Deutscher Tropentag 2003
Göttingen, October 8-10, 2003
Conference on International Agricultural Research for Development

Estimation of a potential landscape development regarding factors of forest conversion and soil degradation in eastern Bolivia

Krüger[a], Jens-Peter, Gerhard Gerold[a]

a University of Goettingen, Institute of Geography, Landscape Ecology, Goldschmidtstr. 5, 37077 Goettingen, Germany. Email jkruege@gwdg.de.

Abstract

The eastern Bolivian lowland is part of the largest remaining area of intact deciduous tropical forest in the world. Over the last decades Deforestation of these forests accelerated basically due to the use of large-scale mechanized agriculture. The mechanized cropping led to a high proportion of degraded soils due to inappropriate use. Most of these areas turned over to pasture when the land is abandoned. As a consequence, a rapid eastward expansion of the agricultural frontier is observed. However, the economic basic conditions force the Bolivian government into action to intensify industrial agriculture. That is why this region has been characterized as one of the most endangered areas in the Neo-tropics.

This paper presents the development of a GIS-based approach to identify potential landscape changes, including potential deforestation areas as well as areas with a high probability of soil degradation in the main cultivation zone east of the city of Santa Cruz. For this purpose environmental and remote sensing data (Landsat TM, ETM 1984, 1992 and 2001) were compiled in a GIS data base and subsequently analyzed for factors like infrastructure, settlements and soil quality, which could explain the observed deforestation. These outcomes were combined to perform a deforestation and soil degradation risk assessment on a regional scale.

Key words: Bolivia, deforestation, soil degradation, spatial modeling, remote sensing, GIS

Introduction

Over the recent years, the interest to gain more information about factors that influence forest conversion and soil degradation has been growing. Since this subject is very complex, there is an increasing demand for more and new types of information. In this context models could be a helpful tool to predict potential land use changes in the future. KAIMOWITZ and ANGELSEN (1998) identified a lot of models which try to answer questions concerning deforestation and related processes.

Compared to other countries possessing tropical forests, the Bolivian tropics received low rates of deforestation in the past. However, this changed recently, particularly in the tropical lowland of eastern Bolivia (KAIMOWITZ et al. 2002). This region still encompasses large areas of relatively undisturbed tropical deciduous forest (KILLEEN & SCHULENBERG 1999). Due to the location in an ecological transition zone between the Chaco in the south, the Cerrado in the east and the Amazon basin in the north, these forests maintain a high degree of biodiversity (MYERS et al. 2000). Since the agrarian reform in 1953, these forests were gradually cleared for agriculture.

Study area

The producing area is a broad alluvial plain situated between the Andean foothills to the west and the Brazilian shield to the north-east. The region comprises an older mechanized zone (*integrated zone*) and a new *expansion zone* to the east of the Río Grande. The soils are young alluvial soils (mainly Alfisols and Inceptisols[1]) which are predominantly highly fertile and suitable for agriculture but also susceptible to compaction (BARBER 1995).

The climate is characterized by a pronounced seasonality with a dry season between May and October. The precipitation displays a gradient from the north to the south that ranges between 1800 mm and 550 mm/year and is characterized by a distinct annual variability (GEROLD 1986, IADB 2000). This permits the cultivation of two crops per year for the northern part, while the drier conditions to the south constrain annual cropping. This problem has been faced recently with the installation of irrigation systems.

Agricultural development

Over the last decades the mechanized farm sector in eastern Bolivia has grown rapidly. The most intense development occurs east of the city of Santa Cruz. Beginning in the 1940s with the production of rice and sugar cane in the *integrated* zone. From the 1950s to the 1970s spontaneous colonization gradually took place along the major roads and several planned resettlement programs for migrants from the Andes were implemented (BARBER 1995, PACHECO 1998, THIELE 1995). Forest clearing accelerated during the 1970s and 1980s with the establishment of large agricultural colonies by Japanese and Mennonite farmers (KAIMOWITZ et al. 2002). The highest deforestation rates occurred in the 1990s mainly in the *expansion* zone, where, for large-scale commercial soybean production, wide areas were cleared by foreign agroindustrial farmers and Mennonites. For this period STEININGER (2001) calculated an annual deforestation rate of about 890 km^2/year. The total amount of cleared land in the study area exceeds 10.000 km^2 over the 17-year period (1984 – 2001) investigated (Fig.1).

Problem

The combination of the natural environmental conditions (e.g. frequency of erosive winds) as well as soil-types that are susceptible to degradation (e.g. poor soil structure, (GEROLD 2001)) led to the classification of an ecological risk zone, which responds very sensitively to human impacts (MOLL 1981). According to the governmental land-use plan of the department of Santa Cruz (PLUS 1996), a significant proportion of the deforestation corresponds to areas not suitable for agriculture.

Crop yields are declining due to soil degradation caused by inadequately soil cultivation techniques (e.g. land preparation on wet ground, use of heavy machinery for clearing, preparation and harvesting, lacking vegetation cover during the windy season). This has resulted in a high amount of moderately to severely compacted soils (BARBER 1995, DAVIES 1996, GEROLD 2002). As a consequence numerous abandoned fields or pastures remain a few years after clearing and intensive agriculture. To maintain the average production new sites have to be cleared. This is normally more profitable than the rehabilitation of degraded land. This cycle is well known in countries possessing tropical forests. Furthermore plans exist to improve and extend the existing

[1] according to US Soil Taxonomy, SOIL SURVEY STAFF 2003

road infrastructure, which attract new settlements in turn. Most likely the same effect could be expected by a new gas pipeline toward Brazil which requires new roads for its construction and maintenance.

Methods and data

The main objective of our study is to develop a GIS-based methodology, which is capable to identify potential future landscape changes on a regional level. This relates to potential deforestation areas as well as to areas with a high probability of soil degradation under the present conditions. Spatial data analysis gives valuable insights into processes of land cover and land use change and their underlying causes. To obtain the required information over a large area, remote sensing and GIS techniques are going to be applied.

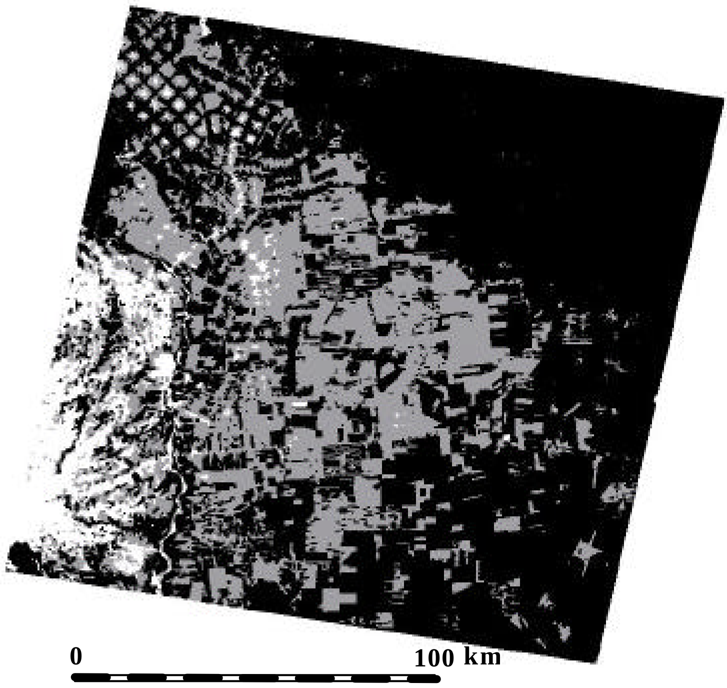

figure 1: *conversion of forest into agriculture in the Santa Cruz region of Bolivia (time period 1984 – 2001). The city of Santa Cruz is located in the south west of the image. White patches are relating to areas already cleared in 1984, whereas the gray patches display areas still not cleared in 1984 but in 2001. Black patches are representing the actual forest cover (including savannas)*

The spatial and temporal patterns of deforestation as well as the conversion into agriculture, pasture, secondary growth etc. are quantified by digital processing of satellite imagery from 1984 through 2001 (**change detection**). The results are compiled together with soil, climatic and infrastructure data in a GIS data base. With respect to relevant parameters related to people - environment interactions (**driving forces)** practical deciding factors will be deduced, tested and evaluated (Fig. 2). Of main importance is the question, where future deforestation and soil degradation will occur.

The GIS-based assessment involves the integration of attribute data from different types and sources. To estimate the influence of different variables on deforestation and soil degradation we focus on the following information:

- land use / land cover in 1984, 1992, 2001
- land use potential (soil quality, topography)
- precipitation

- infrastructure
- urban areas
- forest concessions
- colonization zones
- land use system

Landsat TM and ETM images were obtained for scenes 230-72 and 230-73 for 1984, 1992 and 2001. All images were acquired during the dry season. We co-registered the images to the georeferenced 2001 images with an RMS error less than one pixel width and resampled them to a 30 m ground resolution. An unsupervised classification was used together with field observations to classify the land cover using a maximum likelihood analysis. The analyzed spectral classes were combined into nine land use/land cover classes: forest, savanna, water, secondary growth, cropland, pasture, fallow, urban areas.

For assessing impacts on the ecosystem a change detection analysis is going to be performed. The deforestation rate are of central interest, because this is the best indicator for current trends.

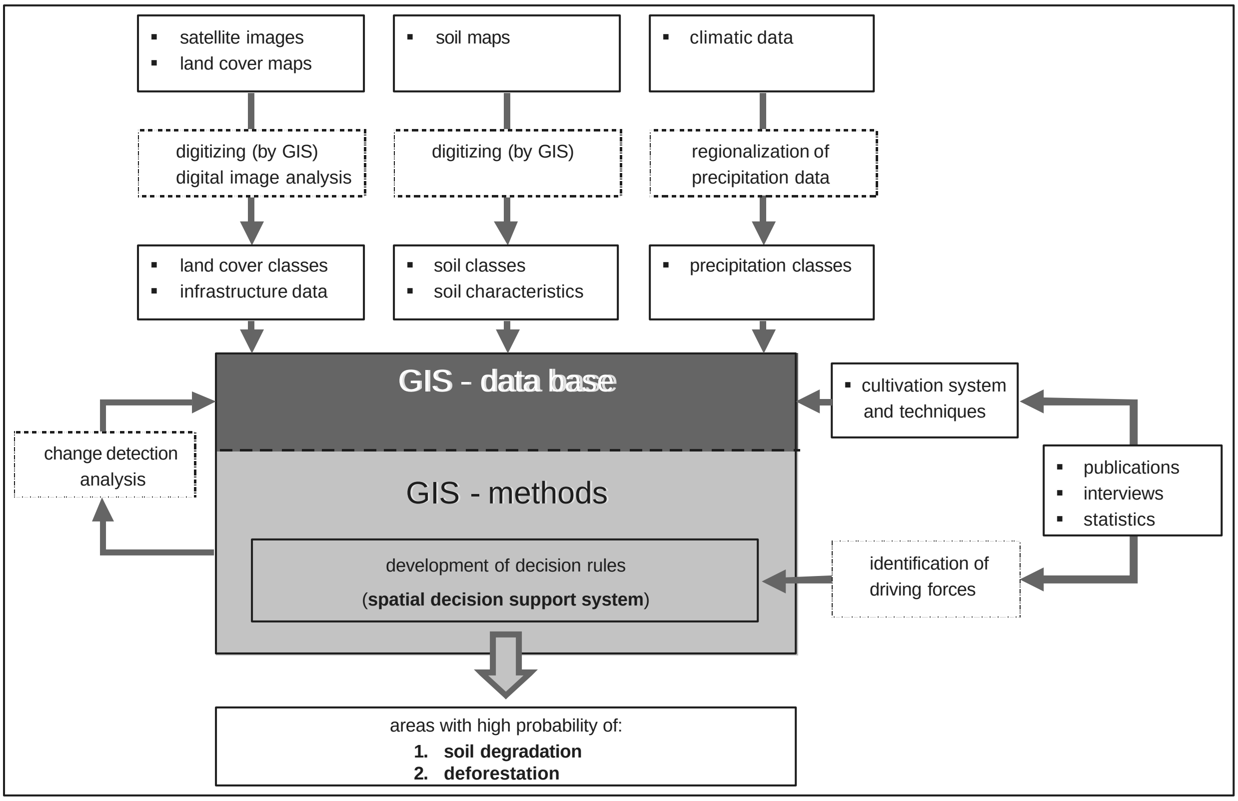

***figure 2**: flow chart of methodology*

Precipitation data of about 90 gauging stations is going to be regionalized using a geo-statistical kriging interpolation to obtain different precipitation classes. This method is favored because the region is topographically simple. Climate data relates to RAFIQPOOR et al. (in press). Terrain parameters as well as the stream network were derived from SRTM[2] data. These data are well suited for an appropriate terrain representation.

[2] SRTM shuttle radar topography mission (http://srtm.usgs.gov/)

Infrastructure data were digitized from the satellite imagery with the help of different maps. Roads are subdivided into different categories according to their importance (first, second and third order). Transport and production infrastructure are poorly developed in the region. The road quality for instance is highly variable. Only a few roads are paved. Furthermore, a high number of logging roads and roads for the exploration of petroleum exists. Data on distances to roads and markets (settlements) are calculated using GIS techniques.

Population and socioeconomic data were taken from the national statistic institute (INE 2002). A population density map is going to be created taking into account percentages of urban population. All other socioeconomic data serve only as an additional information about the economic situation over the past decades. It is not proposed to use these data for the GIS-based assessment because required spatial data for these variables cannot be easily obtained. Anyway, underlying causes like social processes and economic policies are not direct and obvious but play also a major role in soil degradation and deforestation processes.

Colonization zones as well as forest concessions boundaries used in this approach, were obtained from a map produced by a Bolivian organization called CIMAR (Centro de Investigación y Manejo de Recursos Naturales Renovables). Data of Concessions for the oil and gas industry, which has become very important in Bolivia in recent years were acquired from the oil company YPFB (Yacimientos Petrolíferos Fiscales Bolivianos).

For creating a digital soil map information about soils were derived from a governmental land-use plan, which was developed in the middle 1990s for the whole Santa Cruz department (PLUS 1996). These data were digitized from maps and partially supplemented with information from other sources, such as measured soil parameters in various studies (GUAMÁN 1988, GUAMÁN 1999, MARKUSSEN 2002, KARSTEN 2000, KUBACH 1997). The soil map were classified into different suitability classes for land use.

All information will be compiled as single layers in the GIS data base and aggregated to one spatial resolution, which is used as the unit of analysis. The GIS-based assessment is going to be applied with respect to different assumptions: The probability that an area is cleared increases with higher soil quality, favorable precipitation conditions, road quality and better access to markets. Also forest fragments and colonization areas are more likely to be cleared. On the other hand areas with poor soils, less precipitation, bad infrastructure as well as areas with forest concessions are less endangered to get cleared. Of particular interest too, are differences in forest conversion between large scale mechanized agriculture and small farmer colonists.

The identification of potentially endangered areas to soil degradation is going to be assessed by soil characteristics, topographic parameters, precipitation distribution and land use. Additionally, information on cropping and clearing practices as well as on the use and non-use of windbreaks, respectively, are crucial. Windbreaks are advantageous in the zone because the soils are mostly fine textured and therefore susceptible to wind erosion. The trouble is, that those are often misaligned or composed of inappropriate trees and scrubs. Information about windbreaks can easily be obtained from the satellite imagery.

The causal relationships between these variables will be examined in a spatially explicit approach and their respective direction quantified. Maps, at least, should visualize the estimated landscape changes.

Perspectives

Farming in the study area is not sustainable. Most soils are highly fertile (alluvial deposits) and suitable for agriculture but soil cultivation techniques are applied inadequately. This has resulted in a high amount of moderately to severely compacted soils and declining yields. In 2001, great parts of the deforested area were covered with secondary growth. In this context, BARBER (1992) estimated that those high quality soils can be cultivated continuously for at least 60 years if appropriate management techniques are applied.

Anyway, if present rates of deforestation continue, the agricultural frontier will quite probably progress eastwards. This trend is most likely as it is not profitable to rehabilitate degraded land. The potential for northward expansion is limited by the poor soils of the Brazilian Shield, where livestock farming is the main activity (STEININGER 2001).

This leads to the conclusion, that a regional environmental plan is therefore essential.

Acknowledments

This research is funded by the German research society (DFG). We would like to thank the Fundación Amigos de la Naturaleza (FAN) for their excellent support.

References

BARBER, R. G. & O. DÍAZ (1992): Effects of deep tillage and fertilization on soya yields in acompacted Ustochrept during seven cropping seasons, Santa Cruz, Bolivia. Soil and Tillage Research, 22, p. 371-381

BARBER, R.G. (1995): Soil degradation in the tropical lowlands of Santa Cruz, eastern Bolivia. Land Degradation & Rehabilitation 6:95–107

DAVIES, P. (1996): Valuing Soils in the Tropical Lowlands of Eastern Bolivia. In: P. Abelson (ed.), Project Appraisal and Valuation of the Environment, General Principles and Six Case Studies in Developing Countries. London: Macmillan Press

GEROLD, G. (2002): Traditional and modern soil management techniques for sustainable land use in the lowlands of Bolivia (Santa Cruz). In: Faz, A., R. Ortiz, and A. R. Mermut (eds.): Sustainable use and management of soils in arid and semiarid regions. Vol. I, SUMASS 2002, p. 130 - 147

GEROLD, G. (2001): The pedo-ecological consequences of traditional and mechanised land use systems in the lowlands of Bolivia (Dep. Of Santa Cruz). Proceedings of ICLD 3, session II, extended abstract, p. 17

GEROLD, G. (1986): Klimatische und pedologische Bodennutzungsprobleme im ostbolivianischen Tiefland von Santa Cruz. Jahrbuch der GGH, Hannover, p. 69-162

GUAMÁN, C. A. (1988): Levantamiento integrado de recursos naturales sector Pailon-Pozo del Tigre Los Troncos (nivel de reconocimiento): estudio de suelos. Sección de recursos naturales, CORDECRUZ, Santa Cruz, Bolivia

GUAMÁN, C. A. (1999): Estudio de Suelos del municipio Cabezas. Cooperación Técnica Boliviano-Alemana, Prefectura del Dpto. Santa Cruz – IP/GTZ, Proyecto Masrena. Santa Cruz de La Sierra, Bolivien

IADB (2000): Strategic Environmental Assessment of the Santa Cruz - Puerto Suarez Corridor, Bolivia. Project No. TC-9904003-BO, final report

INE (2002): Estadísticas del Departamento de Santa Cruz. Instituto Nacional de Estadística

KAIMOWITZ, D. & A. ANGELSEN (1998): Economic Models of Tropical Deforestation: A Review. Bogor, Indonesia: Center for International Forestry Research (CIFOR)

KAIMOWITZ, D., P. MENDEZ, A. PUNTODEWO & J. VANCLAY (2002): Spatial Regression Analysis of Deforestation in Santa Cruz, Bolivia

KARSTEN, R. (2000): Pedoökologische Auswirkungen des Brandrodungsfeldbaus in den wechselfeuchten Tropen (Santa Cruz – Bolivien).- Unpublished Thesis, University of Goettingen

KILLEEN, T. J. & SCHULENBERG, T. (1999): Conservation of Noel Kempff National Park.- Washington, DC, USA: Conservation International.

KUBACH, T. M. (1997): Estudio de Suelos – Zona Centro Izozog (Cmd. Ivasiriri), Provincia Cordilllera – Departamento Santa Cruz – Bolivia. Unpublished study, University of Goettingen

MARKUSSEN, M. (2002): Pedoökologische Folgen des mennonitischen Landnutzungssystems im Oriente Boliviens (Departamento Santa Cruz). ibidem-Verlag Hannover, 175 p. (ISBN 3-89821-189-4)

MOLL, M. (1981): Problemas ecológicos en el desarrollo agrícola de Santa Cruz (Bolivia): Un estudio modelo. Direktion für Entwicklungszusammenarbeit und humanitäre Hilfe. Eidgenoessisches Department für Auswaertige Angelegenheiten EDA, Bern.

MYERS, N., MITTERMEIER, R.A., MITTERMEIER, C.G., DA FONSECA, G.A.B. & KENT, J. (2000): Biodiversity hotspots for conservation priorities. Nature 403: 853 – 845

PACHECO, P. (1998) ; Estilos de desarollo, deforstación y degradaciódelos bosques en las Tierras Bajas de Bolivia Unpublished report,Centro de Estudias para el Dasarollo Laboral y Agrario (CEDLA), La Paz, Bolivia: 389 pp.

PLUS (1996) : Memoria del PLUS – Plan del Uso del Suelo del Departamento de Santa Cruz, Bolivia. Cooperación Finanziera del Gobierno Alemán – Prefectura del Departamento – Consorcio IP/CES/KWC, Santa Cruz

RAFIQPOOR, D., C. NOWICKI, R. VILLARPANDO, A. JARVIS, H. SOMMER, P. JONES & P.L. IBISCH (in press): The factor that most influences the distribution of biodiversity: the climate. In: Ibisch, P.L. & G. Mérida (Eds.): Biodiversity: the richness of Bolivia. State of knowledge and conservation. Ministerio de Desarrollo Sostenible y Planificacion / Editorial FAN, Santa Cruz

SOIL SURVEY STAFF (2003): Keys to Soil taxonomy. United States department of Agriculture and Natural Ressources. Conservation Service, 9th Edition

STEININGER, M.K., C.J. TUCKER, P. ERSTS, T.J KILLEEN, Z. VILLEGAS & S.B. HECHT (2001): Clearance and Fragmentation of Tropical Deciduos Forests in the Tierras Bajas, Santa Cruz, Bolivia. Conservation Biology, Vol. 15, No. 4, p. 856 – 866

THIELE, G. (1995): Thiele, G. 1995. The displacement of settlers in the Amazon: the case of Santa Cruz, Bolivia. Human Organization Vol. 54, No. 3, p. 273–282