SPATIAL ASSESSMENT OF FOREST SITE QUALITY FOR AFFORESTATION USING MULTI CRITERIA DECISION ANALYSIS

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Abstract

Forest resources management at regional scale using traditional techniques is a challenging task especially in rugged terrain mountainous areas. The study area was selected in District Kohistan and District Battagram, of Khyber PukhtonKhwa (KPK), Pakistan using the 1°x1° confluence points as defined in FRA 2010. Cloud free satellite image of Landsat TM acquired in September 2009 was used for achieving the objective. Multi-Criteria Decision Analysis (MCDA) procedure was adopted in ArcGIS software for spatial modeling of site quality for afforestation. Analytical hierarchical process (AHP) defined multiple criteria using pairwise comparison matrix and the rating (weight) of each criterion was calculated. The results revealed that, by applying the selected parameters, 42% of land had the potential for afforestation within which 4% was recommended for dense afforestation. MCDA was found useful tool in breaking down the problem of identification and classification of the sites for afforestation in the management of hill forests.

Key words: Afforestation, Confluence Points, MCDA, AHP, Deforestation, AOI.

Introduction

Forests play an important role in global carbon cycle, being potential carbon sink and source of up to 20% (IPCC, 2007). The forest sector contributes approx 17% of global greenhouse gas emissions, i.e. 5.8 Giga tonne of carbon dioxide equivalent (CO2e) per year (IPCC, 2007). Forest resources management at regional scale using traditional techniques is a challenging task especially in rugged terrain mountainous areas (Ali, 2006). FAO has linearly forecasted in Forest Resource Assessment programme i.e. (FRA 2010) that the area of coniferous forest of Pakistan has been reduced to 1.1million ha in 2010 which was 1.9million ha in 1990 and the annual deforestation rate was above 2% (Ridder, 2007).

Due to the carbon budget trading framework incorporated in the Kyoto Protocol, techniques for cost- and time-efficient above-ground biomass estimation on forestlands are necessary (Bettinger, 2006). In this regard GIS provides an environment for measuring past forest change and modeling of its future change (Singh, 2003). Moreover, remote sensing is widely used in developed nations to estimate above ground biomass, volume, carbon content and leaf area index in different vegetation systems (Gunawardena, 2008).

Kohistan forest of Pakistan has an extremely difficult terrain therefore no extensive field survey has been done so far. Deforestation is common due to high

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rate of illiteracy. Reduced agricultural production in the region and limited access to plain areas after frequent disastrous events i.e. Earth quake, Floods and landslide turned the fate of forests to serve not only for keeping the locals warm in the winters but also have to compensate for the provision of land to fulfill the food requirements (ERRA, 2007). In order to avail the opportunities of saving these forests for trading the forest carbon appears a viable proposition Therefore a reliable system of assessment of forest is required. Thus the forest managers need a scientific assistance in managing and monitoring of the forests (FMC, 2000). This paper is based on the study of the effectiveness of RS and GIS on designing a methodology to implement geospatial technologies in the selection of a site according to its suitability for carrying out afforestation works.

Study Area

The study area boundary mainly included area of Palas Forest Range of lower Kohistan Forest division and Allai Forest Range located at Lat 73.00E & Long 35.00N (figure1). It was selected based on the methodology of FRA 2010 in which FAO and the University of Maryland defined a 1° x 1° lat/ long sampling frame of 10 Km x 10 Km which resulted in 13,482 intersection points on terrestrial land surface on earth, including islands. (Ridder, 2007). Out of total of 13,482 confluence points 85 fall in the territories of Pakistan including Azad Kashmir. The confluence point lying in District Kohistan was however selected for representing important natural flora and the terrain quality of the hill forests of Pakistan. However a sample of 20 Km x 20 Km was used in this study to cover the 5 km buffer of the boundary of the sample plot for better visualization. Forest demarcation in the area has not yet been carried out due to administrative difficulties and hostile attitude of local communities. The forests are protected as no land record is available due to settlement of the area is still awaited. Since 1955, the provisions of Hazara forest act 1937 and the area has been declared as Guzara forest. The forests are owned by the local communities who for centuries have been enjoyed their rights (FMC, 2000).

Based on latest Forest Working Plan (FMC, 2000) Broad leaved forest is dominant at the foot hills of the study area with trees of *Quercus spp*, *Monotheca buxfolia* (gurgura), *Punica granatum* (pomegranate), *Acacia modesta* (phulahi), *Adhatoda vesica*, *Zyzyphus sativa* and *Dodonaea viscosa* (sanatha) at an elevation range of 1000-1800m elevation (FMC, 2000). Blue Pine Forest is distributed along the north western and western aspects at an elevation range of 1700-2700m elevation (FMC, 2000). Mixed blue pine forest prevails with tree species of Deodar, Fir and Spruce forests at an altitudinal range of 1800-2900m (FMC, 2000). Fir/Spruce forest is dominant in kolai and Palas valleys prevailing at an altitudinal range of 2100-3200m (FMC, 2000). Sub-Alpine scrub forest lies between 3000-3360m elevation and its main specie is *Betula utilis* (Birch). Under growth of this forest type consists mainly of *Vibernum* spp*.* The forest types prevailing in the study area were modeled using the basic overlay tool of ArcGIS software based on the aspect and elevation range of each forest type for selection of suitable tree spp for afforestation (Figure 2).

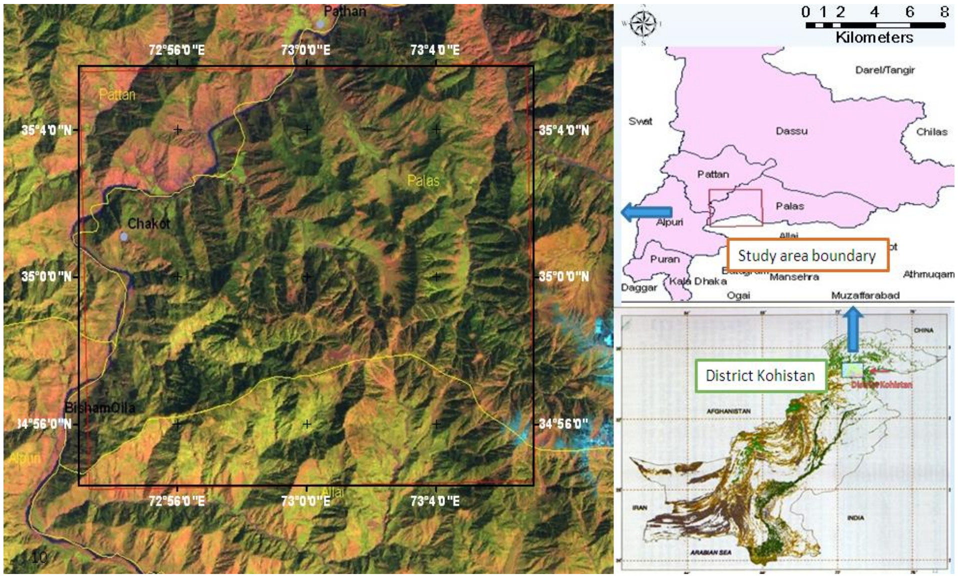

Figure 1

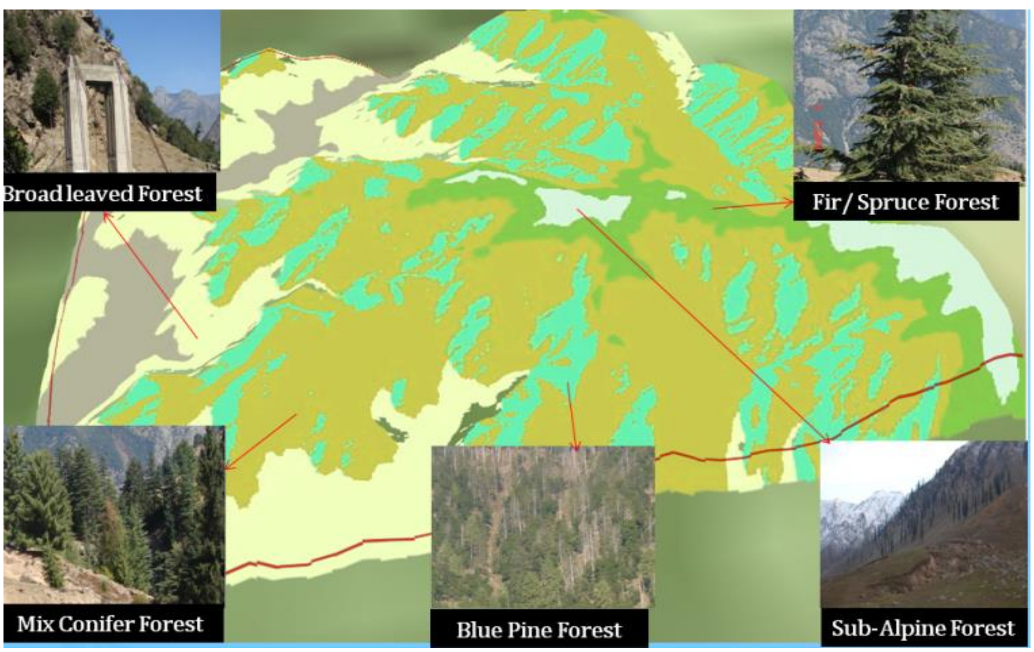

Figure 2

Methodology

The satellite image of Landsat TM, acquired in September 2009, was used to meet the required objective. Study area was extracted using “Image Subset” function of ERDAS Imagine using the Area of Interest (AOI) layer provided by FAO (Table 1). The projection system used in Landsat Image is Universal Transverse Mercator (UTM) which is most suitable for transforming accurate locations, shapes, sizes and directions between all features (Smith, 1997). The image was acquired in vegetation peak season with minimum cloud cover (i.e. September, October & November) for better visualization of vegetation classes (Bhagat, 2009). Histogram equalization and standard deviation stretch was applied on each satellite image to enhance the visual interpretation and understanding of imagery (Qamar, *et al.,* 2010).

Preparation of Criterion map layers

The quality of a locality for growing suitable forest trees is directly related to the biotic and abiotic factors of the ecosystem. Soil moisture and land cover type are useful parameters for identifying the quality of a locality to afforest a land (Bhagat, 2009). The decision making process is much complex if more parameters are included. The selection process used in this study involved Multi Criteria Decision Analysis (MCDA) used for breaking down the problem in selecting the parameters of land cover type, soil moisture level, proximity to roads, soil type and slope. A satisfactory area of afforestation was supposed to have minimum social interference and maximum environmental values. In this study, keeping in view the dry temperate nature of forest, the regions were screened out in phases for excluding the unsuitable area and to point out areas that support afforestation (Phua, 2005).

The parameter of Land cover type was prepared by the supervised classification of Landsat image using spectral signatures collected during field survey.

In the inaccessible areas the training areas were collected using the customization of Arc Map integrated with Google Earth software. A number of Land cover classes were mainly targeted for representing suitable land cover type and their influence in the study which included Forest (i.e. Dense canopy Forest, Medium canopy Forest, Open canopy Forest), Cultivated Land, Barren Land, Eroded Land, Water Channel, Snow, Flood Plain, Grasses and Bushes (figure 5).

Soil wetness Index (SWI) was generated by using at-satellite reflectance based tasseled cap co-efficient (Huang, *et al.,* 2002). The co-efficient values of wetness were extracted from the available Landsat 5 TM image 2009, using tasseled cap function of ERDAS Imagine. The SWI was extracted by the following equation:

$$\text{Soil Wetness Index} = (0.1446 \times \text{Band1}) + (0.1761 \times \text{Band2}) + (0.3322 \times \text{Band3}) + (0.3396 \times \text{Band4}) - (0.621 \times \text{Band5}) - (0.4186 \times \text{Band7})$$

(Bhagat, 2009).

The minimum value of SWI as calculated by the software was -68.2934 where as maximum value observed was 55.6799. The maximum values were mostly observed in the river Indus where as minimum values were observed in rocky lands on southern aspects having maximum exposure to sunlight showing maximum dryness (figure 3). The values were assigned to five categories (table 2) and classified as per natural breaks. Similarly the criteria Slope was classified based on the levels of suitability for afforestation and classified as very high, high, moderate, low and very low (figure 4). It was calculated that more than 45% area lie in the precipitous slope area (>40% Slope) which is very low in suitability for afforestation. The accessibility to roads and soil type parameters were also prepared and classified according to the ranks assigned (Table 2). These classes were assigned ranks from 0 to 5 representing unsuitable to very high suitability respectively for afforestation as shown in table 2.

Analytical Hierarchy Process (AHP)

Saaty in 1980 developed pair wise comparison method in context of AHP. In this technique ratio matrix was generated for comparison of multiple criteria in which a scale with values from 1 to 9 has been used to rate the relative preference between two criterions (Malczewski, 1999). After defining the criteria weights as shown in table 3, the overall score for each alternative is generated using the overlay analysis tools. Lambda (λ) is derived which is the average value of the consistency vector and consistency index (CI) is computed which provides a measure of departure from consistency described by the equation (Table 4):

$$CI = (\lambda - N) / (N - 1)$$

Where N = number of criteria

Table 1. Material dataset acquired from different sources

Type of Data	DESCRIPTION
DEM	30 m
GT Sheets	43A-16, 43B-13
Rainfall data	Past 20 years
Forest working plan	Tehsil Palas and Pattan

Table 2. Ranking of multiple criterias

Parameter 1	Parameter 2	Parameter 3	Parameter 4	Suitability	Rank
SWI	Slope (%age)	Land Cover Type	Roads Proximity		
-2.91 to 15.485	0 to 8%	Grasses & Shrubs	0 to 500m	Very High	5
-15.0236 to -2.91	9 to 18%	Open Canopy Forest	500m to 2 km	High	4
-29.06 to -15.0236	19 to 35%	Barren Land	2km to 5 km	Moderate	3
< -29.067	35 to 40%	Eroded Land	5km to 10 km	Low	2
>15.485	> 40%	Other Land	> 10 km	Very Low	1

Table 3. Estimated weights of the criteria

Criterion	Weights
Land cover type	0.434
Soil Wetness	0.277
SLOPE	0.192
SOIL TYPE	0.064
ROAD	0.033
Total	1

Table 4. Values for calculating CR

λ	5.169
CI	0.04225
RI	1.12
CR	0.038

Consistency ratio (CR) is calculated which is;

CR = CI/RI

CR = 0.038

Where RI is the random index and depends on the number of elements being compared. CR less than 0.10 indicated a reasonable level of consistency in the pair wise comparison (Malczewski, 1997).

The final values for Potential areas of afforestation were obtained by multiplying the criterion layers with their respective weights, and then simply adding them all up (Malczewski, 1999).

PAA = [Land Cover Type] × 0.434 + [SWI] × 0.277 +
[Slope] × 0.192 + [Road Accessibility] × 0.033 +
[Soil Type] × 0.064

Results and Discussion

The resultant raster based map was classified into five categories according to the suitability of the site for afforestation, i.e. Very high, high, moderate, low and very low. The areas very low in suitability for afforestation mainly included river, nallahs, dense/medium canopy forests and cultivated lands. The results also revealed that, by applying the selected parameters, 42 % of land had the potential for afforestation whereas only 4% area supported dense afforestation categorized as very high in suitability for afforestation. Moreover 7700 ha of area also has very good potential for afforestation and was therefore categorized as “high” in the suitability for afforestation as shown in Figure 6. About 8274 hectare area support afforestation with moderate site potential. This area was mainly recommended for growing shrubs and grasses. 1717 ha of area was categorized as low in suitability for afforestation due to steep slopes and unavailability of soil material to grow roots of tree saplings.

Conclusion

The flora and fauna of Kohistan is under a constant stress due to the human interference in the form of deforestation, cultivation of agriculture crops, grazing and browsing as well as climatic factors like land sliding, earthquakes and floods. Close observations indicated an evident replacement of forest lands with cultivated lands and other land covers especially in the period of 2000-2009. Multi-criteria decision analysis was very useful in breaking down the problem of identifying and categorizing the sites for afforestation.

Recommendations

The study encountered a range of constraints including;

The pixel size of TM and ETM+ images used was $900m^2$. A minimum mapping unit of 3x3 pixels i.e. 1 ha was the limit to quantify forest cover. Use of high resolution imagery is therefore recommended for more accurate quantification of the resources.

The situation of district Kohistan was critical due to the Taliban fear and lack of support from forest department staff, the broad leaved and conifers could not be separated at the time of validation.

High topographic relief of the study area resulted in considerable shadowing effects, more pronounced on the northern and north-western aspects with slopes greater than 30%, in the satellite images. As the information on deforestation was not accessible therefore in the forest management plan this area has also been included in area for further assessment.

The study results recommend to involve the applications of remote sensing and GIS along with the on ground forestry operations.

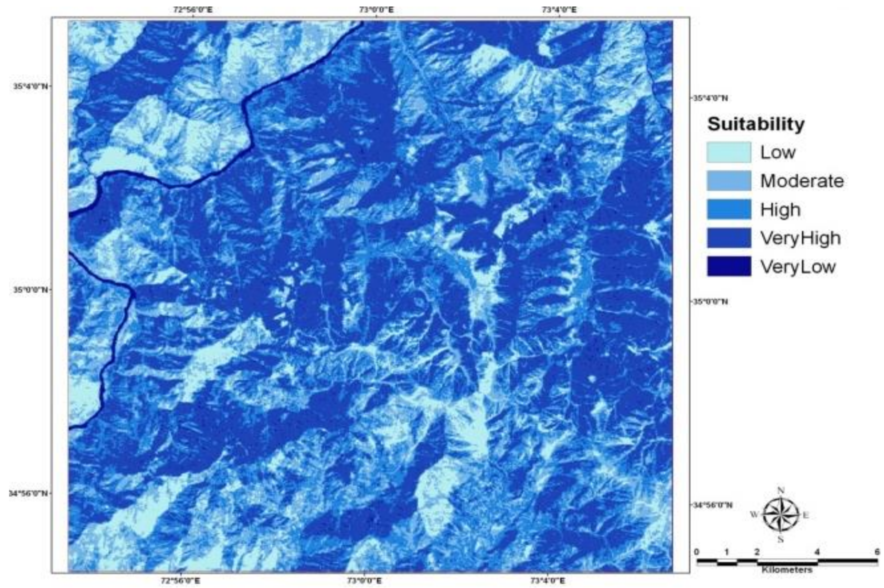

Figure 3

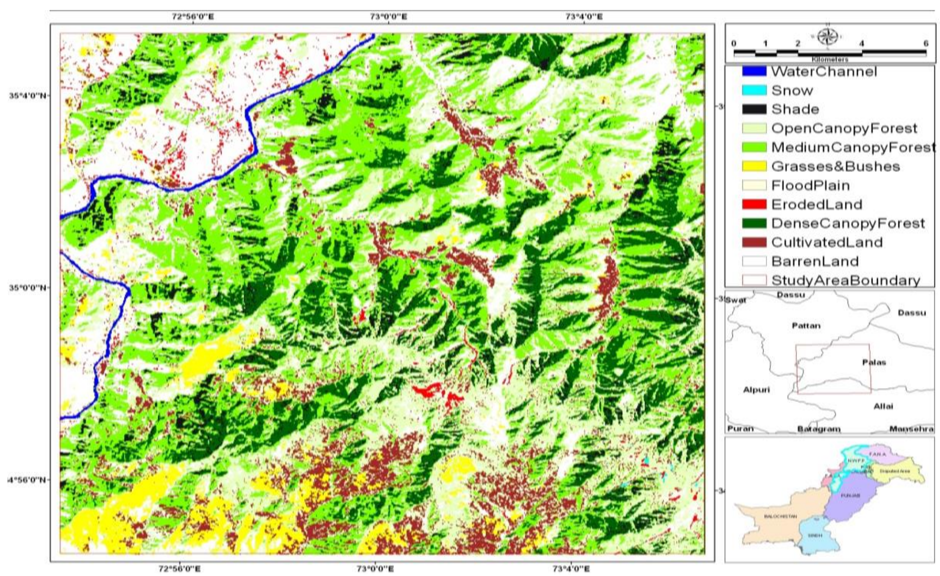

Figure 4

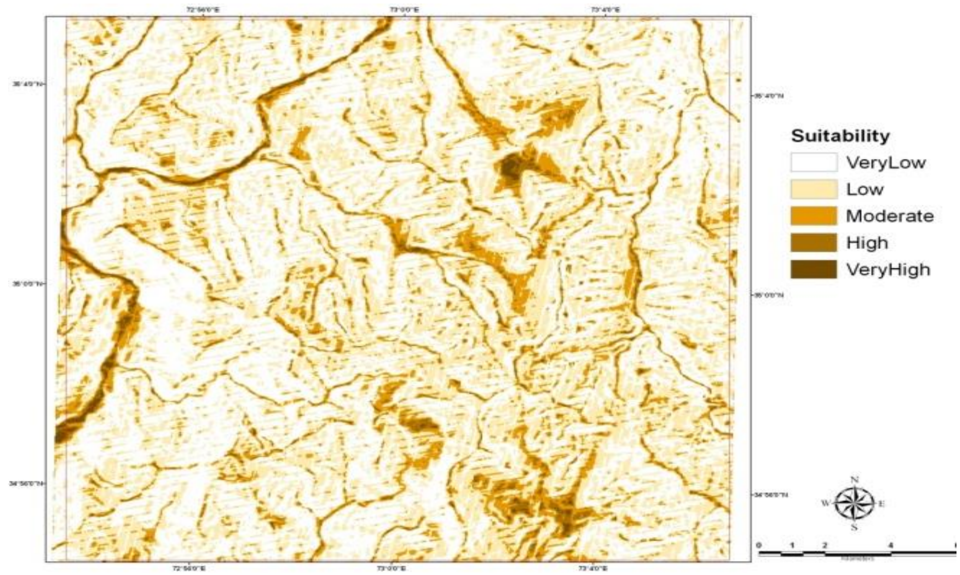

Figure 5

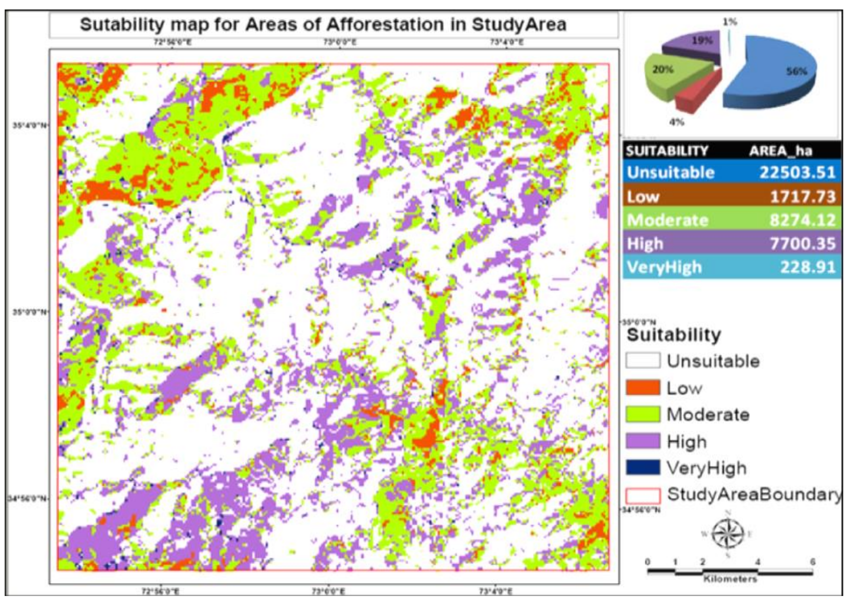

Figure 6

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