Prioritization of sub-watersheds for sustainable development and management of natural resources: An integrated approach using remote sensing, GIS and socio-economic data

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The study area is one of the watersheds of North Pennar basin, covering an area of 570 km^2 and lies between latitude 13°55′–14°17′N and longitude 77°05′–77°25′E in Pavagada area, Tumkur District, Karnataka and a small portion in Ananthpur District, Andhra Pradesh, India, forming a part of the hardrock terrain. The drainage network shows dendritic to sub-dendritic pattern and is non-perennial in nature. Poor soil cover, sparse vegetation, erratic rainfall and lack of soil moisture characterize the area for most part of the year. Recurring drought coupled with increase in groundwater exploitation results in decline the groundwater level. The entire study area has been further divided into nine sub-watersheds, namely Byadanur, Devadabetta, Talamaradahalli, Gowdatimmanahalli, Naliganahalli, Nagalamadike, Maddalenahalli, Paluvalli tank and Dalavayihalli, ranging in geographical area from 49 to 75 km^2. It has been taken up for prioritization based on available natural resources derived from satellite images and socio-economic conditions, including drainage density, slope, water yield capacity, groundwater prospects, soil, wasteland, irrigated area, forest cover and data on agricultural labourers, SC/ST population and rainfall. On the basis of priority and weightage assigned to each thematic map, the sub-watersheds have been grouped into three categories: high, medium and low priority. The prioritization results reveal that Nagalamadike, Maddalenahalli and Dalavayihalli sub-watersheds rank highest on the basis of weightage and are considered as high priority. These sub-watersheds may be taken up with development and management plans to conserve natural resources on sustainable basis with immediate effect, which will ultimately lead to soil and water conservation.

Keywords: GIS, natural resources, remote sensing, sustainable development.

LAND and water resources are limited and their wide utilization is imperative, especially for countries like India, where the population pressure is increasingly continuous. These resource development programmes are applied generally on watershed basis and thus prioritization is essential for proper planning and management of natural resources for sustainable development. Watershed deterioration is a common phenomenon in most parts of the world. Amongst several causes, the major ones are improper and unwise utilization of watershed resources without any proper vision, which is observed in developing countries[1]. In order to combat and address these problems, sustainable development is no doubt the appropriate policy strategy. Drainage basins, catchments and sub-catchments are the fundamental units of the management of land and water, identified as planning units for administrative purposes to conserve natural resources[2–4]. The watershed management concept recognizes the inter-relationships among the linkages between uplands and low lands, land use, geomorphology, slope and soil[5]. Soil and water conservation is the key issue in watershed management while demarcating watersheds. While considering watershed conservation work, it is not feasible to take the whole area at once. Thus the whole basin is divided into several smaller units, as watersheds or sub-watersheds, by considering its drainage system. A case study has been developed on the Doddahalla sub-watershed, Bijapur District, Karnataka, wherein micro-watershed prioritization has been carried out using criteria cutting across hydrogeological, demographic and socio-economic parameters[6]. Earlier, prioritization of watersheds using remote sensing and Geographical Information System (GIS) data has been successfully attempted by several workers. They have all arrived to the conclusion that the integrated approach plays an important role for sustainable development and management of watersheds[7–13]. Sustainable development is an effort to encompass its relevant envi-

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ronmental facts, human ecological and planning basis and review of agricultural resources in their all-pervading aspects of forming intensity, productivity trends and strains, management impact on traditional and commercial systems under the ever increasing pressure of global growth of population, industrialization, urbanization, mass migrations and above all, the world-wide public awareness and concern for deteriorating environment and its conservation and to pursue a sympatic approach vis-à-vis sustainability[14].

Karnataka covers 1.91 million hectares of geographic area, accounting for 5.8% of the total geographic area of the country. Compared to other states and the country as a whole, irrigation development in Karnataka is low. Being predominantly a dry farming state like Rajasthan, drought is a serious problem in Karnataka. To combat the situation, adoption of integrated approach and developing a watershed area is the only way out. One of the approaches to address this issue is prioritization of sub-watershed on the basis of available natural resources as well as socio-economic data. It is not possible for the administration to implement watershed development and management programmes in all the areas at a time. Hence the concept of prioritization plays a key role in identifying areas which need immediate attention. Keeping this in mind, the present study has been taken up for prioritization of sub-watersheds through an integrated approach with an objective to select sub-watersheds to undertake soil and water conservation measures in 67 effective villages in Pavagada area, Tumkur District, Karnataka, using inputs from remote sensing and socio-economic data.

Study area

The study area lies between latitude 13°55′–14°17′N and longitude 77°05′–77°25′E in Pavagada Taluk, Tumkur District, Karnataka and a small portion in Ananthpur District, Andhra Pradesh. It forms one of the watersheds of the North Pennar river basin covering an area of 570 km^2 (Figure 1). The area is characterized by poor soil cover, sparse vegetation, erratic rainfall and lack of soil moisture for most part of the year. Recurring drought coupled with increase in groundwater exploitation results in declining in groundwater level. The climate of the area is semi-arid and is characterized by hot summer months, low rainfall and pleasant monsoon during winter season. The temperature varies from 22.6°C to 35.3°C during summer and 16.7°C to 27.3°C during winter season. The average annual rainfall is 560 mm.

Drainage

The drainage network shows dendritic to sub-dendritic pattern and is non-perennial in nature (Figure 2). It is also observed that in almost all sub-watersheds, new drainages have come up and a stream has changed its course in the northern side of Maddalenahalli village, as revealed by the satellite imagery. Also new tanks have been identified in Dalavayihalli and Nagalamadike sub-watersheds, covering an area of 0.27 and 0.02 km^2 respectively, and field visits to these places confirmed the same[15]. Digital Elevation Modelling (DEM) has also been carried out for the study area, which revealed that the slope is towards northeast, drainages flow in a northeasterly direction, the groundwater flow direction is from SW to NE and it finally joins the North Pennar river[16].

Slope

Slope is one of the major controlling factors in the development and formation of different landforms. The NNE, NW, western, southern and SW parts of the area show maximum relief (between 710 and 1080 m amsl), while the eastern and northeastern parts show minimum relief with elevation values ranging from 530 to 700 m amsl. The area is plain in the central and northeastern parts, whereas the topography is undulating in the remaining parts.

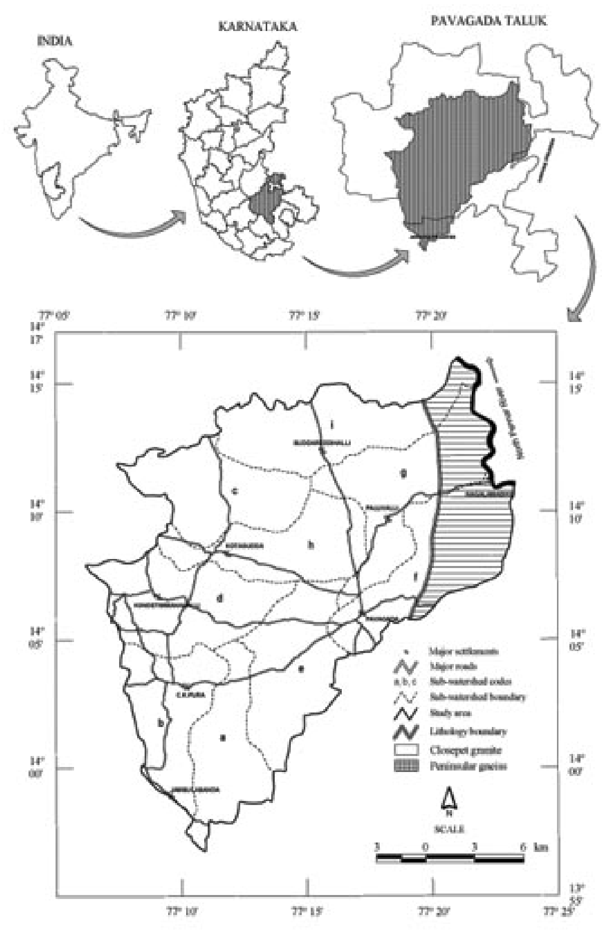

Figure 1. Location map of the study area.

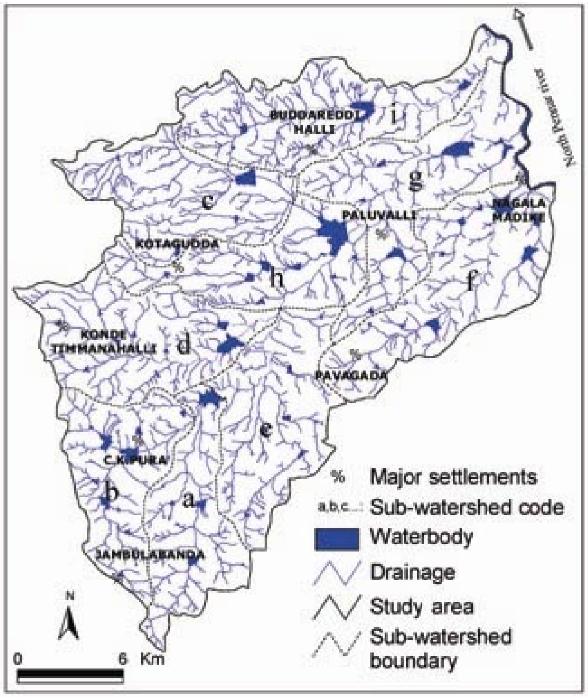

Figure 2. Drainage map of the study area.

Nearly level (0–1%), very gentle (1–3%; low-lying areas) and gentle sloping areas (3–5%) are better than the much steeper, hilly areas (5–10, 10–15, 15–35 and >35%) from the groundwater point of view.

Geology

The area forms a part of the hardrock terrain and includes two rock types, namely gneisses and granites[17]. The gneisses are intruded by a number of dolerite dykes that demarcate the boundaries of some of the sub-watersheds and are found mostly in the low-lying areas in the form of small mounds in the eastern and northeastern part of the study area. The granites form a part of the northern extension of Closepet granite batholith, which divides the Dharwar Craton into the western and eastern blocks. These younger granites constitute a well-defined narrow range of hills which run in the north-south direction and form the western part of the study area. The exposures of formation are noticed as hillocks located near Kondetimmanahalli, Maridasanahalli and Yerrammanahalli in the western part of the study area. The near-surface exposures of these granites in the low-lying areas are weathered and decomposed up to a depth of 20 m, and are coarse-grained and coarsely porphyritic in nature. These hard rocks contain no primary porosity and hence water percolates through secondary porosity formed by fracturing and weathering.

Hydrogeomorphology

An integrated approach was adopted using remote sensing and GIS techniques in the study area for evaluation of groundwater potential zones based on the characteristics of geomorphic units together with slope, geology, lineaments and borewell data[18]. The area has been classified into denudational hill, residual hill, inselberg, pediment inselberg complex, pediments, shallow weathered pediplain, moderately weathered pediplain and valley fill, which were observed both in the Closepet granites and gneisses. They are classified for groundwater prospective zones as valley fills and moderately weathered pediplains forms, very good to good; shallow weathered pediplains, good to moderate; pediment inselberg complex and pediments; moderate to poor, and denudational, residual hills and inselbergs; poor to very poor groundwater prospect zones.

Data used and methodology

In the present study, the parameters considered for prioritization of sub-watershed were from the natural resources thematic map data, including soil, drainage density, groundwater prospects, irrigated area, forest cover and wastelands derived from satellite imagery and socio-economic data (population of agricultural labourers and Scheduled Caste/Scheduled Tribe (SC/ST)). The slope map was prepared from contours of Survey of India (SOI) topographic maps (57F/4, F/7, F/8 and 57G/1) having contour interval available at 10 and 20 m. The thematic maps, excluding slope, socio-economic and rainfall data were derived from geo-referenced false colour composite (FCC) satellite image of the Indian Remote Sensing (IRS) satellite series 1-C and 1-D (LISS III and PAN fused data of 5.8 m resolution) on 1 : 50,000 scale with corresponding SOI topographic maps as reference. Initially, each thematic map was delineated based on the image characteristics like tone, texture, shape, colour, association, background, etc., following standard visual interpretation techniques[19]. The IRS satellite images for different seasons, viz. kharif and rabi have also been used for further update. For better accuracy of the thematic map, ground truth check was done for verification and necessary modifications were made in the thematic maps during post-interpretation. These thematic maps have been classified based on the methodology of Natural Resource Information System Node Design and Standards[20]. The socio-economic details pertaining to agricultural labourers and SC/ST population were drawn from Census of India 2001 sources. The station-wise average annual rainfall data for 30 years and water yield data collected from the Drought Monitoring Cell, and Department of Mines and Geology, Govt of Karnataka respectively, were also considered for prioritization of sub-watersheds. Details of data sources collected are given in Table 1.

Table 1. Details of data sources collected for each parameter for sub-watershed prioritization

Parameter	Data source	Factors
Drainage density	Derived from drainage map	Higher the drainage density, more the priority
Slope	SOI topographic maps	More the sloppiness, more the priority
Water yield capacity	Department of Mines and Geology, Govt of Karnataka	More the yield, less the priority
Groundwater prospect	Derived from satellite imagery with limited field check	More the area of good to very good groundwater prospect zones, less the priority
Soil	Derived from satellite imagery with limited field check	More the soil depth, less the priority
Wastelands	Derived from satellite imagery with limited field check	More the wastelands, more the priority
Irrigated area	Derived from satellite imagery with limited field check	Less the irrigated area, more the priority
Forest cover	Derived from satellite imagery with limited field check	Less the forest cover, more the priority
Agricultural labourers	Census of India, 2001	More the population, more the priority
SC/ST population	Census of India, 2001	More the population, more the priority
Rainfall	Drought Monitoring Cell, Govt of Karnataka	Less the rainfall, more the priority

Database development through GIS

With the advent of GIS, it is possible to store and retrieve all the theme maps on the computer by digitization in a systematic manner. The GIS has a unique advantage of integration of all the data for assessing the distinct characteristics of each unit, and assesses the aggregate weightage of each unit, which then can be normalized by working out the weighted average to find the rating of the watershed. In the present study, after finalization of visual interpretation, the maps were scanned and digitized with appropriate scale and attributed using AutoCAD Map 2000 software, followed by quality evaluation and converted to '.dxf' file format. These files were then exported to 'coverage' files format under the GIS environment[21]. The GIS software, viz. ArcInfo (v 8.1.2) and ArcMap (v 8.1.2) have been used for analysis and integration of thematic maps, which leads to prioritization of sub-watersheds. The various tools provided in ArcGIS have been used to create the scheme for feature dataset, tables, etc. in the geo-referenced database. Topologies were cleaned and built for all the themes using ArcInfo before creating a spatial database. Once the analysis of all the themes was over, ArcView (v 3.2a) software was used to create layouts for output generation. The tabular data (non-spatial) of census information, viz. agriculture labourers and SC/ST population have been linked to the geographically rectified village boundary (spatial) under GIS environment and used for the present study.

Sub-watershed delineation

Watershed is a natural hydrological entity from which surface run-off flows to a defined drain, channel, stream or river at a particular point. For mapping of watersheds and their boundaries, information on height provided through contours and spot heights given in SOI topographic maps were used. The ridge-to-valley concept was followed while delineating watershed boundaries as this provides information such as location of the highest and lowest elevated points and water divide. According to the guidelines of the All India Soil and Land Use Survey[22], the mean area of the watershed is less than 500 km^2. The watershed is further classified into sub-watersheds (30–50 km^2), mini-watersheds (10–30 km^2) and micro-watersheds (5–10 km^2) based on Integrated Mission for Sustainable Development Technical Guidelines[23]. Hence, the entire watershed has been divided into nine sub-watersheds, namely Byadanur, Devadabetta, Talamaradahalli, Gowdatimmanahalli, Naliganahalli, Nagalamadike, Maddalenahalli, Paluvalli tank and Dalavayihalli, ranging in geographical area from 49 to 75 km^2 and taken up for prioritization. These sub-watersheds have been named based on villages and tanks at the outlet[15] (Figure 1).

Prioritization methodology

Considering the massive investment in the watershed development programme, it is important to plan the activities on priority basis for achieving fruitful results, which also facilitate addressing the problematic areas to arrive at suitable solutions. The resources-based approach is found to be realistic for watershed prioritization since it involves an integrated approach. In the present study, knowledge-based weightage system has been adopted for sub-watershed prioritization based on its factors and after carefully observing the field situation. The basis for assigning weightage to different themes was according to the relative importance to each parameter in the study area. The weightage system adopted here is completely dependent on local terrain and may vary from place to place. The water-holding capacity or porosity and permeability of the formation in the area was also considered while assigning weightage. With respect to socio-economic aspect, the study area has poor potentialities because of SC/ST population, which constitute the significant portion of its population. They are generally land less people and represent the lowest level in economic ranking of the social group and have no or insignificant land property. Priority has been given to villages/sub-watersheds having large

Table 2. Weightage assigned to various thematic maps

Thematic map	Related features	Symbol	Weightage assigned
Drainage density	High	2–4 km/km^2	4
	Low	0–2 km/km^2	2
Slope	Gently sloping to very steep slope	>50%	4
	(3 to >35%)	<50%	2
Water-yield capacity	High	>1000 gph	2
	Low	<1000 gph	4
Groundwater prospects	Very good to good (>1000 gph)	>20%	2
		<20%	4
Soil	Deep soils with sandy clays	>20%	2
		<20%	4
Wastelands	–	>5%	4
		<5%	2
Irrigated area	–	>10%	2
		<10%	4
Forest cover	–	>5%	2
		<5%	4
Agriculture labourers	–	>15%	4
		<15%	2
SC/ST population	–	>50%	4
		<50%	2
Rainfall (mm)	Average annual rainfall	>550	2
		<550	4

economically weaker population, viz. agricultural labourers and SC/ST, depending on local priority and certain areas were ultimately given greater attention than others. The weightage assigned for various parameters against each thematic map are given in Table 2.

Results and discussion

The study emphasizes on prioritization of sub-watersheds for their development and management on a sustainable basis, based on available natural resources, rainfall and socio-economic conditions. The various themes, which include drainage density, slope, water capacity, groundwater prospects, soils, wastelands, irrigated area, forest cover, data on agricultural labourers, SC/ST population and rainfall conditions are briefly discussed below. The results of analysis of these parameters are given in Table 3.

Drainage density

The drainage pattern of any terrain reflects the characteristics of surface as well as subsurface information. The drainage density (in terms of km/km^2) indicates the closeness of spacing of channels. More the drainage density, higher would be the run-off. Thus drainage density characterizes the run-off in the area or, in the other words, the quantum of rainwater that could have infiltered. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zones. The drainage density in the area has been calculated and varies from 1.55 to 2.16 km/km^2. Based on the priority factor (Table 1), the highest priority has been given to Talamaradahalli and Dalavayihalli sub-watersheds, as they had high drainage density compared to the remaining sub-watersheds (Table 3).

Slope

The slope of any terrain is one of the factors controlling the infiltration of groundwater into the sub-surface and also a suitability indicator from the groundwater prospect point of view. Higher slope area facilitates high run-off allowing less residence time for rainwater, whereas in the gentle slope area the surface run-off is slow, allowing more time for rainwater to percolate and hence comparatively more infiltration. The slope map of the study area is given in Figure 3. In the present study, the slope area between gently sloping and very steep slope (3 to >35%) has been considered for prioritization, as the area needs more attention. Sub-watersheds having >50% of this slope class has been considered as high priority, while sub-watersheds with <50% of the area fall in the next lower priority. As a result Byadanur, Devadabetta, Talamaradahalli, Gowdatimmanahalli, Naliganahalli and Dalavayihalli sub-watersheds fall under the high priority category (Table 3).

Soil

Erosion and deposition of sediments are both dependent upon the nature of the surface and its characteristics. Generally, in steep slopes soils are shallow and usually have thin surface horizon and medium-to-coarse texture,

Table 3. Results of analysis of various parameters against each sub-watershed

SWSD code	SWSD name	Area (km²)	Drainage density (km/km²)	Slope (between 3 and >35%)		Good to very good groundwater zones		Deep soils with sandy clays		Irrigated area	
				Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
a	Byadanur	49.44	1.75	34	69	8.35	17	7.88	16	7.75	16
b	Devadabetta	51.98	1.82	35	67	11.14	21	6.55	13	9.11	18
c	Talamaradahalli	59.95	2.16	38	63	8.05	13	17.4	29	5.48	9
d	Gowdatimmanahalli	68.2	1.88	45	66	13.98	20	16.95	25	10.54	15
e	Naliganahalli	64.07	1.73	45	71	10.11	16	8.84	14	8.63	13
f	Nagalamadike	74.6	1.55	33	44	9.25	12	16.38	22	3.98	5
g	Maddalenahalli	72.22	1.59	32	44	9.02	12	16.33	23	6.26	9
h	Paluvalli Tank	55.78	1.85	36	64	11.38	20	14.3	26	8.99	16
i	Dalavayihalli	72.44	2.13	38	52	10.14	14	15.12	21	6.8	9

SWSD code	SWSD name	Forest cover		Waste lands		Total population	Agriculture labourers population		SC/ST population		Average annual rainfall
		Area (km²)	Area (%)	Area (km²)	Area (%)		Number	Percentage	Number	Percentage	
a	Byadanur	8	16	0.29	0.59	5078	922	18	2166	43	541
b	Devadabetta	0.28	1	0.05	0.10	8477	1988	23	3352	40	537
c	Talamaradahalli	10.7	18	2.23	3.72	11518	1563	14	5668	49	535
d	Gowdatimmanahalli	2.8	4	0.55	0.81	13611	2182	16	5225	38	544
e	Naliganahalli	2.22	3	1.18	1.84	13197	1690	13	4747	36	555
f	Nagalamadike	2.58	3	6.24	8.36	5902	541	9	3304	56	537
g	Maddalenahalli	–	–	6.05	8.38	8190	548	7	4695	57	532
h	Paluvalli Tank	1.98	5	0.88	1.58	8414	1480	18	4191	50	551
i	Dalavayihalli	4.24	6	2.64	3.64	7555	932	12	3872	51	506

SWSD, Sub-watershed.

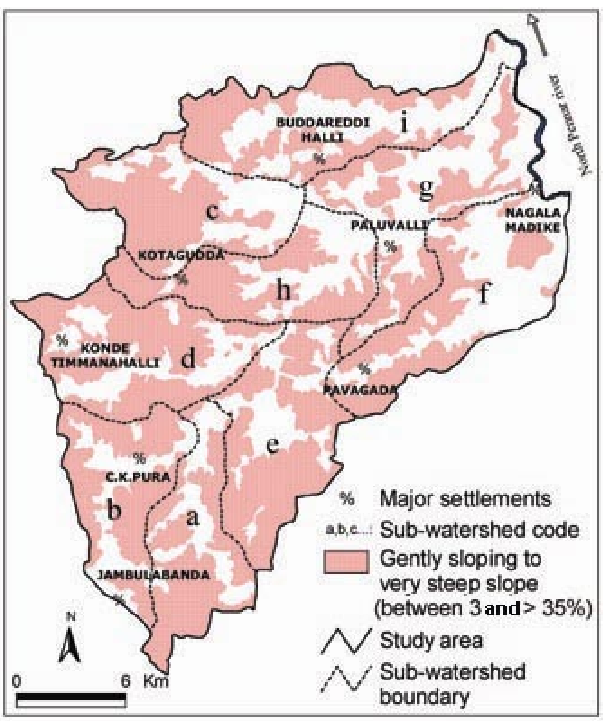

Figure 3. Slope map showing the area with gently sloping to very steep slope (between 3 and >35%).

while the sub-soils are deep and heavily textured. Soil mapping has been carried out to determine soil types in the study area with the help of satellite imagery. Field study has also been conducted to determine soil depth, texture and erosion conditions with general information from the villagers of the area. Alkaline soil patches were found around Nagalamadike village and occurrence of lime kankar was also seen in Nagalamadike and other parts of the study area[24]. The soil map (Figure 4) depicting deep soils with sandy clays, technically called Typic Ustropepts, which are moderately deep, well-drained and yellowish-red was considered for prioritization. It indicated that sub-watersheds having this type of soil in more than 20% of the total geographical area are considered as less priority as these soils have good vegetation. Thus Byadanur, Devadabetta and Naliganahalli, having <20% area occupied by this soil type are categorized as high priority (Table 3).

Groundwater prospects

The groundwater prospects zone mapping was carried out in the study area and grouped into different zones as very good to good, good to moderate, moderate to poor, and poor to very poor[18]. In the present study, areas having good to very good groundwater potential zones with average water yield capacity of >1000 gph were considered for prioritization, which indicates that more the area of good to very good groundwater potential zones, less the priority. Byadanur, Talamaradahalli, Naliganahalli, Nagalamadike, Maddalenahalli and Dalavayihalli fall under the high priority category (Table 3, Figure 5).

Forest cover

Basically, the SOI topographic maps have been used for delineation of forest boundary. Based on tonal and textural variations in the FCC satellite images, the forest class comprises of thick and dense canopy (within the notified forest boundary) bearing an association of predominantly trees and other vegetation types. Scrub forests, degraded forests and forest plantations have been considered while delineating forest cover class. It was observed mostly on the hill slopes and distributed in the northwestern, west, south and southwestern parts of study area (Figure 6). The forest cover was observed in eight sub-watersheds, except in the Maddalenahalli sub-watershed. The maximum area of forest cover was noticed in Talamaradahalli sub-watershed covering an area of 10.70 km^2, while minimum area was noticed in Devadabetta sub-watershed covering an area of 0.28 km^2. High priority was also given to the sub-watersheds having less forest cover (<5%). As a result, Byadanur, Talamaradahalli and Dalavayihalli sub-watersheds were given less priority (>5%), while the remaining sub-watersheds were given high priority. The Maddalenahalli sub-watershed was also considered under high priority category, as there is no forest cover in its geographical area (Table 3).

Irrigated area

It may be defined as the land primarily used for farming and production of food, fibre, horticultural and other commercial crops. The multi-dated satellite data were used to delineate various agricultural lands, including crop land, double crop and agricultural plantation and brought under this category, which is extensively observed in the study area (Figure 6). The irrigated area was calculated from the total cultivable area after excluding the non-cultivable areas like settlements, water body, forest area, etc.; the area varies from 3.98 to 10.54 km^2. The lowest irrigated area was observed in Byadanur, Devadabetta, Gowdatimmanahalli, Naliganahalli and Paluvalli tank having <10% with high priority, while the remaining sub-watersheds got less priority (>10%; Table 3, Figure 6).

Wastelands

These may be described as degraded land which is currently under unutilized. The land may be deteriorating due to lack of appropriate water and soil management or

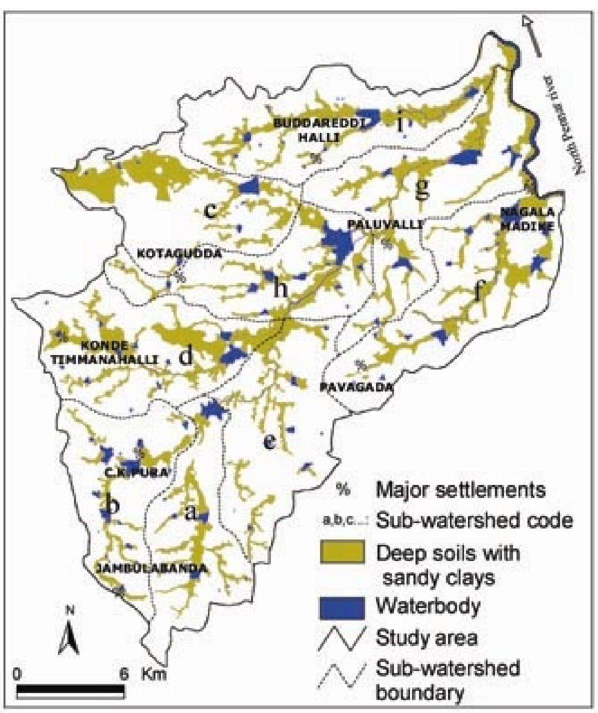

Figure 4. Soil map showing the area with deep soils having sandy clays (Typic Ustropepts).

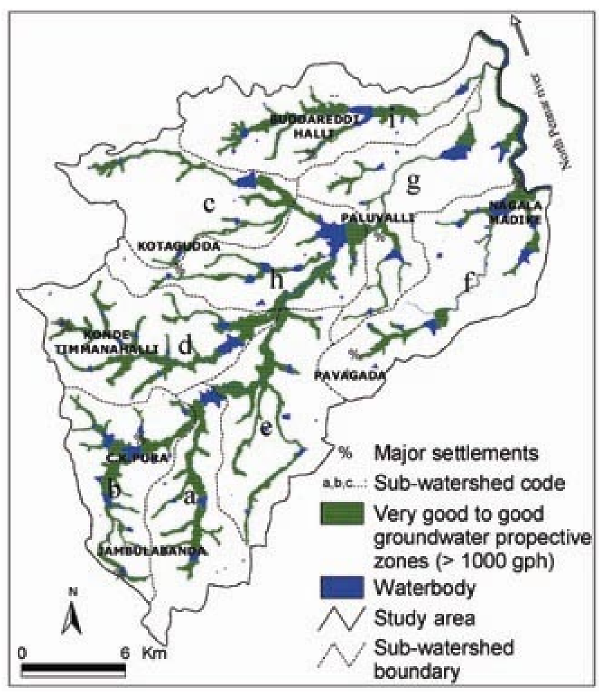

Figure 5. Groundwater potential map showing area with good to very good zones (>1000 gph).

due to natural causes. Wastelands can result from inherent/imposed constraints such as location, environment, chemical and physical properties of the soil, or financial/management constraints. These lands can be brought under vegetative cover with reasonable efforts. The wastelands comprise of salt-affected land, land with scrub, land without scrub, and *Prosofis juliflora* (locally named as Bellary jaali), delineated and brought under this category. It is observed dominantly in the eastern and north-eastern part of the study area (Figure 6). Details of the wastelands observed in each sub-watershed are presented in Table 3 and the area varies from 0.29 to 6.24 km^2. The maximum area (6.24 km^2) has been observed in Nagalamadike sub-watershed, while the minimum area was noticed in Byadanur sub-watershed (0.29 km^2). Sub-watersheds having maximum area (>5%) of wastelands were categorized under high priority. Hence, Nagalamadike and Maddalenahalli sub-watersheds were under high priority, as they have maximum area of wastelands compared to remaining sub-watersheds.

Agricultural labourers population

'Agricultural labourer' is a person who works in another person's land for wages, money, kind or share. He has no risk in the cultivation, and has no right of lease or contract on the land on which he works. Data on agricultural labourers are given in Table 3. The spatial distribution of agricultural labourers is given in Figure 7. Table 3 reveals that maximum agricultural labourers were observed in Byadanur, Devadabetta, Gowdatimmanahalli and Paluvalli tank sub-watersheds, categorized under high priority, while the remaining sub-watersheds were placed in the next lower category.

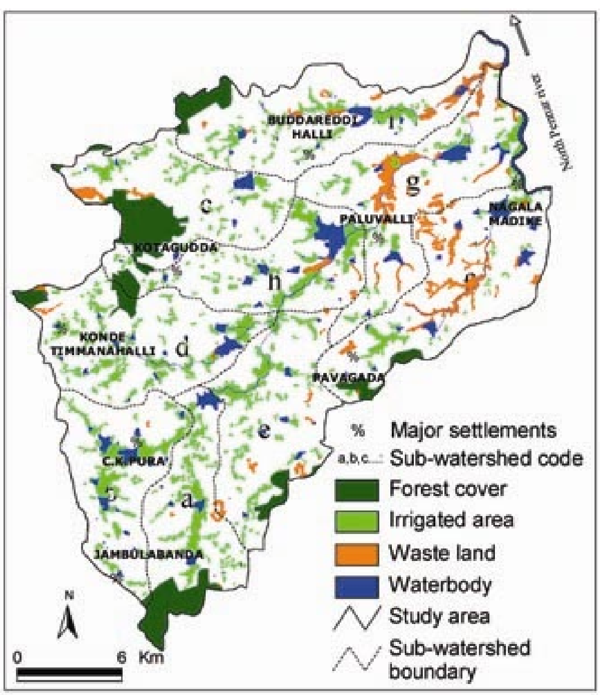

Figure 6. Spatial distribution of thematic maps depicting forest cover, irrigated area and wastelands.

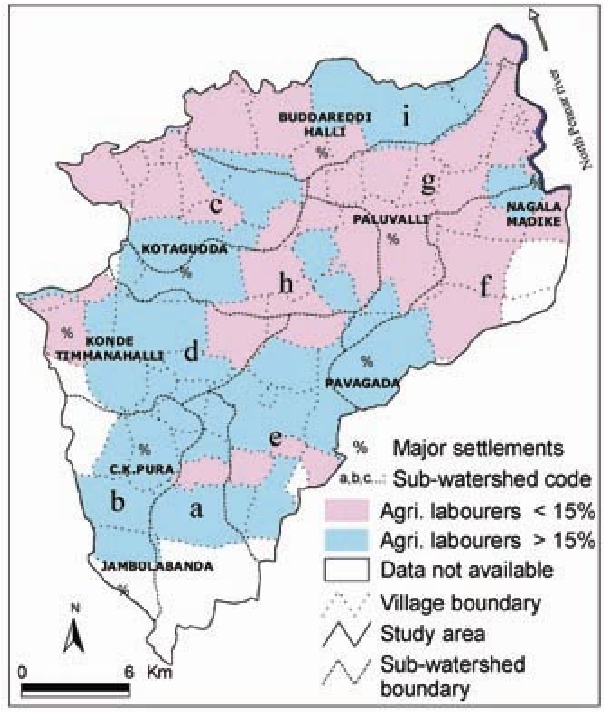

Figure 7. Spatial distribution of population of agricultural labourers.

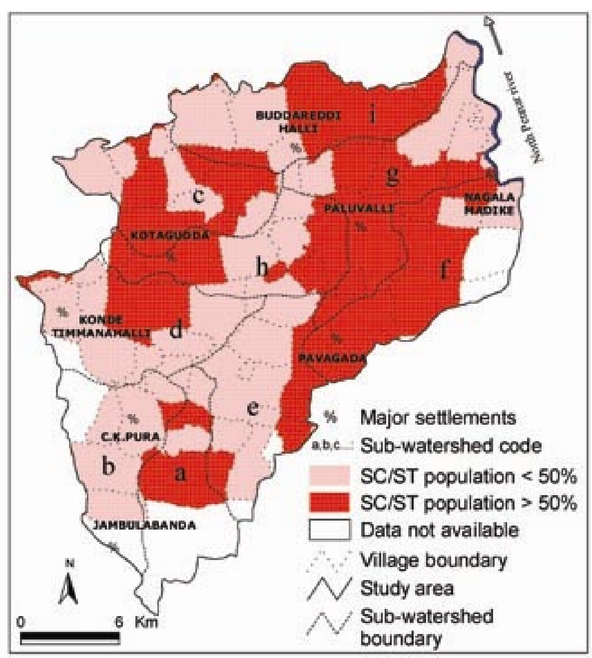

Figure 8. Spatial distribution of populations of SC/ST.

SC/ST population

The SC/ST population was also considered for prioritization of sub-watershed, since they are economically backward and mostly landless. The statistics of village-wise population was drawn from Census 2001 data and the percentage against total population for each sub-watershed was calculated (Table 3). Spatial analysis was carried out for the distribution of SC/ST population (Figure 8); segregated as >50% and <50% of population. More the SC/ST population, more the priority. Hence sub-watersheds with >50% of these populations (Nagalamadike, Maddalenahalli, Paluvalli tank and Dalavayihalli) were under high priority category and the remaining sub-watersheds with <50% of population were placed in the next lower category.

Rainfall

The station-wise rainfall data were collected for 30 years up to the year 2001, and average annual rainfall was calculated for the entire study area. The spatial distribution of rainfall has been generated and analysed by overlaying the boundary of the sub-watershed on it reveals that the average annual rainfall varies from 506 to 555 mm (Table 3, Figure 9). The highest rainfall was observed in Naliganahalli sub-watershed, while the lowest was in Dalavayihalli sub-watershed. The results reveal that Byadanur, Devadabetta, Talamaradahalli, Gowdatimmanahalli, Nagalamadike, Maddalenahalli and Dalavayihalli were under high priority, as they experienced less rainfall (<550 mm).

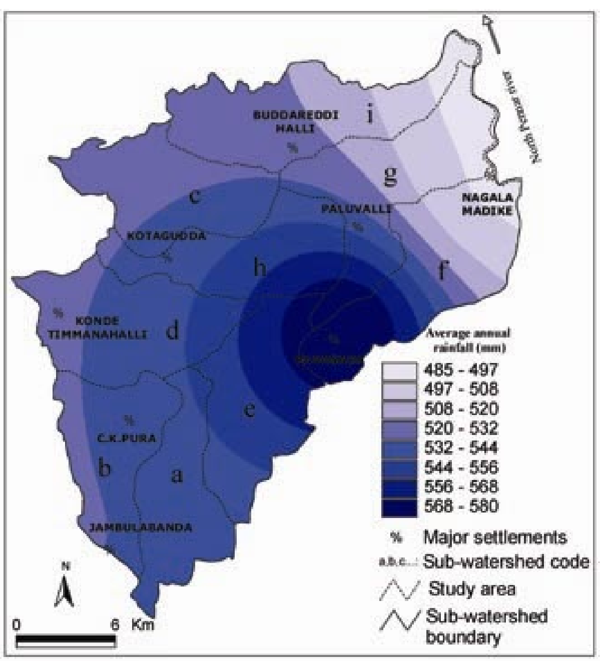

Figure 9. Spatial distribution of rainfall.

Prioritization results

All the nine sub-watersheds in the study area have been prioritized by considering the results of various thematic maps derived from satellite imagery as well as rainfall and socio-economic data. The prioritization results for all nine sub-watersheds of the study area have been categorized on the basis of cumulative weightage to different features of the thematic map. The prioritization results of various parameters against each sub-watershed are given in Table 4 and spatial distribution of prioritization is given in Figure 10. On the basis of priority and cumulative weightage assigned to each thematic map, the sub-watersheds are grouped into three categories: high, medium and low priority. The prioritization analysis results reveal that Nagalamadike, Maddalenahalli and Dalavayihalli sub-watersheds rank highest in weightage and are

Table 4. Results of prioritization carried out for each sub-watershed

SWSD code	SWSD name	Total weightage	Priority result
a	Byadanur	30	Medium
b	Devadabetta	30	Medium
c	Talamaradahalli	30	Medium
d	Gowdatimmanahalli	28	Low
e	Naliganahalli	28	Low
f	Nagalamadike	32	High
g	Maddalenahalli	32	High
h	Paluvalli Tank	28	Low
i	Dalavayihalli	32	High

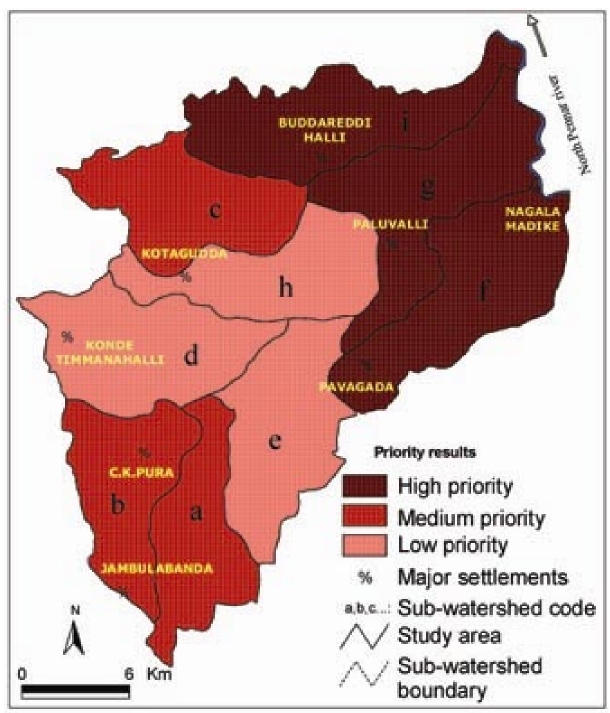

Figure 10. Spatial distribution of priority results for each sub-watershed.

considered under high priority. They can be taken up for development and management plans on sustainable basis with immediate effect. Out of the remaining six sub-watersheds, Byadanur, Devadabetta and Talamaradahalli fall under medium priority, while Gowdatimmanahalli, Naliganahalli and Paluvalli tank sub-watersheds fall under low category of prioritization. These prioritized sub-watersheds may be taken up for development and management plans in a phased manner.

Conclusion

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programmes. The present article summarizes the integrated approach for developing a preliminary prioritization of sub-watersheds in Pavagada area, Tumkur District, Karnataka. Hence, the entire area has been divided into nine sub-watersheds and prioritization has been carried out considering various parameters, viz. drainage density, slope, water capacity, groundwater prospects, soil, wastelands, irrigated area, forest cover and data on agricultural labourers, SC/ST population and rainfall. On the basis of priority and cumulative weightage to each thematic map, the sub-watersheds are grouped into three categories: high, medium and low priority. The result of prioritization analysis reveals that Nagalamadike, Maddalenahalli and Dalavayihalli sub-watersheds had highest weightage and were considered under high priority. These sub-watersheds may be taken up with detailed survey for soil and water conservation measures, water resources development, scientific land-use planning for preservation of eco-diversity, integrated study for development of natural as well as social resources, moisture conservation, sustainable forming system, etc. to accelerate the rehabilitation of the micro-environment and to generate a detailed database in each natural resources theme, which is a pre-requisite for formulation of watershed plan for its sustainable development and management.

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ACKNOWLEDGEMENTS. S.S.V. thanks the Regional Director, Director and scientists of Central Ground Water Board, Mid-Eastern Region, Patna and Karnataka State Remote Sensing Applications Centre (KSRSAC), Bangalore. He also thanks the Chairman, Department of Geology, University of Mysore for encouragement and support. Help rendered by Dr Govindaraju, S. R. Anand, K. S. Nagesh and R. Mamatha during preparation of thematic maps is acknowledged. We thank Census of India; India Meteorological Department, Govt of India; Department of Mines and Geology, and Drought Monitoring Cell, Govt of Karnataka for providing necessary data for the study. A. M. Ramesh and S. Sarangmath provided valuable suggestions. We also thank the anonymous referees for their critical review comments and useful suggestions to improve the paper.

Received 2 July 2007; revised accepted 24 June 2008