Application
EOS-Terra, Landsat TM

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Portraying and modelling the Okavango delta, Botswana

Detailed description of the subject

The Okavango wetland in Botswana is one of Africa's and the world's most pristine inland delta areas. The delta is fed by the Okavango River and its tributaries Cubango and Cuito in Angola that passes through Namibia and spreads out as an alluvial fan (delta) over the Kalahari sand until only a small stream remains (Fig 1). Namibia, one of the driest countries in southern Africa, wants to extract water for its capital Windhoek from the Okavango river, Angola have plans for hydropower production. For Botswana the wetland is a refuge for agriculture and tourism development.

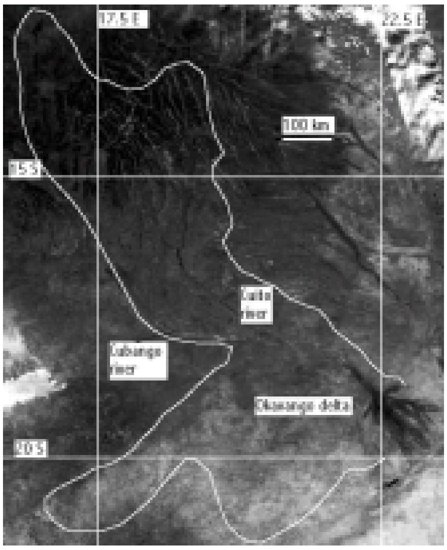

Figure 1: Catchment of the Okavango delta (NOAA-AVHRR visible band)

The annual 500 mm precipitaion over the delta falls during the summer from November to March. The main water input to the delta, however, is from the Okavango river - peak flow reaches the delta in April and takes 4 months to traverse. Water inflow varies strongly not only seasonaly; early travellers and studies in the delta reveal that flow in the past must have been both much larger and much smaller than at present (e.g. McCarthy et al., 2000).

The overall aim of the proposed reaseach project is to create a spatially and temporally distributed dataset and to use this dataset for establishing a hydrological model of the Okavango system that can be used for predicting hydrological and ecological effects of natural and anthropogenic changes in e.g. climate, land use and cover, water extraction and damming. The suggested study emphasises the use of geographic information technology, especially satellite borne earth observing measurements, for portraying and modelling patterns and processes on the Earth's surface.

Scientific and technological background

<u>2.1. Mapping catchment land cover / use and change</u>
Due to inaccesibility, poorly developed data sets and lack of models, the catchment characteristics and their relation to precipiation and the water flow in the Okavango river are poorly known. The proposed study includes the creation of a catchment wide database from various data sources: the digitial chart of the world, GTOPO30 (30 arc seconds resolution elevation data), NOAA-AVHRR satellite images of 1 km resolution, and NOAA-AVHRR derived timeseries of Normalised Difference Vegetation Index (NDVI) images at 7.6 km resolution. As the study area partly falls within the SAFARI 2000 (see below) – data from the recently launched Terra satellite (MODIS and MISR instruments, if possible also the airborne simulators of those instruments – MAS and MASTER) will be used for estimating

the accuracy of the dataset.. From the data seasonal maps of vegetation cover for improved estimates of evapotransipration over the last 20 years will be created.

<u>2.2. Mapping the flood wave and inundated area</u>
The water surface of the delta varies between 5000 km^2 and 13000 km^2 (Fig. 2). However, the extent of flooding and the spatial advancement of the floodwave are poorly understood. Historical records show that the main drainage channel and the flooded area have shifted. These changes are induced by external climate changes and El Niño/Southern Oscillation (ENSO) effects, and internal factors including sedimentation, channel blockage and avulsion (Ellery et al., 1993). The general trend during the last 20 years has been towards a decrease in runoff and inundation. The proposed study will include the interpretation of historical NOAA-AVHRR images (1982 to present) of 1 km resolution to create a time series of the extent of the inundated area. Data for this is secured, and an initial interpretation of 3 years of data is presented in Gumbricht et al (2000), also illustrated in Figure 2. The most recent flooding will also be "near real time" recorded and interpreted using ATSR and SeaWifs satellite data (freely available via the internet). The accuracy of the estimations will be done using night time data from ATSR and daytime data from Terra (ASTER, and if possible also form the airborne simulator, MASTER) combined with field collected ground data.

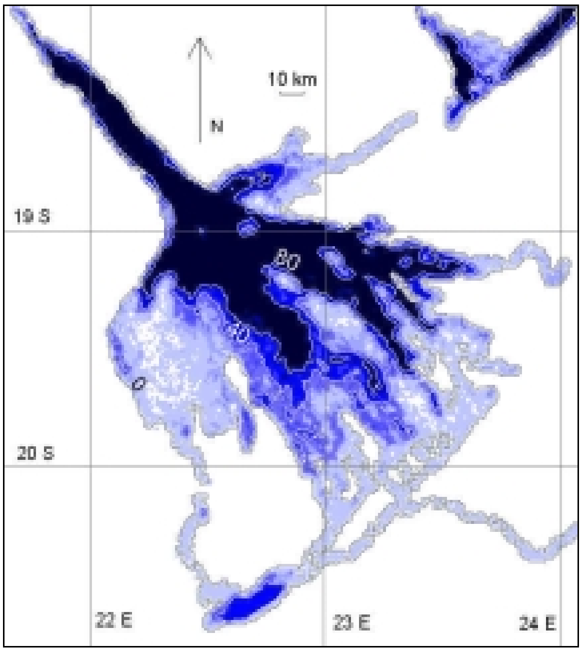

Figure 2: Percent of time with water cover – isolines for 0, 40 and 80 % water coverage are shown. Data from Gumbricht et al 2000, based on interpretations of 92 NOAA-AVHRR scenes.

<u>2.3 Mapping the delta and its features</u>
The delta is divided into four distinct physiographic regions; the pan handle - a transitory entry valley confined in a tectonic graben, the permanent swamp, the seasonal swamp and the dryland at the distal end. Water level in the pan handle and seasonal swamp vary up to 2 meters annually, whereas the permanent swamp has a less varied water level. Both the swamp physiography and the island types vary from region to region. The islands are major bodies for evapotranspiration of water also inducing chemical precipitation of salts – thus balancing both water and solute flow through the delta (McCarthy et al, 1993). Island types and distribution is hence hypothesised to strongly influence flow diversion, water balance and water chemistry of the delta. However, there is a lack of quantitative estimation of the distribution of islands as well as of hydroclimatic data allowing for corroboration of this hypothesis. In the proposed study Landsat TM (and if possible the airborne TMS, Themaitc Mapper Simulator), Terra-ASTER and SPOT XS data will be adopted to create an object-oriented classification of the delta and its major features. An initial algorithm for this classification has been presented and shown to work in Gumbricht et al (2000). Historical satellite data is already captured and available within the research team. Data for the year 2000 will be obtained through co-operation

with SAFARI 2000, which will give access to Landsat 7 TM and Terra – ASTER data (and also from the air borne simulator, MASTER, if possible. Data from both 2000 and 2001 will be collected and co-ordinated with field campaigns for ground truthing.

2.4. Digital elevation model

A digital elevation model (DEM) in 500 meters resolution of the delta will be created by geostatistical interpolation (kriging) from different sets of field surveyed data. When elevation data from the Shuttle Radar Topographic Mission (SRTM) becomes available over the study area, the 500 meter DEM will be refined to a 50 m resolution DEM. If data from AIRSAR, flown within SAFARI 2000 will become available also this data will be used. The field surveyed data is already captured.

2.5. Vegetation cycle mapping for estimating evapotranspiration

Corrected NDVI images derived from NOAA-AVHRR archived data in 7.6 km resolution (Eidenshin & Faundeen, 1998) will be used for analysing the seasonal vegetation changes in different parts of the delta, also aiming at detecting anthropogenic impacts (Fig. 3). Methods and data are established. This data will form part of the subsequent modelling effort, specifically for estimating evapotranspiration in the delta.

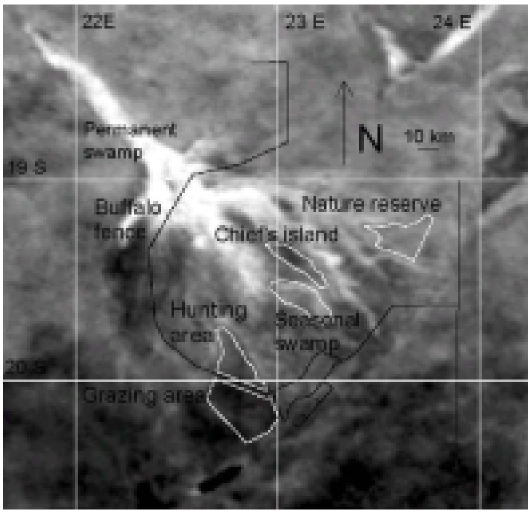

Figure 3a: Average vegetation density (NDVI) over the Okavango Delta – bright areas have the highest NDVI. From Gumbricht et al, 2000.

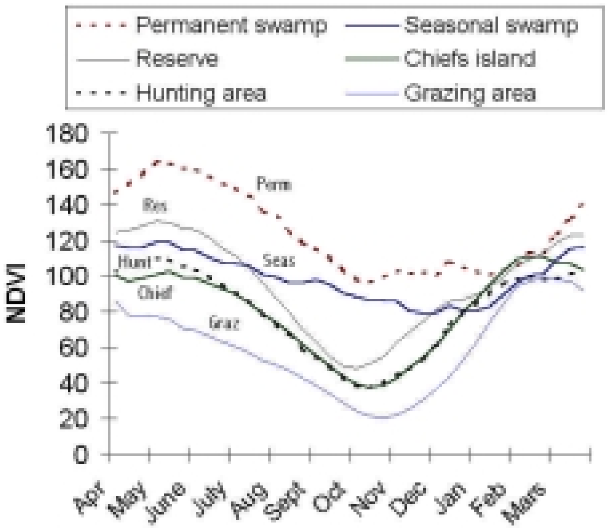

Figure 3b: Moving 2 month average NDVI for different areas in the Okavango Delta. The grazing area has a strong anthropogenic fingerprint. From Gumbricht et al., 2000.

2.6. Interpolation and mapping of hydroclimatic surfaces

Application of distributed models for simulating ecological, hydrological and climatological processes need distributed estimates of driving variables like precipitation, temperature and solar insolation. Methods for interpolating point measures range from Thiessen polygons and simple trend surface analysis (Hughes, 1982) to more sophisticated statistical methods that honours apriori known dependencies of the estimate (precipitation) and e.g. elevation, slope, aspect, vegetation density and spatial correlations. Methods to be tested in the proposed study include geostatistical methods (Hevesi et al, 1992; Phillips et al, 1992), thin plate splines (Hutchinsson, 1996), and vertically exaggerated proximal polygons (Running and Thornton, 1996), which incorporate elevation as an apriori factor determining the spatial distribution of precipitation. The application of cloud temperature and vegetation as proxys for hydrocliamte will also be evaluated. As the number of climate stations is relatively low all interpolation methods will be applied by subsequently leaving out one sation and then use estimated versus measured value of the omitted stations as an indicator of method reliability.

Hydroclimatic conditions of the Earth's surface and atmosphere will be mapped with the Terra-CERES instrument. The symmetry between mapped and modelled surface conditions will be evaluated.

2.7. Distributed hydrological modelling

Previous efforts in modelling the delta have focused on forecasting outflow from the delta (e.g. UNDP, 1976; Dincer et al., 1987; Gieske, 1996). As the relief of the delta is very subtle, topographically based models are not applicable for modelling water flow and inundation in the delta itself. The delta could instead be compared with a large aquifer with extremely high transmissivity. Hence the modelling will divide the catchment into two parts; topographically based modelling upstream the delta and flow resistance modelling within the delta. Calibration and validation of the modellingwill use measured flow at the panhandle and spatial extent of the flooded area for calibration and validation of its respective parts. The success of the modelling effort is dependent on the creation of the datasets in the steps 2.1 to 2.6.

Specific objectives and expected significance of the research.

The main objective with the study is to create a reliable hydrological model of both the timing, volume and spatial extent of the hydrological cycle in the Okavango river. Specifically the following objects will form the basis of the study:

1. Characterization and mapping of the topography and land cover of the Okavango catchment, that represent a transect from mountainous to flat topography and wet to dry climatic conditions using various spatial data sources,
2. Quantitative estimates of spatial extent and timing of the annual flood in the Okavango delta using NOAA-AVHRR, ATSR and Terra-MODIS satellite data,
3. Object oriented classification of the Okavango delta and its major components governing the delta hydrological cycle, using SPOT XS, Landsat Tm and Terra-ASTER data
4. creating a digital elevation model of the Okavango delta in two steps, an initial 500 m resolution DEM from available field surveys, with refinement to 50 m when SRTM data becomes available,
5. Quantitative estimates of the annual vegetation cycle in a transect representing different hydroclimatc and anthropogenic conditions using NOAA-AVHRR derived vegetation index,
6. Estimating and evaluating methods for creating distributed hydrocliamtc surfaces (temperature, precipitation, insolation) from point data, and
7. Develop, test and evaluate an integrated hydrological model for the Okavango (incl. Cubango and Cuito) rivers and the Okavango delta.

A more comprehensive study of processes driving the hydrological cycle over southern Africa is much needed to understand and predict the region's sensitivity to and impact upon regional changes in climate and precipitation. The general knowledge on hydrological processes in African climates and environments is comparatively poor. Most hydrological models applied in Africa are developed for other climatic regions, and hence seldom perform satisfactory. The proposed research hence holds bearings for the regions water resource management. The issues have a wider relevance for regional sustainable development as well as for understanding and predicting global change. The results are hence expected to contribute to the development of improved policies and practices affecting the environment.

Methodology and plan of work

<u>4.1. Mapping catchment land cover/use and change (Wits, RSA, with supervision from KTH)</u>
Data source: NOAA-AVHRR (captured), ATSR (captured), Terra-MODIS and Terra-MISR (available)
Task: Vegetation classification (method developed see section 2.1, data processing falls within the proposed project, suitable as MSc degree work).

<u>4.2. Mapping the flood wave and inundated area (Wits, RSA – with supervision from KTH)</u>
Data source: NOAA-AVHRR (captured), ATSR (captured), SeaWifs (available), Terra-MODIS (available).
Task: Water classification (method developed see section 2.2, data processing and accuracy evaluation falls within the proposed project, suitable as MSc degree work).

<u>4.3 Mapping the delta and its features (data procesing - KTH, S; field data -Wits, RSA)</u>
Data source: SPOT XS (captured), Landsat 5 TM (Captured), Landsat 7 TM (available), Terra-ASTER (available).
Task: feature classification (method developed see section 2.3, data processing and accuracy evaluation fall within the proposed project).

4.4. Digital elevation model (Wits, RSA)
Data source: surveyed data from different sources (captured), SRTM (to become available within 2 years), AIRSAR (airborne SAR instrument that might be available via SAFARI 2000).
Task: georeferencing (finished), determination of ellipsoid and geoid, and geostatistical interpolation (falls within the proposed project).

4.5. Vegetation cycle mapping for estimating evapotranspiration (mapping - Wits, RSA Evaotranspiration estimation -KTH, S).
Data source: NOAA-AVHRR derived NDVI (captured)
Task: evaluation of dynamic signal for various parts (see section 2.5, falls within the proposed project)

4.6. Interpolation and mapping of hydroclimatic surfaces (KTH, S)
Data source: point data of temperature, precipitation and insolation (captured), digital elevation model (captured), terra-CERES data (available)
Task: Test and evaluate various geostatistical interpolation techniques and mapping surface conditions from Terra-CERES data (as specified in section 2.6, falls within the proposed project).

Suitable as MSc degree thesis for African student within the internation MSC program in Environmental Engineering at KTH.

4.7. Distributed hydrological modelling (modelling – KTH, S; field evaluation – Wits, RSA)
Data source: time series data on hydroclimate (captured), data created from steps 4.1-4.6
Task: Select, develop, test and evaluate hydrological model alternatives for integrating the delta and its catchment in a single model (falls within the proposed project).

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