Sustainable development planning in Pathri Rao sub-watershed using geospatial techniques

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This study demonstrates the application of remote sensing, GIS and GPS for preparation of sustainable land and water resources development action plans for Pathri Rao sub-watershed in Haridwar district of Uttarakhand. High resolution IKONOS satellite imagery was used for detailed land use/cover mapping on 1 : 12,500 scale. Various primary and secondary database layers on land use/cover, forest density, biodiversity, slope, aspect, elevation, hydrogeomorphology, soil types, soil erosivity and crop suitability were generated. The study also considers the social, ecological and economic factors. A set of decision rules was then applied and data layers were integrated in GIS environment for preparation of the scientific and sustainable land and water resources development action plans for the study area. The exercise indicated a good scope for geospatial techniques in integrated watershed development planning.

Keywords: GIS, remote sensing, sub-watershed, sustainable development.

WATER and land are the basic natural resources on which the existence of mankind depends. It has slowly and steadily been realized that the consumption of natural resources by the rapidly growing human and livestock populations is higher than their natural regeneration capacity. This has affected the carrying capacity of the ecosystems throughout the world and created an ecological imbalance. The disregard to the conservation of nature and natural resources is likely to impact the future generations, who stand to lose a lot in terms of the availability of natural resources. The scientists, planners and decision makers are slowly turning their attention towards sustainable development, a concept suggested by the World Commission on Environment and Development (WCED). Sustainable development has been defined as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'[1]. The Food and Agriculture Organization's definition, 'sustainable development is the management and conservation of natural resources base and the orientation of technological and institutional changes in such a manner so as to ensure the attainment and continued satisfaction of human needs for present and future generations'[2], is considered to be the most comprehensive. The essence of sustainable development planning is to look for the management practices in which the resources are handled and managed sustainably. Such a development emphasizes the maintenance of productivity of natural resources, especially land and water, while retaining the ecological equilibrium.

The concept received much needed impetus after the Rio Conference in June 1992, mainly through the 27 principles on sustainable development and the action plan called Agenda 21 (ref. 3). The approach was followed up in a big way during the World Summit on Sustainable Development in 2002 at Johannesburg. The summit re-emphasized the need for strengthening the three pillars of sustainable development, viz. economy, society and the environment[4]. The watershed forms an appropriate unit for analysing the development-linked resource problems, designing the appropriate solutions of identified problems and eventually testing the efficacy of the prescribed solutions[5,6]. Because watersheds and their environments also have direct or indirect bearing on human lives, it becomes necessary to devise the proper management of resources in these areas. The watershed approach is a system-based approach that facilitates the holistic development of agriculture, forestry and allied activities in the watershed[7]. Sustainable watershed development planning requires high resolution and accurate spatial data, and knowledge of the ecology and socio-economy.

Remote sensing provides effective support in terms of relevant, reliable and timely information[8,9]. A number of studies, carried out worldwide, demonstrate the capability of remote sensing and GIS in development planning[10–15]. Spatial analysis is vital to economic performance and GIS is important for planning from local to global scales[16]. By interfacing remote sensing with GIS, different management scenarios could be generated, which could help the planners assess the feasibility of various alternatives before selecting the one that would be most suitable[17]. Kushwaha *et al.*[18] have demonstrated the method for integrated sustainable rural development planning using remotely sensed data and GIS. The objective of this study was to create a comprehensive bio-geo database using geospatial technologies, and to generate environmentally

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and socio-economically sound and sustainable land–water resources development action plans.

Study area

Pathri Rao sub-watershed (29°55′–30°03′N and 77°59′–78°07′E), covering an area of approx. 44 sq. km, is located at the foothills of Shiwaliks in Haridwar district of Uttarakhand (Figure 1). The area is drained by the river Pathri Rao and its tributaries – Chirak Rao and Harnaul Rao (*Rao* means river). It experiences three distinct seasons – summer, winter and monsoon. The temperatures range from 2°C in winter to more than 40°C in summer. The average elevation varies from 250 to 800 m above mean sea level (msl). The upper part of the sub-watershed, falling in the Rajaji National Park (RNP), has moderate to steep slopes. The RNP, a protected area, is the natural habitat for a large variety of flora and fauna, including elephants and tigers. A portion of the sub-watershed in the park is dominated by dry deciduous forests. The downstream plains are characterized mainly by the agricultural fields, where both winter (locally called *rabi*) and rainy season (locally called *kharif*) crops, viz. wheat, sugarcane, groundnut and maize, are grown. Besides, there are mango and guava orchards and eucalyptus, poplar and bamboo plantations.

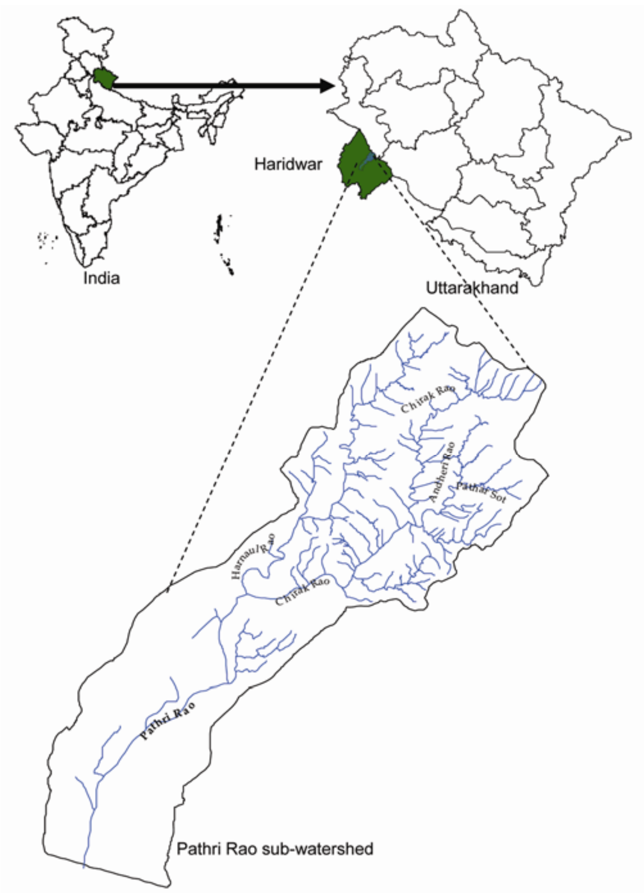

Figure 1. Location of the study area.

Water scarcity is a major problem and most of the agriculture is rain-fed. Riverbank erosion and consequent loss of productive agricultural land is common during the monsoon. The groundwater table has receded over time due to over-use of water for drinking and irrigation in the lower piedmont area. Local people have turned to other professions for sustenance in spite of the availability of agricultural land. The area is deficient in food grains as well as fodder. The situation worsened with the relocation of the gujjars in the sub-watershed from the RNP. There are also large tracts of culturable wasteland. No major soil or water conservation measures are practised in the area.

Data

The Survey of India (SOI) topomaps on 1 : 25,000 scale (Lambert conformal conic projection), IKONOS satellite image of November 2004 (1 m resolution) and LISS-III + PAN merged data (5.8 m resolution) were geo-referenced using WGS 84 zone 44N datum, Universal Transverse Mercator (UTM) projection and ground control points (GCPs). The scale of the study was 1 : 12,500.

Methods

Database generation

A watershed boundary was procured from the Uttarakhand Watershed Management Directorate at Dehradun. This was used as the reference for delineation of the final watershed boundary using the contours at 10 m interval from the digital toposheet on 1 : 25,000 scale, specially provided by the SOI for the study. The boundary was then overlaid on the satellite image to extract the study area. Resource information extraction was done using remote sensing data and field surveys. The land use/cover map was prepared from IKONOS image using on-screen visual interpretation. The land use/cover map was field-verified for classification accuracy assessment. For soil mapping, the satellite image-derived physiographic units were field investigated. Horizon-wise soil samples were analysed for physical and chemical properties. The groundwater potential of the area was inferred from the hydrogeomorphology map prepared using satellite data and field survey. Crop suitability map was prepared using the soil parameters such as pH, texture and erosion to derive criteria and rating for crop suitability following overlay analysis. The crop suitability map was compared to the present land use to determine the most appropriate recommendation for the conservation of soil and the increase in crop yield. Subsidiary information such as roads, drainage, settlement, village locations and slope

Table 1. Decision rules for land resources action plan development

Slope (%)	Groundwater	Land use/cover	Suitability	Action recommended
25–35	Very poor	Dry deciduous (< 10%)	Forest	Reforestation
> 35	Very poor	Dry deciduous (< 10%)	Forest	Reforestation
10–25	Very poor	Dry deciduous (< 10%)	Forest	Reforestation
3–10	Very poor	Dry deciduous (< 10%)	Forest	Reforestation
1–3	Very poor	Dry deciduous (< 10%)	Forest	Reforestation
0–1	Very poor	Dry deciduous (< 10%)	Forest	Reforestation
0–1	Very poor	Dense scrub	Forest	Reforestation
3–10	Very poor	Dense scrub	Forest	Reforestation
1–3	Very poor	Dense scrub	Forest	Reforestation
10–25	Very poor	Dense scrub	Forest	Reforestation
25–35	Very poor	Dense scrub	Forest	Reforestation
> 35	Very poor	Dense scrub	Forest	Reforestation
10–25	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
25–35	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
> 35	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
3–10	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
1–3	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
0–1	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
> 35	Very poor	Dry deciduous (10–40%)	Forest	Gap filling
25–35	Very poor	Dry deciduous (40–70%)	Forest	Gap filling
0–1	Poor	Wasteland with scrub	Not suitable	Fuel and fodder plantations
1–3	Poor	Wasteland with scrub	Not suitable	Fuel and fodder plantations
1–3	Poor	Wasteland with scrub	Not suitable	Fuel and fodder plantations
0–1	Poor	Wasteland with scrub	Not suitable	Fuel and fodder plantations
0–1	Poor	Wasteland without scrub	Not suitable	Fuel and fodder plantations
3–10	Very poor	Wheat/groundnut/maize/mustard	Not suitable	Agroforestry
10–25	Very poor	Wheat/groundnut/maize/mustard	Not Suitable	Agrohorticulture
1–3	Moderate	Sugarcane	Highly suitable for mustard/maize	Mustard/maize
3–10	Moderate	Sugarcane	Highly suitable for mustard/maize	Mustard/maize
1–3	Poor	Sugarcane	Highly suitable for wheat/maize	Wheat/maize

was extracted from the SOI digital topomaps on 1 : 25,000 scale. The socio-economic data were collected by interviewing the local people and discussing with the block and district development officials. This exercise helped in the assessment of user needs.

Action plan generation

A composite layer was generated by intersecting spatial data layers on land use/cover, groundwater potential, crop suitability and slope in GIS domain and a set of decision rules were applied for land resource development action plan generation (Table 1). For generation of water resources development action plan, the soil texture, digital elevation model, slope, run-off potential and the buffer map of settlements and agriculture were integrated following decision rules (Table 2). The integrated mission for sustainable development guidelines[19] were followed for framing the decision rules for data integration. Care was taken to consider the socio-economic aspects and skills of local people before recommending any measures. Site-specific strategies for identifying areas suitable for specific crops, horticultural plantations, agroforestry and fodder development were evolved. Current practices such as cropping pattern, crop rotation, cultural practices, irrigation methods, water harvesting structures, groundwater exploration, soil and water conservation measures were examined to arrive at suitable locale-specific action plans. Figure 2 shows the overall methodology.

Results and discussion

Transport network and settlements

Nine villages, viz. Aneki Hetampur, Puranpur, Mirpur, Garh, Salempur Mahdud, Rajpur, Jhabarpur, Begumpur and Alipur are located in the sub-watershed. The Salempur Mahdud is area-wise the largest village and village Jhabarpur is uninhabited. The roads are mostly unmetalled. They get inundated during heavy rains, making connectivity a problem for the villages (Figure 3).

Soil

The study area was divided into the following four major land forms based on the variations in the physiography: (i) Siwalik hills (SH): This unit comprises moderate to steep slopes of southern Siwaliks, which are covered by trees and shrubs of different densities. (ii) Piedmont

Table 2. Decision rules for water resource action plan development

Structure	Slope	Permeability	Run-off potential
Farm ponds	Nearly level to very gentle	Low	Medium/high
Check dams	Nearly level to gentle	Low	Medium/high
Percolation tanks	Nearly level to very gentle	High	Medium/high
Waterholes in forest area	Nearly level to gentle slopes–low forest density	Low	Low

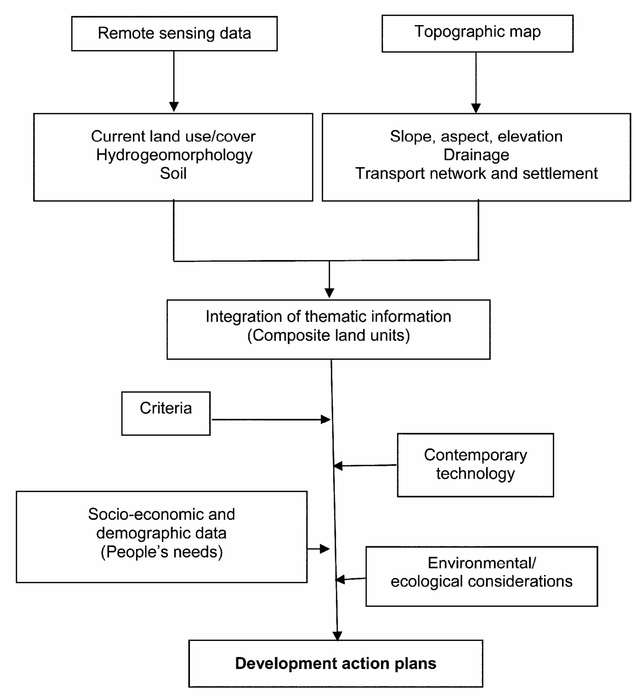

Figure 2. Paradigm of the study.

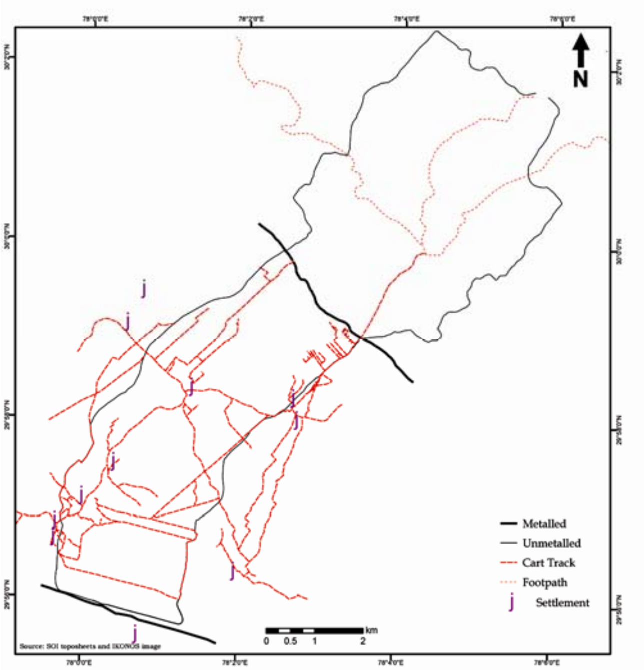

Figure 3. Roads and settlements.

(P): The piedmont plains have slopes ranging from 3% to 7%. Slight to moderate soil erosion was observed. (iii) Alluvial plain (AP): This soilscape unit is formed by the Pathri Rao and its tributaries. The soils are very deep and well to poorly-drained. (iv) Flood plain (FP): The floods affect FP during rainy season for short time. These are used for cultivation of wheat, pea, groundnut, etc. The slope is less than 2% with slight to moderate soil erosion. The physiographic units were further divided into sub-units based on soil types (Table 3 and Figure 4).

Land use/cover

Twenty two land use/cover classes were identified through visual interpretation of IKONOS image (Figure 5). Forests were mapped into type and density classes (i.e. < 10%, 10–40%, 40–70% and > 70%). They were dry deciduous (> 70%), dry deciduous (40–70%), dry deciduous (10–40%), dry deciduous (< 10%), dense scrub, forest plantation, wasteland (with or without scrub), orchards, permanent fallow, agricultural bunds, river and settlements. Table 4 shows the area under each land use/cover class. The mapping accuracy was estimated to be 93%. The land use/cover map is illustrated in Figure 6.

Groundwater potential

The field survey clearly indicated that there is over-exploitation of groundwater. There has been a steady decline of groundwater table in the last few years. More than 50% of the sub-watershed area had poor ground-water potential. Only about 5% of the area had good groundwater potential. The groundwater situation in the sub-watershed is thus, grim (Figure 7). There is, however, ample scope for artificial groundwater recharge.

Crop suitability

About 50% of the area in the sub-watershed is forest. The remaining area, which comprises the agricultural land, was found to be highly suitable for growing mustard and maize. About 4% of the total area was found unsuitable for growing crops and should, therefore, be put to production of fuel and fodder (Figure 8).

Table 3. Physiography and soil

Physiographic unit	Dominant soil type	Area (ha)	%
AP11 (Alluvial plain)	FL Typic Haplustepts	50.82	1.16
AP12 (Alluvial plain)	CLTypic Haplustepts	180.81	4.12
AP13 (Alluvial plain)	CL Fluventic Haplustepts	181.11	4.12
AP21 (Alluvial plain)	CL Typic Haplustepts	247.42	5.63
AP22 (Alluvial plain)	FL Typic Haplustepts	628.47	14.31
AP23 (Alluvial plain)	CL Fluventic Haplaquepts	308.73	7.03
FP1 (Flood plain)	CL Fluventic Haplustepts	56.26	1.28
FP2 (Flood plain)	CL Fluventic Ustorthents	51.34	1.17
LP21 (Lower Piedmont)	FL Fluventic Haplustepts	117.21	2.67
LP22 (Lower Piedmont)	CL Typic Ustorthents	73.12	1.66
LP23 (Lower Piedmont)	CL Typic Ustorthents	39.93	0.91
P11 (Piedmont)	FL Humic Haplustepts	91.43	2.08
SH11 (Siwalik Hills)	LS Typic Haplustepts	733.24	16.70
SH12 (Siwalik Hills)	CL Typic Ustorthents	508.22	11.57
SH2 (Siwalik Hills)	FL Humic Haplustepts	110.27	2.51
SH31 (Siwalik Hills)	LS Typic Ustorthents	157.36	3.58
SH32 (Siwalik Hills)	CL Typic Ustorthents	426.04	9.70
SH4 (Siwalik Hills)	CL Fluventic Haplustepts	136.94	3.12
River	River	292.69	6.66
Total		4391.41	100

CL, Coarse loamy; FL, Fine loamy; LS, Loamy skeletal.

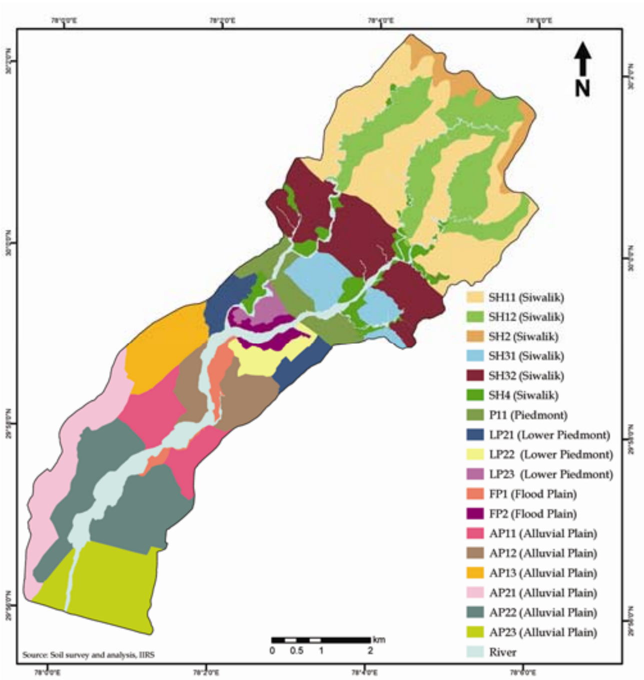

Figure 4. Soil types.

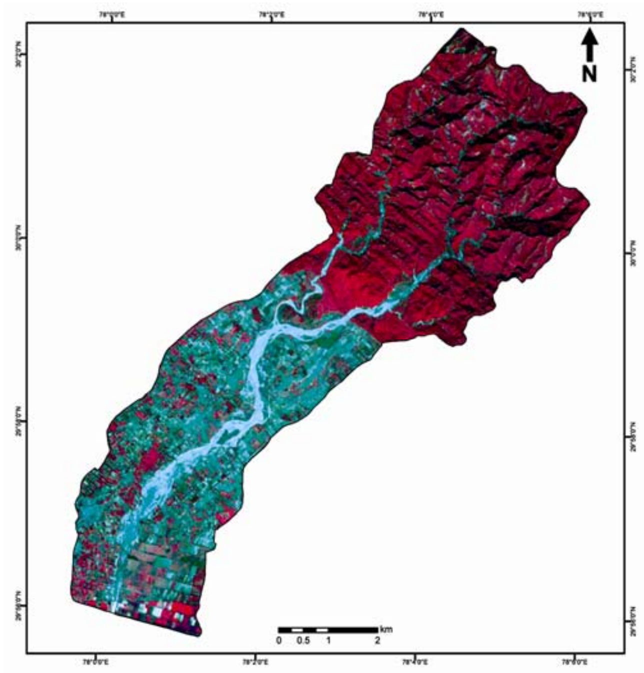

Figure 5. False colour composite (IKONOS, November 2004).

Land resources development action plan

The salient features of the recommendations were the suggestions for appropriate crops in areas that are suitable for agriculture but were not cultivated according to the current land use. Wastelands with scrub were recommended for fuel and fodder plantations to meet the increasing fodder requirements of the villagers. The forests with less than 70% density were recommended for gap filling and density improvement. Agroforestry and agrohorticulture were found useful as alternate land use practices. Sugarcane was one of the major crops grown in the agricultural area but given the poor ground water situation and the scarcity of surface water in the area, it is not recommended. Alternate crops such as wheat, maize and mustard have, therefore, been suggested for the agricultural fields where sugarcane is currently grown. Figure 9 shows the recommended land resources development action plan.

Table 4. Land use/cover classes

Land use/cover	Area (ha)	Area (%)
Forests	2051.99	46.73
Mixed dry deciduous (> 70%)	302.08	6.88
Mixed dry deciduous (40–70%)	1311.24	29.86
Mixed dry deciduous (10–40%)	249.37	5.68
Mixed dry deciduous (< 10%)	189.30	4.31
Dense scrub	116.25	2.65
Forest blank	12.33	0.28
Plantations	328.09	7.47
Forest plantation	236.82	5.39
Bamboo plantation	1.46	0.03
Orchards	89.81	2.05
Wastelands	363.81	8.28
Wasteland with scrub	103.82	2.36
Wasteland without scrub	259.99	5.92
Agricultural land	1124.78	25.61
Wheat/groundnut/maize/mustard	800.09	18.22
Sugarcane	275.88	6.28
Vegetables	2.92	0.07
Permanent fallow	30.05	0.68
Fodder	2.30	0.05
Agricultural bunds	13.54	0.31
Water bodies	279.87	6.37
River	276.77	6.30
Ponds	3.10	0.07
Built-up	102.05	2.32
Settlements	75.43	1.72
Mixed built-up land	26.62	0.61
Roads	12.38	0.28
Total	4391.54	100.00

Water resources development action plan

In rain-fed areas, rainwater harvesting could provide water during lean season for crop production. The rain-

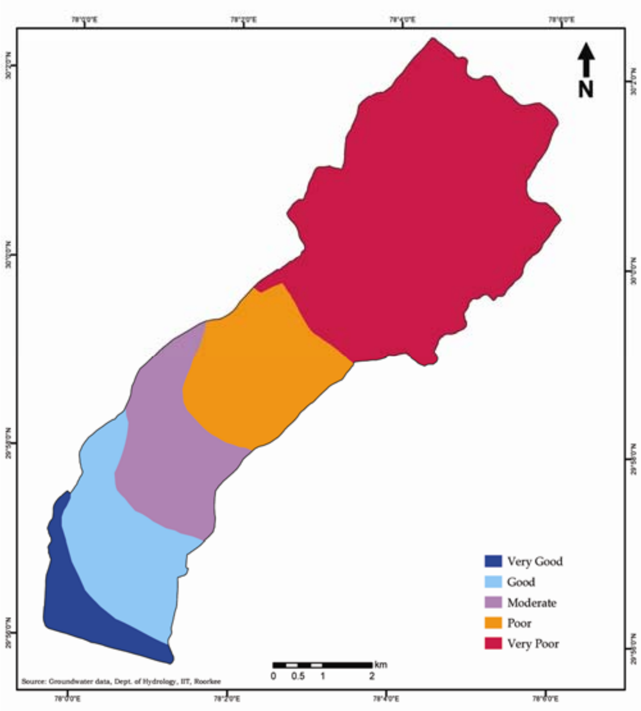

Figure 7. Groundwater potential.

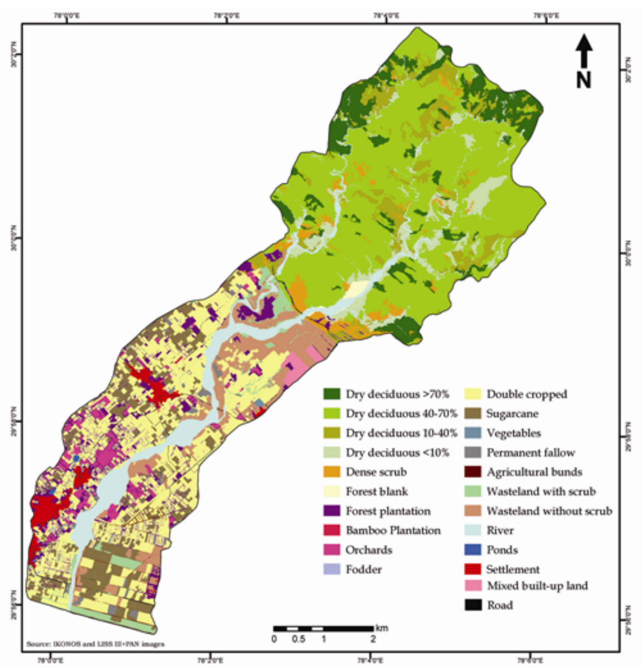

Figure 6. Land use/cover.

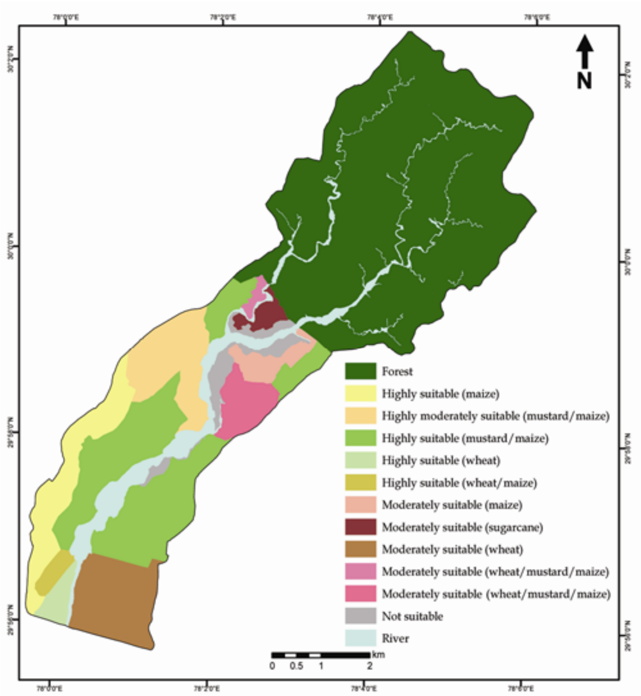

Figure 8. Crop suitability.

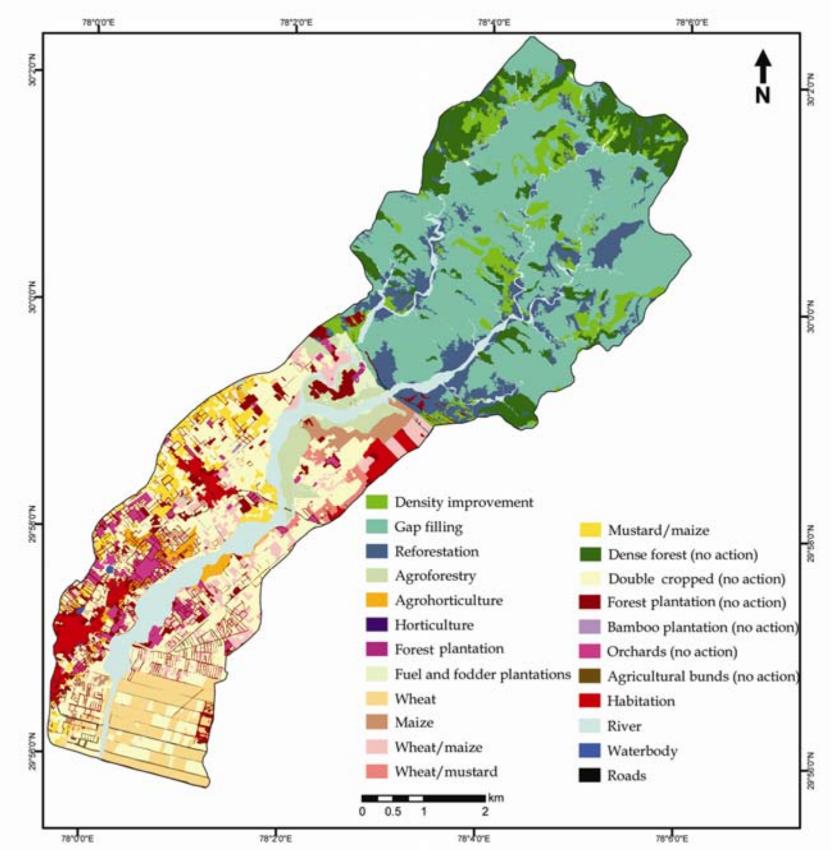

Figure 9. Land resources development action plan.

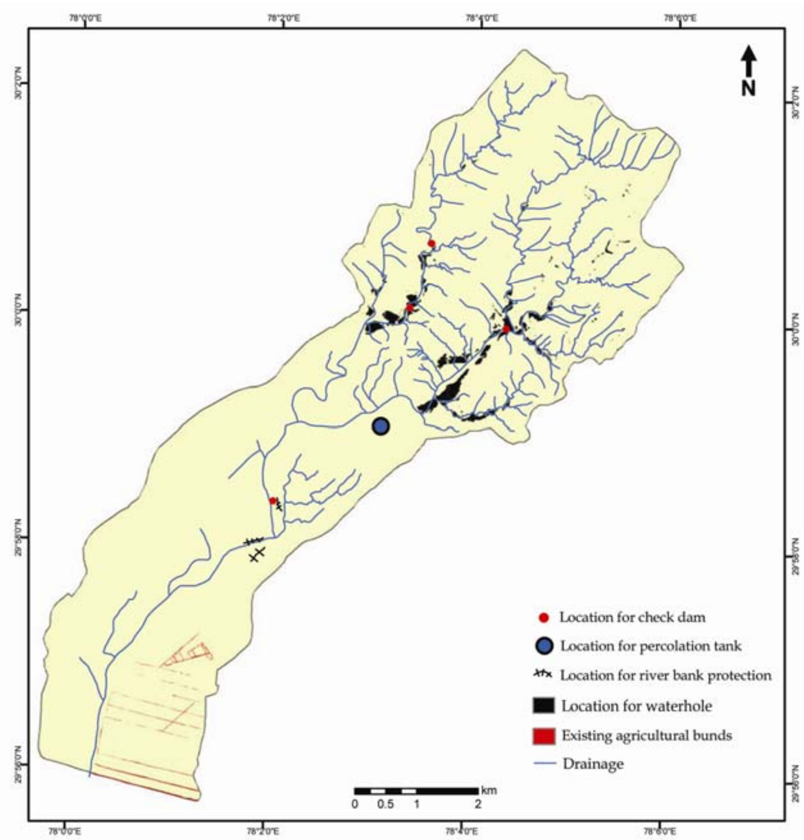

Figure 10. Water resources development action plan.

water has to be conserved and stored in different storage structures for this purpose. The latter will recharge the groundwater for its use during non-rainy months. The water resources development action plan aimed at mitigating the problem of water scarcity and riverbank erosion. Suitable sites for percolation tanks, check dams and gabion structures were identified for this purpose. Sites for waterholes, as sources of drinking water for wild animals in forest area, were also identified (Figure 10). Deepening and desilting of existing ponds and tanks was recommended for storage of rainwater during rainy season. There is also a need for better road connectivity within the watershed because the existing roads get inundated during heavy rains. There is a heavy demand for milk in Haridwar and Dehradun districts and hence, dairy development could be a profitable occupation.

Conclusions

Sustainable development occurs only when management goals and actions are ecologically viable, economically feasible and socially desirable. The underlying concept of sustainability is that of productivity and quality of the environment, and the natural resources. This can be achieved through a set of actions that would help maintain the balance between the exploitation and regeneration/replenishment of the resources within the carrying capacity of the ecosystem. As demonstrated in this study, the geospatial techniques help in generation of a reliable spatial and non-spatial information database. Such a database helps immensely in the efficient and scientific decision-making. The present approach of the sustainable development planning, through use of high resolution data, is expected to provide a model methodology for similar watershed programmes elsewhere.

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