APPLICATIONS OF REMOTE SENSING DATA FOR DISTRIBUTED HYDROLOGICAL MODELLING OF LARGE SCALE AFFORESTED AREAS IN THE NORTHERN EAST CAPE PROVINCE, SOUTH AFRICA

INTRODUCTION AND OBJECTIVES

Because of its limited distribution, water is one of the most important natural resources in South Africa. The variable nature of a large proportion of South Africa’s water resources means that continuous assessment and monitoring of hydrological systems is necessary. Detailed information on geology, topography, land use, etc. are needed for improved hydrological modelling. Particularly the impact of land use, changes on the basin-wide runoff is of interest to water resource planners and managers. Remotely sensed data provide actual and area covering information for hydrological catchment modelling, especially in large scale areas which are difficult to monitor using conventional techniques. The integration of derivatives from remotely sensed data in Geographical Information Systems (GIS) and their analysis can be the primary tool for operational, efficient acquisition of input parameters for distributed hydrological modeling. The major objective of this research study is the delineation of Hydrological Response Units (HRUs) for a hydrological-based, regional catchment parameterization in the Northern Cape Province, South Africa using an integrated approach of remote sensing techniques and GIS analysis. The study is embedded in an actual research project of the Geoinformatics and Hydrology Department at Friedrich-Schiller-University of Jena. The aim of the research project is to investigate the impacts of large scale afforestation on hydrological dynamics of semi-arid and upland catchments in the NECP as well as their analysis and prognostic modelling. Regarding similar geological and geomorphological conditions, semiarid environments, land use changes, especially forestry development, and the socio-economic problems such as population growth, defects in domestic water supply, etc., the Umzimvubu catchment shows a significant system behaviour and depicts the basin as a representative area for broader parts of the sub-tropical South Africa.

Optical remote sensing data were used in this study for land use classification and Digital Elevation Model (DEM) generation. The remote sensing data base consists of two Landsat TM scenes (1995) of the whole investigation area and two parts of SPOT images (1993-1995) covering the mossi river catchment in the western part of the catchment. Furthermore, extensive data sets, e.g. topographic and thematic maps, hydrological data, forestry parameters, etc. are available.

STUDY AREA

The Umzimvubu catchment is located in the southeastern part of South Africa and covers an area of 18 850 km² (Fig. 1). The study area is mainly determined by Karoo semi-arid syntaxon type vegetation with a sparsely distributed Karoo-Season, often intruded in place by shrub and patches of forest dominated by Combretum and canes and a series of sloping plateaus in common. Steep slopes are developed depending of the mostly sandyparent material and hydrological conditions. Climatically the region lies in a summer rainfall area that is characterised by low rainfall from September to April (700-1000 mm) with a pronounced dry summer season from May to August. Precipitation illustrates a high temporal variability over years. The vegetation is characterised by a grassland type namely fynbos vegetation (Fig. 2), in upper parts of the catchment, whereas the environmental problems induced by landuse management schemes are predominant. Extensive trophy burning and annual burning lead to the degradation of the natural grassland. Large scale afforestation (Fig. 3) since the establishment of forest industries in 1989 shows significant changes in land use. Water reservoirs and major watercourses are responsible for changes in catchment behaviour as well as ecological changes (dry out of wetlands, destruction of natural habitats, etc.).

METHODOLOGY

A. Ground Truth

Objectives of the ground truth area are:

- determination of important geological-geospatial and pedological modelling parameters
- surveying of slope cross sections and sub profiles of different geological parent materials and relief situations
- determination of ground control points (GCPs) for the geocoding of the satellite data
- land use mapping within the defined training areas
- evaluation of different vegetation parameters (LAIs) for cover density determinations of several vegetation types

B. Preprocessing

The preprocessing of the remote sensing data included:

- application of threshold algorithms on the TM data to avoid the regular stripe and appropriate edge enhancements filter techniques for image sharpening
- optical correction of the TM data in ENVI
- transfer of satellite data to a unique geographic system (UTM, Zone 35, WGS 84)
- topographic normalisation of the TM data within the mossi river subcatchment considering the DEM

C. DEM Generation

- development of a Digital Elevation Model for the Mossi river subcatchment from the topographic data
- stereoscopic analysis of the images with the photogrammetric ORTHOMAX software package
- accuracy assessment considering supplement data sets like serial photographs, forestry-base maps, etc.

D. Land Use Classification

The hybrid classification approach for the land use classification considers:

- unsupervised ISODATA clustering to define a training set with areal undulated spectral characteristics
- supervised classification procedure using a Maximum Likelihood Classifier considering the mapped training sites
- complex signature analysis to improve classification accuracy
- postprocessing of the classification result, i.e. reclassification of inaccurate classified and "mixed" pixels

E. GIS Analysis

- initialization of a structured GIS database including geographic unified data layers
- evaluation of a river network, drainage area aspect maps
- GIS analysis for the determination of Hydrological Response Units (HRUs) as homogenous model entities

F. Modelling

- model parameterization as the physically-based, distributed hydrological Precipitation-Runoff-Modelling-System (PRMS)
- model validation and verification

RESULTS

A. DEM-Generation

The rectification of the stereo-SPOT data to UTM Zone 35 (Spheroidal and Date: WGG 84) utilized 19 ground control points (GCPs). A polynomial second order transformation with nearest neighbor resampling was used. The ground control point data set was composed of measured GSP points during the field byrepid taken from 1200 topographical maps. The achieved accuracy is less than the geometric resolution of the SPOT data, that excluded methodological failures.

The second phase included the initialization of the ORTHOMAX system. First the triangulation process was performed, i.e. interior and exterior orientation, bundle block, etc., have been calculated. Following the stereopair, that have been resampled in an apriori orientation, was utilized from the overlapping imagery. Based on the created stereoscanar a DEM of the Mossi river catchment was extracted. Fig. 4 illustrates a subset of the created DEM (a) and derivatives such as elevation map (3b) and 3-D relief view (c). Furthermore products like river network, slope and aspect maps have been calculated from the DEM.

The statistical analysis and the comparison with contour maps has shown that the developed DEM achieves a horizontal accuracy of about 0.9 m and a height accuracy of about 12 m. Several techniques were examined to enhance the DTM. These methods included the analysis of different topographical maps and the integration of aerial photographs (1:m 1:10 ground resolution). At all the moment the available data sets from local stakeholders including height informations of about 10 m accuracies will be integrated for the validation of the DEM.

B. Land use classification

The TM data were associated with 71 ground control points, the geographic system was congruent compared to SPOT data rectification. As a result of the unequipped classification 12 classes were derived. Based on these classes, 80 distribution training areas per class were defined and land use specifically mapped during the ground truth in October 1997. The mapping results were classified using an approach with 11 classes (a subset of the origin and the associated classes in Table 1).

As shown in Fig. 5b several classes such as agricultural areas, barren lands, different water bodies and wetlands are separable with mean accuracies about 86 %. Residential areas and different grasslands have shown a problematic spectral separability, because of the spectral inhomogeneity of these classes. A problem depicted the land use changes since the image acquisition: there are differences in land use between May 1995 (acquisition) and October 1997 (ground truth). For this reason additional areas with uniform characteristics were mapped in the field and considered during the classification process.

Future needs:

- more detailed land use mapping in field campaigns
- improving land use map accuracy using secondary data such as forestry maps
- multitemporal analysis to detect land use changes considering the affectionation utilizing actual satellite data
- GIS analysis and parameterization of the PRMS model using the information derived from remote sensing data

CONCLUSION

Physically-based, distributed hydrological models require anaxial analysis of the water cycle components. Besides topographical, geological and pedological factors the land use is an important input parameter for the modelling of the water supply. The study has shown that remote sensing is a valuable tool for the parameterization of hydrological models.

Optical remote sensing data were used for the determination of parameter inputs for distributed hydrological models. The Umzimvubu river catchment in the Northern Cape Province, South Africa. Hence, preprocessed stereo-SPOT PAN images were approximated to generate a Digital Elevation Model of the Mossi river subcatchment. Mean height accuracies of about 12 m could be achieved. Furthermore, Landsat TM data were used for an areal determination of land use in the Umzimvubu catchment. After the data preprocessing a hybrid approach was applied. First an unsupervised classification was chosen for estimation of spectral characteristics within the 12 landuse classes. The supervised classification was utilized a Maximum-Likelihood classifier and enabled to generate a land use map with 14 classes in total. Finally the classification result was postprocessed utilizing several filter algorithms.

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Figure 1: Subset of TM image (390X390, Channels 4, 3, 2) and associated classification data from the same subset

Figure 2: Location of the Umzimvubu catchment and focus areas

Figure 3: Nutkoi (predicted site type) and 3D model of the Awareness in the same area

Figure 4: Subset of the extracted DEM (a) and derived elevation map (3b) and 3-D relief view (c)

Figure 5: Land use classification

(a) b) c)