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Research Article

GIS Based Sustainable Land Use Planning using Spatial Variation of Soil and Terrain Information

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ABSTRACT

Scientific assessment on existing soil and land resources with respect to their spatial distribution, characteristics, potentials, limitations were the pre-requisite for formulating sustainable land use strategies to obtain higher land and water productivity. For quick collection of data and analysis, in this study, various thematic maps were generated like slope, existing land use, available water capacity, organic carbon, soil texture and bulk density were prepared and overlaid to develop integrated Composite Land Development Unit (CLDU) map. A set of decision rules were applied on CLUDs to generate action plan map, showing location specific recommendations on sustainable land use planning in the watershed. The lowland rice areas which were presently under single cropping, could be converted to double/triple cropping, particularly in fields where irrigation could be given. The rainfed lowlands with higher available water capacity had a lot of residual soil moisture which could be utilized to grow low water requiring crops like green gram, blackgram etc after rice. The irrigated lowland could be utilized by incorporating one legume crop like green gram into cropping system after rice and one short duration vegetable crops. Long duration rice of 150 days was to be avoided to convert mono-cropping to double cropping. Since organic carbon content of the soil was low to medium, emphasis was also given for organic carbon sequestration in the cultivable soil through conservation tillage. Morphometric analysis of drainage network revealed that prominent drainage pattern of the watershed was dendritic with low drainage density. Thus, the region had highly permeable subsoil material and had low relief.

Key words: Watershed development, Crop planning, Remote sensing, GIS

Introduction

Rapid increase in population, urbanization, industrialization, over-utilization of ground water resources, large scale deforestation etc., have resulted in ever increasing demand on land and water, and caused enormous degradation of land and environment. Therefore, conservation of land, soil and water resources through sustainable agricultural land use planning are the most important tasks now in hand to obtain food, nutrition and environmental security in future. Management of natural resources on watershed basis has already been proved successful for optimal and sustainable production with the minimum negative impact to natural resources and environment (Kar *et al*., 2004; Srivastava and Saxena, 2004; Solanke *et al*., 2005; Velmurugan and Carlos, 2009; Shukla *et al*., 2009; Kashiwar *et al.,* 2009; Patil *et al*., 2010; Kar *et al.,* 2009).

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Precise knowledge on existing soil and land resources with respect to their spatial distribution, characteristics, potentials, limitations and studying their suitability are the pre-requisite for formulating land use strategies to obtain higher land and water productivity on sustainable basis. This requires systematic and reliable inventory of natural resources like soil, available water capacity, land use, slope, elevation, soil fertility etc. at a quicker phase. The remote sensing and GIS technology have revolutionized in mapping and management of voluminous spatial and non-spatial natural resource information which helps to develop decision support system for achieving sustainable land use and land cover plan (Srivastava and Saxena, 2004; Velmurugan and Carlos, 2009, Bodhankar *et al.,* 2002; Sharma *et al.,* 2001, Shukla *et al*., 2009; Patil *et al*., 2010). Remote sensing has become an indispensable scientific tool for gathering information from inaccessible areas and mapping and monitoring of natural resources (Kasturirangan *et al*., 1996). This technique was frequently used in the characterization of the soil and other natural resources on watershed basis (Saxena *et al*., 2000; Srivastava and Saxena, 2004; Suresh *et al*., 2004; Bodhankar *et al*., 2002; Sharma *et al*., 2001).

Considering the above points in view, as a case study, the present investigation was under taken to assess the soil and other key natural resources of Darpanaranpur watershed of Nayagarh district, Odisha for sustainable land use planning using remote sensing and GIS. The input thematic maps were overlaid and a Composite Land Development Unit (CLDU) was created through union of different resources layers to arrive at an action plan. A set of decision rules were applied on CLDU to generate action plan map, showing location specific recommendations in the watershed. The morphometric analysis of the watershed was carried out using GIS.

Material and Methods

Based on the contour and ridge lines extracted from the Survey of India toposheet and DEM extracted from Google earth, the Darpanarayanpur watershed was delineated which is located in Nayagarh district of Odisha, India. The study watershed lies between latitude 20.098 N to 20.050 N and longitude 85.785 E to 85.239 E and belongs to the South eastern coastal plain zone of Odisha state. The location of watershed in India is given in Fig. 1. Mean maximum and minimum temperatures are 40.82°C and 10.1°C, respectively. The average annual rainfall is 1450 mm. The length of growing period, which indicates the availability of water for plant growth, is about 140-150 days in a year. It starts from the middle June and continues up to the end of December.

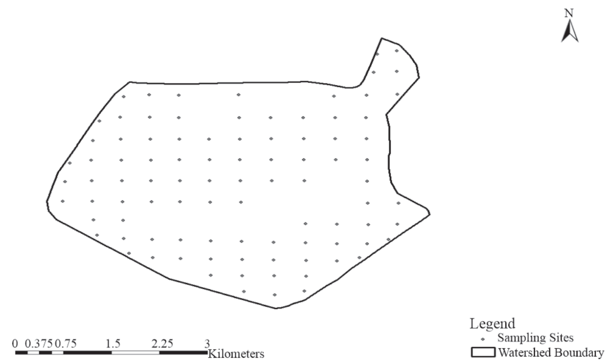

Fig. 1. Location of sampling sites in the watershed

The study watershed has an area of 1814.2 ha with cultivated area of 1063.6 ha. The elevation of the watershed varies from 76 m at the outlet to 292 m above mean sea level in the northern and southern side of the watershed. The digital elevation of the watershed is given in Fig. 2. The main source of water is Darpanarayan pur check dam and some small ponds.

Soil sampling and interpolation

A total of 93 soil samples were collected in the field from the delineated watershed area through random sampling. A portable global positioning system (GPS) was used to collect each sample site (Fig. 2). The undisturbed soil samples at depths of 0–0.20 m, was collected with three soil cores each to determine bulk density. These soil samples are then well mixed into a composite soil sample. Soil samples were air dried and passed through a 2 mm sieve for laboratory analysis of soil texture by International Pipette method. Soil water retention at field capacity and permanent wilting point was measured using

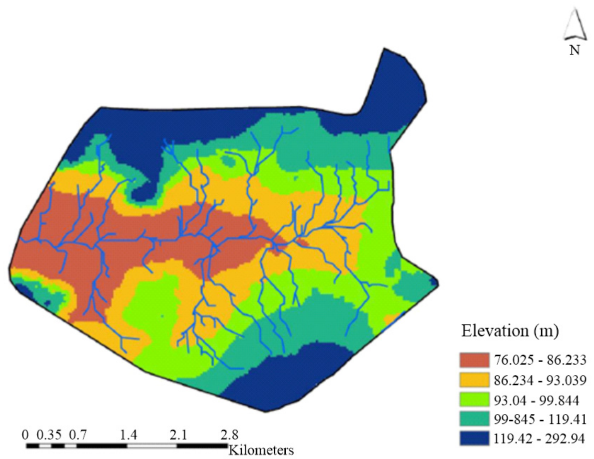

Fig. 2. Contour map with Digital elevation model (DEM) of the watershed

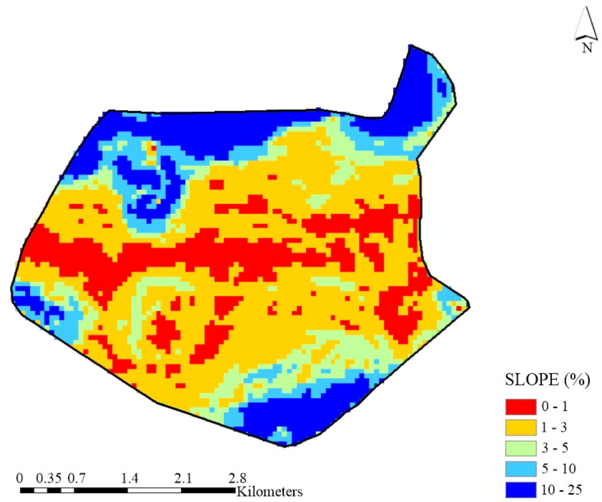

Fig. 3. Slope map of the watershed

pressure plate apparatus. The bulk density was measured by core sampler method.

Using measured sample points from a study area, Inverse Distance Weighted (IDW) interpolation method was used to create predictions for other unmeasured locations within the same area.

Results and Discussion

Digital Elevation Model, slope and contour map

The digital elevation model (DEM) map and contour map of the area were merged together and a composite map having information about contours as well as spot height was formed (Fig. 2). Figure shows the elevation of the watershed varies from 76 m at the outlet to 292 m above mean sea level in the northern and southern side of the watershed. The DEM derived above was used to derive slope map of the watershed (Fig. 3). This slope map was used to identify land suitability for different land use and landcover. The slope map of the area shows that most of the watershed area falls under slope categories from 1-3%.

Thematic maps of soil physical and chemical properties

The point soil samples were analysed and interpolated using IDW method of ARCINFO software to prepare surface available water capacity map (Fig. 4), organic carbon map (Fig. 5), soil texture map (Fig. 6) and bulk density map (Fig. 7). The water content at permanent wilting point (1500 kPa) was deducted from the water content at field capacity (33 kPa) to derive available water capacity (AWC) map. The value of AWC (%, v/v) varied from 0.09-0.11 m^3/m^3 to 0.21-0.23 m^3/m^3 for the surface layer of 0.20 m. Maximum water content was found at the middle part of the watershed, where soil texture was mostly clay loam to clay. The soil organic carbon content was low to medium, varied from 0.35-0.45% to 0.60-0.65%. The soil texture of majority

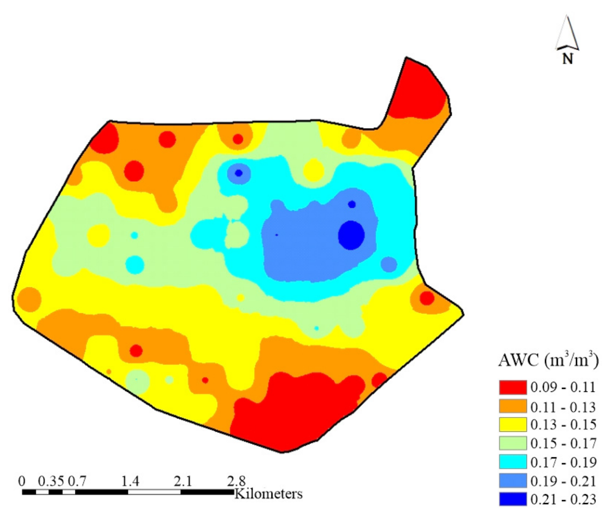

Fig. 4. surface available water capacity map the watershed

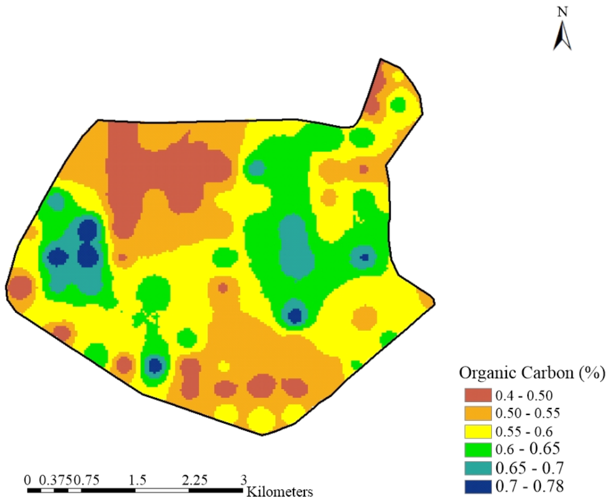

Fig. 5. Soil organic carbon map of the watershed

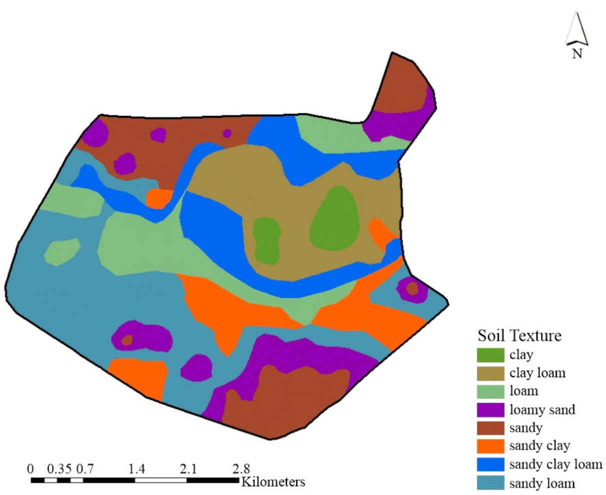

Fig. 6. soil texture map of the watershed

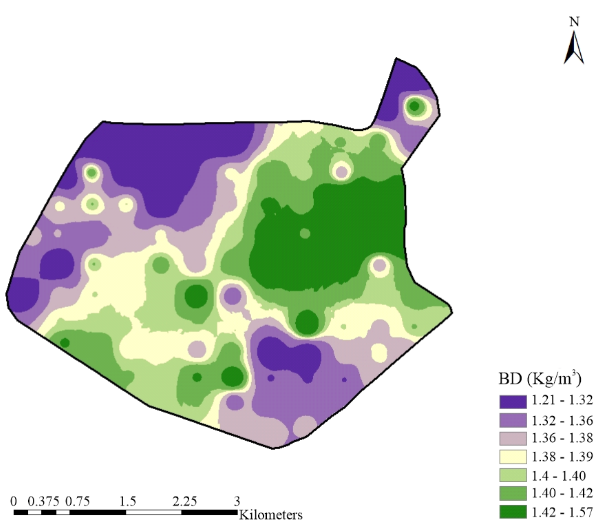

Fig. 7. Bulk density map of the watershed

of cultivable areas was sandy loam to sandy clay loam (Fig. 6). The texture of hilly terrain was mainly fine sand to coarse sand. The bulk density of the surface soil ranged between 1.21 kg/m^3 to 1.54 kg/m^3.

Existing land use and generation of alternate sustainable land use plan

The existing land use category for Darpanarayanpur watershed is given in Table 1. The major land use /land cover classes identified were upland and lowland cultivated areas (single crop and double crop), plantation, scrubland, and forest. The study had indicated that 1063.60 ha (58.6%) area of the watershed was under cultivation (Fig. 8). Out of that, 113 ha (6.23% of total watershed area) had provision of supplemental irrigation from a checkdam. The watershed was dominated by traditional land use

Table 1. Existing land use statistics for Darpanarayanpur watershed

Land use category	Area	
	Hectare	%
Built-up area	99.85	5.5
Forest area	449.21	24.76
Low land cropped area(rainfed)	506.93	27.94
Low land cropped area(irrigated)	113.04	6.23
Upland cropped area(rainfed)	443.63	24.45
Plantation area	160.1	8.82
Scrub land	2.28	0.13
Waterbodies, WHS, Nallah etc	39.25	2.16
Total	1814.29	100%

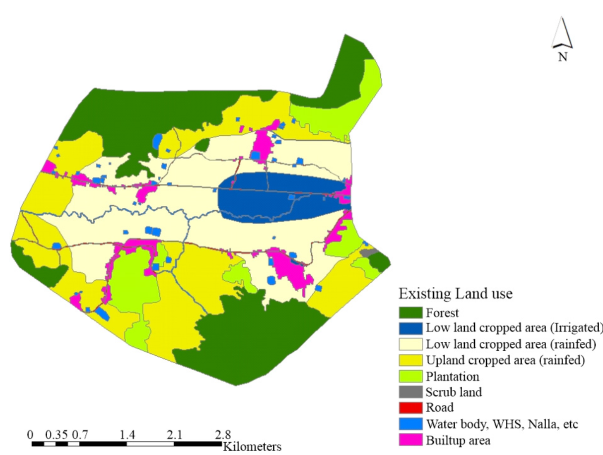

Fig. 8. Existing land use map of the watershed

Table 2. Suggested land use statistics for Darpanarayanpur watershed

SI. No.	Land use category	Area	
		Hectare	%
1	Afforestation	295.13	16.27
2	Built-up area	80.93	4.46
3	Dry land horticulture	336.05	18.52
4	Horti-pasture	157.82	8.7
5	Maize-horse gram/seasamum	233.13	12.85
6	Plantation	14.55	0.8
7	Rice (120 days)-groundnut/black gram/green gram	279.68	15.42
8	Rice (120 days)-vegetables/maize/sunflower-green gram	29.36	1.62
9	Rice (135 days)-groundnut/black gram/green gram	173.44	9.56
10	Rice (135 days)-vegetables/maize/groundnut-green gram	83.67	4.61
11	Rice(90-days)-horse gram	72.34	3.99
12	Road	18.93	1.04
13	Waterbodies, WHS, Nallah etc	39.25	2.16
	Total	1814.29	100%

system, therefor there was lot of scope to introduce sustainable land use plan in the watershed. Therefore, in this study, based on potential and limitation of different natural resources like slope, soil texture, organic matter, bulk density, available water capacity etc,, an alternative land use and land cover plan was developed using remote sensing and GIS which will be sustainable and profitable. For that purpose, an integrated layer of CLDU was developed by overlaying thematic natural resources layers. A set of decision rules were applied on CLUDs to generate action plan map, showing location specific recommendations in the watershed. The comparison between the existing land use and proposed action plan gives considerable amount of growth in vegetative cover (Table 2). There is ample scope for diversification of the cultivable area through profitable cropping system with short duration field crops and vegetables. Other location specific recommendations were also suggested (Fig. 9). The moderately dense/ degraded forest areas were recommended to cover under afforestation. Climatically adapted fast growing tree species like Australian teak (*Aacia mangium*) should be planted in the area. The highland sandy and stony area needs to cover with silvipasture i.e. combination of trees and grasses viz. *Cenchrus*

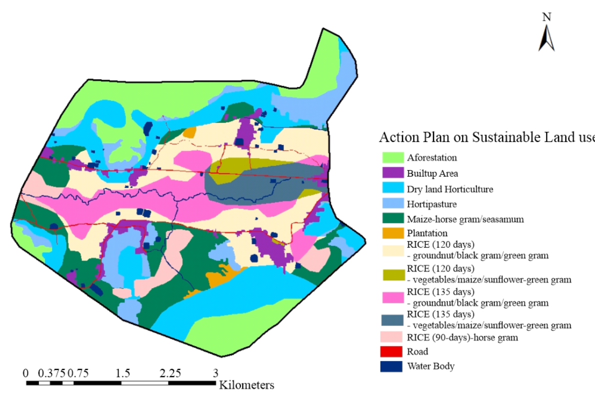

Fig. 9. Action plan map on alternative land use of the watershed

ciliaris, Dichanthium annulatum, Heteropogon contortus etc. alongwith forest trees.

In the arable part of the watershed, rice in the upland area needs to be diversified with short duration low water requiring crops like maize, groundnut, greengram, blackgram. By adjusting sowing dates, even two crops through maize-cowpea/horse gram can be grown in rainfed upland. The upland with little higher slope can be used for growing short duration crops like mungbean, urdbean and sesamum and fodder sorghum under some soil water conservation practices. Also plantations of timber/fruit and medicinal plants (Lemon grass, Palamarosa, Khus) and flowers like marigold have great potential on these lands.

The low-lying areas, which are presently under single, long duration rice, cropping, can profitably be cultivated can be converted to double/triple cropping, particularly in areas where supplementary irrigation can be given. The rainfed rice lowlands with higher available water capacity have lot of residual soil moisture which can be utilized to grow low water requiring crops like green gram, blackgram etc after rice. The irrigated lowland can be suitable utilized by incorporating one legume crop like green gram into cropping system after rice and one short duration vegetable crops. Long duration rice of 150 days needs to be avoided to convert mono-cropping to double cropping. Since organic carbon content of the soil is low to medium, emphasis also needs to be given for organic carbon sequestration in the cultivable soil through conservation tillage. Interpolated spatial variability maps indicate high spatial distribution for organic carbon. The ordinary krigging interpolation technique predicted significant low organic carbon in light texture soil where agricultural crops were not grown. Though, in agricultural field organic carbon was found to be moderate but certain management practices like minimum tillage, cover crops, and crop rotations etc. were advocated to improve organic carbon content of the topsoil.

The sloping areas and wastelands, in general, need urgent soil conservation measures viz. contour bunding, gully plugging and small check dams. Very gently sloping plateau to be put under vegetative cover of fast growing trees/crops to minimize the risk of soil erosion hazard. It is to emphasise here that to grow double/triple crops successfully, additional farm ponds/ storage tanks are required to be constructed at suitable sites.

Conclusions

The study again demonstrated the capability of remoted sensing and GIS techniques for developing sustainable land use system on watershed basis. Various thematic maps generated above were overlaid to arrive at an action plan (a set of suggested land use activities) for sustainable development of the area using GIS. An integrated layer of CLDU was developed by overlaying thematic natural resources layers. A set of decision rules were applied on CLUDs to generate action plan map, showing location specific recommendations in the watershed. The comparison between the existing land use and proposed action plan gives considerable amount of growth in vegetative cover. There is ample scope for diversification of the cultivable area through profitable cropping system with short duration field crops and vegetables. The valley-soils, which were presently under single cropping, could be converted to double/triple cropping, particularly in areas where irrigation was possible. The rainfed lowlands with higher available water capacity had a lot of residual soil moisture which could be utilized to grow low water requiring crops like green gram, blackgram *etc* after rice. The irrigated lowland could be utilized by incorporating one legume crop like green gram into cropping system after rice and one short duration vegetable crops. Long duration rice of 150 days was to be avoided to convert mono-cropping to double cropping. Since organic carbon content of the soil was low to medium, emphasis was also given for organic carbon sequestration in the cultivable soil through conservation tillage.

References

Bodhankar, R.M., Srivastava, R., Saxena, R.K. and Prasad, J. 2002. Integrated approach of RS and GIS in characterization and evaluation of land resources for watershed management-A case study in (Dhyani et al.) Resource conservation and Watershed Management: Technology Options and Future Strategies. *IASWC*, Dehradun, India, 435 p.

Kar, G., Kumar, A. and Singh R. 2009. Spatial distribution of soil hydro-physical properties and morphometric analysis of a rainfed watershed as a tool for sustainable land use planning. *Agricultural Water Management* **96**(1): 1449-1459.

Kar, G., Singh, R. and Verma, H.N. 2004. Productive and profitable management of rainfed lowland rice through intensive cropping and efficient water use. WTCER, Bhubaneswar. *Research Bulletin* 17, 56.

Kashiwar, D.Y., Nagaraju, M.S.S., Srivastava, Rajeev, Jagdish Prasad, Ramamurthy, V. and Barthwal, A.K. 2009. Characterization, evaluation and management of Salai watershed in Nagpur district of Maharashtra using remote sensing and GIS techniques. *Agropedology* **19(1)**: 15-23.

Kasturirangan, K., Aravamudan, R., Deekshatulu, B.L., Joseph, George and Chandrasekhar, M.G. 1996. Indian remote sensing satellite IRS IC. The beginning of new era. *Curr. Sci.* **70:** 495-500.

Patil, S.S., Nagaraju M.S.S. and Srivastava, R. 2010. Characterization and evaluation of land resources of basaltic terrain for watershed management using remote sensing and GIS. *Indian journal of soil conservation* **38(1)**: 16-23.

Sakthivel, R., Jawahar Raj, N., Sivasankar, V., Akhila, P. and Omine, K. 2019. Geo-spatial technique-based approach on drainage morphometric analysis at Kalrayan Hills, Tamil Nadu, India. *Applied Water Science* **9**: 24. https://doi.org/10.1007/s13201-019-0899-7

Saxena, R.K., Verma, K.S., Chary, G.R., Srivastava, R. and Barthwal, A.K. 2000. IRS-1C Data application in watershed characterization and management. *Int. J. Remote Sensing* **21(17)**: 3197-3208.

Sharma, T., Satya Kiran, P.V., Singh, T.P., Trivedi, A.V. and Navalgund, R.R. 2001. Hydrologic response of a watershed to land use changes: A remote sensing and GIS approach, *Int J. of Remote Sensing* **22(11)**: 2095-2108.

Shukla, E.A., Jagdish, P., Nagaraju, M.S.S., Srivastava, R. and Kauraw, D.L. 2009. Use of Remote Sensing in Characterization and Management of Dhamni Microwatershed of Chandrapur District of Maharashtra. *Journal of the Indian Society of Remote Sensing* **37(1)**: 129-137.

Solanke, P.C., Srivastava, R., Prasad, J., Nagaraju, M.S.S., Saxena, R.K. and Barthwal, A.K. 2005. Application of remote sensing and GIS in watershed characterization and management. *J. Ind. Soc. Remote Sensing* **33(2):** 239-244.

Srivastava, R. and Saxena, R.K. 2004. Technique of large scale soil mapping using satellite remote sensing. *International Journal of Remote Sensing* **25**: 679-688.

Suresh, M., Sudhakar, S., Tiwari, K.N. and Chowdary, V.M. 2004. Prioritization of watersheds using morphometric parameters and assessment of surface water potential using remote sensing. *Journal of Indian Society of Remote Sensing* **32**(3): 249-259.

Velmurugan, A. 2009. Guillen Carlos G. Soil resource assessment and mapping using remote sensing and GIS. *J. Ind. Soc. Remote Sens*. **37**: 511-525.

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