A systematized workflow for assessing land resources using readily available spatial datasets

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Land degradation as well as land conservation maps at a (sub-) national scale are critical for project planning for sustainable land management. It has long been recognized that online accessible and low-cost raster data sets (e.g. Landsat imagery, SRTM-DEM's) provide a readily available basis for land resource assessments for developing countries. However, choice of spatial, temporal and spectral resolution of such data is often limited. Furthermore, while local expert knowledge on land degradation processes is abundant, difficulties are often encountered when linking existing knowledge with modern approaches including GIS and RS.
The aim of this study was to develop an easily applicable, standardized workflow for preliminary spatial assessments of land degradation and conservation, which also allows the integration of existing expert knowledge.
The core of the developed method consists of a workflow for rule-based land resource assessment. In a systematic way, this workflow leads from predefined land degradation and conservation classes to field indicators, to suitable spatial proxy data, and finally to a set of rules for classification of spatial datasets. Pre-conditions are used to narrow the area of interest. Decision tree models are used for integrating the different rules.
It can be concluded that the workflow presented assists experts from different disciplines in collaboration GIS/RS specialists in establishing a preliminary model for assessing land degradation and conservation in a spatially explicit manner. The workflow provides support when linking field indicators and spatial datasets, and when determining field indicators for groundtruthing.

1 INTORDUCTION

Land degradation maps at a sub-national scale have long been recognized as an important basis for land management planning. For efficient planning of sustainable land management (SLM), spatial information on well conserved areas is equally important. While information on land degradation allows focusing efforts, information on well conserved land is crucial to identify the potential of land resources in the area as well as to learn from local examples of successfully implemented land conservation measures (Liniger & Critchley 2007).

Especially in mountainous regions with typically limited accessibility, remotely sensed datasets provide the opportunity to efficiently gain an overview on the state of land resources (Heinimann et al. 2003). It has long been recognized that readily available raster datasets (e.g. Landsat satellite imagery, SRTM DEM's) are potentially useful for preliminary land degradation assessments, especially for developing countries in need of low cost datasets. However, choice of spatial, temporal and spectral resolution of such datasets is often limited. For the assessment of spatially heterogeneous areas, thereto belong also mountainous regions, special challenges must be expected in connection with influences of exposition, shadow etc. Furthermore, while local expert knowledge on land degradation processes is abundant, difficulties are often encountered when linking existing knowledge with modern approaches such as Geographic Information Systems (GIS) and Remote Sensing (RS). Thus tools are needed to facilitate collaboration between land management experts and GIS / RS specialists.

The aim of this study was to develop an easily applicable, standardized workflow for preliminary spatial assessments of land degradation and conservation, which also allows the integration of existing expert knowledge. This tool should support governmental and non-governmental institutions when conducting preliminary assessments of land resources. The operational target was to work in an open-source GIS software environment. A project financed by the World Bank, provided the framework for this study (Wolfgramm et al. 2008).

1.1 *The World Bank project in Tajikistan and its case study areas*

The Bank-financed Community Agriculture and Watershed Management Project (CAWMP) in Tajikistan aims at building productive assets of rural communities in four selected mountain watersheds in order to increase agricultural productivity and household incomes, and to curtail degradation of fragile lands and ecosystems (World Bank 2004). Within this project a spatial basis for project management (site selection, monitoring of activities, impact assessment) was required. However up-to-date data was missing. The study was conducted in the four case study areas of the CAWMP project; the watersheds of the Zerafshan, Surkhob, Vanj, and Toirsu river (Figure 1).

Figure 1 Overview of case study areas; the four watersheds of Zerafhsan, Surkhob, Vanj and Toirsu rivers in Tajikistan (black boundaries).

2 DATA

Readily accessible raster datasets may be defined to be low cost, well accessible (online availability) and to cover large areas at sufficient spatial resolution. An overview on such widely used data applied in this study is provided in Table 1.

Table 1 Overview on readily available raster datasets available for the sub-national / regional scale

Topic	**Dataset**	**Spatial resolution**	**Records**	**Source**
Satellite imagery	Landsat ETM+, orthorectified	30 (15) m	Path/row of images: 152/033, 153/033, 154/033, 153/034	www.landsat.org
Topography	SRTM[1]	90 m		http://seamless.usgs.gov
Climate (temperature and precipitation)	Worldclim	1000 m	Records covering at least 10 years between 1960 and 90.	www.worldclim.org (Hijmans et al. 2005)

[1] Shuttle Radar Topography Mission (SRTM)

Such datasets are normally not fine-tuned to the needs of the specific study. For example, the choice of satellite images from specific recording dates (years and / or specific seasons) is generally restricted. Thus, available datasets will often only proxy the information required.

When selecting satellite imagery for observation of vegetation, the date of recording is very critical. This is especially true in semi-arid areas, where vegetation cover sensitively reacts to precipitation and thus seasonal variability of vegetation cover is high. In Tajikistan, records from the dry season were expected to show the most consistent vegetation cover for various years and were selected to cover the whole project area.

3 METHODS

3.1 *Study approach*

Important requirement for the approach to be developed was its practicability for developing countries. This included the (1) application of readily accessible raster datasets, (2) use of existing classification systems and (3) suitability of the model approach also for highly heterogeneous areas.

Application of readily accessible raster datasets: Due to the quality of the available spatial data layers, ways had to be found to make best use of the available datasets. For enhancing the information derived from satellite imagery, a wide range of indices exists, which allow approximation of plant and soil features (Ustin et al. 2006). Such indices provide the most direct way to derive spatial information. However, sometimes workarounds are necessary to derive the information needed. Such workarounds may include the determination of pre-conditions (e.g. specific slope ranges on agricultural area) for degradation and conservation processes, in order to delimit the area of interest. Focusing on the degradation and conservation classes in order of their relevance (e.g. relevance ranking according to size of area concerned as identified by experts) is also a pragmatic approach for increasing efficiency of the spatial assessment.

Classification systems: Using widely applied classification systems in the field of land use, land degradation and conservation, ensures comparability between different studies. Such classification systems have been developed by the World Overview on Conservation Approaches and Technologies (WOCAT) (Liniger & Critchley 2007).

Classification tree models: In mountainous and highly heterogeneous environments, rule-based classification tree modeling (both expert-knowledge and statistically based models) has been successfully applied in a range of studies (Shrestha et al. 2004, Breu 2007, Wolfgramm et al. 2007). Classification tree models show crucial advantages with regard to efficient modelling. First they are non-parametric models and thus well adapted to heterogeneous environments (Shrestha et al. 2004). Second, such models have the capability to integrate different types of datasets (vector / raster data, continuous / discrete data). Third, tree based models are very efficient when combining hierarchically grouped data. And forth, rule-based systems are closely linkable to field procedures (e.g. to distinguish soil types using hierarchical systems), and thus facilitate inclusion of expert knowledge.

3.2 *Systematized workflow*

The core of the developed method consists of three steps, which have to be conducted for every major land degradation / conservation class previously identified (figure 2). For each class (such as rill erosion on cropland or vegetative measures on grazing land) steps 2-4 are conducted. In a systematic way, these steps lead from field indicators, pre-conditions and relevance identified for each class to spatial information providing proxy data that represents the field indicators and the pre-conditions, and finally to a set of rules for classification of the spatial proxy data.

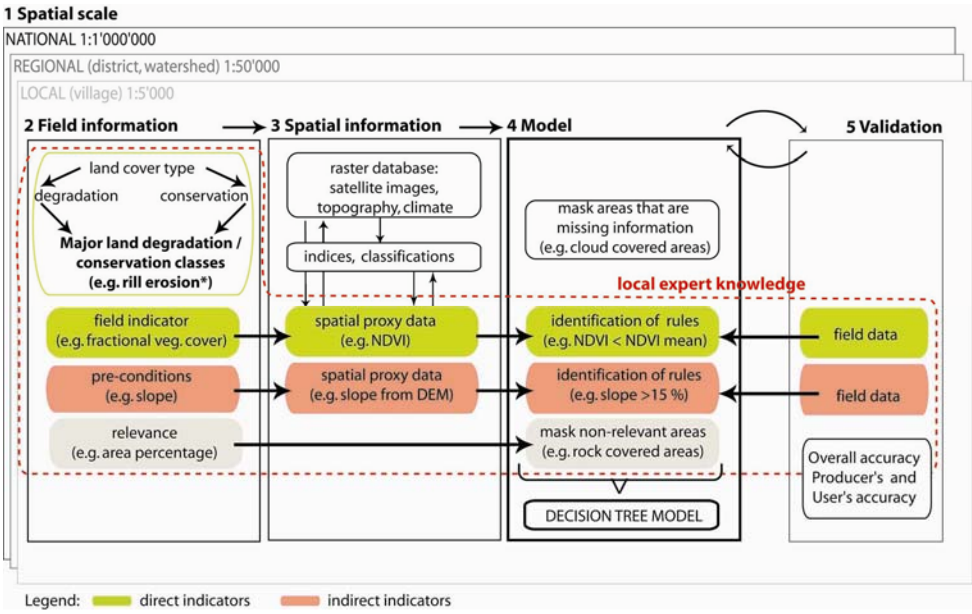

Figure 2 Workflow for preliminary assessment of land degradation and conservation using readily available spatial datasets

In detail, the different steps of the developed workflow are as follows: (1) First the spatial scale at which the project is working is selected. While datasets describing the ecological condition may be included even if their spatial resolution is coarser than the project scale, raster data representing the land cover / land use, should be matching the spatial scale of the planned assessment. (2) Second, land cover types are determined. For these land cover types, degradation or conservation processes are identified. The combination of land cover types and degradation / conservation processes characterizes typical and generalized land degradation and conservation classes for specific local conditions. For each class field indicators, pre-conditions and additionally its relevance (area percentage) are determined. In this way the area affected by land degradation or benefiting from conservation is narrowed down. (3) Third, the spatial information is elaborated. First a database including a range of datasets is established. Datasets are coherently named and projected, and stored in a file-based database. Then, indices and classifications (e.g. land cover classification) are derived suitable to proxy field indicators and ecological pre-conditions. Examples for such spatial proxy data are slope, precipitation, or the widely used normalized difference vegetation index (NDVI) (Rondeaux et al. 1996). (4) In a forth step, a classification tree model is elaborated. Based on rules derived from expert knowledge the different spatial factors are integrated in a hierarchical model.The hierarchical classification tree structure as well as the classification rules are determined based on participatory assessments conducted during workshops. Areas that are missing information (e.g. due to cloud cover) and non-relevant areas (e.g. non-agricultural areas, e.g. covered by rock) are masked. For each spatial layer thresholds and rules for mapping the land degradation and conservation classes are identified. (5) In the fifth and final step the model is validated. For each land degradation and conservation class, validation data is collected in the field allowing the calculation of validation statistics. For the case study here presented, groundtruth will be collected during the dry season, from July to August 2008. Field indicators have to link up with the degradation and conservation classes identified. The output resolution fits the dataset with the highest resolution, which is the pansharpened Landsat Imagery in the study presented here.

3.3 *Software solution: open source software Quantum GIS*

Finally, appropriate technology is crucial with regard to successful implementation of GIS (Ehrensperger et al. 2007). In this project, the open-source GIS software called “Quantum GIS” (www.qgis.org) was used, ensuring open access and providing the possibility to develop tools (e.g. extensions) and share them freely. Quantum GIS is available for all widespread operating systems, and in a large range of different languages. For the Tajik context, the Russian translation was crucial.

4 RESULTS AND DISCUSSION

The workflow developed yields a decision tree integrating various expert-based rules allowing classification of raster datasets, and thus to map land degradation and conservation classes. These rules were developed for the specific context in Tajikistan and are thus only valid for the area concerned. Figure 3 shows an example of a simple decision tree and the corresponding map.

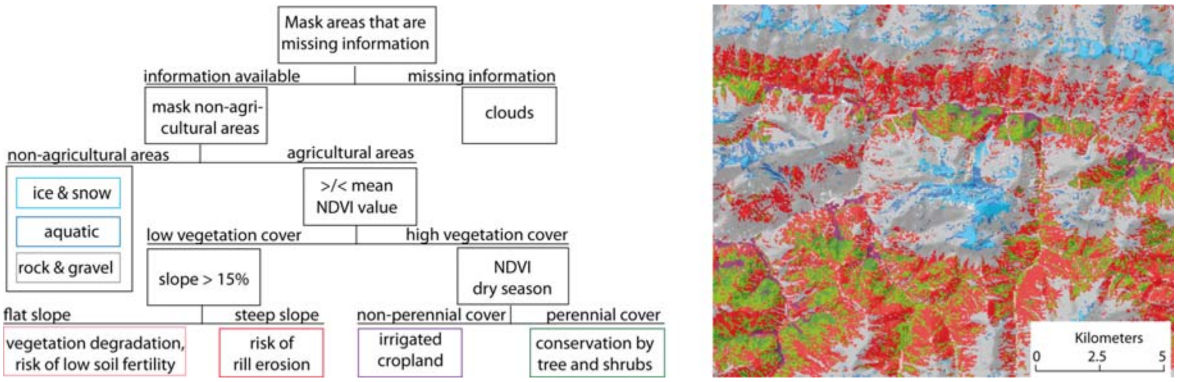

Figure 3 Decision tree showing rules applied for preliminary land degradation and conservation modeling (left) and extract from the preliminary mapping product for Zerafshan watershed.

Mapping of land degradation using combinations of spatial proxy data, especially mapping of areas showing erosion using erosion controlling factors (e.g. topography, climate and vegetation cover), is common practice (Vrieling 2006). When it comes to differentiate land conservation classes, the procedure is not as straight forward, as land management is much more difficult to approximate using spatial data. Often however, vegetation characteristics (e.g. seasonal characteristics, crop types) represent specific land management measures. In the example in figure 3, agricultural areas with high vegetation cover is sub-divided, on the one hand into areas showing perennial cover and thus expected to be covered by trees and shrubs, and, on the other hand, areas showing dense, but non-perennial cover, thus indicating irrigated cropland. While the first is likely to represent well conserved areas, the conservation state of the irrigated cropland is unsure, and would need integration of additional expert-based rules. Besides vegetation characteristics, other possibilities to map conserved areas must be found, such as spatial data showing terraced area (e.g. derived from geo-referenced high-resolution imagery obtained from GoogleEarth or from existing maps). Seasonal vegetation cover is possibly the single most important indicator for the conservation state of areas and thus satellite imagery representing vegetation cover must be chosen very carefully. Generally, it can be expected that the more images included the more stable the results.

5 CONCLUSIONS

It can be concluded that the matrix presented provides a tool which assists experts from different disciplines, to collaborate with GIS / RS experts in order to establish a preliminary model for assessing land degradation and conservation. Specifically, the matrix provides support with regard to the following tasks: Linking field indicators and spatial datasets, identifying additional spatial datasets required for more detailed land degradation assessments as well as to determine indicators when collecting field data during groundtruthing.

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