20° slope and considered higher runoff zone with lower groundwater recharge (Fig. 2.2b, c). Dense forest cover obstructs reduces the velocity of surface runoff thus increases infiltration, while build-up (settlement, roads) allows flow of water due to higher degree of relative imperviousness therfore contributes to very low infiltration. In Upper Kosi watershed, 64% area is covered under forest and provides fair amount of infiltration (Fig. 2.2d). But at the same time, 40.8% (153.4 km^2) area lies under reserved forest where intervention is not possible without collaboration with forest department. Relief aspects of basin such as slope, drainage, stream order and density affect the recharge potential by controlling runoff and, therefore, need to be studied in identifying ideal site for groundwater augmentation.

2.3.2 Structural Aspect and Recharge Potentiality of Basin

Soil permeability coefficient among the leading factors in recharging groundwater (Eid et al. 2006). Major soils in the watershed are ‘Typic Udorthents associated with Dystric Eutrochrepts’ which are a moderately deep, coarse loamy soil with moderate erosion tendency (61.4%). Further, Dystric Eutrochrepts associated with Typic Udorthents are also found at upslope and hilltop which are characterized as deep, fine loamy soils, with slight erosion (18.4%), and Typic Udorthents as moderately deep, coarse loamy soil (20.2%) found at high slopes which is moderately eroded soil (Fig. 2.3a). Ayazi et al. (2010) stated that lithology influences the porosity and permeability of aquifer rocks. Basin lithology is dominant by quartzite of *Berinag formation*, schist and gneiss of *Saryu_Gumalikhet_Munsiyari Formation*, slate of *Ratgaura* formation, dolomite of *Deoban (Gangolihat) Formation* and gneiss of Augen Gneiss (after Valdiya 1978, Fig. 2.3b). Two elongated tectonic belts of sedimentary/meta-sedimentary rocks are separated by ESE-WNW trending crystalline zone, namely, Almora-Dudhatoli. The outer sedimentary belt, i.e. Krol Belt, lied to the southern side of the crystalline mass, while the inner sedimentary belt, i.e. Deoban-Tejam zone, lied to the north (Gansser 1964; Valdiya 1978). The impact of variable rock group reflects spatial variability in recharging capacity in the study area. Lineaments reflect a general surface appearance of fractures lied underground

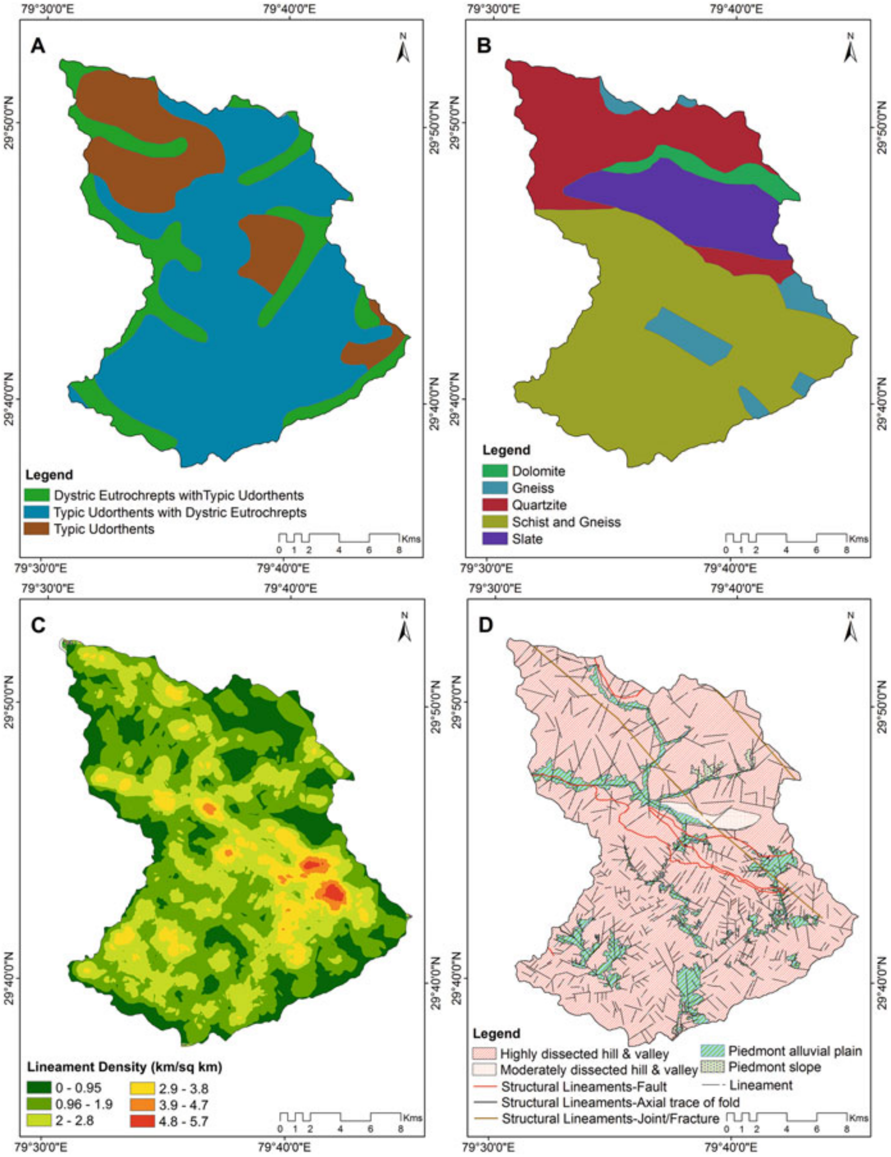

Fig. 2.3 Structural aspects of basin controlling hydrological behaviours of the region. (**a**) Soils, (**b**) lithology, (**c**) lineament density and (**d**) geomorphology and lineaments type

(Pradhan 2009). Lineaments in the form of faults and fracture/joints represent geological discontinuities and act as pathway for groundwater percolation and storage. The contribution of lineaments on runoff, infiltration and groundwater recharge are well documented by Subba Rao et al. (2001) and Chenini et al.

(2010). Quantification of lineaments was done either on the basis of density (Dinesh Kumar et al. 2007) or presence and absence of lineament (Babus and Sashikumar 2010). The Upper Kosi basin is characterized by structural lineament (Fault, fracture/joint) and fluvial lineament (drainage parallel) as indicated in Fig. 2.3c. For quantification of the relative influence of lineament, the density of lineament (km/km^2) was computed.

Evolution of landforms provides helpful information to understand the incidence of permeable and porous zones; and therefore, for recharging groundwater the study of geomorphology of a region is considered as an essential component. Four major geomorphic units have been identified in the study area, viz. highly dissected hills and valley, moderately dissected hills and valley, piedmont alluvial plain and piedmont slope (Fig. 2.3d). Major geomorphology of the area is highly dissected hills and valley (89%) which has moderated capacity of infiltration. Krishnamurthy et al. (2000) suggested that less compact zone with higher degree of fracturing and weathering assist runoff infiltration and therefore are comparatively suitable in hard rock terrain for recharging groundwater. This way, the structural aspect of basin has been thoroughly studied and assigned comparative weightage based upon expert knowledge and published literature for assigning impact of these factors in evaluation of recharge potential.

2.3.3 Recharge Potential Evaluation and Mapping

With the aim to evaluate potential of recharge in the watershed, relief aspect and structural aspect of watershed have been studied. Simple approach of assigning weightage has been adopted for quantification of complex hydrogeology. Different relief and structural components as well as LULC of watershed have been classified into different categories by assigning rank on 1–5 scale. Rank has been assigned based upon comparative recharge capacity of different classes as a controlling factor. Rank 1 has been assigned to class in a layer having higher recharge potential than other categories. Similarly, higher rank has been assigned to class with lower potential for recharge. Different layers and their ranks have been shown in Table 2.1. After assigning rank, weighted sum analysis method was used for calculation of a multi-criteria analysis between thematic layers of controlling factors.

The weightage assigned to each factor was equally distributed in different classes of corresponding factor for computing overall weightage. Thereafter, sum of weightage in each class was computed and divided into five equal categories indicating excellent to poor recharge potential. Recharge potential zones are identified though weighted sum indicated that 5.1%, 14.5% and 33.4% area in the basin lies under excellent, good and moderate recharge potential, respectively, while 31.7% and 15.2% area under fair and poor recharge potential. Recharge potential area identified in Fig. 2.4 can be used as a base map for identification of ideal sites for implementing suitable groundwater augmentation measures and conservation of watershed.

Table 2.1 Hydrogeological controlling factors, their categorization and rank assigned

Controlling factors and their weight	Categories	Rank on scale (1–5)
Slope (19.2)	< 3 = excellent	1
	3–8 = good	2
	8–15 = moderate	3
	15–20 = poor	4
	>20 = nil	5
Lithology (15.4)	Dolomite = excellent	1
	Schist = good	2
	Slate = moderate	3
	Quartzite = poor	4
	Gneiss = nil	5
Soil (11.5)	Typic Udorthents associated with Dystric Eutrochrepts = excellent	1
	Typic Udorthents = good	2
	Dystric Eutrochrepts associated with Typic Udorthents = moderate	3
Geomorphology (11.5)	Piedmont alluvial plain = excellent	1
	Piedmont slope = good	2
	Moderately dissected hill and valley = moderate	3
	Highly dissected hill and valley = poor	4
Land use /land cover (15.4)	Agriculture = excellent	1
	Forest = good	2
	Wasteland/ barren = moderate	3
	Build-up/settlement = poor	4
Stream density (15.4)	<0.83 = excellent	1
	0.84–2.28 = good	2
	2.29–3.40 = moderate	3
	3.41–4.31 = poor	4
	>4.31 = nil	5
Lineament density (11.5)	<0.95 = negligible	5
	0.96–1.90 = poor	4
	1.91–2.80 = moderate	3
	2.81–3.80 = good	2
	> 3.80 = excellent	1

Groundwater augmentation measures in the form of chal-khal, percolation tank, contour trenches, bioenineering structures like live check dams, rip-rap drains etc. store water in recharge zone and facilitate infiltration which helps in increasing the aquifer storage and sustenance of drying spring. Recharge potential in current study has been predicted using remote sensing-based data and GIS tools and found that these data and technique provide excellent platform for quantification of spatial data for assessing groundwater recharge potential. But the limitation of identifying recharge potentiality is that the error or accuracy in methods of proportionate weight

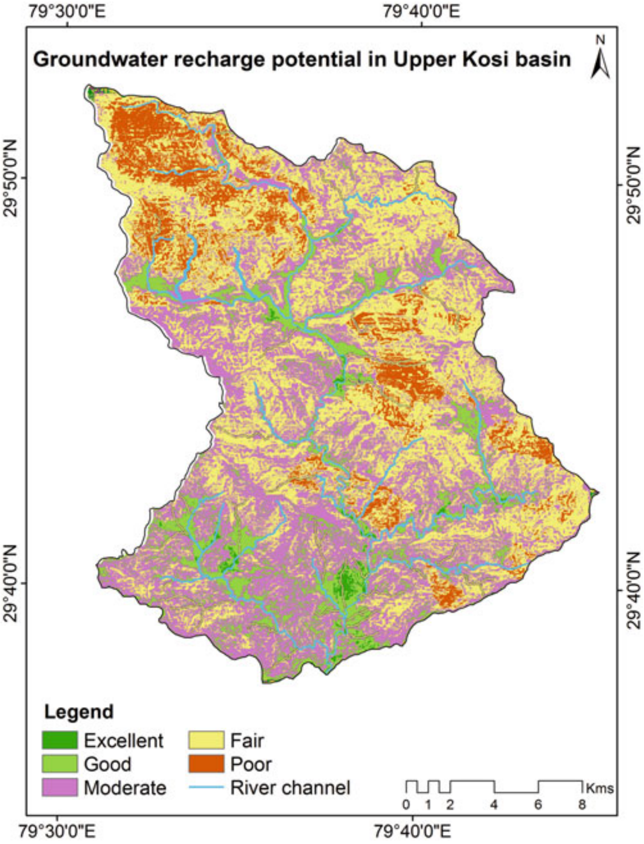

Fig. 2.4 Groundwater recharge potential in Upper Kosi basin, Almora, Uttarakhand

assignment is not assessed. On the other hand, some factors work independently in recharging groundwater. In case of lineament, the control of other factors becomes negligible because the water flows through joints or cracks independent of other factors (slope, lithology, LULC, etc.). Similarly, in case of drainage, the area around channel is saturated with very poor or nil recharge potentiality, while other factors in same area may indicate good or positive sign of recharge potential (low slope, agricultural land, alluvial deposit, etc.). In such cases, the water body buffer has been masked and assigned poor potential. The technique of assigning weightage and ranking is good for comparing and identifying in case of remaining factors, but alternative techniques can be developed through discussion with expert for quantification of these two factors, viz. lineament and drainage.

2.4 Conclusion

Thematic data availability, level of accuracy, hydrogeological conditions and government policies play a vital role in groundwater management activities. The relationship of hydrogeological factors is extremely useful for recharge estimation and groundwater resources evaluation in any kind of topographical region. Remote sensing data with integration of GIS techniques provide facility for utilizing various hydrogeological components like slope, lithology, structure, rainfall, soil, LULC and drainage on single platform and provide quantification techniques of these components in a judgmental way for identification of groundwater recharge potential zones. The study has established the ability of remote sensing data together with GIS technique for delineation of groundwater projection, especially in the complex hydrogeological terrain. Identifying the groundwater recharge potential zones in Upper Kosi basin of Almora district using remote sensing and GIS methods is competent to curtail the time, manpower and money. Although the proficiency in assigning weightage and quantification of accuracy level (ground truth data accuracy) is a limitation, it provides spatial view of recharge potential area with various degrees of variability and provides flexibility of decision-making by modifying the weightage. The recharge potential map prepared in this study can provide a guideline for construction of recharge structures and adopting conservation measures to preserve hydrological sustainability of the watershed. The recommended methodology will guide researcher and water departments for future groundwater exploration, development, and management in mountainous catchment. Future scope of the new emerging space technology-based modelling techniques lied in (1) understanding and quantification of independent and interdependent factors that control the spatial distribution hydrological factors, (2) challenges of modelling cumulative impact of these factors with altering land use and changing climate, (3) identification of suitable sites for augmentation work for recharging aquifer for sustainability of groundwater resource.

Acknowledgements The financial support provided by the National Mission on Himalayan Studies (NMHS), Ministry of Environment, Forest and Climate Change (MoEF&CC), New Delhi, for conducting this research is duly acknowledged. The authors also wish to acknowledge the Principal Investigator of the project Er. Soukhin Tarafdar, Scientist D, G.B. Pant National Institute of Himalayan Environment & Sustainable Development (GBPNIHESD), Garhwal Unit, Srinagar, Garhwal, Uttarakhand. The efforts and hard work of Junior Project Fellow Mr. Darshan K Bhatt, Field Assistants Mr. Vikram Negi, Mr. Pramod Kandpal and Mr. Mohit Chandra are appreciated for collecting water samples and conducting field surveys. Authors are grateful to the Director, GBPNIHESD, Kosi-Katarmal, Almora, Uttarakhand, for providing lab facility and field instruments.

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