Using spatial technology for analyzing disturbed areas and potential site selection in Chihuahua, Mexico

V. M. Tena[1], A. C. Pinedo[2], A. H. Rubio', P. de L. G. Barragan3,
A. A. Pinedo[3], M. V. Hernandcz[3] & C. Velez2
'Investigadores del INIFAP, Chihuahua, Chihuahua, Mexico
[2]Profesores-Investigadores. UACh, Chihuahua, Mexico
[3]Estudiantes de Doctorado, Chihuahua, Chihuahua, Mexico

Abstract

The objectives were to: 1) analyze the physical-chemical variables of a site in order to characterize the disturbed area's suitability for planting; 2) detect disturbed areas through spectral transformation techniques; and 3) generate cartographic maps with the location of the disturbed areas suitable for planting. The field data, Landsat TM 7 images, and digital elevation models were analyzed with IDRISI and ArcView. Multivariate Cluster Analysis, and Principal Components Analyses were applied to valuate the biometric and physical-chemical variables of the soil, and detection of disturbed areas. Physical-chemical analyses showed similar characteristics for the whole area in the study; only soil depths are considered important for the establishment of forest plantations. The combination of bands 3, 4 and 5 allowed detection of, in a preliminary way, the disturbed areas. The Principal Component Analysis showed that the first component reduced the dimensionality of the data while the second component detected the disturbed areas.
Keywords: reforestation, disturbed areas, detection, spatial, Chihuahua, Mexico.

1 Introduction

Worldwide, deforestation is associated with increasing demands for forest products due to increased human populations (1). Mexico has a deforestation rate estimated at 600,000 hectares per year PI This is one of the highest rates of deforestation in the world with the presence of associated problems like erosion, desertification, less biodiversity, and lost productivity of the land. This problem hurts the economy of the forested regions of the State of Chihuahua, where ecological damage includes irregularities in weather, water, soil, flora and wildlife among others. In addition, protection measures and commercial tree planting activities showed a series of limitations and obstacles to success, because they do not result in clear and well defined objectives due to the lack of reliable and up to date information related for possible areas to be planted.

To establish successful plantations that provide wood sources for the forest industry and to diminish pressure in the natural forests, environmental factors must be considered such as the biophysical and chemical features of the planting sites. Field data analysis combined with satellite imagery and digital elevation models (DEM) of high spatial resolution allow the generation of up to date and reliable information to make decision making easier [3,4]. This helps in making adequate planning and execution of recovery programs in disturbed areas, looking to reactivate their productivity as well as conserving and preserving the associated natural resources.

The objectives of this study were to analyze the physical and chemical variables of a site to characterize the disturbed areas for suitability for planting, to detect the disturbed areas through spectral transformation techniques, and to generate cartographic maps with the location of the suitable areas to be planted.

2 Regional setting

The study was conducted in four areas: (1) San Juanito, (2) Bocoyna, and (3) San Ignacio de Arareco, all in the Municipality of Bocoyna, and (4) the commonly owned area called Cusarare in the Municipality of Guachochi, Chihuahua, located in the Sierra Tarahumara. Geographically, these areas are located in the UTM coordinates 228369 E, 3046635 N and 265236 E, 3105332 N.

2.1 Climate

The study areas are humid and temperate (C(E)W2) with a mean annual precipitation of about 600 mm. The mean annual temperature is 12.9 °C with a minimum of -9.9 °C and a maximum of 26.7 °C. Extreme temperatures varied from -18 °C in December of 2003 to 40 °C in June of 1992.

2.2 Geology

The area has outcrops of extrusive igneous rocks dominated by the acid types of rhyolite and tuff of the superior tertiary Ts (Igea). Rough topography of the study area includes a great diversity of topographic shapes such as plateaus, canyons, mountains, and hills. Most of the surveyed sites where on plateaus with elevation ranges from 2,212 meters to 2,572 meters.

2.3 Physiography

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2.4 Soils

The soils of the municipality of Bocoyna are the eutric regosol type and those in the Cusarare in the Municipality of Guachochi are haplic feozem type. In general, the soils have shallow depths fluctuating from 35 through 250 cm with textures that range from sandy clay loamy soils to sandy barns that are medium high in organic matter content and nitrogen, and deficient in phosphorous, with a highly acid pH and a hydraulic conductivity from moderate to moderately fast.

2.3 Vegetation

The study areas are characterized by a mixture of tree species that are dominated by *Pinus arizonica, Pinus duranguensis*, and *Pinus engelmannii* and associated with *Quercus spp., Populus spp., Juniperus depeana, Pinus leyophila, Pinus chihuahuana, Pinus ayacahuite,* and *Picea chihuahuana.*

3 Analysis

Information was analyzed with IDRISI and ARC/VIEW 8.x programs. There were four data sources: (1) Landsat TM7 January 2003 images, (2) four digital elevation models (DEM) in 1:50,000 scale, (3) edaphology, topography, and soil use thematic charts, and (4) field data collected for variables of interest.

A radiometric analysis procedure was applied to the bands used from Landsat TM7 with geometric correction to fix possible noise effects, pollutants attenuation, relative humidity, and cloudiness levels [5]. The sub-scene of interest was adjusted according to the analysis of the study areas for better details in the analysis of the variable. Quadrangles of the DEM in 1:50,000 scale were segmented in sub-scenes according to the location of each site. Once the DEM was generated, two conversion algorithms were applied to generate the Slope Digital Model (SDM) and the Exposure Digital Model (EDM). Through the Boolean operator (AND), the slope was reclassified in the next range: 0-2% commercial plantations, 3-5%. forest recovery, and >5% for protection of other existing resources. for a preliminary detection of disturbed areas, a monoband analysis of landsat TM was explored, and a band combination was selected according to the suggested procedures of Pinedo [6] to better discriminate the disturbed areas. Once the areas were detected, the SEEDTOOLS module from ERDAS was used, interpolated by the ARCVIEW program to generate in an automatic way the masks of the areas, the same that were overlain in the sub-scenes derived from landsat TM as well as from the DEM, SDM and EDM.

Under a stratified random sample, data from the variables of interest were collected using three sampling techniques: (I) a I square meter plot for location

(GPS), elevation (altimeter), exposure (Silva compass), slope (clinometer), and soil variables, (2) 12.56 square meters (2 meters radius) for the arboreal vegetation regeneration data, and (3) 200 square meters plots (4 meters radius) where forest variables included plant species, total and commercial tree heights, normal diameters, product distributions, ages, annual increments, and year pass).

Statistical analyses were conducted with a multivariate technique of Cluster Analysis of the MIN1TAB program. To know the relation of each of the landsat TM bands and reduce the possible dimensionality of the spectral data, a principal component analysis was applied beside the newly derived images which allowed the detection of disturbed areas suitable of being planted [71.

4 Results

4.1 Disturbed areas analysis

The correlation matrix of the principal component analysis (PCA) showed, with exception of band 4, a high degree of association with the rest of the spectral bands of Landsat TM (Table I), in a way that the combination of any of the three bands can generate a cover type map with an easy detection of the disturbed areas. Although, band 4 was chosen as the least correlated and combined with an infrared and one visible band, it was used to generate a composition of false color using band 3 in the blue channel, band 4 in the green channel, and band 5 in the red channel. This process was useful in this study since it allowed the generation of actual land use cartography to discriminate in a preliminary way the disturbed areas, locate the sample sites, and then, quantify the polygons of areas suitable for planting.

Besides attenuating the effects of the differences of variability between bands and diminishing the dimensionality of the data between them, the PCA allowed the generation of new images, making as many components as bands that were introduced in the analysis.

The first component synthesized 94.37% of the total variability while the second component explained 3.55% of the total variability. The two components represented 98% of the total variability of the original variables, while the rest of the components synthesized 2.08% of the total variability. Even when the first component reduced the dimensionality of the data preserving almost all the information, the second component showed clearly the disturbed areas of detection.

41 Cluster analysis

4.2.1 Distribution and grouping of the sites

Variables from the 40 sites were grouped among the four resulting clusters of the multivariate analysis. (Clusters analysis) based on the similarity in values of the studied variables, in a way that cluster 1 grouped 6 sites located in the lands of San Juanito and San Ignacio de Arareco, cluster 2 grouped 9 sites in San Juanito, San Ignacio de Arareco and Cusarare, cluster 3 grouped 10 sites of the four study areas while cluster 4 grouped 15 sites from the four areas (Table 2).

Table I: Matrix of correlation between bands of the sub scenes of landsat tm7 image for the study area.

Scene	TM1	TM2	TM3	TM4	TM5	TM7
band_1	1.0000					
band_2	0.9814	1.0000				
band_3	0.9725	0.9877	1.0000			
band_4	0.7520	0.8112	0.7833	1.0000		
band_5	0.9162	0.9421	0.9467	0.8408	1.0000	
band_7	0.9307	0.9468	0.9591	0.7661	0.9830	1.0000

Table 2: Created clusters based on the interest variables.

Clusters	Sites
1	9,10,13,14,15,17
2	1,2,5,8,16,18,36,38,40
3	4,11,12,26,27,30,31,33,37,39
4	3,6,7,19,20,21,22,23,24,25,28,29,32,34,35

4.2.2 Physical and chemical **analysis of the sites**

The grouped variables in the four clusters showed similar physical and chemical qualities for the whole area under study, with a relative difference shown by the variable "soil depth", which values are higher in the sites grouped in clusters 1 and 2 with regard to the sites grouped in clusters 3 and 4. Because of this, they showed better conditions for plantation establishment. (Table 3).

4.23 Cartography of the planting susceptible areas

The masks of the disturbed areas that originated in component 2 of the PCA were overlaid for their visualization and analysis in the composite image. This cartographic product represents the base map that in a thematic and digital format contains the necessary information to cover the necessities of other variables that were not analyzed in this study as the estimation of the disturbed areas, commercial type of affected threes, severity degree of the disturbance, and ecological impact analysis, among other variables.

The planting areas have a total of 5,820 hectares (Table 4) that are a consequence of diverse factors that determine the conditions of the existing forest. In all the studied areas, condition is associated with management history and includes over-harvesting, illegal harvesting, forest fires, and changes in soil use.

4.2.4 Surfaces analysis

Besides elevation, the processing and analysis of the DEM gave data for various slopes, which is important in commercial planting and environmental restoration programs. Slopes greater than 5% are present in approximately 88% of the areas with gradients from 62% in at San Juanito to 94% in Cusarare. This physiographic situation is associated in an inverted way to the class 0-2 % where San Juanito has the highest percentage of plain or nearly flat land (23%) while Cusarare has only 1% of this class. Diverse authors [8,9,101 assure that the selection of the right species, slope, soil, and climate among other factors are variables that determine the success of plantations since the intended commercial plantations are meant to be established in preferred nearly flat soils, while the areas dedicated to protection are meant to be planted on steep slopes.

Table 3: Values of interest variables and their grouping in the four resulting clusters.

Variable	Cluster			
	1	2	3	4
Elevation	2390.00	2410.28	2456.66	2318.41
Soil Depth (cm)	34.5000	33.7143	26.6000	25.0000
Mould (cm)	0.9167	0.4429	1.0800	0.6667
ApDens.	0.6220	0.6624	0.7226	0.8039
E. Poros (%)	63.9307	64.6811	62.0351	60.4064
C. E. (mmhos /cm)	0.2200 Normal	0.1743 Normal	0.1867 Normal	0.2000 Normal
pH	4.18 Highly acid	4.32 Highly acid	4.36 Highly acid	4.20 Highly acid
Org. Mat.(%)	1.7183 M. high	1.6671 M. high	1.5407 M. high	1.1325 M. high
RAS	9.51 Normal	7.27 Normal	7.58 Normal	7.27 Normal
N-NO (Kgm/ha)	404.69 M. high	469.29 M. high	235.75 M. high	230.62 M. high
P (Kgm/ha)	12.78 Deficient	14.88 Deficient	11.84 Deficient	9.43 Deficient
K (ppm)	770.83 Excessive	278.57 High	210.83 High	275.00 High
C. H. (cm/hr)	6.473 MF	6.68 MF	4.44 M	8.62 MF
Sand (%)	52.7280	45.1337	57.6853	60.9947
Clay (%)	23.1520	25.0720	20.0800	20.2787
Bare soil (%)	39.0667	49.5571	27.3333	41.7250

Table 4: Planting susceptible surfaces based on the spectral analysis.

Property	Area (ha)	Planting area (ha)
San Juanito	5229	1877.83
Bocoyna	6055	956.46
San Ignacio de Arareco	21051	1370.04
Cusárare	29914	1616.09
TOTAL	62249	5820.42

5 Discussion

The creation of preliminary maps was very useful because it allowed the generation of actual use of soil cartography to discriminate the disturbed areas, locate the sampling sites, and then quantify the polygons of the areas suitable for planting. The careful selection of these three bands was made according to the suggestions of Richards [11] and Beaubien [12] who recommended the reduction in the number of bands and use of those whose combination maintained the level of discrimination for the types of cover of interest.

From a statistical point of view, the PCA easily made a first interpretation over the variability axles of the image and allowed identification of those features that showed up in almost all of the bands and those others that are specific to some group of bands [7,13,14]. Although Muchoney and Haack [15] referred to the temporary changes and disturbance in vegetation that arc observed in the last components of Landsat TM, in this study the component 2 allowed discrimination in a clear way for the disturbed areas which indicates the importance of using this multivariate tool to ease the processes for this type of study.

Variables of interest among the 40 sites were grouped in the four resulting clusters from the multivariate analysis (Cluster analysis) based on the similarity of the values of the studied variables that allowed the distribution and grouping of the sites. Johnson [16] noted that this multivariate technique involves techniques that produce classifications from data that initially are not classified and must not be confused with the discriminating analysis in which from the beginning it is known how many groups exist, and it has data that comes from each one of these groups.

The site analysis showed similar physical and chemical features for the whole study area, with a relative difference expressed by the variable soil depth whose values are greater in the grouped sites in clusters I and 2 (34.5 and 33.7 cm.), in respect to sites grouped in clusters 3 and 4 (26.0 and 25.0 cm.), for which they showed the best conditions for plantation establishment.

This matches another study [17] where soil depth was one of the edaphic variables of greatest impact in determining the quality of sites for plantations, since with greater depth the water retention increases in the soil and makes it easier to incorporate organic matter from the decomposition of logs, branches, and twigs among others. This permits an adequate radicular development for the establishment of crops [18]. In respect to this, Narvaez and Armendariz [19] noted that verticiles in plantations of *Pinus arizonica, Pinta duranguensis,* and *Pinus engelmanii* depend on the total depth of the soil.

The planting area on the assessed properties, which together make a total of 5,820 hectares, is a consequence of diverse factors that determine the actual forest conditions, which is associated with the management history of the properties related to factors like over-harvesting, illegal harvesting, forest fires, and changes in land use.

Besides elevation, other processes and analysis gave important features of the terrain, mainly in the derivation of slope, which is an important variable in commercial plantations and environmental restoration programs. Diverse authors [8,9,10] pointed out that the selection of adequate species, slope, soil, and climate among other factors, are variables that determine the success of plantations.

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