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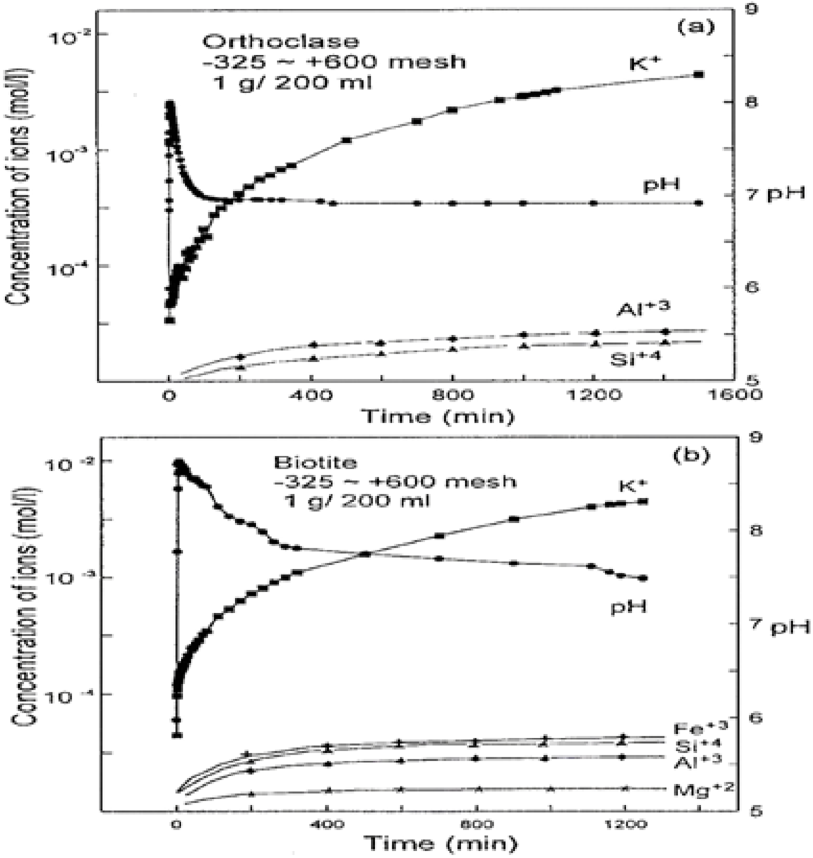

Fig. 1. Experimental dissolution of rock-forming minerals. Note the pH and ion release from (a) orthoclase- and (b) biotite-water reactions at initial pH 5.7 (Lee, 1996).

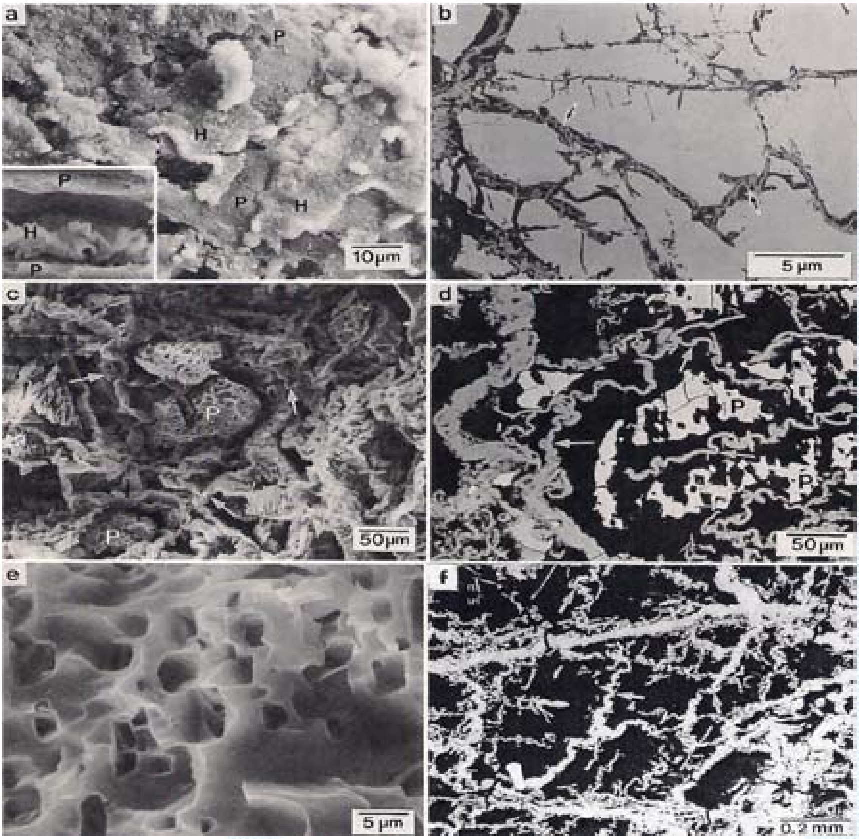

Fig. 2. SEM micrographs showing the formation of halloysite boxwork. a, c, e : Secondary electron images. b, d, f : Back-scattered electron images. (a) Detachment of halloysite plate (H) from the plagioclase (P) and subsequent wrinkling of the plate (insert). (b) Wrinkling of the halloysite plate after detachment from plagioclase walls in microfissures of plagioclase. Black indicates voids. (c) Plagioclase grains (p) with many etch pits and wrinkled halloysite walls (arrows). (d) Thin section showing the halloysite boxwork. Note the wrinkling of halloysite walls (arrows), the large free spaces (black), and remnants of skeletal plagioclase (p) with angular etched surfaces. (e) Skeletal plagioclase showing many etch pits. (f) Highly porous microscopic boxwork fabric with halloysite walls (white indicates voids) (Jeong and Kim, 1993).

Information, Assessment and Mapping of Land Degradation and Desertification

Application of Advanced Technology for Combating Land Degradation and Desertification in Mongolia

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Abstract

The aim of this research is to apply some advanced technologies based on modern remote sensing (RS) and geographical information system (GIS) for different land degradation and desertification studies in Mongolia. For this purpose, three different case studies are highlighted. The first case study describes a land degradation and desertification study using a water balance model, while the second case study reviews a forest land degradation study and forest biomass mapping. The last case study highlights a pasture land degradation study and pasture vegetation mapping at regional and local levels. For the analyses, optical and synthetic aperture radar (SAR) satellite images with different spatial and spectral resolutions, topographic and thematic maps of varying scales as well as some ground truth data are applied. Overall, the research indicates that modern RS and GIS techniques and technologies are reliable tools for different environmental studies, including land degradation and desertification.

Keywords: Advanced technology, Land degradation, Desertification, RS images, GIS

1. Introduction

Geographically Mongolia is divided into such zones as forest taiga (northern part), forest steppe (central part), steppe (eastern part), dry steppe (southern part), rocky mountains (western part) and Gobi (the southern most part). The main type of land use is pastureland for semi-nomadic livestock husbandry and it covers about 81% of total land of the country. The availability of pasture is determined by rainfall, and access to fodder is determined by the availability of water during summer and of snow during winter. Natural hazards include dust and snowstorms, grassland and forest fires, and drought and dzud (heavy snow). Man-made problems such as illegal logging, fires, increased livestock, and mining are the main factors for land degradation and desertification, including deforestation, overgrazing and soil erosion [3].

Mongolia has harsh continental climate. The summer high temperatures often result in drought, while the winter low temperatures result in dzud. And 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. Moreover, due to tremendous increase of livestock, natural vegetation is being consumed with such intensity and speed that more yearly species are demolished and annual species cannot flower and produce seed for reproduction [2].

The drought, high temperature and high radiation 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, because even improved weather conditions might not immediately restore the old vegetation cover. 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. Many rivers and lakes are drying out. Soils are becoming more and more saline and loose their regenerative capacity. Meanwhile, the mobility of sand has been increased. A recent study has shown that, about 73% of Mongolian total territory has been degraded. Thus, there are many problems related to the environment and natural resources in Mongolia which in turn influence the socio-economic sustainable development of the country [2,3,9].

In general, for monitoring and management of any environmental phenomena, the detailed spatial information can play an important role. For example, such information can be successfully used for many different disciplines including environmental monitoring, land cover/use change detection, natural resources assessment and many others [1]. In environmental context, spatial information can be collected from a number of sources such as field survey, planning maps, topographic maps, digital cartography, thematic maps, global positioning system 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 [5,6]. This means, it is possible to extract different thematic information at various scales and integrate the extracted information with other historical data sets stored in a GIS and to conduct sophisticated analyses.

The aim of this research is to demonstrate how advanced technologies based on RS and GIS can be used for land degradation and desertification studies in Mongolia. For this purpose, three case studies conducted for different applications have been described. For the final analyses, multisource satellite images with different spatial resolutions as well as topographic maps of varying scales have been compiled within Erdas Imagine 9.3 and ArcGIS 9.2 systems and different RS and GIS techniques were applied.

2. The relationship between land degradation and desertification

One of more generally accepted definitions of desertification given by the UNCCD is described as “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities”. The term “desertification” is not applied to deserts zones. It is used to refer to degradation processes resulting from anthropocentric and natural factors, such as land overexploitation, overgrazing, bad irrigation practices, deforestation, bush and forest fires, etc. Along with these human activities, a range of climatic factors such as year-round aridity, high variability in rainfall and recurrent drought are believed to influence the process of land degradation. In practice, it means that to analyze desertification one has to look at trends and changes, unsustainable land use in combination with climate. In case of Mongolia, a naturally dry area such as the Gobi desert with its high variability in rainfall is not necessarily a desertification prone area, although the living conditions may be very difficult [9].

As it is known, the drought is one of the most influencing factors of land degradation as well as desertification. Drought affected area is defined by the WMO as “an area where the annual precipitation is lower than 60 % of the normal values, at least during two consecutive years in more than 50 % of its area”. The main environmental problems related to drought are decrease of the groundwater table, decrease in river flow, increased water pollution, soil and water salinization, soil pollution by fertilizers, increase in soil erosion risk by wind, sometimes by water if rainstorms are less frequent but more intense, increase in wild fire and forest fires risk, vulnerability of vegetation to other damaging agents, and so on [9].

3. Case studies

3.1. Case study-1: Land degradation and desertification study using a water balance model

The purpose of the water balance model is to predict spatial differences in water availability and estimate recharge to the groundwater. These changes and patterns can then be interpreted in terms of land degradation and desertification. As a test site, Bayan soum, located in about 130 km toward the southeast of Ulaanbaatar city, has been selected. It has an area of 4736 sq.km. The land use is mainly grazing and the northern part has a better grass cover than the southern edge. There are many small catchments especially in the south and east that lead to local depressions, that sometimes fill up with water temporarily, and some are permanent (Figure 1). These are parts of bigger watersheds, but the main river channels are very sandy and will not carry runoff water far. At the edge of the hills springs can be found that there is a constant source of water. This indicates that a shallow groundwater table and possibly shallow soils underlain by bedrock in the hills that cause the water to emerge at a brake of the slope. A soil map of the study area is shown in Figure 1.

In the present study, we wanted to elaborate a model that can compare quantitatively and spatially both changes in plant available water and in groundwater recharge, from year to year. The model uses three data sets such as meteorological, terrain and vegetation. Meteorological data set contains a table with daily rainfall, a table with average daily values of incoming radiation (w/m2), relative humidity (%), temperature (C) and wind speed (m/s), and a map with the position of the Bayan soum meteo station. Terrain data set contains a digital elevation model, a map with hydrological units based on soil texture, a table with the soil hydrological characteristics, and a map of the initial soil moisture content. Vegetation data set contains a series of moderate resolution MODIS satellite NDVI images of plant cover, and the dates they were taken. Since the model directly uses satellite images, it is assumed that the plant growth is adequately represented and does not need to be modelled explicitly to determine water use in the area. The actual evapotranspiration (ETa) represents the water used by the plants and the potential evapotranspiration (ETp) the maximum possible water use. If the ratio ETa/ETp equals 1 throughout the season, there is no water stress and optimal growth (whatever the biomass). In photosynthesis the ratio ETa/ETp directly and linearly affects the amount of carbon hydrate produced from CO_2 and H_2O. Therefore, this ratio is an indication for water stress. The model also calculates the cumulative percolation leaving the root zone. It is assumed that this will eventually reach the groundwater system as recharge and is therefore an indication of recharge. As the model is spatial, one can analyze if certain soils and locations are more prone to water shortage than others, and also what happens if the rainfall is higher or lower than the average. The real analysis comes when different years are compared with each other and trends or variability is assessed. The get a final result, the above mentioned data sets should be compiled within a GIS and the model should run [9].

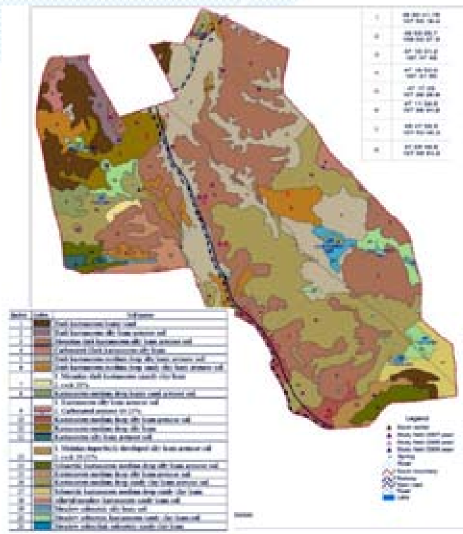

Figure 1. Soil map of the Bayan soum area.

The model principles and outputs

The model is based on one-layer root zone water balance, with as incoming flux direct rainfall and throughfall under the canopy with and as outgoing fluxes plant transpiration and soil evaporation on the upper boundary and percolation downward out of the root zone. The outgoing fluxes are strongly determined by the moisture content of the soil. Plant cover also plays a role, which is derived from a series of MODIS images. The model can calculate a runoff fraction for every rainfall based on the available storage, and the runoff can infiltrate down slope. It should be noted that the sandy dry river beds have high infiltration capacity will almost never contain water. Discharge is therefore not considered at this point. Also the area under consideration has administrative boundaries cross cutting several small catchments, so from a hydrological point of view it is not easy to calculate discharge at this point. Groundwater is deep and has no influence on the root zone through capillary rise, and the roots do not use the groundwater storage as far as is known. These boundary conditions make the model relatively simple. The actual evapotranspiration however must be calculated in detail because of the direct relation with drought. The model delivers many outputs in the forms of graphs, tables and maps [9]. Some of the most important outputs represented in map forms are shown below.

Output 1: Water use and water deficiency

The water use in itself is not a direct indicator, only in relation to the results of other years. For instance, 2009 appears to be a wet year while other years are drier, which may then indicate the relative status of a year and eventually the appearance of trends. The water use equals the actual transpiration if the cover of the MODIS images are a good measure for plant development. In the simulated season the water use in the area varies from 40 to 60 mm depending on the different soils, rainfall input and plant cover (Figure 2a). The water stress is related to the ratio of actual evapotranspiration and potential evapotranspiration (ETa/ETp). It is a measure of the functioning of the plants, whereby a value of 1 indicates no water stress and an optimal evapotranspiration [9]. Figure 2a shows that the frequency of the rainfall prevents all out drought and keeps the evaporation deficit limited between 0.6 and 0.4. Figure 2b shows the soil moisture deficit map at the end of the season.

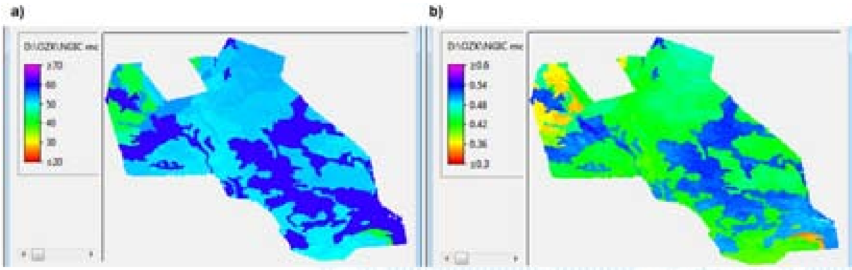

Figure 2. The total estimated water use (a), and average seasonal water stress in the area (b).

Output 2: Groundwater recharge

The amount of water leaving the root zone can be seen as an indicator for groundwater recharge. The model produces a map with the total recharge. The average of the area is 42 mm of recharge with variations in the area between 50-60 in the NW to <30 mm in the SE [9]. The reason for this pattern is primarily an assumed decrease in rainfall towards the SW (Figure 3).

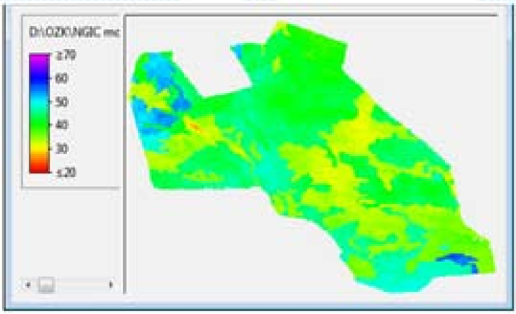

Figure 3. GW recharge map at the end of the season. The more permeable soils have more recharge (about 50 mm).

3.2. Case study-2: Forest land degradation study and forest biomass mapping

Forests are an important natural resource that should be carefully managed, because on one hand they maintain an ecological balance and on the other hand they provide the raw material for a wide range of wood-based industries. Over the years, RS has been extensively used for forest monitoring and management, because it provides real-time information about the state and conditions of forests. However, most forest management practices mainly use optical RS data sets and applications of the combined use of optical and advanced microwave RS technologies are still limited. The combined application of optical and microwave data sets can provide unique information because passive sensor images represent spectral variations only of the top surface of the forest canopy, while active sensors with canopy penetrating capability, can provide additional data and information about forest structure and biomass [4].

The aim of this study is to use optical and SAR data sets for forest land degradation study as well as forest biomass mapping. As a test site, Bogdkhan Mountain situated in central part of Mongolia has been selected. As data sources, Landsat TM image of August 1989, Landsat ETM image of August 2001, JERS-1 SAR intensity image of April 1997 and ERS-1/2 SAR tandem pass single look complex (SLC) images acquired on 10 and 11 October 1997, have been used. In addition, a topographic map of 1969, scale 1:50.000 and a forest taxonomy map of 1988, scale 1:100.000 were available, accordingly.

Forest land degradation study

In order to carry out forest land degradation analysis, initially, the optical images were thoroughly analyzed in terms of brightness and geometric distortion. The images were of a good quality but the Landsat TM image of 1989 had a haze effect and it was removed by subtracting the haze values [10] from the actual data distribution thus shifting the data histogram to the origin. Then, the Landsat images were successively geometrically corrected to a Gauss-Kruger map projection using a topographic map of the study area, scale 1:50.000. The ground control point (GCP)s were selected on clearly delineated sites and in total 9 regularly distributed points were chosen. For the actual transformation, a second order transformation and nearest neighbour resampling approach have been applied and the related root mean square (RMS) errors [7] were 0.98 pixel and 0.92 pixel, respectively. The geometrically corrected Landsat images are shown in Figure 4a,c.