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Abstract - Water resources management in Southern Africa is a complex challenge which requires an appropriate integrated approach if strategic and prognostic planning should be based on sound scientific findings in order to optimize and conserve the precious land and water resources. The prototype Integrated Water Resources Management System (IWRMS) will be a toolset of validated computer based procedures, where remote sensing is the major methodology to provide areal data sources to hydrological models assisting water resources managers through their decision strategies.

I. INTRODUCTION

With its objective to develop an Integrated Water Resources Management System (IWRMS), the project is addressing contentious challenges for water resources management in Southern Africa. The present water management situation in Southern Africa can be characterised by using the findings of an "International Misson on Environmental Policy from South Africa" (Whyte, 1995, p. xxiii): *"Water is scarse in South Africa, and water resources are seen as a key limiting factor to future development. Key policy issues for the environment are reallocation of water among producing sectors; the management of rising demands for water, especially with respect to the rate of abstraction from natural systems; the need to provide domestic water to millions of poor households; and problems of water quality and pollution control in both rural and urban areas."*. From this viewpoint, sustainable water resources management is of paramount economic and political importance for semiarid Southern African countries. The climate in this region is characterised by precipitation patterns unfavourably distributed in space and time and high evapotranspiration rates reaching up to 90 % of the incoming annual precipitation. As a result, water resources management is forced to balance the water supply between areas and times of water deficiency and those having a managable water surplus.

The prototype IWRMS will be developed and validated for selected meso-scale and semi-arid catchments in three Southern African countries. The remote sensing evaluations serve as input data into the hydrological models and concentrate on water balance and water quality. It include the following topics:

- Derivation of Land Surface Temperature and Leaf Area Index for the determination of evapotranspiration,
- Detailed mesoscale land cover classifications of catchments up to 15 000 sqkm with optical and microwave datasets,
- Derivation of high resolution Digital Terrain Models from stereo satellite imagery,
- Detection of rural settlements to assess their contribution to the water quality,
- Identification of gully erosion features comparing historical and recent aerial photography as well as satellite images.

II. STUDY AREA

The Southern African region has a semi-arid climate with highly variable rainfall resulting in competing water demands from different stakeholders. Severe erosion visible as large gully systems caused mainly by overgrazing is induced through intensive precipitation. The three test catchments were selected due to different scale and water usage conflicts and include the Mkomazi River in Kwazulu-Natal (South Africa), the Mbuluzi River in Swaziland and the Mupfure in Zimbabwe (Fig. 1).

The Mkomazi catchment area comprises 4390 km², the mean annual precipitation is 500 - 1500 mm. The conflict is caused by extensive water demand for irrigation purposes and from large scale afforestations with demanding alien species like eucalypt as well as a population explosion, which makes the rural water supply difficult in terms of water availability, water allocation and water quality.

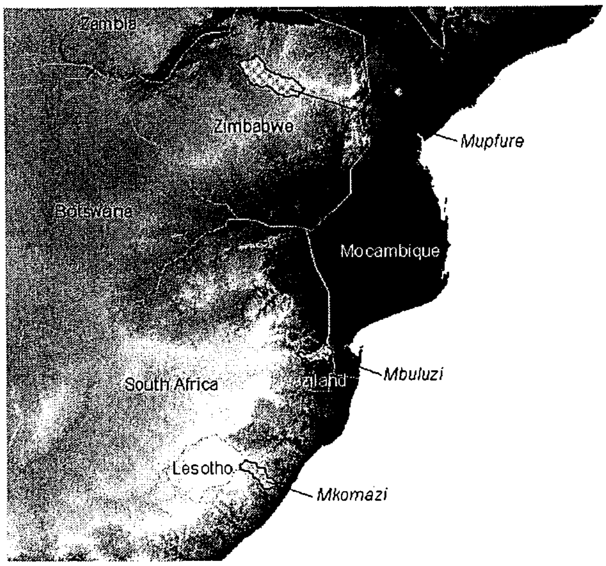

Fig. 1: Location of test catchments in Southern Africa.

The Mbuluzi catchment (3100 km², 800 - 1200 mm) has extensive irrigated sugar cane plantations and is suffering from severe land degradation. The Mupfure catchment (11866 km², 750 mm) is much larger with a lower precipitation variability. Here, water balance problems occur due to irrigation, water quality is affected by non point source pollution from agriculture.

III. REMOTE SENSING APPLICATIONS

Integrated Water Resources Management has to consider natural impacts (precipitation, extreme events or climate change, etc.) as well as socioeconomical interests to plan the resources and the demand properly. This requires a distributed hydrological modelling for decision making. The models outputs are so called what-if-scenarios or spatial surplus-deficit balances and are the better, the better the input is. Here remote sensing will play a major role in future since the number of hydrologically relevant parameters derived is manifold and ranges from precipitation estimates, evapotranspiration over land use and Digital Terrain Models (DTMs) to soil moisture and vegetation parameters, although some of them are indirect products (Engman and Gurney 1991, Rango and Ritchie 1996). Especially in remote areas like most parts of rural Africa with lack of field measurements of components of the hydrological cycle, remote sensing data is the only way to provide areal input. Major drawback of all these high resolution satellite systems in the hydrological sense is the limited time resolution (Mauser et al. 1997). Therefore the determination of the hydrological components by conneting field measurements with earth observation methods is one of the major goals of the remote sensing data evaluation for IWRMS. It consists of the following steps:

A. Derivation *of LST and LAI for the determination of evapotranspiration*

Evapotranspiration is an important model input, which is required spatially and not only from uneffective and expensive point measurements. Remote sensing data (NOAA, Vegetation) provide parameters to derive the evapotranspiration like surface temperature. There are different ways to compute the evapotranspiration (Haude, Penman) or methods based on the gradient between land surface temperature and air temperature.

For the test areas in Southern Africa areal distributions of the land surface temperature have been derived from NOAA data on a daily, weekly (Fig. 2) and monthly basis according to the required model input. Landsat channel 6 temperatures have been used for calibration.

B. *Land Cover Classifications*

The optical land cover classifications (based on recent Landsat TM scenes from 1996 to 1998 together with panchromatic SPOT data for improvement of the spatial resolution) followed the standard land cover classification scheme for remote sensing applications in South Africa (Thompson 1996) with three hierarchical levels (a fourth level could be enclosed by aerial photo interpretation and field mapping). This scheme has been improved in hydrological terms i.e. to distinguish between planted alien and indigenous forests, to distiguish settlements according to their imperviousness instead of classes of income or to assess agricultural areas according to their site preparation and their above surface layers (litter, mulch, etc., Schulze & Hohls 1993). A common legend has been developed for all testsites in Level I and II. In Level III each testsite has a unique differentiation of the Level II classes. Depending on the degree of detail required by the models, land cover information is available in all levels.

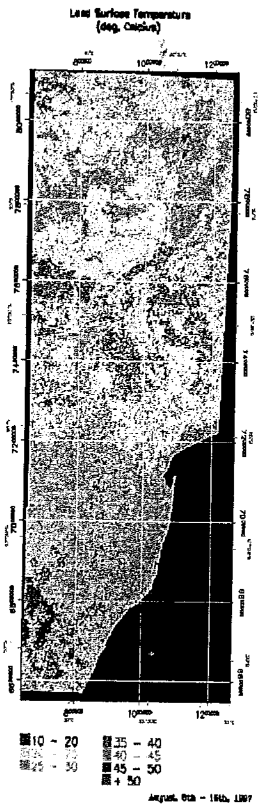

Fig. 2: Land surface temperature on a weekly basis.

C. *Detection of rural settlements*

The anthropogenic impact in water resources management are of tremendous importance. It is therefore necessary to provide information of the location of the population since it has strong influence on availability, pollution, demand and even allocation of water in the catchments. Census data is of course the common source for that information, but can be realized only once a decade or so. Remote sensing seems to be an adequate media because conflicts or resettlements took place often and bring the census data out of date.

The Southern African rural settlements are usually built on bare soil most time having at least one building with a metal roof. Such settlements can be very small and are often not visible on optical remote senisng data due to the surrounding ground. With the use of SAR data it is possible to detect objects even smaller then the spatial resolution (Mangolini et al . 1993). Strong relief in the catchments made an orthorectification of the multitemporal SAR data necessary. The extraction of points with high backscatter coefficient was made with multiresolution analysis using wavelet transforms (Ranchin 1999). The restrictions are that only settlements with metal roof will be detected and that the SAR technology is a side looking system with foreshortening and shadow areas were settlements won't be detected.

D. *Identification of gully erosion*

The study includes the identification of the sediment source areas to obtain input data for soil erosion modelling which is crucial for water quality assessment. For this purpose basic information on sediment production, transport and deposition were needed.

Therefore several aerial photography sets from 1977, 1984 and 1996 were evaluated using a photogrammetric planicomp stereoplotter. The resulting high resolution DEMs had a spatial resolution of 1 m. A first modelling approach was done by the interpolation between the different stages combined with GIS sediment loss and gully volume analysis carried out by subtracting the derived gully shapes from the initial surface.

IV. HYDROLOGICAL MODELLING AND DECISION SUPPORT

Integrated water resources management is based on physiographical data of the catchment (obtainable through remote sensing), socio-economic conditions (also partly available by earth observation techniques), hydrological knowlegde (implemented in hydrological models and rule-based expert systems, defining the constraints for the models) and "What-If" scenarios (analysed by hydrological models) (Lam 1997). This enables a decision process with knowledge of spatial catchment data.

The water resources of a hydrological system can be managed by considering the three components i) water availability and quality, ii) water demand and iii) water allocation policies (McKinney et al. 1997). For the improvement of current management practices, many aspects of these components have to be optimized, but always based on actual data, obtained from space. Furthermore, a system is needed, which is able to store the data, manage the knowledge as a rule-base, provide hydrological models and feed them with data and display meaningful information generated by the entire system.

processes at a detailed level, a sound physically based hydrological model is necessary (Fluegel 1996). Such complex models require many physiographical up-to-date data, such as soil properties, landuse, vegetation cover and topography, normally hardly available, particularly in developing countries. The only way therefore is to use routine job data delivered from satellites.

A system supporting decision makers in making better decisions combining models that simulate hydrological response, models assessing water demand, expert knowlegde and water policies must be build around a sound database developed with the help of remote sensing, more than ever, when we face insufficient databases in general and uneven data coverage in the three test areas of this study in particular. This has to be resolved as soon as possible by gaining new data through modern techniques.

ACKNOWLEDGEMENTS

The study has been carried out with financial support from the Commission of the European Communities, INCO-DC, contract no. IC18-CT97-0144, "The development of an innovative computer based 'Integrated Water Resources Management System (IWRMS)' in semiarid catchments for water resources analysis and prognostic scenarion planning". It does not necessarily reflect its views and in no way anticipates the commissions future policy in this area.

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