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INTEGRATED APPROACH OF USING REMOTE SENSING AND GIS TO STUDY WATERSHED PRIORITIZATION AND PRODUCTIVITY

D. MARTIN@ AND S.K. SAHA*
National Bureau of Soil Survey and Land Use Planning,
Regional Center, IARI Campus, New Delhi - 110 012, India
*Indian Institute of Remote Sensing, Dehradun - 248 001, India
@Corresponding author : mrteve@rediffmail.com

ABSTRACT

Soil data obtained from soil resource inventory, land and climate were derived from the remote sensing satellite data (Landsat TM, bands 1 to 7) and were integrated in GIS environment to obtain the soil erosion loss using USLE model for the watershed area. The priorities of different sub-watershed areas for soil conservation measures were identified. Land productivity index was also used as a measure for land evaluation. Different soil and land attribute maps were generated in GIS, and R,K,LS,C and P factor maps were derived. By integrating these soil erosion map was generated. The mapping units, found not suitable for agriculture production, were delineated and mapped as non-arable land. The area suitable for agricultural production was carved out for imparting the productivity analysis; the land suitable for raising agricultural crops was delineated into different mapping units as productivity ratings good, fair, moderate and poor. The analysis performed using remote sensing and GIS helped to generate the attribute maps with more accuracy and the ability of integrating these in GIS environment provided the ease to get the required kind of analysis. Conventional methods of land evaluation procedures in terms of either soil erosion or productivity are found not comparable with the out put generated by using remote sensing and GIS as the limitations in generating the attribute maps and their integration. The results obtained in this case study show the use of different kinds of data derived from different sources in land evaluation appraisals.

Introduction

Land evaluation using scientific procedures is essential to assess the potentials and constraints of a given piece of land for agricultural needs (Rossiter, 1996). The problems associated with intensive agriculture are alarming with declining soil fertility and erosion in association with low input

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farming against a background of over exploitation of natural resource base in some industrialized countries and scarcity of external inputs in the least endowed countries (Fresco, 1990; Lanen Van *et al.*, 1992). For preserving the ecological balance between natural resources development and conservation, the concept of watershed is assumed to be a very important land unit, particularly in fragile and heterogeneous hilly ecosystem (Sharma *et al.*, 1992). To ensure optimum and sustained productivity through scientific planning, it needs basic knowledge on watershed for appropriate land resources inventories and a scheme for interpretation of land use capability with risk of land degradation as main criterion (Krishna and Sharma, 1995). Land degradation has been associated with failure to identify the areas that are vulnerable to erosion. Land evaluation in terms of its productivity may also address some of the problems by presenting favorable land use that meets the objectives of crop planners and farmers. Land surveying using conventional methods is expensive and time consuming. Soil mapping, soil erosion estimations using the integration of remote sensing and GIS techniques could identify the areas that are at potential risk of soil erosion and also provides quantitative soil erosion loss at different scales (Saha *et al.*, 1992). In hilly areas soil degradation due to erosion is the main threat for sustainable agriculture. These techniques can also be used for qualitative and quantitative physical land evaluation which was demonstrated earlier by several researchers (Beek *et al.*, 1997; Merolla *et al.*, 1994; Rao *et al.*, 1996).

Soil erosion is considered as a specialized form of land evaluation to estimate the erosion quantitatively in different land units in the watershed area. Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978) is best known and most widely used deterministic erosion prediction model. The spatially distributed parameters involved in this equation such as soil and land use could be generated by remote sensing techniques (Moore and Wilson, 1992). These can be integrated with other topographic and ancillary data in GIS environment to produce erosion map and prioritize the big watershed into its sub-watersheds not only based on soil erosion. Land evaluation with respect to its productivity will also give proper understanding of the given land mass. The productivity estimated by the Storie Index method (Storie, 1978) which gives a quantitative estimation of the productivity will help in understanding and estimating the loss of productive soil from the watershed in order to save the landmass. Therefore, it is more meaningful to prioritize the watershed not only in terms of its erosion threats but also on the basis of land productivity.

Study Area

Ason river watershed occupying an area of 15,000 ha is a part of Doon valley (77° 45' 22" to 78.0° E longitudes and 30° 20' to 30° 28' 21" N latitudes) of Dehradun district of Uttarakhand, with a sub-tropical and semi-arid to semi-humid climate. The mean annual temperature ranges from 30.85°C during summer and 15.22°C during winter. The mean annual rainfall is 1700 mm. The physiography of the watershed comprises the Shiwalik hills in the North and alluvial plains in the South with sloppy terrain with colluvial parent material. It covers a variety of land use diversity and wide range of agricultural practices. The soils were dominantly of Entisols and Mollisols in different physiographic units. The main river in the study area is Ason. The Himalayan snowmelt keeps some of the drains as perennial and irrigation canals are also constructed for agriculture in the upper and middle piedmont areas. Paddy, wheat, mustard, maize and sugarcane are the major field crops in the area apart from some seasonal vegetables and fruit crops. Horticulture plantations are present in some areas.

Results and Discussion

Physiography/ soil map

Physiographic map was generated by using topographic data derived from survey of India (SOI) toposheet (53 F/13) on 1:50,000 scale and interpretation of FCC. Based on the image characteristics and terrain features of different landforms like hills, piedmont, valleys, side slopes and alluvial plains are delineated. Soil associations in each physiographic unit were mapped by studying soil-physiographic relationship and soil survey data. Final soil map was generated by using all the attribute data in GIS. The results showed that the watershed is occupied with diverse terrain characteristics in the north and alluvial plains in the south with sloppy terrain. Dominant soils found in the study area are Loamy skeletal, Dystric Eutrochrepts, Loamy skeletal Mollic Hapludalfs, loamy, Dystric Eutrochrepts, Fine loamy Typic Hapludalfs, Fine loamy Mollic Hapludalfs, Fine loamy Dystric Eutrochrepts and Fine loamy Typic Hapludolls.

Land use / Land Cover map

Landsat TM data (146-39, Path and Row, March,1,1998) bands 5,3,2 (630-690nm, 520-600nm, 450-520nm) FCC shown in Fig. 1 was used to generate land use/ land cover map by supervised classification using maximum likelihood classifier. PC based raster GIS software; Integrated Land and Water Information System (ILWIS) was used for image processing and GIS aided integrated analysis. Suitable training sets were taken from the sample strips during fieldwork and the map was amended with the ancillary data on land use/ land cover of the study area to generate the final map. Out of the study area, the land under agriculture and non-agricultural practices (Forest cover, settlement and river) were masked by crossing the soil map with land use/ land cover map using "Cross" operation. New attribute data table was also created with the

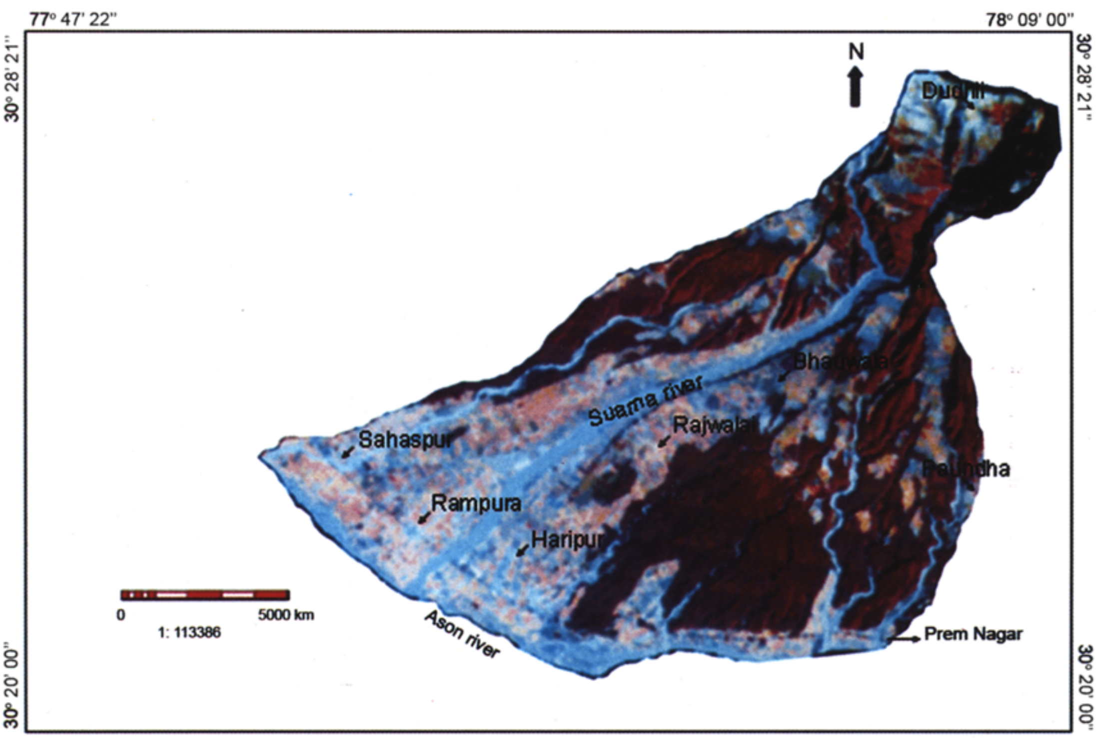

Fig. 1. FCC of the study area used for land use/cover map generation

land units under agriculture. The new map thus generated was subsequently used as an input map for land productivity evaluation analysis. The spatial extent of different land use/land cover presented in table 1 reveals that the maximum area (4541.31 ha) is under agriculture followed by 19.5 % under moderate dense forest. It is interesting to note that the area under degraded forest (1835.46 ha) is also more than the area under dense forest (1619.19 ha), which indicates the deforestation activities in the area.

Table 1: Spatial extent of different land use/ land cover of the study area by supervised classification of Landsat digital data.

Land use/cover	Area (ha)
Dense forest (*Shorea robusta*)	1619.19
Dense forest (mixed)	143.73
Moderatly dense forest	2881.17
Degraded forest	1835.46
Cultivation (dominantly wheat)	4541 31
Cultivation (dominanatly sugarcane, maize)	1429.11
Horticulture plantations (mango)	33.66
Scrub lands	512.73
Settlements	478.89
Rivercourse	1321.56

Soil Loss Estimation and Micro-Watershed Prioritization

The drainage network in the study area is shown in Fig. 2. For prioritization of micro-watersheds, actual (A) and potential (p) soil loss were quantitatively estimated by the empirical Universal Soil Loss Equation (USLE) model (Wischmeier and Smith, 1978), as shown in Fig. 3.

R Factor map was generated from rainfall map using the empirical equation developed for Doon Valley with DEM.

Rainfall = 1384.2+0.329*DEM

R Factor = (0.1059*a*b*c)+52

Where a is the average annual rainfall (cm), b is 24 hours maximum rainfall of 2 years recurrence interval (cm) and c is the 1 hour maximum rainfall of 24 recurrence interval (cm).

K-Factor map is a combination of soil characteristics like permeability, texture, structure and organic matter content. For each soil unit k factor was derived from the soil erodability factor by using the nomograms and placed in the soil attribute table and map was generated by using the relation

K-Factor = Soil map. Soil Table. K-factor column

Polygons containing small drainage units were digitized and average slope length value was attributed for each polygon. LS factor for the slope percentage less than 21 % and more the 21 % was generated separately by using the relationship given by and integrated using "map calc" operator.

LS factor-1: (L/72.6)*(65.41*sin(S) +4.56*sin (S)+0.065)

LS factor-2: $(L/22.1)^{0.7}*(6.432*\sin(S)^{0.79}*\cos(S))$

LS factor= iff (Slope <21, LS factor-1, LS factor-2)

Where LS factor = Slope factor, L is Slope length (m) and S is Slope steepness (%).

Different land cover (C) and management practices (P) obtained for the experimental values were used to take C and P factor values in the Land use/Land cover attribute table and attribute raster maps were generated by using "Attribute raster" operator.

Actual Soil Loss (A) in tons $ha^{-1}yr^{-1}$ was calculated by A = RKLSCP and "Map Calc" function for integration of the individual attribute maps. The

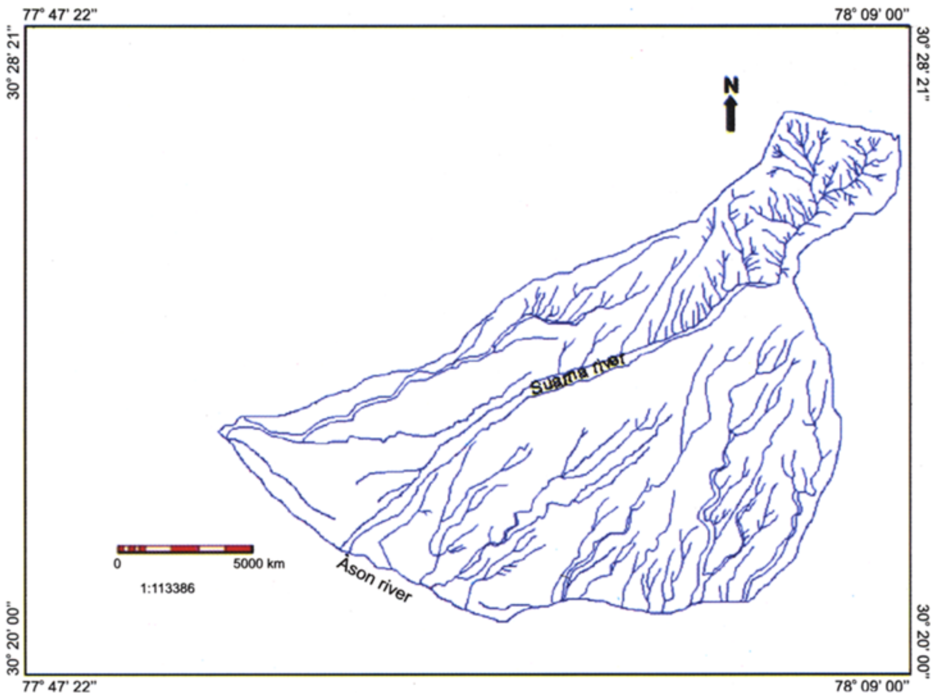

Fig. 2. Drainage network of the study area

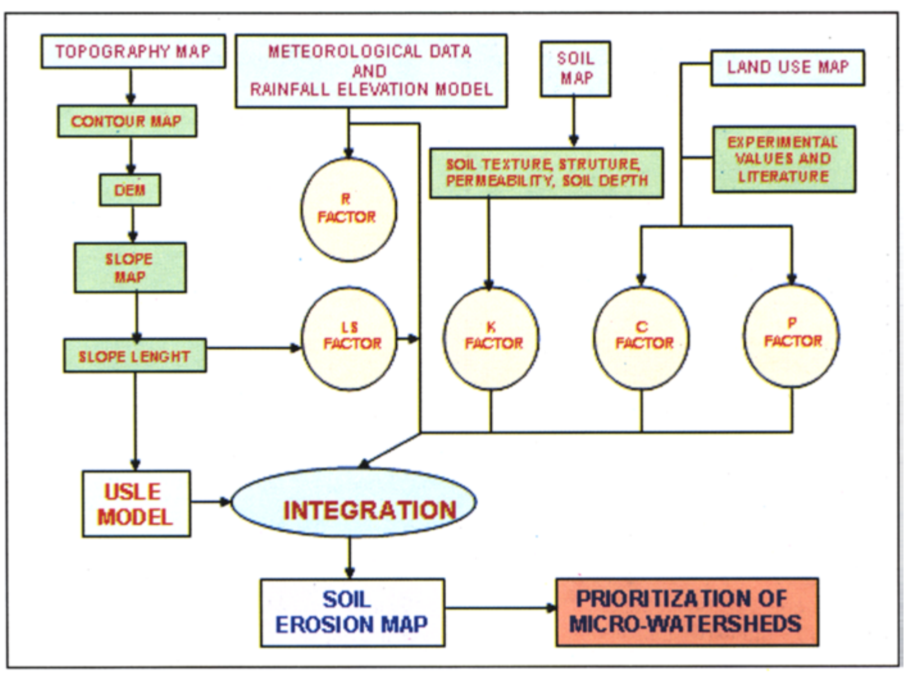

Fig. 3. Methodology flow diagram showing USLE model

actual soil loss for each micro-watershed was calculated using the "column-aggregation" and area weighted average function. Potential and actual soil loss in each micro-watershed area were also compared. The soil erosion map is depicted in the Fig. 4 and the values presented in Table 2 reveal the soil loss ranges from 1 to 34 ton ha^{-1} yr^{-1} in the watershed. As per the priority criteria given in Table 3, the soil loss in different micro-watersheds and their priorities in the study area are depicted in Fig. 5. Among the 12 microwatersheds, 'D' micro-watershed with maximum soil loss (34 tons ha^{-1} yr^{-1}) is put under very high prioritization. Proper management practices of land use/land cover in the microwatersheds Se1 and J1 significantly reduced the soil loss with eventhough the potential soil loss are alarmingly high. Microwatersheds Se1, J1 and G are put under high prioritization followed by Su2 and B for medium priority levels. The land use/land cover management practices are found to be stabilized in all the other five micro-watersheds where, low soil losses are recorded.

Table 3: The priority criteria classess for soil conservation measures.

Soil Loss (Tons ha^{-1} yr^{-1})	Priority Class
<5	Least
5-10	Low
10-15	Moderate
15-25	High
25-50	Very High
>50	Very Very High

Ref: NIRS report on Micro watershed development (RRSSC/B/004/94).

Land Productivity Evaluation

The storie index (revised) ratings method (Storie, 1978) was used to quantify the productivity indices. The ratings were selected in percentage values and converted into decimal equivalents for

Table 2: Actual (A) and Potential (P) loss (ton $ha^{-1}y^{-1}$) in different microwatersheds and their proritization.

Micro-watershed	Land use/cover	Area (ha)	Actual	Potential loss (A)	Prioritization loss (P)
B1	Dense forest	3186.0	4	5	
B2	Under intensive cultivation	2453.0	23	49	High
S1	Degraded and moderately dense forest	1761	18	280	Medium
S2	Settlements	327	1.0	1.0	-
C	Dense forest	857	1.0	1.0	-
J2	-do-	442	1.0	2.0	-
B2	-do-	581	1.0	6.0	-
Sn2	Under intensive cultivation	1239	12.0	12.0	Medium
G	Degraded forest	152	23.0	24.0	High
J1	-do-	659	11.0	80.0	High
Sn1	Open, moderate dense forest, under low intensive cultivation	1645	34.0	28.0	Very high
11 D1	Scrub (open)	958	34.0	28.0	High

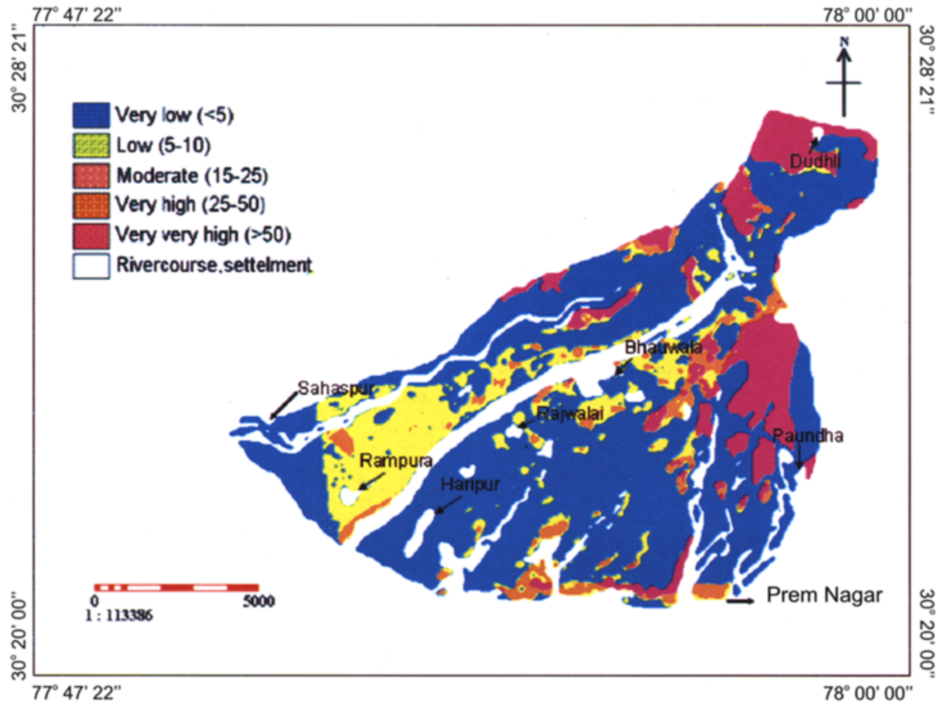

Fig. 4. Soil erosion

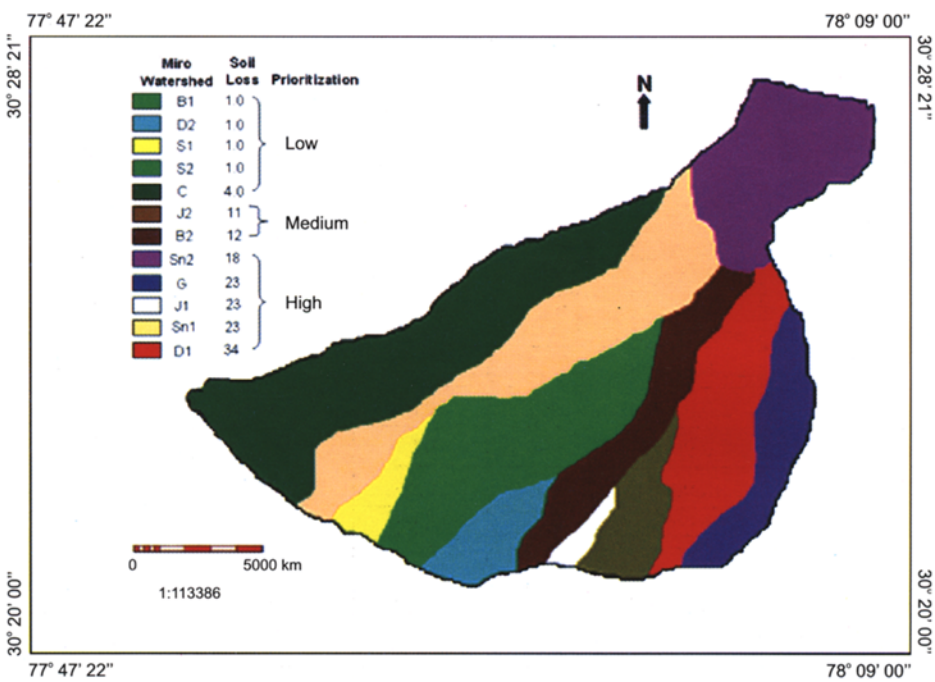

Fig. 5. Micro watersheds prioritization

use in formula and final values were converted into percentage. The methodology is dipicted in Fig. 6.

Land Productivity Index (LPI): A*B*C*X*Y

Where, A is percentage rating for the general soil profile characteristics, B is percentage rating for the texture of the surface horizon, C is percentage rating for the slope of the land, X is percentage rating for the site conditions (salinity, soil reaction etc.), Y is percentage rating for the annual rainfall.

Percentage rating for the each above mentioned parameters were enumerated and attribute maps of different indicies were generated. The final LPI map (Fig. 7) showing different values of productivity indices in the study area was generated by integrating all the attribute maps. Land productivity values are presented in Table 4. The land productivity in different mapping units of the watershed is rated from good (70 LPI) to poor (22 LPI). The maximum area (3153.8 ha) of the watershed in upper and lower piedmont areas is rated as fair, which contributes to nearly 55% of the area under cultivation. A considerable extent of area (2374 ha) in the uplifted terraces and river terraces were also classified into good (>60 LPI) land productivity index ratings. The physiographic soil units M11 and M12 gave poor (22) productivity index rating.

Conclusion

The results demonstrated in the present paper show the use of remote sensing satellite data together with soil survey data in the study of the mountainous areas where, acquiring the soil and land use/land cover data always remains a difficult task. The multiple integration options offered by GIS technology helped to know the possible ways and obtain the remote sensing data derivatives. GIS analysis provided the platform for getting the required results quickly to utilize the natural resources judiciously.

Table 4: Rating of different attribute factors for land units and land Productivity index (LPI)

Land Unit	Attribute factor					LPI	Rating
	A	B	C	X	Y		
M11	0.75	0.85	0.50	0.81	0.84	22	Poor
M12	0.75	0.85	0.50	0.81	0.84	22	Poor
P11	0.85	0.90	0.90	0.81	0.84	47	Fair
P12	0.85	0.90	0.90	0.81	0.84	47	Fair
P21	0.85	0.90	0.90	0.81	0.84	47	Fair
P22	0.85	0.90	0.90	0.90	0.84	52	Fair
T1	0.90	0.95	0.90	0.84	0.84	60	Good
T2	0.90	0.95	0.90	0.92	0.84	60	Good
AT1	0.75	0.95	1.00	0.97	0.84	58	Fair
AT2	0.90	0.95	1.00	0.97	0.84	70	Good
AT3	0.90	0.95	1.00	0.97	0.84	70	Good

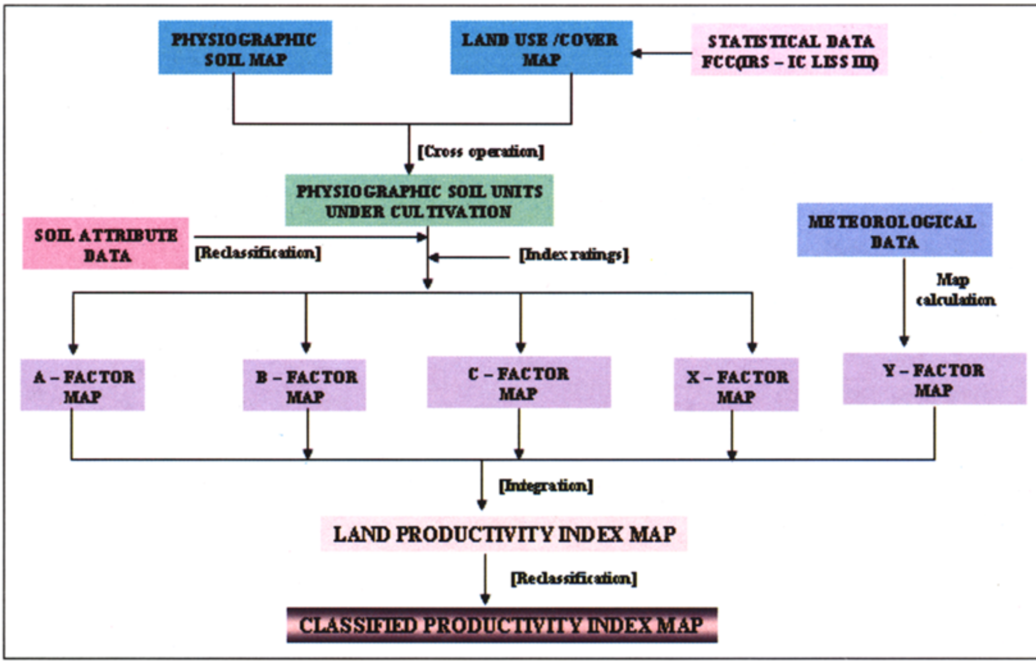

Fig. 6. Methodology flow diagram showing Land Productivity Index using Storie index method

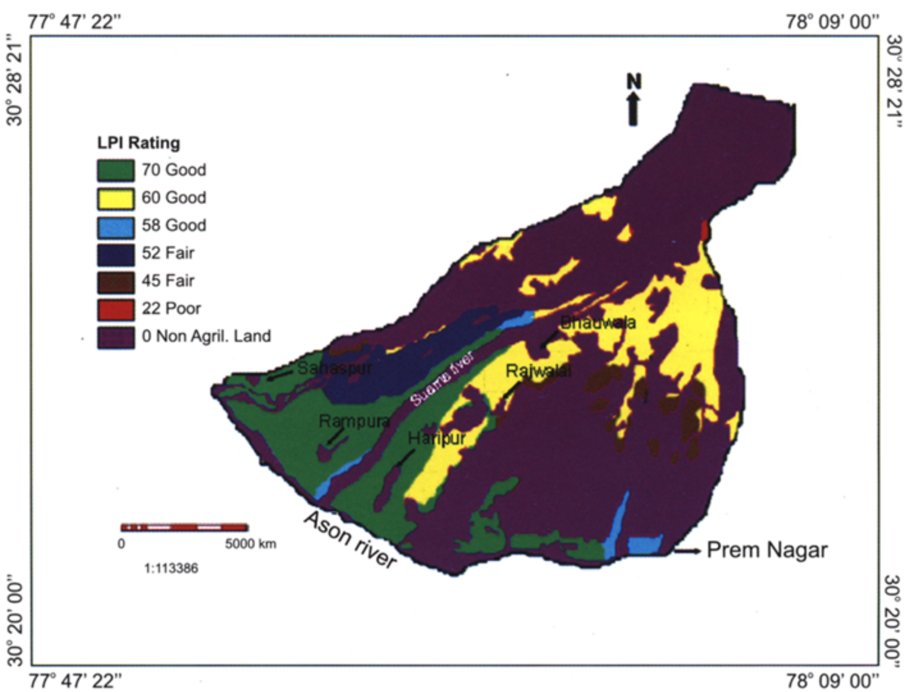

Fig. 7. Land productivity index map

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