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Research Article

Integration of Earth Observation Data and Spatial Approach to Delineate and Manage Aeolian Sand-Affected Wasteland in Highly Productive Lands of Haryana, India

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The western part of the country India is surrounded by Thar desert. Due to climate change, many regions in the world are facing different challenges. The objective of the study was to quantify the aeolian sand-affected land through integrated approach. The LANDSAT-ETM+ satellite image of 2009 has been used to distinguish recently affected areas by aeolian sand. A combined approach of digital classification backed with visual interpretation and ground verification was adopted. In addition to classification accuracy assessment was performed using field observations. Evidence based results of aeolian sand-affected areas have suggested that wasteland area has increased up to 4,427.55 ha (6.79%) of total geographical area. Two types of aeolian sands areas have been detected, namely, moderately affected (3,881.77 ha) and severely affected (545.79 ha). Moderately and severely affected aeolian soil lands have been more accurately mapped with reasonably good accuracy whereas smaller aeolian affected areas within croplands are mapped with low accuracy. The present study provides easy methodology for delineation, classification, and characterization of aeolian affected sands.

1. Introduction

Land resources are a valuable natural resource and it acts as a key for sustenance of mankind [1, 2]. Overexploitation of land resources causes a significant change to the landforms, which has adverse effect to the environment [3]. The high population pressure, fast urbanization, rapid industrialization, and extensive agriculture have put great stresses on land resources, resulting into the substantial reduction in agricultural area and natural resources [4]. Tremendous population pressure is also leading to deforestation and resource degradation that has disturbed ecological balance of terrestrial ecosystems [5, 6]. Hence, quantitative information about the nature, degree of extent, and spatiotemporal distribution of affected soils of India and the world is needed. It is essential for improved planning and need to implement strategic reclamation programs in proper time and cost-effective manner for huge crops production. In India at national level wasteland mapping was conducted by conventional surveys and integrated (remote sensing and GIS) approaches from last four decades.

Management of land and water resources is essential to meet the economic growth of people in any country [7, 8]. Land degradation is a serious problem; it can be controlled by afforestation practices on available wastelands in more scientific way [9, 10] and keep natural ecosystem in harmony and maintain ecological balance. Thus, the up-to-date and appropriate information about location and spatial extent of vacant/wastelands has played very important role for better planning of afforestation and treatment to eradicate the negative effects of land degradation [11, 12]. Hence, there is great demand to identify and reclaim these degraded lands in many countries [6] and in district of Sirsa of Haryana [13, 14].

Recent developments in geographical mapping allow the researchers to exercise the spatiotemporal distribution pattern and location aspects of land use/land cover (LULC) that can be studied more accurately using geospatial techniques (Saha 1990, [15–17]). Many studies have proven the applications of Remote Sensing and GIS in monitoring and management of natural resources [6, 18–20]. Remote sensed data sets are used widely in studies, namely, groundwater [21], lake and wetlands [22, 23], land use/land cover mapping [24, 25], land use/land cover modeling [26, 27], crop suitability (Mustak et al. 2013), urban land use dynamics, forest mapping [28], soil characterization [29], slope estimation [30], landscape ecology [31], and watershed management [32]. Further, RS technology has proven its application in assessment of wasteland and its temporal monitoring [33, 34]. With the advent of satellite remote sensing mapping of degraded land has been started more efficiently at much finer scales [35]. The raw data which are affected by panoramic distortion, earth curvature, sensor detector failed, and detector line losses which are primarily corrected by data providers [36], hence, provide better mapping possibilities. Satellite remote sensing provides unbiased information about the objects. Satellite remote sensing has advantage over field based method in the forms of multispectral, synoptic coverage, very high temporal resolution, and cost effectiveness [37, 38]. Grunwald [4] has identified the spatial patterns and variations in landforms, land use, wasteland, and demographic characteristics and their spatial associations in satellite data. Genesis of wasteland and its typologies into degraded forests, undulating land, gullied and ravinous land, and degraded pastures, waterlogged, salt-affected, and sand-affected areas can be mapped and analyzed accurately with special reference to their relationship to natural environment [7]. Satellite data are of immense use for fine scale mapping of wastelands and may be helpful in implementing the schemes for wastelands development in given time [9, 39, 40].

Saha et al. [41] integrated LANDSAT-TM dataset into GIS environment to map salt-affected and surface waterlogged/marshy lands with an accuracy of about 96% in parts of Aligarh district, Uttar Pradesh, India. Jain et al. [33] have identified the highly degraded scrub and sandy land on fringes of town and provided recommendations for future urban planning of the town where further development can be planned to avoid encroachment on good agricultural lands. Wasteland mappings of Karnal district (Haryana, India) using visual, monoscopic interpretations of MS LANDSAT-TM dataset of 1986 and ground truth were attempted [42, 43]. Pramila [18] used LANDSAT-TM dataset of 1988 and found that a major reason for formation of wasteland was severe wind erosion (Jalor and Ahor Tehsil of Jalor district of Western Rajasthan). The reflection of sand particles is being high; hence the sandy soil could be easily identified by false color composition (FCC) in LANDSAT-TM dataset. Sugumaran et al. [15] used IRS-1A, LISS-II data sets to delineate more accurately the wastelands at microlevel in *Matar taluka* of *Kheda* district (states of Gujarat, India) and generated area statistics of wastelands. Status of desertification was mapped with the application of satellite data in dry subhumid region of Panchkula district of Haryana by Arya et al. [44]. They found that nearly 47.5% of the total geographical area faces desertification (formation of wasteland states). Major outcomes from the study were that near about 32% of the total area of district's scrublands converted into desert mainly due to the unchecked desertification process. The change status of sodic lands has been prepared using satellite remote sensing data by Singh [16]. The desertification process is going on these regions; hence, we formulated our study with objectives as (i) identification and delineation of wastelands (at 1 : 50,000 scale) using LANDSAT-ETM+ (2009) data set and (ii) creation of digital database in GIS environment.

2. Materials and Methods

2.1. Study Area. Sirsa district has an area of 4,276 km^2 (29.5400°N, 75.0300°E) with its headquarters being situated in Sirsa town (Figure 1). It is situated at nearly 255 km west of Delhi and 280 km from Southwest of Chandigarh. The Ghaggar River is flowing through central part of study area and Bhakra Canal is prime source of surface water for irrigation and drinking uses. The climate of region is tropical in nature with intensive hot summer and cool winter with a temperature variation of 47°C in June and 3°C in December and January. The average rainfall ranges between 200 and 300 mm and 80% precipitation is received during the four months (July to September; [45]). Consequently the agriculture in Sirsa district is threatened with nonavailability of water and the land related constraints too which is rendering a sizeable area into unproductive land due to aeolian spread of sands from the adjoining lands in the summers of each year. The terrain is broadly classified into moderately slopy to steep slope and highly undulating [46]. The terrain is divided into three major types, that is, Haryana plain, alluvial bed (Ghaggar or *"nali"*), and sand dune tract. The general slope varies from North to South.

2.2. Data Used and Analytical Procedures. In study the wastelands of Sirsa district, Haryana, have been delineated and mapped on 1 : 50,000 scale through digital image processing of LANDSAT-ETM+ image of 2009. Geocoded data was processed using image processing (ERDAS IMAGINE 8.7) software supported with the visual interpretation and ground truth. ArcGIS 9.3 was used for creation of digital database. LANDSAT-ETM+ digital data of 2 October 2009 was downloaded from web site (https://glovis.usgs.gov), and gap filling was applied using ENV4.8ver.

Collateral Data. For reference purposes, latest published reports, papers, and maps were used. For identification of village location, major transport networks, cultural features, and annotation of major towns and cities topo-sheets were obtained from different agencies and used. The groundwater report was used from Central Groundwater Board Report [46], *agriculture information from* [45], and information about the forestry from [45].

3. Methodology

Geometric correction was performed and later overlay was carried out using administrative boundary. False color composition (FCC) was generated using bands 2, 3, and 4 in blue, red, and green filters (Figure 2). Based on the standard

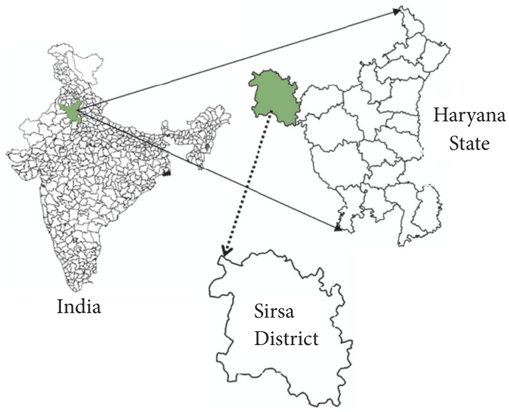

Figure 1: Location map of study area (Sirsa district of Haryana, India).

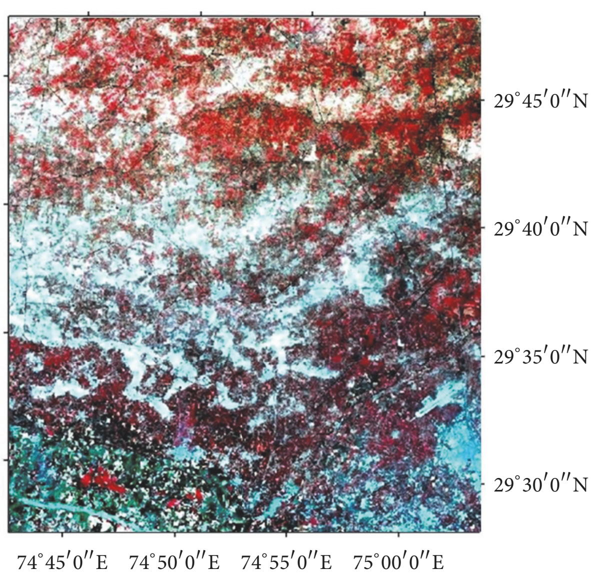

Figure 2: LANDSAT-ETM5+ false color composite map showing area affected by aeolian sand (in bright color, tones, and textures).

image interpretation key such as tone, texture, pattern, shape, size, location, and association, image was classified using Maximum Likelihood Classification (MLC) and visual interpretation. The readers can find the details of MLC in any standard remote sensing book (e.g., [48]). Following a standard legend prepared by Department of Space, Government of India (DOS, GOI) to delineate different wastelands categories was performed. A separate layer of settlement areas along with their names and major roads was also prepared. These maps were kept in GIS format further to create the database.

Training Signatures and Object Identification. By operating the classifier panel of the ERDAS IMAGINE 8.7, training signatures of the target (aeolian sand soil) were identified in two steps as (i) marking of training windows for various features by locating ground truth sites in the images and (ii) generation of signatures for training windows. Prior to training signature generation, identification of target is important. It was found that different objects had unique spectral signatures. Differences in photographic tone or texture or both are the basis for target identification coupled with knowledge of the target. They depend on the reflectance power of leaves and also on the soil cover ratio, which in turn depends on the stage of nutrient status and moisture status of the soil. Photographic texture depends on nature of soil and spacing between soil particles and scale of the photograph. The spectral signature of soil is influenced by the underlying soil and residue. The signature is subsequently modified by the appearance and gradual increase in surface coverage of particular soil. Knowing the manner in which soil characteristics is recorded photographically and the ability to associate these with the knowledge of soil identification was done successfully. The exact locations of ground truth sites were recorded with the help of Global Positioning System (GPS). Before freezing the training signatures, trial classification was run on respective sampled images. As per the requirement some training sites which were not suitable were hence discarded while some were modified to proceed with classification process. MLC method was used to classify LANDSAT-ETM+ (Path/Row 148/40) imagery using ground truth data which widely used parametric classifier for satellite data analysis and it relies on the second-order statistics of Gaussian probability density functions (PDFs) used to classify unidentified pixel belonging to each category.

Table 1: Accuracy assessment report.

Class	Severely affected	Moderately affected	Settlement	Row total
Severely affected	70	5	0	75
Moderately affected	3	55	0	58
Settlement	0	0	121	121
Column total	**73**	**60**	**121**	**254**
	Error matrix			
Agreement/accuracy (in %)	95.89	91.67	100	
Omission error (in %)	4.11	8.33	100	
Commission error (in %)	6.67			
Overall accuracy (in %)	96.85			

4. Results and Discussions

The accuracy assessment in Table 1 shows that the overall accuracy of classified image is 96.85. The delineated wasteland areas are illustrated (Figure 3). The district is comprised of 4.27 lac hectares (ha), which is 9.66% of area of Haryana state. The area taken under study was 65,176.93 ha which constitutes nearly 15.24% of the total geographical area of the district. It was found that the wastelands in the study area covered approximately 4,427.55 ha which constitutes nearly 6.79% of the total geographical extents. The main wasteland category is aeolian sand. This analysis has completely upgraded the land use statistics of district which can be used for effective planning of its proper development and management of resources in a more sustainable manner.

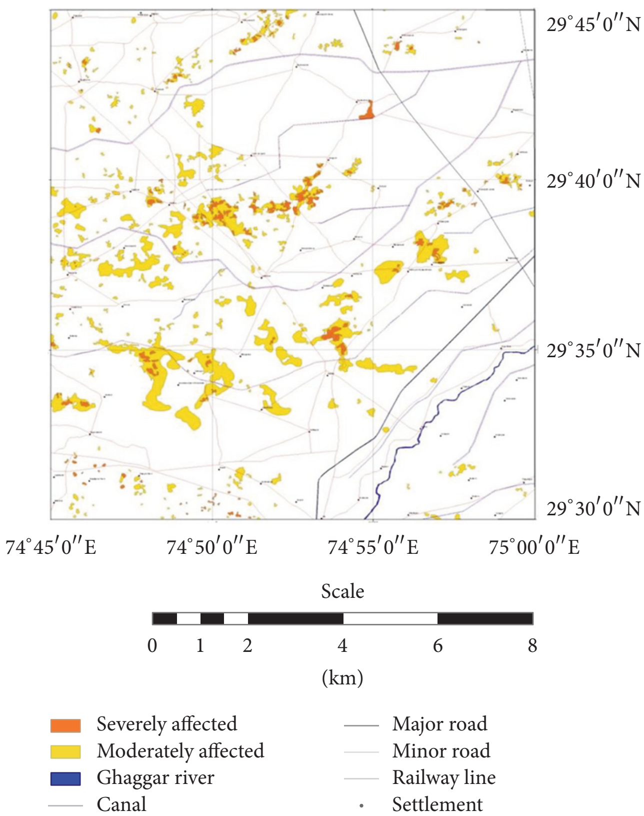

Figure 3: Map showing area affected by aeolian sand in Sirsa District of Haryana, India.

4.1. Aeolian Sand. The majority of land areas is sandy and is characterized by accumulation of sand in the form of varying size of sand dunes having variable shapes and sizes that have developed as a result of transportation of soil through wind processes. The main cause of aeolian sand is due to adjacency to the Rajasthan State that lies under arid climatic condition and resulted into soil erosion due to wind. The directional flow of sand is more in the Sirsa region. The area encompasses sandy soils with low to very low soil moisture and low organic matter. The productivity of such types of soil is low. Hence soil loss in the form of deposits of sand dune and sand transportation is very frequent by wind erosion. Wind erosion generally forms two types of wasteland, which are discussed below.

4.1.1. Lands Moderately Affected by Aeolian Process. Areas that come under this category were found to be approximately 3,881.77 ha (5.96%) of study area. The majority of land is moderately affected by aeolian sands and has good amount of organic matter content and higher soil moisture retention compared to severely affected lands. The slightly better soils have good agricultural activities in this region and have better productive yield. However, it still needs to be managed through appropriate agricultural practices in proper manner. In condition of extreme utilization without proper conservation and management practices, it enhances severe soil loss condition and complete degradation. Moderately affected soils may convert into fertile soil by adopting proper agricultural practices and thus can be optimized for better agriculture utilities.

4.1.2. Lands Severely Affected by Aeolian Process. The severely affected soils have covered approximately 545.79 ha (0.84%); hence urgent need is required to take proper care and management. The moderately affected land is also getting converted into severely affected land because of deforestation and nonscientific agriculture practices. It is very difficult to ameliorate severely affected soils because of their bad physical and biological conditions, although they can be used for horticultural plantations, agri-silvi or agri-silvi-pastoral purposes, and for conservation agriculture to some extent with much effort on soil conservation measures.

4.2. The Piedmont Plains of Ghaggar River. The Ghaggar, an important rain fed river of length 85 km in district, has major drainage channel. The area occupied by the *piedmont plains of Ghaggar River* is approximately 0.14%. The river flooded in South West monsoon and causes extensive damage to crops and property. Soils around the river region are sandy to loamy sand at places underlined by lime concretion and gypsiferous substrata. Some places are also covered with sand hummocks and sand dunes. The soil is low in nitrogen, organic carbon, and phosphorus contents.

Most of the area is covered by aeolian sand; it has fine particles and is continuously varying. Because wastelands are an important aspect in land use planning and developmental activities of any area, so all the database on wastelands was created and put in GIS.

5. Recommendations and Reclamation Measures, Management, and Adaptation

Wind erosion is a major problem. The top soil erosion leads to loss of organic matter, damage to crops, and burial of productive agricultural lands. Farmers are protecting and managing their agricultural fields especially through crop residue and fencing during critical periods. Two major control activities are recommended as aeolian sand stabilization and shelter belt plantation (Table 2) and some improved methods are also given below for aeolian sand stabilization being followed in similar conditions elsewhere in the world [8, 49–53].

Gap Filling/Regeneration of Tree Species on Degraded Forest Land. Afforestation can be used in gap filling with transplanting. Suitable plant species like *Acacia nilotica, Acacia tortilis, Dalbergia sissoo, Azadirachta indica, Eucalyptus camaldulensis, Popular, Tamarix* species, and so forth can be used for the transplanting. The ground flora should be enriched by growing suitable shrub and grass species in contour furrows. However, uncontrolled grazing should be restricted and properly regulated for forest regeneration.

Brushes and Mulches. Brushes or mulches act as surface covers and wind barriers against erosion from the wind. They prevent loss of top soil, retain moisture and provide shelter for developing seedlings, and enhance sand accretion. Accreting

Table 2: Plant species suitable for aeolian sand stabilization.

Annual rainfall zone (mm)	Trees	Shrubs	Grasses
150–300	*Prosopis juliflora, Acacia tortilis, A. senegal*	*Calligonum polygonoides, Ziziphus nummularia, Citrullus colocynthis, Ziziphus mauritiana*	*Lasiurus sindicus*
300–400	*A. tortilis, A. senegal, P. juliflora, P. cineraria, Tecomella undulata, Parkinsonia aculeata, Acacia nubica, Dichrostachys glomerata, Colophospermum mopane, Cordia rothii*	*Z. nummularia, C. polygonoides, Citrullus colocynthis*	*C. setigerus, L. sindicus, Saccharum munja, C. ciliaris*
400–550	*A. tortilis, P. cineraria, P. juliflora, A. senegal, Dalbergia sissoo, Ailanthus excelsa, Albizia lebbeck, P. aculeata, T. undulata, D. glomerata, C. mopane*	*Z. mauritiana, Cassia auriculata*	*Cenchrus ciliaris, C. setigerus, S. munja, Panicum antidotale*

Source. Adopted from [47].

sand stimulates the growth of primary colonizing grasses such as *Spinifex*.

Liquid Sprays. Liquid sprays such as emulsified bitumen or dispersed organic polymers provide temporary stabilization by aggregating or cementing sand grains so that they cannot be moved by the wind. Unlike brushes and mulches, these products do not enhance sand accretion; mobile sand simply passes over the surface and continues until intercepted by other obstacles. Recommended sprays do not interfere with the germination or with the growth of seedlings, transplanted culms, or runners. Most allow reasonable air and water exchange between the atmosphere and stabilized sand [54].

Cover Crops. Cover crops are generally intolerant of strong winds and significant sand burial. Thus, where there is no migrating sand to accrete and it is a matter of holding the sand surface in place while secondary or tertiary species are established, then a living plant mulch or cover crop is appropriate. By necessity, cover crops must germinate rapidly and grow vigorously to provide a dense vegetative cover capable of reducing the wind velocity at the sand surface. Cover crops may be used to provide sand surface stability and to protect emerging secondary species or they may be used in their own right as a longer term surface stabilizer. The length of time they persist can be controlled by species selection and by management of fertilizer inputs.

6. Conclusions

In this work, wasteland mapping has been carried out of year 2009. The satellite image was classified using MLC based supervised classification, and total 65,176.93 ha of land area is classified as wasteland, in which 3,881.77 ha area was mapped as moderately and 545.79 ha as severely affected by aeolian sand. The more accurate mapping of aeolian soil encrusted lands with large contiguous areas whereas slightly affected land having less affected areas within croplands was mapped less accurately. The previous and current national scenarios of aeolian affected soils using traditional and RS approaches can be refined and all other national estimates of wasteland (especially aeolian sand-affected soil) mapping can be subjected to the present methodology and approach can be subjected to the reconciliation. It can be stated that fine resolution satellite data sets facilitate interpretation to further differentiate a wasteland class delineated on moderate spatial resolution satellite data. Moreover, these data are found to be useful in achieving high mapping accuracy in delineation of wasteland classes.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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