Portraying the geophysiology of the Okavango Delta, Botswana

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Abstract - The article presents the application of remote sensing for capturing hydrological and ecosystem patterns and processes (geophysiology) of the Okavango inland delta in Botswana. The whole catchment is portrayed from NOAA-AVHRR images at 2 to 8 km resolution, the physiographic regions of the Delta, the annual flooding and the vegetation cycle are analysed from 93 10-day composite NOAA images at 1 km resolution. Landsat TM data is used for creating an object-oriented classification of Delta islands, channels and lakes.

1. INTRODUCTION

The Okavango wetland in Botswana is one of Africa's most pristine inland delta areas. The Delta is fed by the Okavango River and its tributaries in Angola that passes through Namibia and spreads out as an alluvial fan (delta) over the Kalahari sand until only a small stream remains (cf. 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.

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).

Due to inaccesibility, poorly developed data sets and lack of models, the catchment characteristics and their relation to the water flow in the Okavango River are poorly known. In this study the catchment was studied with the help of data from digitial chart of the world, GTOPO30 (30 arc seconds resolution elevation data) and NOAA-AVHRR (henceforth: NOAA) images.

The water surface of the Delta system varies between 4000 km^2 and 18000 km^2. However, the extent of flooding and the spatial advancement of the floodwave is 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. In this study NOAA images of 1 km resolution were used to study the present spatial extent of inundated areas over three years. Corrected NDVI images derived from the same dataset (see Eidenshink & Faundeen, 1998) were used for analysing the seasonal vegetation changes in different parts of the Delta, also aiming at detecting anthropogenic impacts.

The Delta is divided into four distinct physiographic regions; the Panhandle - a transitory entry valley confined in a tectonic graben, the permanent swamp, the seasonal swamp and the dryland at the distal end (table 1, Figs 1 and 2). Water level in the Panhandle 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. There is a lack of quantitative estimation of the distribution of islands. In this study Landsat TM data was adopted to create an object-oriented classification of the Delta and its major features (table 1).

Table 1
Major features in the Okavango Delta

Physiographic region	Wetland area	Islands and dryland
Panhandle	meandering channels, lakes, reed swamp (*Phragmites* and *Papyrus*)	sand banks, grasslands

Table 1 continued

Permanent swamp	channels, lakes reed swamp (*Cyperus Papyrus* and *Miscanthus junceus*)	scrollbar islands, anthill islands, salt pan islands
Seasonal swamp	channels, lakes, reed swamp (*Phragmites*, and other grasses)	inverted channel islands, anthill islands, saltpan islands
Dryland	-	Savannah, forest

2. METHODS

10-day composite NOAA derived NDVI images at 7.6 km resolution for the period 1982-1998 covering the whole catchment were retrieved from the internet (Anonymous, 1996), as were four sets of 2 km resolution NOAA images (Eidenshink & Faundeen, 1998) representing different seasons. The four NOAA scenes were used to create land cover classifications and red-green-blue (rgb) colour images for visualising the Delta.

The spatial extent of the annual flooding was estimated from 93 10-day composite NOAA scenes from the years 1992, 1993 and 1995 in 1 km resolution (*ibid*). Two different sets of rgb images where created for visualization, a simple linear stretch with 99 % saturation using bands 3 (r), 2 (g) and 1 (b) and a more pleasing (true colour) rgb image using band 1 as blue, a ratio of bands 1 and 3 for green and band 2 for red. The images were used for creating animations, and geo-correcting all scenes individually.

A rationing and threshold formula for classifying water content in five classes was individually calibrated for each scene, using the rgb images as backdrops. Clouds where separately classified by using bands 1, 4 and 5. A three-dimensional contextual and weighted filter – using the preceding and proceeding 10-day composites as the third dimension, smoothed the initial water classification. Cloudy days were eliminated by always seeking the next cloud free composite. From the filtered images the average time of water coverage and an animation of the annual flood was created.

In the Delta land use is sometimes sharply divided by cordon fences and nature conservation areas. NDVI images derived from the NOAA 10-day composites (*ibid*) were used for analysing the annual vegetation cycle in 6 different physiographic regions in the Delta. The NDVI images were 3-D filtered and smoothed in the same way as the water images. For each scene the average NDVI was extracted for each area. The extracted data was used for calculating an average NDVI cycle, using a 7 period (2 month) un-weighted moving average function.

Classification of topography and land use/land cover was done with Landsat TM data (August 1995 scene, 175/73) and a combination of statistical and expert rules (Chmiel & Gumbricht, 1996). Initial maximum likelihood classification adopted known field sites from the fieldwork by T. McCarthy and colleagues as training areas. A land-water mask was created and used for nucleation of different types of islands (table 1). An object-oriented classification of islands was done with forward driven rules considering island area, shape, and object related contextual variation of transformed NDVI, tasselled cap calculated wetness and brightness, and occurrence of saltpans.

After islands were categorised the initial classification was generalised based on area and fragmentation, and the islands were allowed to grow into the surrounding wetland given a low wetness index and/or the classification indicating transitory vegetation (woody vegetation, sand and soil). The final classification was vectorised and information on land cover, tNDVI, fringe vegetation etc. for each feature was extracted as attributes to the island polygons.

Image processing was done using ER-mapper, rule structuring and raster GIS functionality was written in Pascal, calling functions from the IDRISI GIS-software when applicable. ArcView was used for vectorisation and creation of the attribute database.

3. RESULTS AND DISCUSSION

Visualisations and animations are to be found on the internet at ”www.geoinformatik.geo.uu.se/research/ okavango.html”. Catchment extension is shown in Fig. 1 using the visual (first) band of a NOAA composite (Oct. 92) as backdrop. The water area of the Delta was found to vary from 3000 to 16000 km^2 (Figs 2 and 3).

Of the major arms of the Delta (Fig. 2) the most westerly is clearly dormant, the central arm has the most pronounced seasonal variation, and the easterly a rather constant extension.

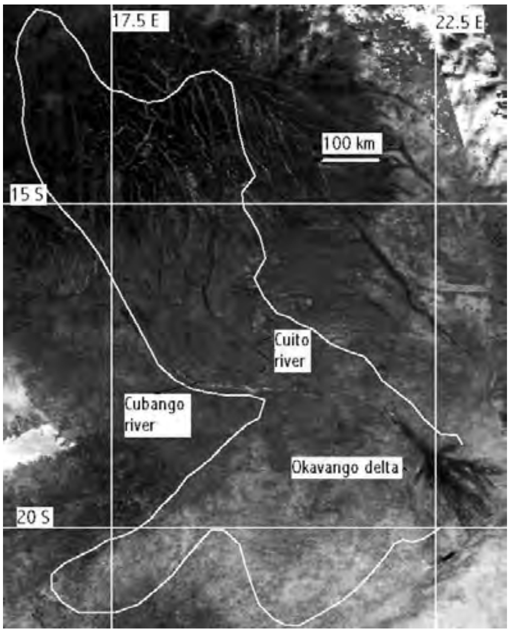

Figure 1: Catchment of the Okavango Delta.

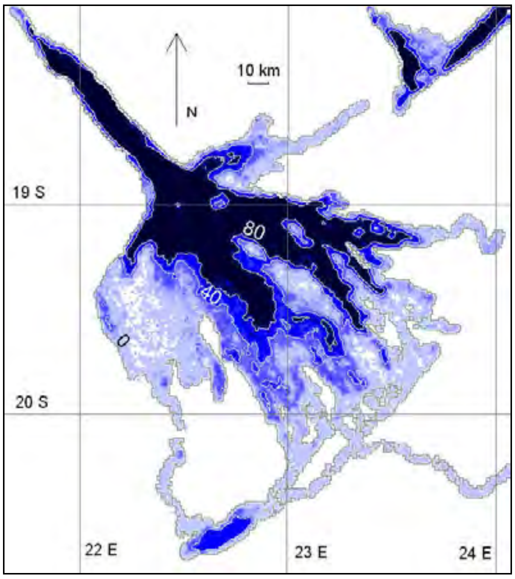

Figure 2: Percent of time with water cover – isolines for 0, 40 and 80 % water coverage are shown.

There is a pronounced NDVI difference between different parts of the Delta (Figs 4 and 5). The permanent and seasonal swamps show a vegetation cycle mainly related to the flow regime of the Okavango River. The more rainfed areas have a different cycle, with a peak in vegetation related to the rainy season. Also the vegetation in the seasonal swamp is related to the rainy season.

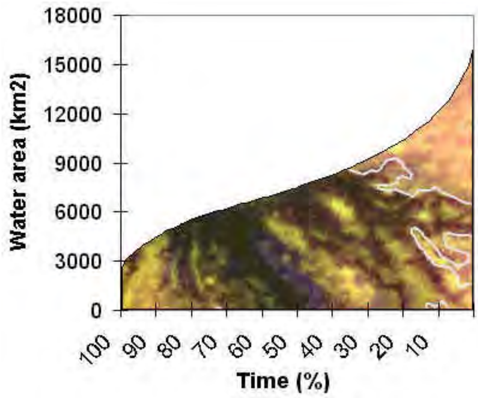

Figure 3: Water covered area in the Okavango Delta as a function of time.

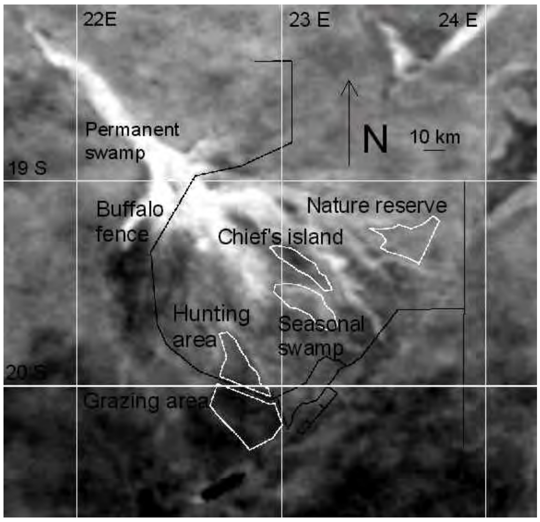

Figure 4: Average vegetation density (NDVI) over the Okavango Delta – bright areas have the highest NDVI.

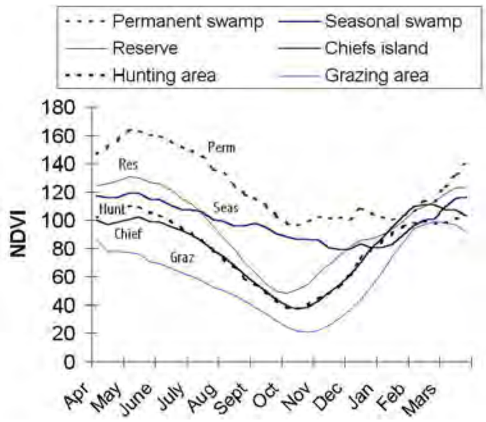

Figure 5: Moving 2 month average NDVI for different areas in the Okavango Delta (see text).

The NDVI cycle in the permanent swamp can be related to the input of nutrients with the annual flood in this otherwise oligotrophic environment. Only in the seasonal swamp water and nutrient levels allow sustained vegetation growth over the year. The effect of grazing can clearly be seen. However, after the rainy season the vegetation in the grazing area recovers to the same levels as in other drylands.

The land/water separation in the Delta from Landsat TM seemed to be accurate, comparing the result with known field sites and maps (Fig. 6). As the initial classification was kept to rather few classes the result is potentially less error prone. The object-oriented generalisation is shown in Fig. 7, the final rule structuring will be done after field data collection.

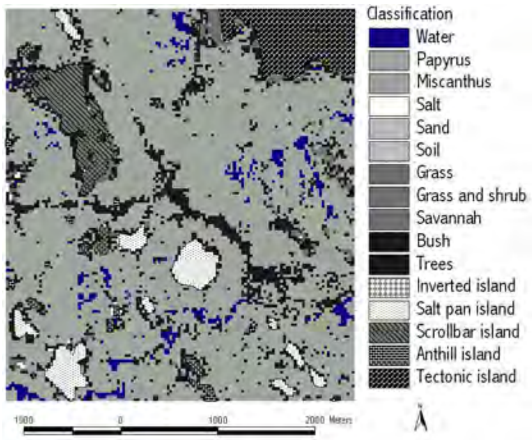

Figure 6: Landsat TM classification with core island delimitation (see text).

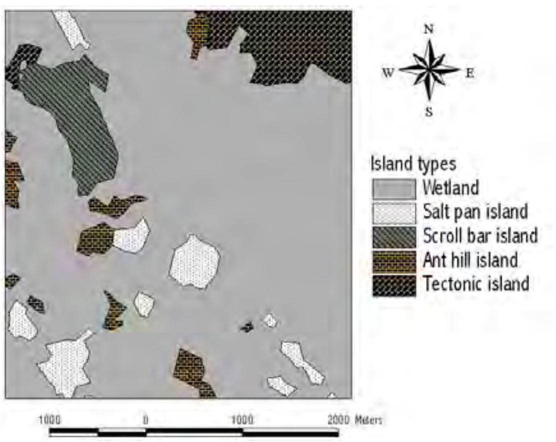

Figure 7: Object-oriented island classification of the same area as in Fig. 6 (see text).

4. CONCLUSION

There is a strong relation between processes and patterns at different scales in the Okavango – the functioning is hence best described using hierarchy theory (Allen and Starr, 1982). Portraying and modelling such a complex system need to i) discriminate relict and active features, ii) adopt an evolutionary perspective, iii) relate entities in hierarchical scales, and, iv) allow diffuse boundaries. It is concluded that remote sensing is the most, or even only, effective mean to capture the necessary data for this, but also that lack of sufficient field data hampers assessment of the accuracy of the created data set. It is also concluded that comprehensive remotely sensed time series data have a large potential, but that the application of such data is strongly hampered by costs, and errors in both geometry and signal patterns. Further research will focus on linking the spatial patterns with climate, and hydrological and ecological processes.

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