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Development of an Integrated Water Resources Management System in Southern African Catchments

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Abstract. Water resources management is a contentious challenge in Southern Africa. Scarce resources, often poor quality, unfavourable temporal and spatial distribution and competing stakeholders characterise the water resources in this region. The following general objectives and techniques are investigated: (a) Development of dynamic water balance and erosion models for three study catchments using remotely sensed and other data, (b) assessment of water demand and usage of the different user sectors and stakeholders, (c) design and simulation of "What if ?" scenarios to investigate trends and interactions of the complex water resources planning process, and (d) development and implementation of strategies to solve water allocation conflicts. The product of the project, the prototype IWRMS, is an innovative computer based toolset designed as an assembly of tested, validated and well documented procedures comprising techniques of database management, remote sensing, GIS, process modelling, decision support and implementation strategies. The modelling results and first prototype installations in Southern Africa show the applicability of this system.

1 Introduction

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 optimise and conserve the precious land and water resources. Sustainable water resources management is of paramount economic and political importance for semi-arid Southern African countries. The climate in this region is characterised by precipitation patterns unfavourably distributed in space and time (Fig. 1) 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 manageable water surplus. The proposed Integrated Water Resources Management System (IWRMS) will be a toolset of validated computer based procedures, integrated into a database-centred, spatial decision support system. Its concepts and components are shown in Fig. 2.

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1.1 Study areas

Three test catchments, reflecting typical water resources conflicts and being under enormous pressure for an improved management strategy, were selected and comprise the Mkomazi River in Kwazulu-Natal (A = 4400 km²) in South Africa, the Mbuluzi River (A = 3000 km²) in Swaziland and the Mupfure (A = 12000 km²) in Zimbabwe (Fig. 1). A still strong diversity between communal (tribal, small scale farming, poor) and commercial (plantations, large scale farming and foresting, prosperous) land is significant for test areas like it is for most of the whole subcontinent. All three countries involved face the challenge of implementing a new water law, which is characterised by emphasising principles of Integrated Water Resources Management, mainly to improve equity in access to water resources for all people, and to strengthen the environmental demands.

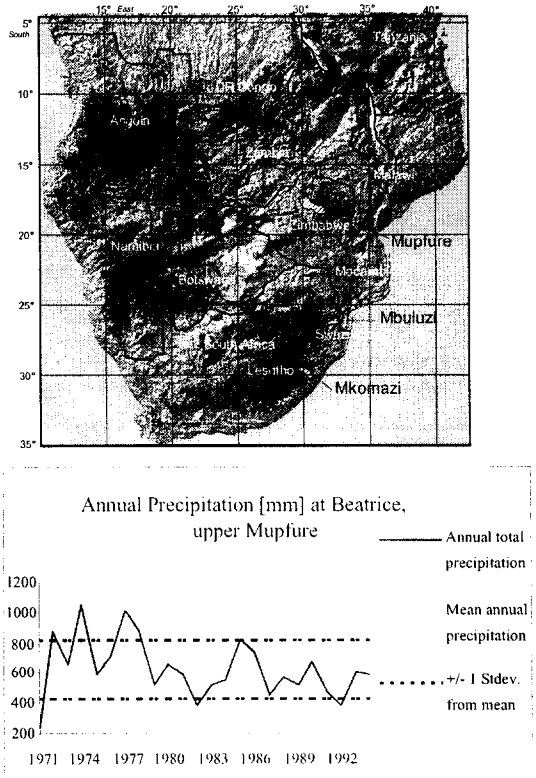

Fig. 1: Locations and typical precipitation pattern of the study areas in Southern Africa.

2 Methods

2.1 Data acquisition and management

Gaining and managing information must be the initial step in the development of a data-centred computer based water resources management system. Therefore the first project stage was mainly characterized by developing a well-structured data management. The other component were remote sensing activities (Table 1) comprising (i) standard methods and the verification of their applicability in the target region, as well as (ii) the investigation of new methods for hydrologically relevant data acquisition and (iii) the generation of hydrological model input and validation data by applying these techniques. A general feature is the fusion of differently scaled data with different temporal, spatial and spectral resolution for the upscaling from the hillslope scale to the catchment scale. The results of the remote sensing components of this project have been published extensively (e.g. Hochschild et al. 2000, Lahoche et al. 1999) and hence will not be discussed here.

Besides the activities to obtain data in order to feed the catchment models for water availability simulation, information on demand and use of the resource is as important. One component is the compilation of available sectoral water demand information, either published or managed by the catchment authorities. This refers mainly to commercial water uses (industrial, commercial agriculture). The other component is gathering information on rural primary water demand. Extensive surveys by questionnaires of the social use of water have been carried out in communities of each test catchment. The derivation of a generic rural water demand structure from this data was the main purpose of it, as the amount of rural primary water demand is negligible if compared to commercial uses such as irrigation.

2.2 Systems analysis, modelling and integration

The middle phase of the project was dominated by using the acquired information to create detailed conceptual, spatially distributed catchment models using the ACRU system (Schulze 1995), a daily model simulating the vertical and lateral water fluxes on and between spatial units derived by subdividing a catchment. It allows the simulation of different present and future scenarios for prognostic water resources planning. After the successful validation of the models (by comparing the simulated results of the present state scenario against measured variables), scenarios (Table 2) have been developed by implementing water management issues of concern and information needs in order to simulate the impacts of future system changes on the water resources and sediment balance of the test sites. In order to combine the results of both the hydrological models and the water demand analysis, GIS applications are developed. The objectives are to balance supply and demand under various runoff and demand scenarios and to analyse new allocation principles based either on conventional overlay or on network analysis using the river network, abstraction data (water permits) and the outcome of the simulated hydrological scenarios. Results of this component have been published in Flügel and Staudenrausch (1999).

Erosion and the related sediment transport in the rivers is a special concern for water resources management, as it influences water quality and affects the life time of water reservoirs. In conventional erosion modelling (as it is part of ACRU), linear features like gullies are neglected, despite their considerable contribution to the overall sediment yield in the region studied. The combined investigation of different sediment sources is the major objective of the erosion modelling component of this study. The topographical analysis of the hillslope DEMs were used to parameterise detailed gully evolution models (Sidorchuk 1998). On the other side, the catchment wide topographic and land use data was used together with soils information to estimate sheet erosion induced sediment balances. The results from the gully models were regionalised to the catchment scale using the erosion reference units mapped from air photos and a process-based approach referred to as ERU (Erosion Response Units). Combining the two components lead to an enhanced erosion model, described in Flügel et al. (1999).

Table 1: Remotely sensed data used

Main IWRMS activities and data products	Data source	No. of datasets	Spatial resolution	Return period	Spectral resolution
Hillslope DEMs, erosion feature map, validation for other objects	Aerial photography	several hundreds	~ 1m	several years	1 band b/w (panchromatic)
Catchment DEMs, land use	Spot Pan	4	~ 10 m	30 days	1 band (pan.)
Land use map	Landsat 5 TM	6	~ 30 m	~5-16 days	7 bands (blue – IR)
Settlement map land use,	ERS 1/2 SAR	10	~ 30 m	35 days	microwave
Meteor./vegetation time series	AVHRR	~ 700	~ 1 km	Once a day	5 bands (blue – IR)

Table 2: Catchment scenarios developed and simulated with ACRU in IWRMS

Scenario description and purpose
Present catchment state: For model validation and comparison against other scenarios
"Baseline conditions": potential natural vegetation ("veld types") used
Climate change: Implementation of results of an atmospheric Global Circulation Model with double CO_2 concentration (Murphy and Mitchell 1995)
Reservoir building: Integration of projected dam for water transfer out of catchment
Total degradation: All WRRUs with veld in bad condition
Total rehabilitation: All WRRUs with veld in good condition