Environmental Studies of Mongolia Using RS and GIS Techniques

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Abstract— **The aim of this study is to apply some remote sensing (RS) and geographical information system (GIS) techniques for environmental studies in Mongolia. For this purpose, four different case studies are highlighted. The first case study describes forest change analysis using multitemporal high resolution satellite images. The second case study highlights analysis of environmental conditions using multitemporal interferometric synthetic aperture radar (InSAR) images. The third case study reviews a pasture land degradation study and pasture vegetation mapping at regional and local levels. The fourth case study describes a land cover mapping using hyperspectral satellite image. For the analyses, multisource satellite images with different spatial and spectral resolutions, topographic and thematic maps of varying scales as well as some other spatial data are applied. Overall, the research indicates that modern RS and GIS techniques and technologies are reliable tools for environmental monitoring and management.**

Keywords-RS, SAR, hyperspectral, GIS, environmental study

I. INTRODUCTION

Mongolia is situated at the Central Asian highland and borders with Russia in the north and with China in the south. The geography of Mongolia is characterized by great diversity and is divided into such zones as forest taiga, forest steppe, steppe, dry steppe, rocky mountains and Gobi. The country is mainly mountainous with an average altitude of 1,580m above sea level. The principal mountains are concentrated in the west, with much of the region having elevations above 2,000m and the country's highest peaks permanently snow-capped land covered with glaciers. The lowest point is Hukh lake (560m above sea level) located in Eastern Mongolia, and the highest point is Huiten peak in the Mongolian Altai mountain range (4,374m). The country stretches about 2,400km from the west to the east and about 1,260km from the north to the south. The total area of the country is about 1,565,000sq.km and the length of the country's borders is 8,158km.

The country has harsh continental climate. The winter low temperatures result in heavy snowfalls and the summer high temperatures often result in drought. Moreover, there are frequent forest and steppe fires during spring periods. These adverse climatic conditions often influence the country's fragile economy, specifically, agricultural crop production and animal husbandry. The drought and dzud also affect the productive capacity of the land. When there is drought, the fodder production is too low to feed all animals. As a result, extensive overgrazing occurs. The drought and high temperatures decrease the cohesion of the exposed fertile topsoil and strong winds blow away the topsoil particles, resulting in dust storms, including yellow dust. Such sustained damage over a longer period of time will result in irreversible changes. With continued pressure of drought and overgrazing, the land degrades and may finally turn into desert. Currently, in Mongolia the process of desertification is being strongly observed everywhere. For example, compared to 1960, a number of days with dust storms have been increased by a factor of more than four, while grasslands' productivity has been decreased by a factor of five [2,12].

For environmental studies, the spatial information can play an important role and such information can be collected from a number of sources such as a field survey, planning maps, topographic maps, digital cartography, thematic maps, GPS and RS. Of these, only RS can provide real-time information that can be used for the real-time spatial analysis. Over the past few years, RS techniques and technologies, including system capabilities have been significantly improved. Meanwhile, the costs for the primary RS data sets have drastically decreased. Now the highest spatial resolution image can be acquired with centimeters-accuracy, whereas the ordinary high-resolution images can be acquired with a few meters accuracy [4]. This means that it is possible to extract different thematic information at various scales and integrate the extracted information with other historical GIS data sets and to conduct sophisticated analyses [3].

The aim of this study is to demonstrate how RS and GIS technologies can be used for environmental studies in Mongolia. For this purpose, several case studies conducted for different applications have been described. For the final analyses, multisource satellite images with different spatial resolutions as well as some other spatial data sets have been used and different RS and GIS techniques were applied.

II. CASE STUDIES

A. Forest change study using multitemporal Landsat images

In the present study, it is assumed that there is an operational GIS that stores different thematic layers and there is a need to check the reliability of a forest layer using multitemporal RS data sets. In order to carry out multitemporal forest analysis, initially, the optical images were thoroughly analysed in terms of brightness and geometric distortion. The images were of a good quality. Then, the Landsat images were successively geometrically corrected to a UTM projection using a topographic map of the study area, scale 1:50.000. The ground control points were selected on clearly delineated sites and in total 12 regularly distributed points were chosen. For the actual transformation, a second order transformation and nearest neighbour resampling approach [8] have been applied and the related root mean square errors were 0.61 pixel, 0.68 pixel, and 0.57 pixel, respectively. Figure 1 shows false colour composite images of the multitemporal Landsat images.

Figure 1. Comparison of multitemporal Landsat images: a) TM image of 1989, b) ETM image of 2001, c) TM image of 2011.

To define the forest changes, multitemporal Landsat images have been classified into forest and non-forest classes. For this purpose, training signatures had to be formed and some areas of interest representing the available two classes (ie, forest and non-forest) have been selected. Separability of the training signatures was firstly checked in feature space and then evaluated using TD distance [11]. The values of TD distance range from 0 to 2.0 and indicate how well the selected pairs are statistically separate. The values greater than 1.9 indicate that the pairs have good separability. After the investigation, the samples that demonstrated the greatest separability were chosen to form the final signatures. The final signatures included about 528-895 pixels. As the classification features, the combinations of Landsat bands 3, 4 and 5 were used.

For the actual classification, a maximum likelihood classification (MLC) has been used assuming that the training samples have the Gaussian distribution. The MLC is the most widely used statistical classification technique, because a pixel classified by this method has the maximum probability of correct assignment [14]. To increase the reliability of the classification, to the initially classified images, a fuzzy convolution with a 3x3 size window was applied. The fuzzy convolution creates a thematic layer by calculating the total weighted inverse distance of all the classes in a determined window of pixels and assigning the centre pixel the class with the largest total inverse distance summed over the entire set of fuzzy classification layers, i.e. classes with a very small distance value will remain unchanged while the classes with higher distance values might change to a neighbouring value if there are a sufficient number of neighbouring pixels with class values and small corresponding distance values [7].

The visual inspection of the fuzzy convolved images indicated that there are some improvements on the borders of the neighbouring classes that significantly influence the separation of the decision boundaries in multidimensional feature space. The final classified images are shown in figure 2(a–c). Looking at the classified images, one can observe what kind of changes had occurred in those periods in the forest cover of the Bogdkhan Mountain.

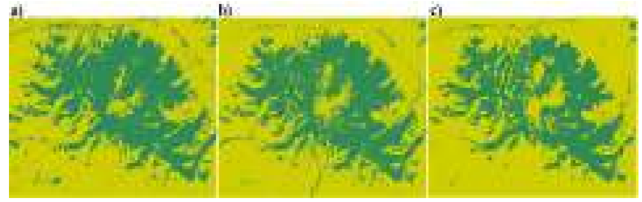

Figure 2. a) Classified image of 1989, b) Classified image of 2001, c) Classified image of 2011.

B. *Analysis of environmental conditions using multitemporal InSAR images*

In general, the SAR which operates in the microwave portion of electromagnetic signal is capable to provide data independent of weather conditions, day and night time [1]. In the present study, we wanted to show how the InSAR data sets can be used for monitoring of the environmental conditions. For this aim, ERS-1 and ERS-2 tandem pass (interferometric) SAR images of Selenge River Basin, Mongolia acquired on 16 and 17 October 1997, and on 08 and 09 August 1998 have been used. As the initial ERS SAR data were represented in a SLC format, it was necessary to generate coherence and amplitude images. The amplitude images of the study area from 08 and 09 August 1998 are shown in Figure 3.

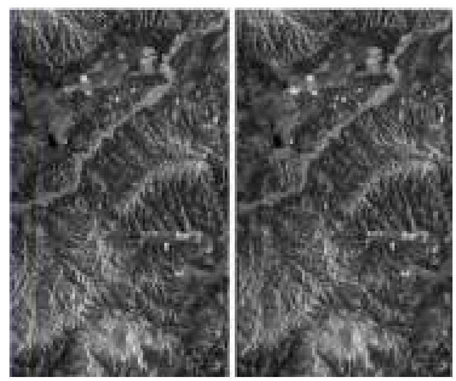

Figure 3. The amplitude images of the study area acquired on 08 and 09 August 1998.

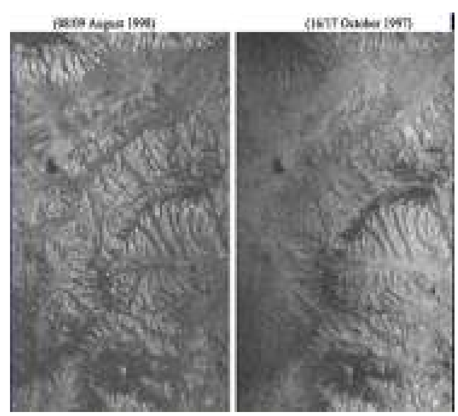

Figure 4. The coherence images of the study area from two different periods.

The coherence images are generated by using both the amplitude and phase information from a pair of SLC images.

The coherence values range between 0 and 1. If some land surface changes had occurred in a target area between the two image acquisition periods, then coherence is low and if no changes had occurred, then the coherence is high [6]. This means that if in the study area some winds or other environmental phenomena had occurred during the image acquisition, then coherence is low. Otherwise, the coherence is high. Looking at the two images shown in Figure 4, one can observe what changes had occurred during the given periods.

C. Pasture land degradation study and mapping at regional and local levels

Pasture land plays an important role for the Mongolian animal husbandry, because they are grazing home to millions of livestock and are used by thousands of herding families. In recent years, the Mongolian pasture land has been seriously deteriorated and there have been different natural and socio-economic reasons on this. The severe droughts for the last few years and the growing number of livestock have been the main factors for the increased land degradation in many parts of the country. The traditional system of grazing rotation between four seasonal pastures, followed by all experienced herders, has been increasingly ignored by the new herders. Out of season grazing for example, winter reserve pastures grazed by trespassers in summer, while the habitual user is absent had become common [9]. At present, the pasture land degradation is a serious problem in Mongolia.

The aim of this research is to conduct a) a study on the pasture land degradation in Arkhangai aimag, Central Mongolia using multitemporal RS images, b) mapping of pasture land degradation using very high resolution satellite images. As data sources Landsat TM data of September 1987, Landsat ETM+ data of September 2001, topographic maps of scale 1:100.000, pasture map of scale 1:200.000, GPS measurements, ground validation data and SPOT 5 images, have been used.

<u>A study on the pasture land degradation</u>

The test site covers Jargalant, Erdene-Mandal and Tsetserleg sums of Arkhangai aimag. By the forest-vegetation classification, the test area is included in the Khangai region and is dominated by the mixed landscapes of forest and steppe. In the isolated rural sites of the study region, it was very difficult to find accurate ground truth information related to the distribution of the winter camps of herders. Therefore, in order to conduct the thorough pastureland degradation study, we had to accurately define the precise locations of the winter camps. For this purpose, a GPS-based field survey was conducted. The Landsat TM image of the study area and the spots of the GPS measurements are shown in Figure 5.

As seen from Figure 5, the winter camps are located too close to each other (i.e. they are within 8km-10km distance from each other) and mainly built up approaching the forest sides. The reason for that is because over the past few years there have been severe droughts in the region due to which some rivers and small lakes have been dried out. Moreover, because of the droughts the vegetation covers have been degraded. As a result, in summer herding families had to move to their camps only in June or July. Meanwhile, during autumn period the hay making has been significantly reduced. Therefore, during both summer and winter seasons many herding families had to live together or closely live in good pasture areas, thus significantly degrading the pasture areas.

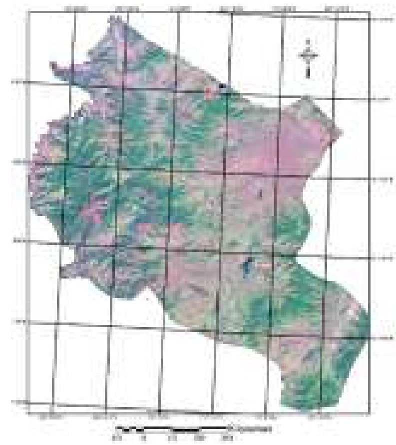

Figure 5. Landsat TM image of Jargalant, Erdene-Mandal and Tsetserleg sums of Arkhangai aimag and the spots of the GPS measurements.

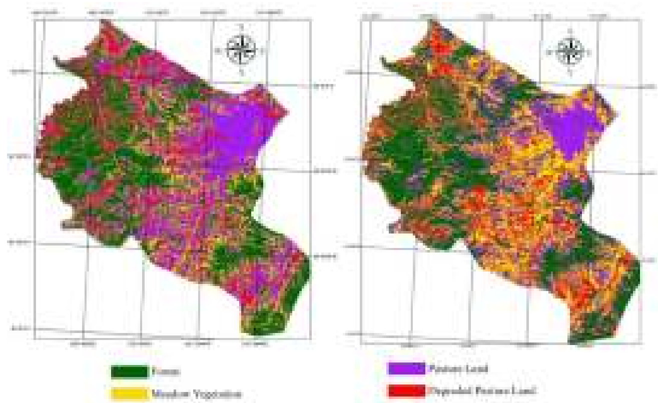

Figure 6. The classified images of Landsat TM of 1987 and Landsat ETM+ data of 2001.

To define the land degradation classes, initially, the RS images have been classified using supervised (Mahalanobis distance) and unsupervised (isodata) classification methods. The results indicated that the supervised method performed more accurately than the unsupervised method (Figure 6). After the classifications, the total areas belonging to the selected classes have been calculated and the areas related to each class presented in hectares (ha) are shown in Table 1. As seen from table 1, in 1987 forest and meadow vegetation occupied 308,168ha and 173,903ha, while by 2001 they had been reduced to 298,421ha and 207,692ha, respectively. Furthermore, as seen from table 1, in 1987 the pastureland and degraded pastureland occupied 276,084ha and 116,883ha, respectively whereas in 2001 they accounted for 252.772ha and 117,533ha, accordingly. Here, the forest reduction is directly related with illegal timber preparation of the local people, while the degradation of the meadow vegetation and pasturelands are related with overgrazing and other environmental factors.

TABLE 1. TOTAL AREAS BELONGING TO THE SELECTED CLASSES.

Land cover types	1987	2001
Forest	308.168	298.421
Meadow Vegetation	173.903	207.692
Pasture land	276.084	252.772
Degraded pasture land	116.883	117.533

Mapping of pasture land degradation

The test site covers the rural area and urban buffer zone located near the capital city of Ulaanbaatar. For a large scale mapping (ie, scale of 1:5000) of pasture land degradation as well as pasture vegetation, panchromatic (2.5m) and multispectral (10m) SPOT 5 images, have been used. The SPOT 5 images of the study area are shown in Figure 7. For pasture land degradation, 3 classes (namely, high, moderate and low) have been identified based on the NDVI values of the SPOT 5 images. For pasture vegetation mapping, a visual interpretation has been applied to the created false colour images [5]. In order to enhance the vegetation classes and their boundaries, different spectral (eg, Brovey transform, intensity-hue-saturation enhancement, etc.) and spatial enhancement (Laplacian and other high pass filters) techniques were applied to the original SPOT 5 images. The final outputs are shown in Figure 8. As seen from Figure 8, using the maps created by the use of high resolution satellite images, one can conduct very sophisticated analysis.

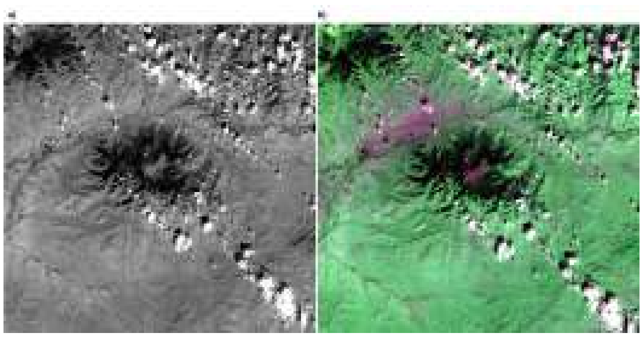

Figure 7. Panchromatic (a) and multispectral (b) SPOT 5 images of the study area.

Figure 8. Pasture vegetation (a) and land degradation (b) maps created by the use of SPOT 5 images.

D. Land cover mapping using hyperspectral image

The aim of this study was to conduct a classification of hyperspectral images for land cover mapping. For this purpose, 242 band HYPERION image of Ulaanbaatar taken on 18 August 2002, has been used. For the actual feature extraction, principal components transformation (PCT) and spectral knowledge were used. The output of each of the feature extraction method was classified using a maximum likelihood classification and spectral angle mapper methods.

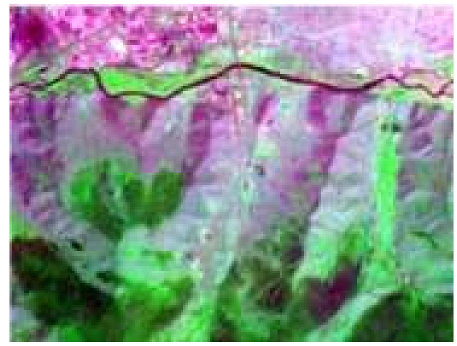

Figure 9. HYPERION image of the test site.

Hyperion is a hyperspectral sensor launched by NASA in November 2000 and it marked the establishment of spaceborne hyperspectral mapping capabilities. It covers 355nm to 2577nm spectral range with 242 spectral bands at approximately 10nm spectral resolution and the data has 30m spatial resolution. The instrument captures 256 spectra over a 7.5km-wide swath perpendicular to the satellite motion [10]. Figure 9 shows a HYPERION image of the test site, and its land cover.

For the feature extraction the following approaches have been used:

- Feature extraction using PCT. The PCT is a statistical technique that transforms a multivariate data set of intercorrelated variables into a set of new uncorrelated linear combinations of the original variables, thus generating a new set of orthogonal axes [14,15]. It is also a data compression technique used to reduce the dimensionality of the multidimensional datasets and helpful for image encoding, enhancement and multitemporal dimensionality [13]. PCT has been performed using all available bands and the result showed that the first three principal component (PC)s contained 98.48% of the overall variance (81.85%, 13.57%, 3.06% for the PC1, PC2 and PC3, respectively). The visual inspection of a PC4 that contained only 0.4% of the overall variance, indicated that it contained noise. Likewise, the other PCs contained noise from the total data set. A colour image created by the use of the first three PCs is shown in Figure 10a.
- Application of spectral knowledge of the classes of interest. Nowadays, application of a knowledge-based approach has more and more usage in spectral classification of RS images. The knowledge in image classification can be represented in different forms depending on the type of knowledge and necessary of its usage. In our case, spectral knowledge of the

classes of objects was used for selection of the features and it is defined on the basis of the general spectral characteristics of the classes of objects and the available spectral knowledge. Initially, the pixels representing the selected classes have been chosen from different parts of the image. Then, the statistics of these pixels was defined and plotted in a feature space and the bands which demonstrated the maximum separabilities were chosen for a further analysis (i.e., bands 38, 82, 100). A colour image created by the use of this method is shown in Figure 10b.

a) b)

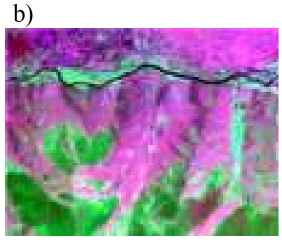

Figure 10. a) Image created by the use of bands 38, 82 and 100, b) Image created by the PCA method.

To define the sites for the training signature selection, areas of interest (AOI) representing the available six classes (built-up area, soil, grass, deciduous forest, coniferous forest and water) have been selected from the hyperspectral image. The separability of the training signatures was firstly checked in feature space and then evaluated using Jeffries–Matusita distance. After the investigation, the samples that demonstrated the greatest separability were chosen to form the final signatures. The final signatures included about 368–474 pixels.

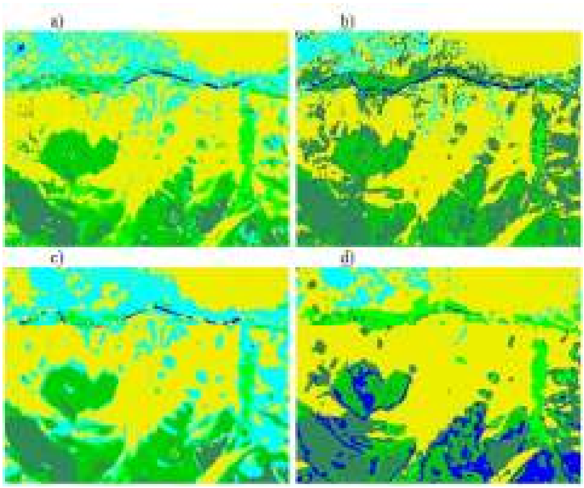

Figure 11. Comparison of the classification results (cyan-urban, yellow-soil, light green-grass, green-deciduous forest, dark green-coniferous forest, blue-water). Classified images using maximum likelihood classification and spectral angle mapper (a,b) bands defined by spectral knowledge, (c,d) PC bands.

For the actual classification, a MLC and spectral angle mapper methods have been used. The final classified images are shown in figure 11. As could be seen from figure 11, the classification results of the PC image give the worst results, because there are high overlaps among classes: built-up area, soil and other classes. However, these overlaps decrease on other images classified using the bands defined by the spectral knowledge. Comparing 2 classification results obtained by the use of the spectral knowledge, one can see that, the performance of the MLC was better than the other method.

For the accuracy assessment of the classification results, the overall performance has been used. The overall classification accuracies for the selected classes were 89.85% and 85.43%, for the results of the spectral knowledge using MLC and spectral angle mapper, and 79,62% and 70.16% for the results of the PC bands using MLC and spectral angle mapper.

III. CONCLUSIONS

The main purpose of this research was to apply some RS and GIS techniques and technologies for different environmental studies in Mongolia. As parts of the study, four case studies were given. The first case study highlighted the forest change study using multispectral high resolution Landsat images from three different years. The second case study described the study on environmental conditions using multitemporal InSAR images. The third case study r highlighted the pasture land degradation study and pasture vegetation mapping at regional and local levels using high and very high resolution satellite images. The fourth case study reviewed the land cover mapping using 242 band Hyperion hyperspectral image. Overall, the research indicated that modern RS and GIS techniques and technologies could be successfully used for environmental monitoring and management.

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