



Preparation of Land Resources Development Plan by Implementing AHP-based Weighted Overlay Analysis on Geospatial Inputs

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Abstract: Planning for sustainable development of land resources demands suggestion for best alternate land-use based on the prevailing geo-environment. This practice is assisted by geospatial analysis that involves evaluation of multiple inputs such as existing land cover, ground water prospects, land capability, geomorphology and slope. Judgement on the basis of relative importance among the input layers is highly subjective which significantly affects the results. This study uses a mathematical method named Analytical Hierarchy Process (AHP) for assigning weights to the input layers while performing weight-based overlay analysis for preparing Land Resources Development Plan (LRDP) of a development Block in arid western plain zone of India. A pair-wise comparison matrix was prepared illustrating the importance of each of the layers with respect to other. Normalized principal eigenvectors generated from this matrix were used as weights in further analysis. The input layers were rescaled on the scale of 1 to 10 considering their favorability towards alternate land-uses like intensive agriculture, agro-horticulture, agro-forestry, silvi-pasture, fodder and fuel wood. Favorability maps were generated for each alternate land-use by applying AHP-derived weights. An integrated output (LRDP) was produced by allocating label to every location depicting name of the alternate land-use that scored best among all the favorability scores at that location. LRDP thus prepared is a cost effective method for planners to combat land degradation incorporating different opinions of experts regarding the weightage of input theme layers.

Key words: Sustainable land use planning, land resources development plan (LRDP), geographic information system (GIS), weighted overlay analysis, analytic hierarchy process (AHP).

Background

Desertification is a land degradation problem of major importance in the arid regions of the world. Deterioration in soil and plant cover that has adversely affected nearly 70% of the drylands is mainly the result of human mismanagement of cultivated and range lands (Chabrillat *et al.*, 2002). Overgrazing, woodcutting, cultivation practices inducing accelerated water and wind erosion, improper water management leading to salinization, are all causes of land degradation (Dregne, 1986). Land transformation keep taking place and these processes cause natural degradation, but they are usually compensated for and corrected by nature's inherent recovery ability. Net degradation occurs whenever the degradation processes significantly exceed nature's curative capacity particularly in fragile ecosystem.

Alternate Land Uses for Sustainability of Land Resources

For dryland regions, land conservation is a major thrust area for preserving the current status of land. Moreover, soil and water conservation are emphasized for physical improvement of land (Dalal-Clayton *et al.*, 2013). There is a need to focus on multi-purpose use of land including wastelands so as not to leave them fallow (Fazal, 2000). Practicing alternate land uses like agro-horticulture, agro-forestry, silvi-pasture, fodder and fuel wood plantation, etc. influence by way of reduced runoff from the associated watersheds, increase in overall crop productivity and crop diversification, increase in cultivated land utilization apart from increase in average annual income per family (Wani *et al.*, 2009; Sharma *et al.*, 2001). Rising agricultural production is potentially contributed by horticulture sector (Chand *et al.*, 2008).

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Practicing best land uses under the given conditions is the key for sustainability of the available land resources. Land use planning is “the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options” (FAO, 1993). Various governments across the world have employed land use planning as a component of sustainable development goals of United Nations (Cao, 2018). As per World Commission on Environment and Development (WCED), sustainable development is “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Accordingly, sustainable land use planning deals with the optimum allocation of land use activities in terms of location and proportion (Cao, 2018).

Applicability in the Rural Development Model

In India, Gram Panchayat (GP) is the basic planning unit in the bottom-up model of decentralized developmental planning. Land resources development planning in rural areas is a subject matter of local authorities from Panchayati Raj Institutions (PRIs). For these local planners, spatial optimization for sustainable land use planning is a challenging task due to their poor or limited expertise in GIS. Often conventional methods are adopted for which time requirements for analyzing the data is more (Paul *et al.*, 2017). While native and traditional technologies and knowledge has to be protected, there is also need for new technologies and know-how that should be developed and adjusted to local conditions. In order to avoid haphazard development, endeavours are being made to orient the space technology towards providing technical assistance in preparing the scientifically justified sustainable development plans.

Over the period, along with the outreach efforts for empowering the PRIs, it has been recognized that the geospatial thematic information needs to be harnessed to a further level for being capable to assist in decision making process. Specifically, there is a requirement of the composite map products derived by optimization mathematical modelling

techniques like Multi-Criteria Decision Making (MCDM).

Optimizing Spatially with GIS

In order to choose the best alternative land use, one needs to evaluate various criteria. It is a kind of spatial optimization problem that needs support tools while making decision by the planners. Geographic Information Systems (GIS) is one such tool. There are three major phases in any decision making process viz. intelligence, design and choice (Malczewski, 1999). GIS has a role to play in each of these phases. Moreover, with web-based enablement, GIS has potential for providing input for development of online platform for spatial land use planning.

For sustainable land use planning, there are various models available to address the spatial optimization problems viz. linear programming models, heuristic models and weighted-sum models (Cao, 2018). While linear programming is used in land use planning (Erenstein, 1993). With problem of integration addressed with minimum conflict of interest under limited resource potential, weighted sum models are best suited because expert opinion of various resources needs integration. Integration of various thematic geospatial layers facilitates adoption of appropriate planning strategy. The weighted overlay analysis has been a routine procedure for integration in GIS environment; although the process has limitations due to subjectivity involved in assigning the weights.

Further, incorporating more than one opinion for weight assignment was not possible. These limitations were overcome by utilizing AHP technique.

The approach of spatial optimization is followed in this article to generate LRDP for a development block in arid western plain zone of India. It describes the implementation of weighted-sum model for sustainable land use planning.

Study Area

The study was performed for Balesar Block of Jodhpur District in Rajasthan (Fig. 1). This is a part of north-western hot, arid ecosystem characterized by low and erratic rainfall and a high atmospheric moisture deficit. High solar radiation, high amplitude of diurnal

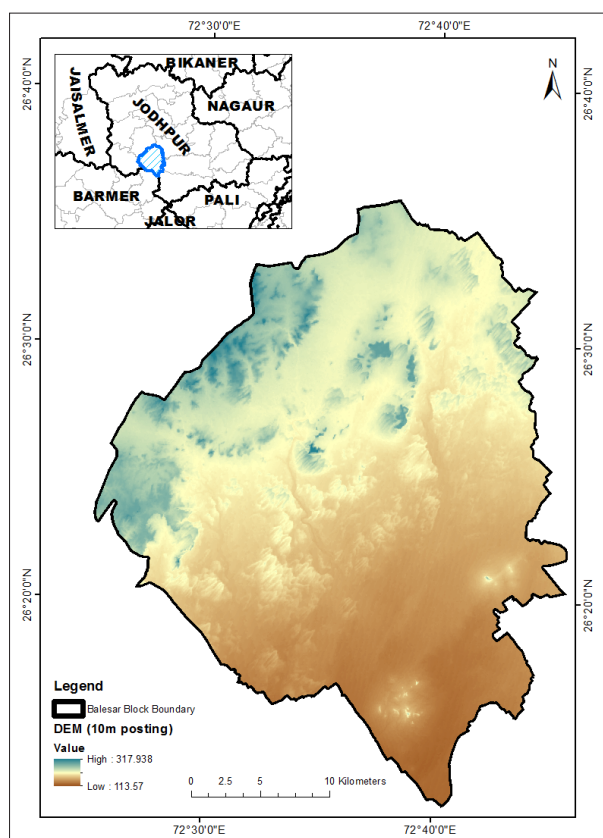


Fig. 1. Digital elevation model of the study area – Balesar Block of Jodhpur District in Rajasthan

temperatures and a strong wind regime are climatic characteristics of the area.

Materials and Methods

Department of Space, Govt. of India has developed a web-GIS based geo-platform named 'Bhuvan' where Panchayat-level developmental planning is also being facilitated (<http://bhuvan.nrsc.gov.in>). 'Space-based Information Support for Decentralized Planning (SIS-DP)' was a project initiated by Department of Space (DoS), Govt. of India, where country-wide large (1:10,000) scale thematic database was prepared using 2.5 m spatial resolution ortho-rectified satellite data product. The database is being hosted on Bhuvan Panchayat Web-GIS Portal (www.bhuvan-panchayat.nrsc.gov.in) for dissemination of information up to the grass root-level users.

Datasets

The following were the datasets used in this study:

Satellite imagery: A 2.5 m spatial resolution natural color composite was prepared using

the fused product of ortho-rectified CartoSAT-1 and LISS-IV, to use in the study as a base layer. The fused imagery was prepared as part of the SIS-DP project.

Land cover: Land cover refers to physical state of the land surface. The land cover layer was prepared under the SIS-DP project based on the 2.5 m satellite imagery with a mapping scale of 1:10,000. The classification scheme adopted comprised of 30 classes which extensively included all the important features across India (Fig. 2a depicts 16 land cover classes present in the study area).

Ground water prospects layer: This layer was taken from the toposheet-wise database prepared under Rajiv Gandhi National Drinking Water Mission (RGNDWM) (Fig. 2b).

Land capability classification layer: It is one of the derived layers (1:50000 scale) from soil map that was prepared under National Natural Resources Data Base (NRDB) project (Fig. 2c).

Geomorphology layer: This layer (1:50000 scale) was taken from nation-wide geomorphological mapping project of National Remote Sensing Centre (NRSC) (Fig. 2d).

Slope: The slope layer, expressed in percentage, was derived from DEM and was classified into 7 classes as shown in Fig. 2e.

Spatial modelling

A spatial model was developed in ArcSDM implemented in ArcMap 10.4.1 (ESRI Inc.). The flowchart of the same is shown in Fig. 3. The model used various thematic layers viz. land cover, ground water potential, land capability classification, geomorphology and slope as input and performed weighted sum analysis for generating favorability maps for each of the intended alternate land use viz. intensive agriculture, agro-horticulture, agro-forestry, silvi-pasture, fodder and fuel wood.

Rescaling/reclassification

Each input layer was rescaled/reclassified on the scale of 1-10 (10 being most favorable for the intended land use) based on the evaluation criteria reported in literature (e.g. Sharma *et al.*, 2001, Paul *et al.*, 2017). Technical guidelines of various governmental schemes like Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Integrated Watershed

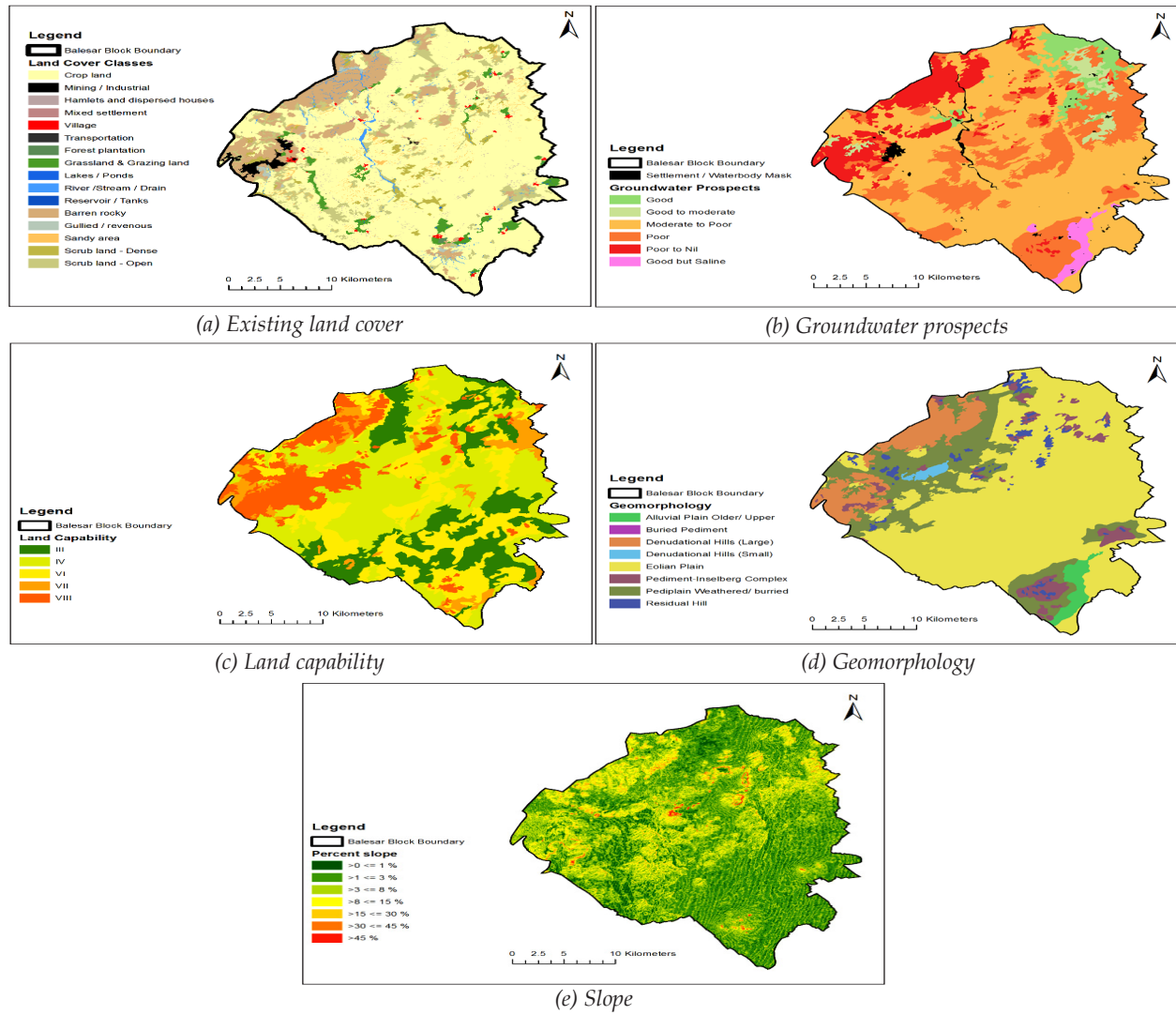


Fig. 2. Various space-based thematic inputs used in the study

Table 1. Rescaling of land-cover classes on the scale of 1 to 10 considering their favorability towards various alternate land-use plans

Existing land cover class in the study area ^a	Favorability for alternate land-use plan				
	Intensive agriculture	Agro-horticulture	Agro-forestry	Fodder & fuel wood plantation	Silvi-pasture
Crop land ^b	10 ^c	10 ^c	10 ^c	1	7
Grassland and grazing land	1	1	1	2	10
Gullied/ravenous	1	1	1	2	6
Scrub land dense	1	1	1	10	10
Scrub land open	1	1	1	10	10
Sandy areas	1	1	1	2	2
Mining/industrial	1	1	1	8	1

a Land cover classes relating to built-up areas, forest land, water bodies and snow/glacial areas are not shown in the above table as none of them are eligible for any alternate land-use and hence all those classes are assigned the lowest value on the scale.

b The land cover class named “crop land” comprises of agricultural farm fields that includes both cultivated as well as fallow land but excludes pastures and grazing land.

c Intensive agriculture/agro-horticulture/agro-forestry are majorly feasible in the areas classified as “crop land”; hence this class is assigned maximum value on the scale of favorability.

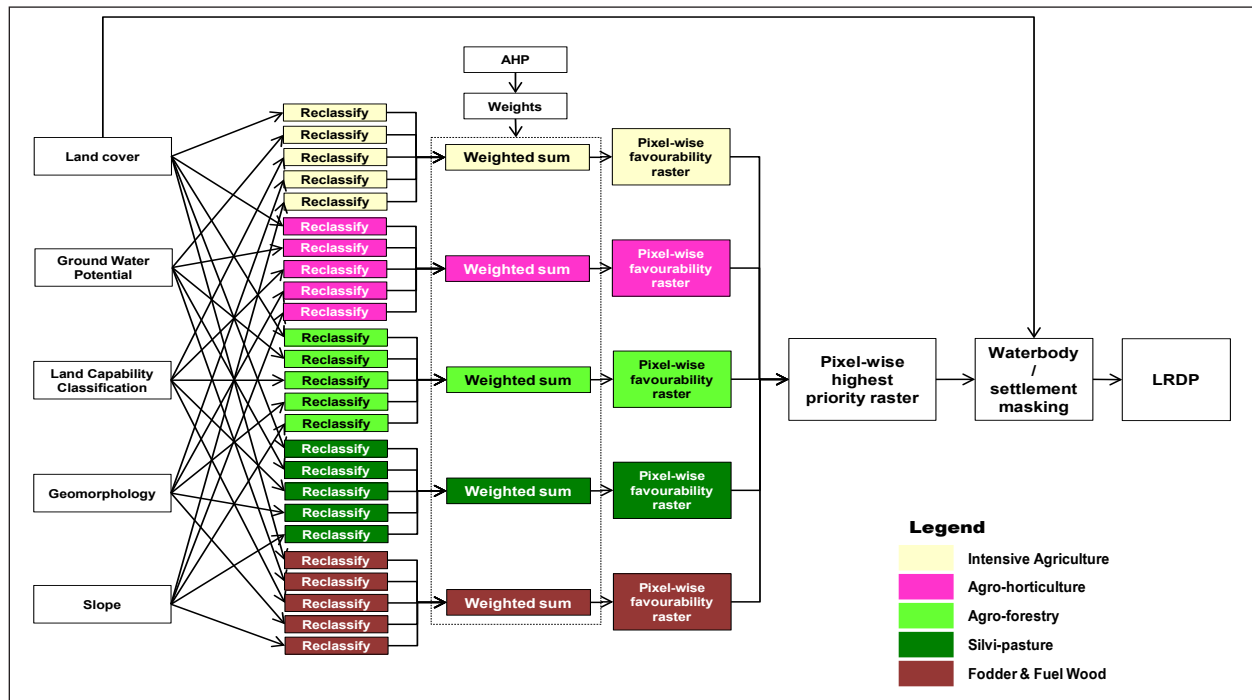


Fig. 3. Flowchart of the methodology adopted.

Management Program (IWMP) and Pradhan Mantri Krishi Sinchai Yojana (PMKSY) as well as guidelines from Integrated Mission for Sustainable Development (IMSD, 1995) were considered while consolidating the evaluation criteria. The rescaled values as per the favourability for alternate land-use plan are shown in Table 1 through Table 5.

Determination of weights using AHP

Quantifying the relative weights have always been a challenging tasks for planners and decision makers (Cao, 2018). Analytical Hierarchy Process (AHP) was used to determine the weights of respective criteria (Table 6).

The weights incorporated in the process were derived by implementing AHP using a Microsoft Excel-based module (Goepel, 2016). Relative importance of each input layer was analyzed in the scale of 1 to 9.

Weighted sum

The model analyzed every pixel by aggregating weighted reclassified values to generate a sum at that pixel. A higher value of sum was expected for the pixels where more of the input criteria were favorable. Thus, weighted sum operation led to generation of a favorability map for a particular alternate land use. The steps of reclassification and weighted

Table 2. Rescaling of land form classes on the scale of 1 to 10 considering their favorability towards various alternate land-use plans

Land form class in the study area	Favorability for alternate land-use plan				
	Intensive agriculture	Agro-horticulture	Agro-forestry	Fodder & fuel wood plantation	Silvi-pasture
Denudational hills	1	1	1	9	10
Residual hills	1	1	1	2	1
Pediment-inselberg complex	2	6	9	8	8
Buried pediment	3	7	2	9	8
Pediplain	5	10	10	10	10
Alluvial plain	10	1	1	1	1
Aeolian plain	7	1	1	1	1

Table 3. Rescaling of groundwater-prospects classes on the scale of 1 to 10 considering their favorability towards various alternate land-use plans

Groundwater-prospects in the study area	Favorability for alternate land-use plan				
	Intensive agriculture	Agro-horticulture	Agro-forestry	Fodder & fuel wood plantation	Silvi-pasture
Good	10	6	4	1	1
Moderate to good	8	10	8	4	2
Poor to moderate	5	9	9	8	8
Poor	3	7	10 ^a	9	9
Poor to nil	2	5	5	10	10
Good but saline	2	3	4	5	5

a. (Sharma *et al.*, 2001)

Table 4. Rescaling of slope classes on the scale of 1 to 10 considering their favorability towards various alternate land-use plans

Percentage slope in the study area	Favorability for alternate land-use plan				
	Intensive agriculture	Agro-horticulture	Agro-forestry	Fodder & fuel wood plantation	Silvi-pasture
0-1	10	3	6	2	1
1-3	8	10	8	3	2
3-8	3	3	10	10	9
8-15	1	1	2	8	10
15-30	1	1	1	2	5
30-45	1	1	1	1	2
>45	1	1	1	1	1

Agro-horticulture is mostly preferred when slope is 1-3%.

Table 5. Rescaling of land capability classes on the scale of 1 to 10 considering their favorability towards various alternate land-use plans

Land capability class in the study area	Favorability for alternate land-use plan				
	Intensive agriculture	Agro-horticulture	Agro-forestry	Fodder & fuel wood plantation	Silvi-pasture
III	10	10	4	1	3
IV	4	6	8	3	6
VI	1	2	10	7	10
VII	1	1	7	10	9
VIII	1	1	3	5	5

sum were repeated for each of the intended alternate land use (Fig. 4).

Integrating the outputs

In the later part of the model, various favorability maps were integrated to generate Land Resource Development Plan (LRDP) as the model output (Fig. 5). The favorability maps generated in the previous step were combined together using the 'highest position' tool in 'spatial analyst' toolbox of ArcGIS 10.4.1. The tool identifies the layer that has highest pixel-

value among all the input favorability maps at each pixel location.

Results and Discussions

The favorability map for a particular alternate land use as depicted in Fig. 4 represents low to high favorability in the form of color ramp. As an example, it can be observed that the North-Western part of Balesar Block is mostly low in favorability for any alternate land use. This is attributed to the combination of barren rocky land cover class, geomorphology layer

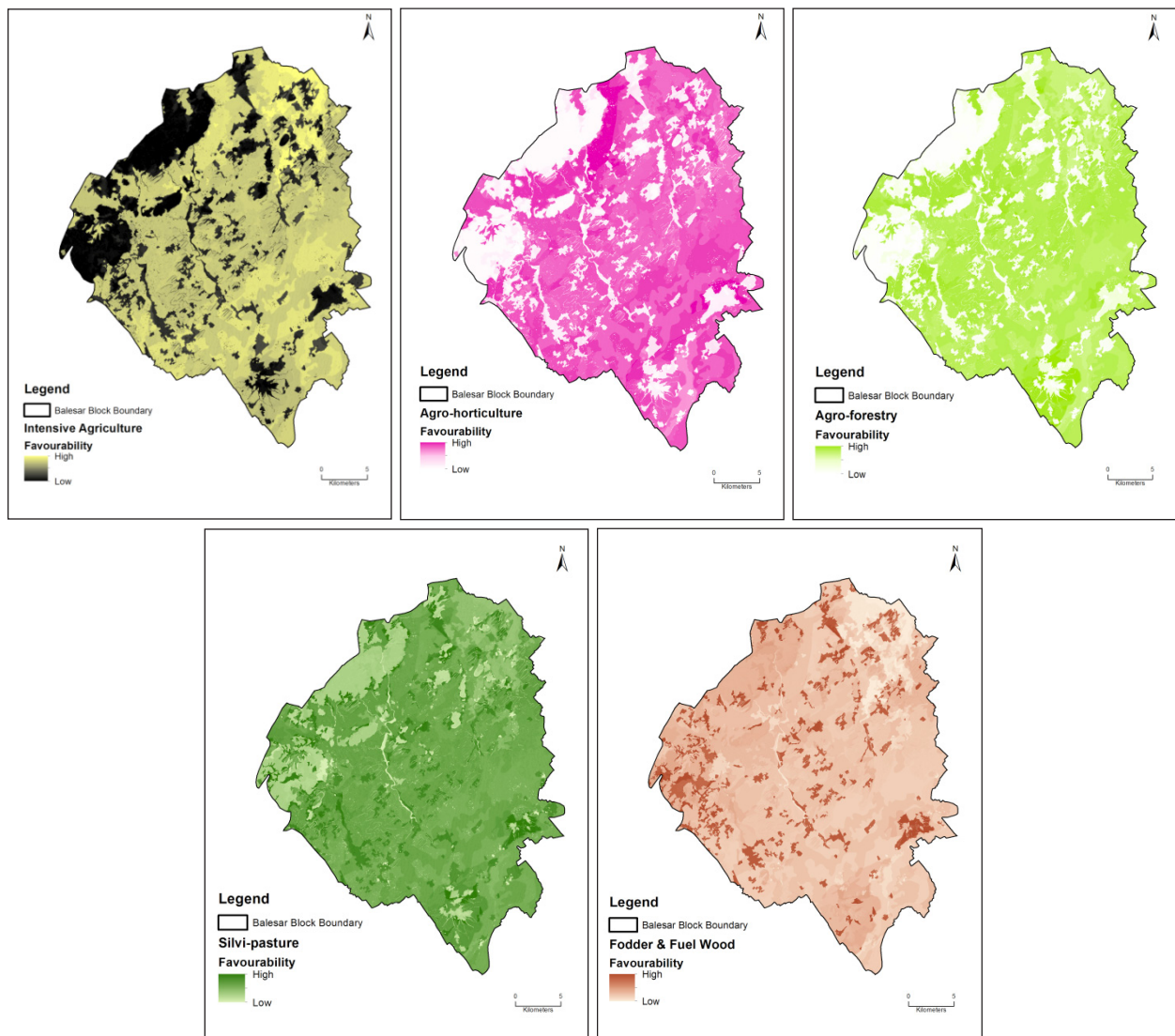


Fig. 4. Weighted sum outputs.

indicating large denudational hills, poor to nil ground water prospects, poor land capability (VII or VIII) and high percentage slope classes.

The Land Resources Development Plan (LRDP) as depicted in Fig. 5 shows the best suggestive alternate land use for the defined land. For example, due to the presence of good ground water prospects towards the North-Eastern side of Balesar Block (Fig. 2b) along with existing agricultural land cover (Fig. 2a), intensive agriculture is suggested in the final LRDP output. This result was influenced due to high weightage assigned to land cover followed by ground water prospects as shown in Table 6. From the output LRDP it may also be observed that much of the intensive agriculture is recommended towards relatively

flatter regions in the valley side of the Block under study. Fodder and fuel wood plantation is recommended as a lower priority measure when no other plan is found suitable for recommended up-gradation. The areas under reserved forest, water bodies and settlements are kept untouched.

The methodology described here is based on the spatial structure at a given point of time. The outputs may be viewed as just one realization of many potential outcomes with the input conditions. For meaningful interpretations, assumption regarding the stationarity of the process is to be made (Dale and Fortin, 2014). The development block in this study is assumed to be regionally having a condition of stationarity. For implementation

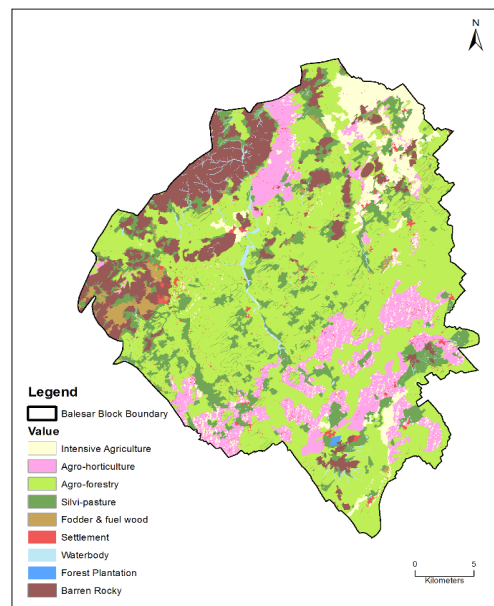


Fig. 5. Integrated output of Land Resource Development Plan (LRDP).

Table 6. Pair-wise comparison matrix for calculation of weights as part of AHP

Importance on the scale of 1 to 9	Geomorphology	Slope	Groundwater prospects	Land capability classification	Land cover	Normalized principal eigenvector (weights)
Geomorphology	1	4	1/4	1/3	1/8	7.09%
Slope	1/4	1	1/4	1/2	1/9	4.06%
Groundwater prospects	4	4	1	3	1/6	18.96%
Land capability classification	3	2	1/3	1	1/6	10.17%
Land cover	8	9	6	6	1	59.72%

of the same model at the country-wide scale, one has to apply spatial partitioning methods to identify homogeneous sub-regions, for the process to remain stationary. Thereafter, the criteria for classification of the zones may be modified as per the prevailing conditions in the partitioned sub-region. The results of this study may be further correlated with the ground-based information for validation.

Conclusion

For a dryland region, land degradation is a major problem and hence land use planning is an important topic of research as it is converged with the sustainable development goals. Spatial optimization techniques are employed along with GIS environment to prepare a planning support tool. The study presented here demonstrated that weighted sum of multiple inputs produced favorability maps that were further integrated to form Land Resources Development Plan (LRDP) for a given development Block. LRDP thus prepared is a

cost effective method for planners to combat land degradation incorporating different opinion of expert regarding the weightage of input theme layers.

References

- Cao, K. 2018. *Spatial Optimization for Sustainable Land Use Planning*, Elsevier Inc., pp. 244 – 252.
- Chabrillat, S., Kaufmann, H., Hill, J., Mueller, A., Merz, B. and Echtler, H. 2002. Research opportunities for studying land degradation with spectroscopic techniques. 9th Int. Symp. on Remote Sensing - Remote Sensing for Environmental Monitoring. *GIS Applications and Geology II* (Ed. M. Ehlers), Agia Pelagia, Greece, 2002, SPIE 4886, 11-19
- Chand Ramesh, Raju S.S. and Pandey L.M. 2008. Progress and potential of horticulture in India. *Indian Journal of Agricultural Economics* 63(3): 299-309.
- Dalal-Clayton, B., Dent, D. and Dubois, O. 2013. Rural planning in developing countries: Supporting natural resource management and sustainable livelihoods. *Routledge*.

- Dale, Mark R.T. and Fortin, Marie-Josée 2014. *Spatial Analysis: A Guide for Ecologists*. Cambridge University Press, Second Edition, pp. 49.
- Dregne, H.E. 1986. Desertification of arid lands. In *Physics of Desertification* (Eds. F. El-Baz and M.H.A. Hassan). Dordrecht, The Netherlands.
- Erenstein, Olaf C.A and Schipper, Robert A. 1993. Linear programming and land use planning. Wageningen Agricultural University.
- FAO 1993. *Guidelines for Land-use Planning*. FAO Development Series 1. Rome.
- Fazal, S. 2000. Urban expansion and loss of agricultural land - A GIS based study of Saharanpur City, India. *Environment and Urbanization* 2(12): 133-149.
- Geertman, S. 2002. Participatory planning and GIS: A PSS to bridge the gap. *Environment and Planning B: Planning and Design* 29(1): 21-35.
- Goepel, K.D. 2016. AHPCalc, Creative Commons Licence - <http://bpmsg.com>
- Integrated Mission for Sustainable Development (IMSD) 1995. Technical Guidelines. *National Remote Sensing Agency: Hyderabad, India*; pp. 1-127.
- Malczewski Jacek 1999. *GIS and Multicriteria Decision Analysis*. John Wiley & Sons, Inc., New York: 392 p.
- MGNREGA, IWMP, PMKSY. *Technical Guidelines*. Govt. of India
- Paul, A., Chowdary, V.M., Dutta, D. and Sharma, J.R. 2017. Standalone open-source GIS-based tools for land and water resource development plan generation. In *Environment and Earth Observation* (Eds. S. Hazra, A. Mukhopadhyay, A. Ghosh, D. Mitra and V. Dadhwal), pp. 23-34. Springer Remote Sensing/Photogrammetry. Springer, Cham
- Sharma, T., Kiran, P.S., 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. *International Journal of Remote Sensing* 22(11): 2095-2108.
- Wani, S.P., Venkateswarlu, B., Sahrawat, K.L., Rao, K.V. and Ramakrishna, Y.S. 2009. Best-bet options for integrated watershed management. *Proceedings of the Comprehensive Assessment of Watershed Programs in India*. International Crops Research Institute for the Semi-Arid Tropics, 312 p.

