Applications of Satellite RS for Environmental Studies in Mongolia

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Abstract: The aim of this study is to demonstrate some applications of satellite-based optical, synthetic aperture radar (SAR) and hyperspectral remote sensing (RS) for environmental studies in Mongolia. For this purpose, three different case studies are highlighted. The first case study describes pasture land degradation study using multitemporal optical RS images, whereas the second case study reviews forest resources mapping using optical and SAR images. The third case study describes land cover mapping using hyperspectral RS images. For the analyses, optical, microwave hyperspectral 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 techniques and technologies are reliable tools for environmental monitoring and management.

Keywords: Optical, SAR, Hyperspectral, RS image, Environmental study

1. 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 [1,2,10].

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 [3,4]. 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.

The aim of this study is to demonstrate some applications of satellite-based optical, synthetic aperture radar (SAR) and hyperspectral RS for environmental studies in Mongolia. For this purpose, 3 different case studies conducted for different applications have been described. For the final analyses, multisource satellite images with different spatial resolutions have been used and different RS techniques were applied.

2. Case studies

2.1. Pasture land degradation study using multitemporal optical RS images

Pastureland plays an important role for the Mongolian animal husbandry, because they are grazing home to 50 million livestock and are used by over 170,000 herding families. It makes up about 82% of total land area of the country and represents the largest remaining contiguous area of common pastureland in the world (NSO, 2015). In recent years, the Mongolian pastureland has been seriously deteriorated. The severe droughts and growing number of livestock have been the main factors for the pastureland degradation in many parts of the country (Amarsaikhan, 2014). The aim of this research is to conduct a pastureland change study in Central Mongolia using an advanced RS technique. As the advanced method, a refined minimum distance classification based on the spatial properties of the available land cover classes, has been constructed.

The test area covers Jargalant, Erdene-Mandal and Tsetserleg sums of Arkhangai Province, Central Mongolia. By the forest-vegetation classification, the area is included in the Khangai region and is dominated by mixed landscapes of forest and steppe. In the test site, it is possible to define such classes as pastureland, degraded pasture, forest, meadow vegetation and water. As RS data sources, green, red and near infrared channels of Landsat 5 data of 14 September 1987, Landsat 7 data of 18 September 2001, Landsat 8 data of 23 August 2014 have been used. In addition, a topographic map of scale 1:100.000, a pasture map of scale 1:200.000, GPS measurements and ground validation data were available. Figure 1 shows the test site and Landsat 8 image of the study area.

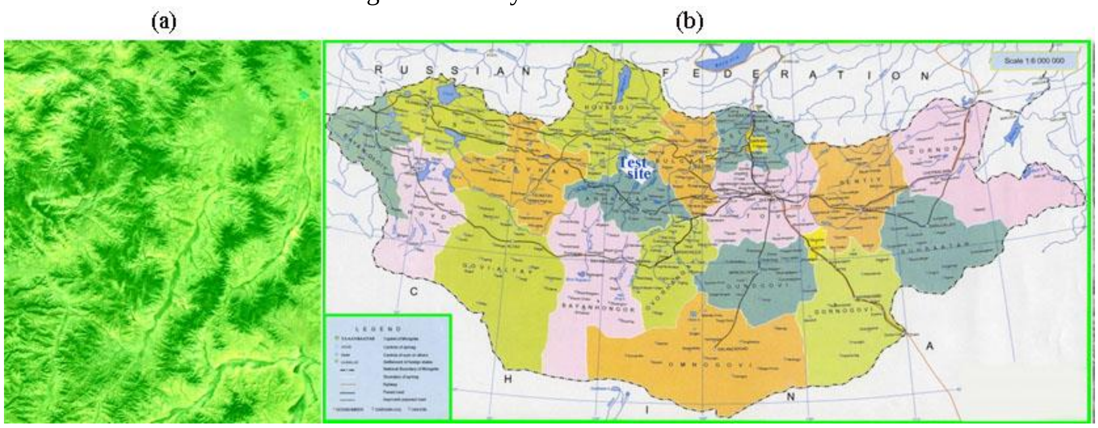


Figure 1. (a) Landsat 8 image of the test area, (b) Map of Mongolia indicating the test site.

Initially, all images have been georeferenced to a UTM map projection using a topographic map of the study area. Then, to form the training signatures 2-3 areas of interest (AOI) representing the available classes have been selected through accurate analysis. The separability of the training signatures was evaluated using J-M distance and the samples that demonstrated the greatest separability were chosen. For the actual classification, the refined minimum distance classification has been used. For the accuracy assessment, the overall performance has been used. Classification results of the multitemporal RS images are shown in Figure 2.

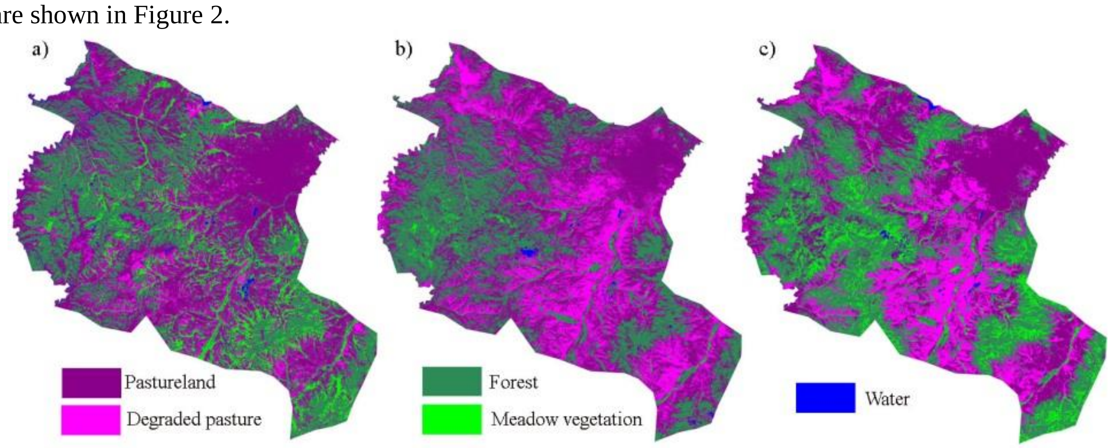


Figure 2. Classification results: (a) Result of 1987, (b) Result of 2001, (c) Result of 2014.

After the classifications, the total areas belonging to the selected classes have been calculated. Although we had 5 classes, in the current study, the change analyses of only 2 classes (pastureland and degraded pasture) have been conducted. As could be seen from the classification results, in 1987, the pastureland and degraded pasture occupied 387,633ha and 85,299ha, respectively, whereas in 2001 these two classes covered 381,176ha and 183,756ha, respectively. As seen, within 14-year period pastureland was decreased by only 1.7%, whereas the degraded pasture was increased more than two-fold. Moreover, it was seen that in between 2001 and 2014, the pastureland had been decreased to 275,639ha and degraded pasture had been increased to 190,427ha.

2.2. Forest resources mapping using optical and SAR images

As a test site, a forest-dominated area around the Khuvsgul Lake located in northern Mongolia has been selected. The area represents a forest ecosystem and is characterized by such main classes as coniferous forest, deciduous forest, grassland, light soil, dark soil and water. As data sources, Landsat ETM+ data of August 2007 with a spatial resolution of 28m, ALOS PALSAR L-band HH polarization image of 17 August 2007 with a spatial resolution of 25m, a topographic map of scale 1:100,000 and a forest taxonomy map have been used. The selected test site in the Landsat ETM+ image frame is shown in Figure 3.

Figure 3. Landsat ETM+ image of the test area.

In order to geometrically correct the PALSAR image, 16 more regularly distributed GCPs were selected comparing the locations of the selected points with other information such as Landsat ETM+ image and the topographic map. Then, the image was georeferenced to a UTM map projection using the topographic map of the study area. For the actual transformation, a second order transformation and nearest neighbour resampling approach were applied and the related RMS error was 1.18 pixel.

Then, from the Landsat ETM+ image, 2-3 areas of interest (AOIs) representing the selected classes (ie, coniferous forest, decideous forest, grassland, light soil, dark soil and water) have been selected using a polygon-based approach. Then, training samples were selected on the basis of these AOIs. The separability of the training signatures was firstly checked on the feature space images and then evaluated using Jeffries–Matusita distance (Richards and Jia 1999). After this, the samples demonstrating the greatest separability were chosen to form the final signatures.

In general, before applying a classification decision rule, the speckle noise of the SAR images should be reduced. The reduction of the speckle increases the spatial homogeneity of the classes which in turn improves the classification accuracy. In this study, to reduce the speckle of the PALSAR HH polarisation image a 5x5 size gamma map filter has been applied (ERDAS 1999). After the speckle suppression, the SAR image was added to the optical bands, thus forming multisource images. For the classification, bands 3,4,5 and 7 of Landsat ETM+ data as well as PALSAR HH polarisation image have been used. As the classification method, a novel refined maximum likelihood classification based on the spectral and spatial thresholds was applied.

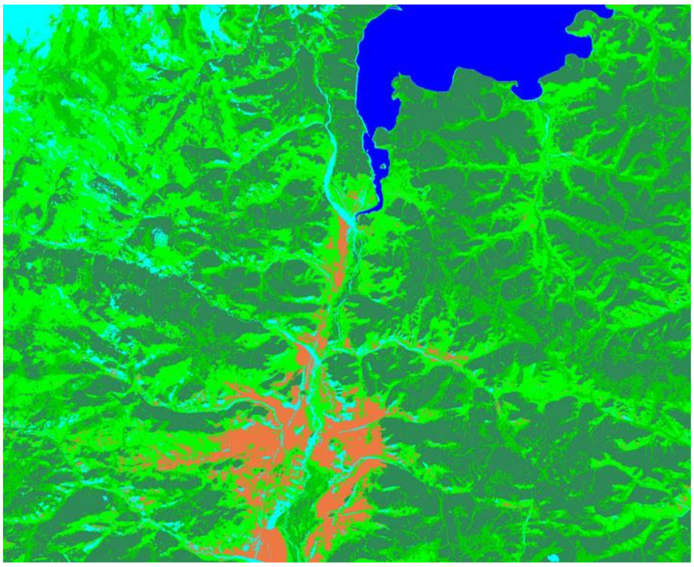


Figure 4. The classification result of the multisource images.

The result of the classification is shown in figure 4. As seen from the Figure 4, there are less overlaps on the decision boundaries among the statistically mixed classes. For the accuracy assessment of the classification result of the multisource images, the overall performance has been used, taking 1285 sample points. The confusion matrix produced for the multisource image classification showed overall accuracy of 91.12%. As the classification accuracy exceeds 90% threshold, the result can be used for forest planning and management.

2.3. 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.

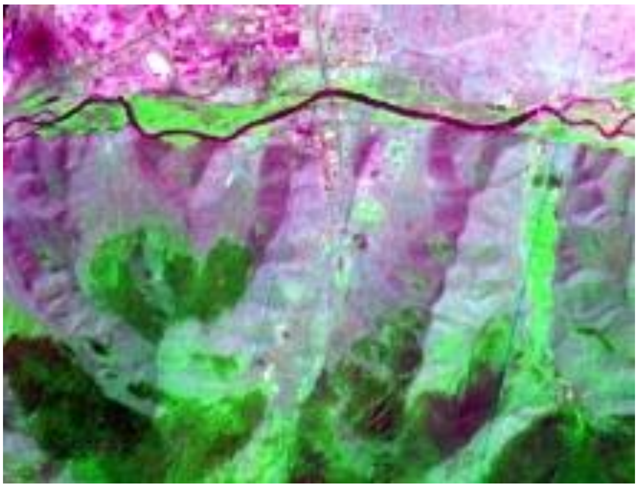


Figure 5. HYPERION image of the test site.

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 (Kruse 2002). Figure 5 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 (Richards and Xia, 1999). 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 (Pohl and Van Genderen 1998). 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 6a.
- 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 6b.

a) b)

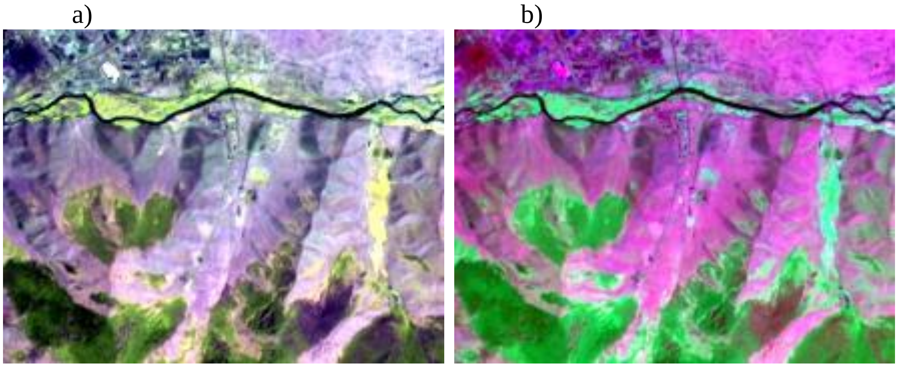
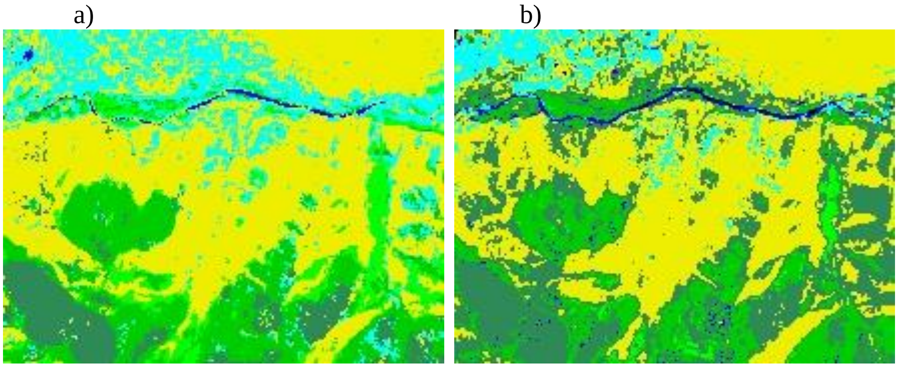


Figure 6. a) Image created by the use of bands 38, 82 and 100,
b) Image created by the PCA method

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.

a) b)



c) d)

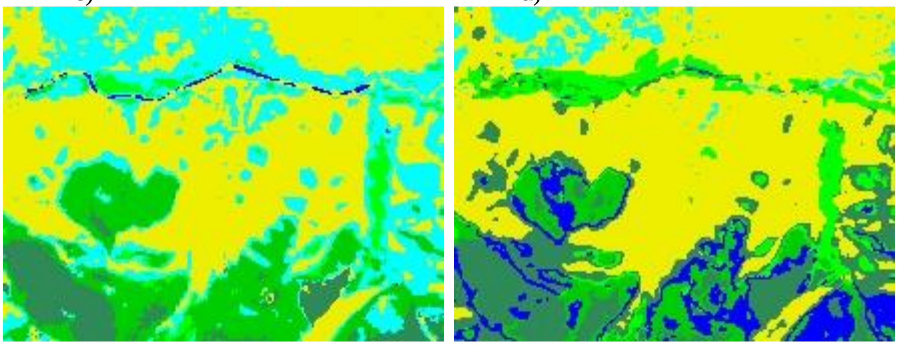


Figure 7. Comparison of the classification results (cyan-urban, yellow-soil, light green-grass, green-deciduous forest, dark green-coniferous forest, blue-water). Classified images using maximum likelihood classification and spectral angle mapper (a,b) bands defined by spectral knowledge, (c,d) PC bands

For the actual classification, a maximum likelihood classification and spectral angle mapper methods have been used. The final classified images are shown in figure 7. As could be seen from figure 7, 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 maximum likelihood classification 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 maximum likelihood classification and spectral angle mapper, and 79,62% and 70.16% for the results of the PC bands using maximum likelihood classification and spectral angle mapper.

3. Conclusions

The aim of this research was to demonstrate how satellite-based optical, microwave and hyperspectral RS could be used for environmental studies in Mongolia. For this purpose, three different case studies were given. The first case study described pasture land degradation study using multitemporal Landsat images. The second case study reviewed forest resources mapping in northern Mongolia using Landsat and PALSAR images. The third case study highlighted land cover mapping using 242 band Hyperion hyperspectral images. Overall, the research indicated that modern RS techniques and technologies are reliable tools for environmental studies in Mongolia.

4. References

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