Deutscher Tropentag 1999 in Berlin
Session: Research and Management of Ecosystems and Natural Resources incl. Forests

Applications of Remote Sensing Data for Distributed Hydrological Modelling of Large Scale Afforested Areas in the Northern East Cape Province, South Africa

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Abstract
Remote sensing data offer an urge potential for the delineation of spatial information on the state of a large variety of hydrological parameters needed for distributed, physically-based modelling. Parameters such as topography, geology, soils, precipitation, land use, etc. are necessary for analysing and modelling the hydrological system behaviour of complex-structured, heterogeneous catchments. In this study optical remote sensing data were used in order to provide such parameters on different scales. Landsat TM data were utilized for a detailed land use map of the Umzimvubu catchment, South Africa. Furthermore a Digital Elevation Model (DEM) of the Mooi subcatchment was developed, using stereoscopic SPOT Pan data.

Keywords: *remote sensing, hydrological modelling, parameterization, land use, DEM*

Introduction

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 causes that continuous assessment and monitoring of hydrological system components is necessary. Detailed informations on geology, topography, land use, etc. are needed for improved hydrological modelling. Particularly the impact of land use changes on the basinwide runoff is of interest to water resources planners, managers, and local authorities.

The presented study is embedded in an actual research project of the Geoinformatics and Hydrology Department at the Friedrich-Schiller-University Jena. The aim of the research project is to investigate the impacts of large scale afforestation on hydrological dynamics of semi-arid upland catchments in the North East Cape Province (NECP) as well as their analysis and prognostic modelling. Regarding similar geological and geomorphological conditions, semi-arid environments, land use changes, especially forestry development, and the socio-economic problems, such as population growth, deficits 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 (FORSYTH et al., 1997).

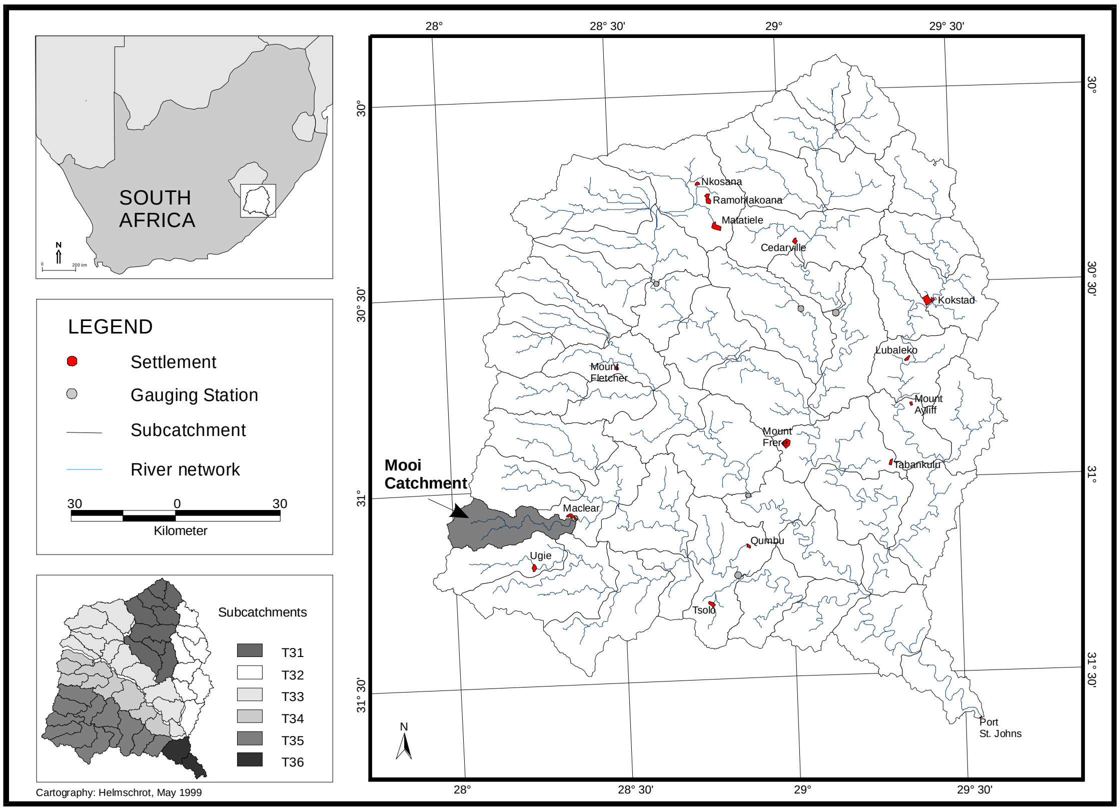
Many studies have demonstrated that remotely sensed data provide both actual and areal information for hydrological catchment modelling, especially in large scale areas which are difficult to monitor when using conventional techniques (KLENKE, 1999, MAUSER et al., 1998). The integration of derivates from remotely sensed data into Geographical Information Systems (GIS) and their analysis can be seen as the primary tool for operational, efficient acquisition of input parameters for distributed hydrological modelling (MEIJERINK et al., 1994).

This paper focuses on providing data for the later delineation of Hydrological Response Units (HRUs) using an integrated approach of field studies, remote sensing techniques, and GIS analyses for a regional catchment parameterization in the NECP. In this context, HRUs can be understood as distributed modelling entities that are used to preserve the spatial, three-dimensional heterogeneity within regional hydrological models (FLÜGEL, 1996).

Study Area

The Umzimvubu catchment is located in the southeastern part of South Africa and covers an area of 19845 km² (Fig. 1). The study area is mainly determinated by triassic sedimentary strata belonging to the Karoo Sequence, often intruded in place by sills and dykes of Jurassic dolerite. Consequently the manifold geological base, a scarpland with wide valleys, numerous canóns and a series of sloping plateaus is common. Severe soils are developed depending on the muddy or sandy parent material and hydrological conditions. Regarding the climate the region lies in a summer rainfall area that is characterised by rainfalls from September to April (750-1500 mm/year). However, temperature and precipitation have a high temporal variability over years. The vegetation is characterised by a grassveld type namely Highland Sourveld in the upper parts and Dohne Sourveld in the lower parts. In the mouth area a typical coastal forest is dominant (ACOCKS, 1988).

Figure 1. Location of the Umzimvubu catchment and basin characteristics



Severe environmental problems which have been induced by lacking landuse management schemes over years are predominant in this area. Extensive stock farming and annual burning led to the degradation of the natural grassveld and to areal soil losses caused by erosion processes. Since the establishment of forest industries in 1989 large scale afforestations have resulted in significant changes in land use. The effects induced by large plantations will be influencing a variety of both changes in the hydrological system behaviour (runoff reduction, interception losses, etc.) and ecological changes (dry out of wetlands, destruction of natural habitats, etc.). Up to now, a quantified description of these phenomena is not available (FORSYTH et al., 1997).

Data Sets

Remote Sensing Data
Two Landsat TM images acquired in May and June 1995 were utilized for a basinwide land use classification. For the development of the DEM, four scenes of panchromatic SPOT scenes from 1992 and 1995 with a spatial resolution of 10 m grid size were available. The stereoscopic area of both data sets is covering about 85% of the Mooi subcatchment in the western part of the Umzimvubu basin.

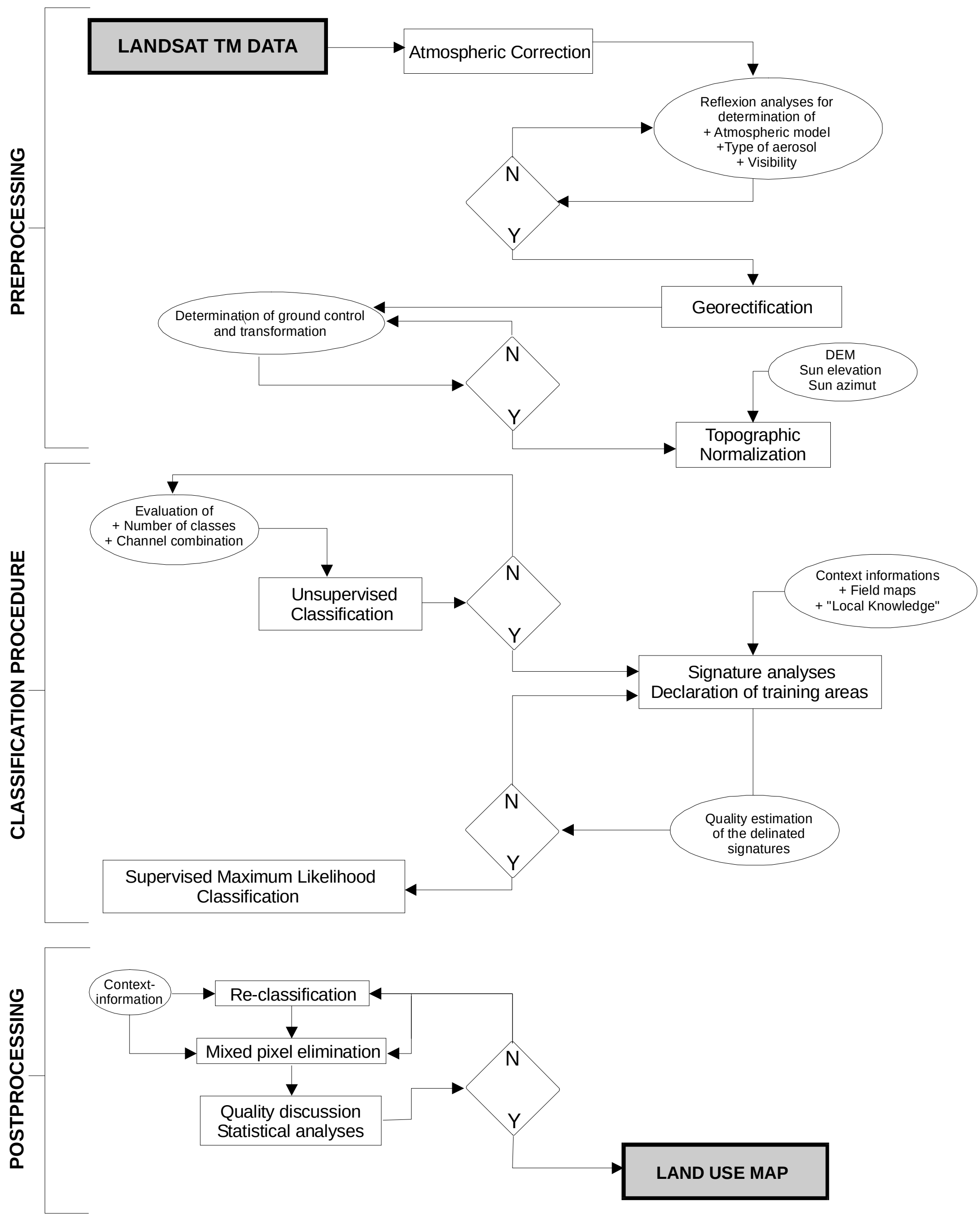
Reference Data
Land use information for greater parts of the Umzimvubu catchment exists from several field mapping campaigns. Additionally, different plant physiological parameters such as, leaf area index, cover density, etc. for pine forest stands could be provided by former studies (HELMSCHROT, 1999). In addition to that, severe supplement data such as topographical and geological maps at different scales, detailed soil maps of the afforested areas and hydro-meteorological data were available. A Digital Elevation Model with 200 m grid size exists for the whole catchment. All used data were integrated in a project GIS data base.

Data Processing and Image Analyses

Preprocessing of Landsat TM data
The preprocessing included the application of a destriping algorithm on the raw TM data to avoid the regular striping and appropriate edge enhancements filter techniques for image sharpening. Afterwards the TM data were atmospherically corrected by using ATCOR 2.1 implemented in ERDAS Imagine 8.3, which resulted in an improvement of the data quality. The following rectification to a unique geodetic system (UTM, Zone 35, Speroid: WGS 84) was done by 98 ground control points using a polynomial second order transformation with nearest neighbor resampling. The ground control points were measured by GPS during the field campaign in October 1997 resp. taken from 1:50000 topographical maps. Mean RMS errors, which ranged from 9 m to 21 m, were achieved, i.e. less then one pixel resolution.

Land Use Classification
A hybrid classification approach was chosen for the land use classification. The approach considered an unsupervised ISODATA clustering to get an overview of the spectral contents of the images. According to the standard South African land use classification scheme (THOMPSON, 1996), 11 classes represented by a set of 394 training areas with unimodal spectral characteristics were defined in the supervised classification procedure. These training areas were specifically mapped and validated during the ground truth in October 1997. Based on a complex signature analysis the classification was performed by using a Maximum-Likelihood-Classifier. Finally a postprocessing of the classification result was done by reclassifying inaccurately classified or „mixed“ pixels utilizing several filter algorithms to improve classification accuracy. A flowchart of the land use classification is shown in Fig. 2.

Figure 2. Flow chart depicting the procedures followed in the land use classification



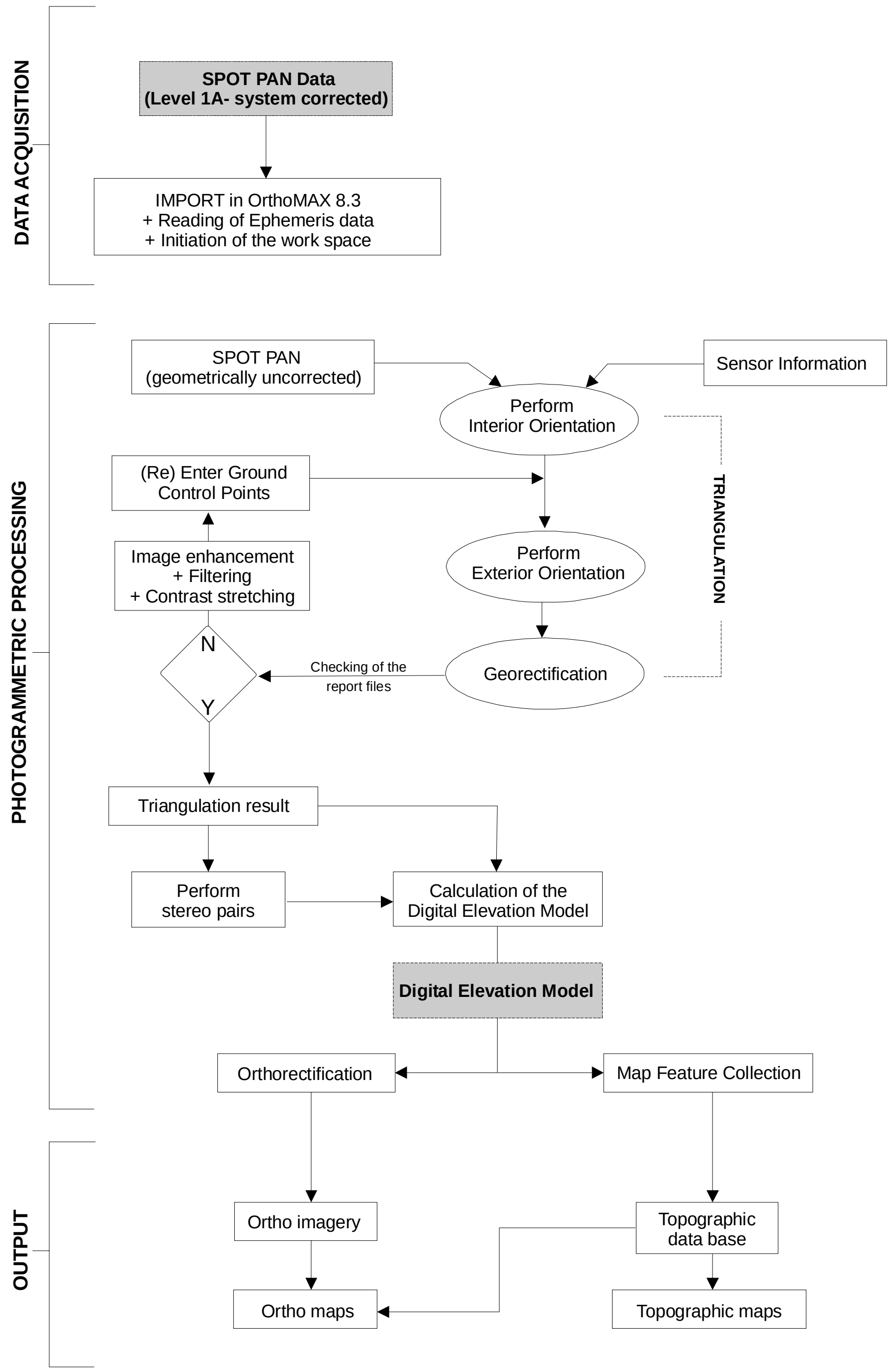
DTM Generation

The official DEM of South Africa has a grid size of 200 m, which is not sufficient for distributed hydrological modelling on regional scale. Hence, a DEM for the Mooi river subcatchment was developed from panchromatic SPOT data (10m x 10m ground resolution). The stereoscopic analysis of the images has been done with the photogrammetric ORTHOMAX 8.3 software package. The rectification of the stereo SPOT data to UTM Zone 35 (Spheroid and Date: WGS 84) utilized 19 ground control points for both stereopairs.

The second phase included the initialization of the ORTHOMAX software. First the triangulation process was performed, i.e. interior and exterior orientation, ground positioning, etc. have been calculated. Following the stereopairs, that have been resampled in an epipolar orientation, were computed from the overlapping imagery. Based on the created stereopairs two DEMs of the Mooi river catchment could be calculated. Afterwards the extracted DEMs were mosaicked with the coarse 200 m DEM data to gain a DEM covering the whole Mooi catchment.

Finally an accuracy assessment of the DEM was done by integrating supplement data sets like aerial photographs, forestry base maps, etc. using several processing algorithmns concluding fill and sink operations, filter techniques, etc. of the ARC/INFO GIS environment. A flowchart of the photogrammetric processing is shown in Fig. 3.

Figure 3. Flow chart depicting the procedures followed in the DEM extraction



GIS Data Management and Analyses

A structured GIS data base was established for the project in order to manage and to analyse the different data sets by diverse GIS algorithms. All data were stored as geographic unified data layers referencing to UTM, Zone 35 (Spheroid and Datum: WGS 84). The analyses considered the delineation of topographic features like river network, slope and aspect maps as well as producing forest and wetland maps.

Results

Land Use Classification

Until recently only sketchy data on land use in the Umzimvubu catchment have been available. For that reason Landsat TM data were utilized for delineation of land use information using a hybrid classification procedure. As the result of the classification a land use map with 11 classes was derived. In general, the land use map represents both the spatial distribution of the land use units in this area and the areal quantification (see Tab. 1).

Table 1. Land use in the Umzimvubu catchment (data base: Landsat TM 29.05.1995)

Land use	Area [km²]	Area [%]
No data	1530.216	7.72
Bare rock	687.099	3.46
Bare soil	2435.641	12.27
Agriculture	1635.317	8.24
Grassland 1	4154.788	20.94
Grassland 2	3953.386	19.92
Grassland 3	1978.992	9.97
Forest plantations	940.739	4.74
Deciduous woodlands	2087.577	10.52
Wetlands	422.792	2.13
Open water	18.303	0.09
	19844.85	**100**

As shown in Table 1 about 50 % of the catchment is dominated by different types of grassland. These were distinguished to 3 stages of degradation (1 = no degradation, 2 = small, 3 = high). The soil class (12 %) is characterized by completely eroded grassland and areas prepared for afforestation respectively. Actual only about 5 % of the basin is covered by forest plantations. Deciduous woodland (11 %) is mainly concentrated in the mouth area. The major part of the cultivated areas (8 %) is characterized by maize, greenfeeding and meadow.

Basically the land uses that could be classified with consistently high accuracies (< 90 %) were water bodies, barren lands and agricultural areas. The latter have been classified more detailed, but there are differences in cultivating between image acquisition date (May 1995) and ground truth (October 1997). Unfortunately the information have been only partially supported by the local farmers. Furthermore accuracies of vegetated areas like grasslands and forests, although slightly lower (81-86 %) than the overall mean accuracy of 86 %, confirm the quality of the land use classification. According to the significant spectral responses it was possible to seperate natural deciduous woodlands and forest plantations quite accurate.

Some problems occured in the wetland areas (80%) and the shaded areas (71 %), because of the spectral inhomogeneity of these classes. For example, a variety of different species of bushes, grass, reeds and additional soil information cause a problematic spectral response within the wetlands. Shaded areas show a high spectral variability. Mainly these areas are spectrally influenced by indigenous forests in the deep valleys.

Extraction of High Resoultion Digital Elevation Data

As the result of the photogrammetric processing, a high resolution DEM was extracted from stereoscopic SPOT Pan data digitally. The analysis and the comparison with reference points, taken from both topographical maps and from GPS measurements, have shown that the developed DEM achieves a horizontal accuracy of about 9 m and a height accuracy of about 13 m. Furthermore for evaluation, all relief contours from topographic maps were compared to the contours automatically computed. The comparison showed a significant correspondence (r = 0.92) between both.

Several techniques were examined to enhance the extracted DEM. These methods included the analysis of more detailed topographical maps and the interpretation of aerial photographs (1m x 1m ground resolution) which were provided by the forest industries. Actually the available elevation data sets from local steakholders including height information of about 1m accuracies were processed and will be integrated for the validation of the DEM.

Furthermore derivates like river network, slope and aspect maps have been calculated from the created DEM using GIS technology. All provided terrain data have been integrated in the data base.

Conclusion and Future Needs

Physically-based, distributed hydrological models require an areal analysis of the water cycle components for parameterization. Besides topographical, geological and pedological factors the land use is an important input parameter for the modelling of the watershed hydrology.

In this study optical remote sensing data were successfully used for the delineation of parameters for distributed hydrological watershed modelling of the Umzimvubu river catchment in the Northern East Cape Province, South Africa. Hence, multispectral Landsat TM data were processed for an areal determination of land use within the catchment. After the data preprocessing a hybrid approach combining unsupervised ISODATA clustering and supervised Maximum Likelihood classification was applied. After several postprocessing techniques which improved the classification accuracy up to 85,93 %, a basinwide land use map considering 11 classes was provided. Furthermore preprocessed stereoscopic SPOT PAN images were appraised to generate a high resolution DEM of the Mooi river subcatchment. The good results have shown that multisensoral data are valuable for delineating of input variables for hydrological models.

Further studies have to concentrate on a more detailed land use mapping in the afforested areas by extracting different stages of forest stands. Thus, more flexible classification techniques like neural networks or texture analyses could be integrated. For multitemporal analyses an operational classification scheme has to be developed. The approach will be used to detect and quantify land use changes considering the afforestation using several satellite data sets. Finally the land use information will be integrated in a GIS-environment and utilized for the parameterization of the Precipitation Runoff Modeling System (PRMS) before modelling.

Acknowledgements

I would like to thank the VW-Foundation and the KFA Jülich for financing remote sensing data, field equipment, and travel expenses. Acknowledgements are also given to Prof. R. Schulze and Dr. S. Lorentz from the University of Natal as well as P. Gardiner from Mondi Forests Ltd. for logistical support and assistance in the field.

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