WETLAND MONITORING IN UGANDA

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ABSTRACT:

Wetlands occupy an estimated 13 percent of Uganda's national territory and they serve a number of functions. They serve for example as granaries for water storage, as nurseries for fish. They may sustain high levels of bio-diversity and represent important bird areas (IBA). Some act as basins for tertiary treatment of urban wastewater, and many people depend for their livelihoods on wetland resources, to name but a few. Considerable wetland areas have been converted in the past and are being encroached and converted at present. The National Wetlands Programme and the Wetlands Inspection Division aim at sustainable use of the wetland resources and protection of wetlands where needed. In order to fulfil these tasks they require up to date information on the extent, location and status of wetland areas, information that is to be provided through a wetlands monitoring programme. This paper gives the first results of a study investigating the feasibility of using remote sensing for systematic monitoring of wetlands. This paper looks at the monitoring requirements, what is to be monitored and at what scale. It addresses issues related to conditions required for monitoring, like the definition of wetland boundary and a land cover classification system. An historical analysis of land cover change of Nakivubo wetland, near Kampala city, is carried out to get insight in the nature of the land cover change. The suitability of a number of remote sensing techniques to identify the various wetland attributes is discussed and illustrated.

1. INTRODUCTION

About thirteen percent of the national territory of Uganda is covered by wetlands, and it is therefore one of the most prominent land cover types. Wetlands have a number of functions. They serve as granaries for water storage as was eloquently put by Uganda's president. They serve as nurseries for fish. They may sustain high levels of bio-diversity and represent important bird areas (IBA). Some act as basins for tertiary treatment of urban wastewater, and many people depend for their livelihoods on wetland resources, to name but a few.

The importance of these wetlands has long been recognised, and herewith also the need to conserve and protect these wetlands. The national policy for the conservation and management of wetland resources, dated 1995, provides the basis for the management and use of the wetland resources. The Wetland Inspection Division (WID) and together with the National Wetlands Programme (NWP) are the main organisation responsible for the implementation of this policy. However, conservation and protection of wetlands is a controversial issue and has been at the centre of political debate.

Wetlands have very fertile soils and, though drainage of wetlands may not be without risks of producing acid soils, large areas of wetland have been converted in the past for purpose of cultivation, especially in the Southwest of Uganda where high population densities prevail. Wetland resources are also used for other purposes, like for brick making. The wetlands in Uganda are presently under increasing threat due to increasing population pressure and scarcity of land. The phenomenon of conversion of wetland for agricultural use and for construction amongst others is nation wide, though near urban areas more severe than in other areas. In Kampala, industrial areas are located in and near wetlands, and experience severe flooding in time of heavy rainfall.

Information on wetland cover only exists on national level. Therefore, the NWP has embarked upon mapping of wetlands at district level, which is currently being carried out by the National Biomass Study, based on the interpretation of SPOT data of the period from 1988 to 1993. Information on change and conversion of the wetlands is lacking, except maybe for a few particular cases. The NWP is therefore interested in monitoring of wetland area at national level and of particular wetland areas that are considered of vital importance and in a critical state. It may be evident that any monitoring activity to be undertaken should make use of remote sensing data. The question however is how this can be done best. Answers to this question are to be generated from a feasibility study.

The feasibility study should typically answers question related to the frequency of the monitoring, spatial and thematic detail and the approach and methods to derive required information from remote sensing data. This paper presents the first results of an exploratory survey of the possible use of remote sensing for the monitoring of wetlands. The first phase aims to identify information requirements and to diagnose the problems associated with the use of remote sensing for mentioned purposes. The Nakivubo wetland has been selected as a study area to investigate a number of aspects associated with the monitoring of wetlands using remote sensing techniques. This paper does not present any quantitative data on the changes in wetlands, but rather aims to discuss the process of change and issues arising with respect to use of remote sensing techniques for monitoring of wetlands in the Ugandan context.

2. THE FRAMEWORK FOR MONITORING OF WETLANDS AND ISSUES ARISING

From the introduction is already clear that monitoring should be done at national level as well as on the level of particular wetlands that require active management. The latter implies that priorities should be assigned to wetlands for monitoring. The recognition that some wetlands are more important to protect than others (in view of the wetland functions mentioned before) carries the acknowledgement that some wetlands are more valuable in socio-economic terms in a modified state. This has severe implications for monitoring, because it requires the location of wetland change to be known, apart from just the total loss in wetland area. The latter could be established using a sampling approach, whereas the former would require mapping. It also probably requires the nature of the change to be known. Another purpose of monitoring could be the identification of hot spots: areas where changes are most pronounced. The identification of hot spots assumes that you have an overview of the total of wetlands, which would preclude monitoring by sampling.

The intended active management of priority wetlands indicates that in future monitoring may serve to provide management information. One could think for example of law enforcement. Such a purpose poses specific requirement with respect to the frequency of monitoring for example, and may not be compatible with monitoring for earlier mentioned purposes.

The concern about wetland conversion seems to result from the concern about the ability of wetlands to perform its functions as mentioned above, like trapping of sediment, fixing and filtering of nutrients and pollutants. The 'performance' of wetlands is difficult to assess, certainly with the use of remote sensing techniques. This means that the performance has to be assessed in an indirect way. However, the parameters to assess 'performance' are not well defined. Also, critical values below or above which the functioning of the wetlands is severely hampered, like for example minimum required papyrus area (since especially papyrus seems to be instrumental in fixing nutrients), are not established. Systematic monitoring will be quite costly. Economic evaluation of these wetland functions would help to determine the importance of these wetland areas and herewith justify the monitoring. Otherwise, conservation of wetland areas is justified form point of view of environmental concern and public interest. Irrespective of these, cost implications will be on of the main evaluation criteria to determine the feasibility of remote sensing for monitoring of wetlands, and should therefore be addressed.

The NWP would be interested in obtaining information on "any changes that take place in Uganda's wetlands" and in the causes of these changes. Causes can be external or internal and both natural of human induced. External causes might, for example, refer to climate change or to changes in land use in the hinterland. This would advocate a more integrated approach to monitoring of the wetlands, and though justified, it is outside the scope of this study. Evaluating change in terms of possible causes and in terms of the magnitude and rate of change requires a reference. Such reference can only be provided by historical analysis of wetland change. Based on historical analysis the rate of change may be anticipated and herewith the required frequency of the monitoring can be set.

2.1 Wetland Area at National Scale

With respect to monitoring on national level, the total wetland area is important. Such information could be obtained through the interpretation of images or image mosaics that cover the whole country or through estimation of national wetland cover by means of sampling using remote sensing data. The sample area would effectively correspond to the field of view of the particular sensor, which could be a digital camera operated from a airborne platform or any high or medium resolution space-borne sensor. Another option is to select a number of representative wetlands that will be monitored individually from which national estimates are derived. The choice which approach to adopt will depend on the required spatial detail to obtain reliable wetland cover estimates, which on its turn depends on the particular configuration of the wetlands in the country, and on the available imagery and of course on the costs.

As shown in Figure 1, larger wetland areas exist alongside a fine network of small and elongated wetlands in narrow valley bottoms. The total length of wetland boundary for the whole country measures up to probably hundreds of thousand of kilometres. Such a constellation of wetlands requires a relatively high spatial resolution. A high spatial resolution and nation wide coverage do not really agree and therefore seems to suggest a sampling approach. A area frame sampling technique as has been used for the MARS (Monitoring Agriculture with Remote Sensing) project of the European Union would be suitable for this purpose (Cochran, 1977; Cotter and Nealon, 1987; ITA, 1989). A stratified sampling approach is advisable since the wetland pattern varies for the different regions in the country. These strata still need to be defined and could be based maybe on wetland systems that are defined as wetlands that belong to the same drainage basin. Sample areas should be large enough to capture the variation within the scene. An area of the magnitude of about 10 by 10 km or even 15 by 20 km as depicted in Figure 1, seems to be appropriate, but should be verified.

2.2 Wetland Boundary and Wetland Fragmentation

In the case of monitoring of individual wetlands, the size and the location of the wetland boundary are important. The latter will indicate where changes occur. It requires wetland boundary delineation. The problem, however, is that the wetland (boundary) is not well defined. The definition generally involves land cover or vegetation characteristics, soil characteristics and/or characteristics related to the water table. But these criteria are not unambiguous. It also raises the question of how wetland change should be described (does wetland conversion imply a decrease in wetland area or does it imply a decrease in the area of characteristics wetland vegetation) and whether the boundaries can be easily recognised using remote sensing techniques. Defining the boundary for seasonal wetlands is probably more problematic than for permanent wetlands. A practical solution might be to define wetland boundary based on spectral characteristics. This would require an investigation into recognition of wetland boundaries using different remote sensing techniques. Again, finding a solution for the seasonal wetlands will be quite problematic.

The fragmentation of wetland area or wetland system is also mentioned as an important criterion for monitoring. Fragmentation refers to the notion that wetlands might be divided in parts or fragments that are separated from each other, but clearly belonging to the same system. The concern probably relates to fragmentation of wetland vegetation.

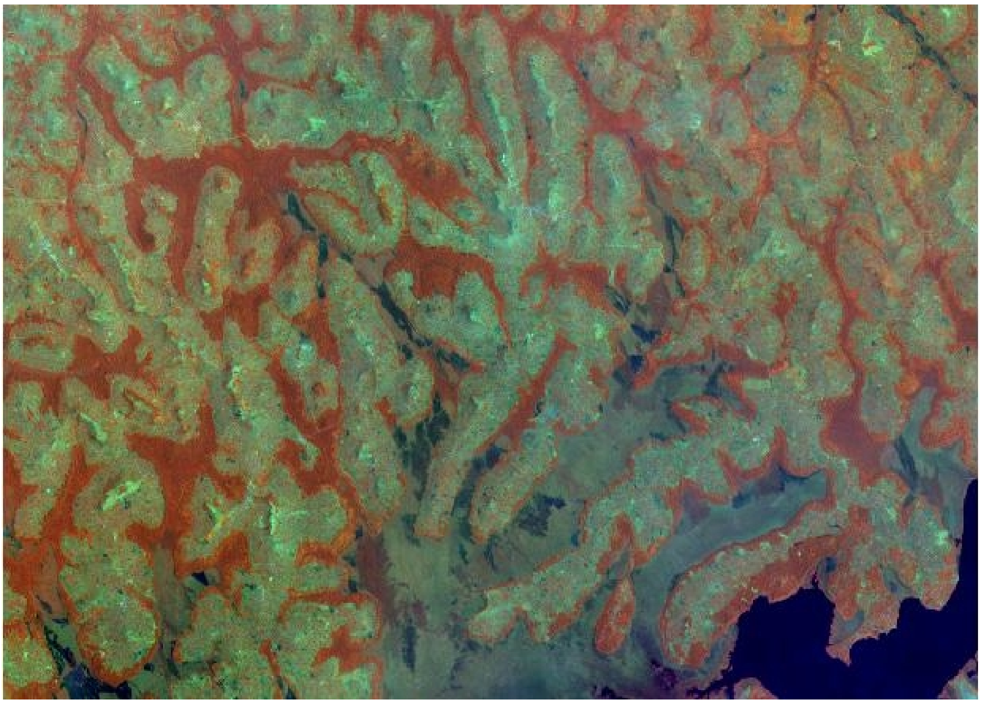

Figure 1. Part of a Landsat-TM image of 1989, showing the configuration of wetlands in Uganda

The shape is another aspect that is considered important, because it relates to the length of the wetland boundary in relation to its size, and is assumed to determine the human-wetland interaction. Shape and fragmentation are related entities. Whether shape and fragmentation relates to the wetland-dry land interface or to specific wetland vegetation depends on the wetland definition. Parameters need to be defined to describe both shape and fragmentation of wetland areas. The length of the wetland edge relative to its surface area seems a logical candidate. Distinction needs to be made between the wetland-dryland border and the wetland-open water border, because in the latter case the human interference will be practically absent.

Instead of going into semantic on the definition of wetlands, a practical solution could be to adopt a fixed location for the wetland boundary and use this as reference and describe changes in terms of changing land cover composition of the wetland. An historic analysis of wetland change should provide input for the definition of the wetland boundary. See Huising (1993) for a comparable approach to map land use change. Historical analysis is also important to provide reference to establish whether changes in size, location, shape and arrangement are natural and recurrent phenomena or whether they constitute a permanent change. This will depend on the nature of the change, which may be derived partly from change in land cover.

2.3 Categorisation of Wetlands

Wetland cover is an important parameter for monitoring. Wetland cover is one of the components defining a wetland. Cover also determines largely the functioning of the wetlands, and wetland use can be derived from it. Monitoring of changes in wetland cover needs to be done at national as well as at the level of individual wetlands.

At national level, it is important to register the type of wetland, which is determined by the dominant cover type as indicated in the classification system below. (This classification system is from an UNEP document entitled Strategic Resources Planning in Uganda, Vol. IX, Wetlands, UNEP. However, the year of publication and where it was published could not be found.)

Level 2	Level 3 Description
High altitude wetlands (level 1)	
> 3000 m. Swamps, bogs and mires of mountainous regions	
1900 – 3000 m Valley swamps	Upland swamps (Bwindi)
	Papyrus swamps
	Sedge-dominated
	Syzygium swamp forest
Rift valley/ Lake Victoria basin (level 1)	
Permanent	Cyperus papyrus and C.papyrus/Raphia
	Phragmites
	Sedges
	Typha
	Swamp grasses, including Miscanthidium
	Swamp forest
Seasonal Edaphic grasslands and sedges	Floodplains
	Dambos

Table 1. A wetland classification system for Uganda

Different classification systems have been designed (see for example Dugan (1990)), but the system presented above has the advantage of being simple and is most suitable for monitoring purposes. Changes are expected in the total area for each wetland type and not in the migration of a wetland from one class to another. However, the latter should be investigated. The classification system itself needs to be evaluated. The question is whether differentiating between wetlands dominated by papyrus, sedges or Typha is relevant or even possible, for example.

2.4 Wetland Cover Classes

For monitoring of individual wetlands the same considerations apply. Wetlands are currently being map at district level by the National Biomass Study (NBS). This is being done based on visual interpretation of SPOT imagery. The classification system being used (Table 2) should be tested for its suitability for monitoring based on spectral classification, and for use with imagery of different resolution.

Wetland category	Cover class
Seasonal	Broad-leaved woodlots
	Swamp forest
	Bushes and Thickets
	Grassland
	Pastures
	Farmland
	Commercial farmland
	Built-up area
Permanent	Woodlots
	Swamp forest
	Bushes and Thickets
	Grassland
	Pasture
	Cyperus and Typha (Papyrus and other sedges)
	Reeds
	Floats
	Farmland
	Commercial farmland
	Built-up area
	Open water

Table 2. Wetland cover classes as adopted by NBS (with some modifications)*

A number of classes represent converted wetland, like the classes ‘pasture’ and ‘farmland’. The user indicated that further detailing of conversion classes is required, suggesting the following classes: Dry land agriculture and wetland agriculture, livestock farming and plantation forestry. The user further indicated that conversion and restoration of wetland is important. This would imply that land cover history be recorded and that land cover actually needs to be mapped, which would imply a rather high level of spatial detail.

With respect to the definition of classes (with respect to both spectral signatures and land cover) the following remarks can be made: First, the classes that are used for monitoring should be exhaustive. That is all possible classes should be included. For example, the classification of Nakivubo wetland, based on airborne digital camera imagery, includes a class ‘water pools’, which is not part of the classification system specified above. Forcing such classes in one of the ‘allowed’ classes will produce errors.

Secondly, the classes should be defined unambiguously and preferably in quantitative terms. This is not the case with the present wetland cover classes. The land cover classification system adopted for the FAO Africover project (Di Gregorio and Jansen, 2000) may provide a solution in this respect.

A third observation is that some of the classes are not really cover classes but rather land use classes, like the classes ‘farmland’ and ‘commercial farmland’. These classes may not always be easily observed form the air or space and might require additional information from the ground to identify them. It raises the question of how to infer information on land cover and land use (and their change) from the spectral imagery that represents an instantaneous recording. For example burned areas, which stand out clearly in the imagery, may refer to papyrus area (and the papyrus will regenerate), cultivated land or other. The spectral information, land cover and land use should be treated as separate items and an inference machine should be devised to derive information of one from the other.

Rules for aggregation and class generalisation need to be defined in a multilevel classification system, where the levels relate to different image resolution. The land cover and land use classification below might illustrate this point. The classification was carried out using airborne digital camera data, mapping was carried out at a scale of 1:6000 (Mugisha, 2000).

Issues raised in this section relate to the temporal, spatial and spectral resolution needed for the monitoring and to the spectral classification and inference of information on wetland change from spectral data.

3. NAKIVUBO WETLAND CASE STUDY

A case study of Nakivubo wetland, which is a permanent wetland, was carried out to provide answers to a number of questions raised in the previous section. The questions relate to the nature and rate of change, the definition and delineation of wetlands, the required spatial resolution and other. To this end aerial photos of 1955, 1964, 1973, 1988 and 1995, with scales ranging from 1:10000 to 1:60000 have been interpreted. A Spot image of April 29, 1992 and a Landsat-TM image of 1989 have been interpreted. Data for 1999 were obtained from an earlier study on mapping of land use and land cover of Nakivubo wetland using high-resolution airborne data (the map presented above). Below some of the findings are presented

3.1 Historical Analysis of Wetland Change

In 1955, the wetland extended more than 400 meters towards the open water body of Lake Victoria compared to the present situation. It probably indicates lower water tables and relatively drier circumstances. This is corroborated by the type of land use that is found in the north-western extremities of the wetland. Here one finds tree plantations, which would not have been planted in wetland area. Also, where the trees have

* Added, for example, are the classes ‘woodlots’ and ‘Built-up area’ for permanent wetlands based on own observation and other existing maps on wetland cover.

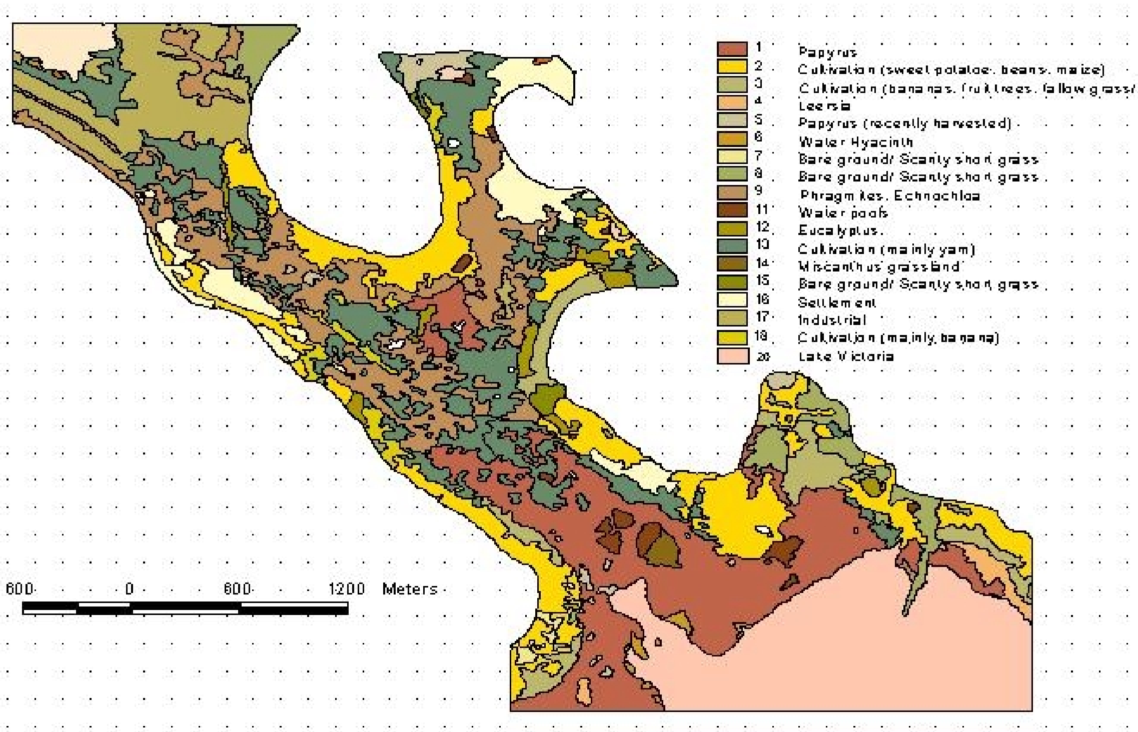

Figure 2. Nakivubo Swamp and surrounding areas: Land use/cover (vegetation) – July 27 1999

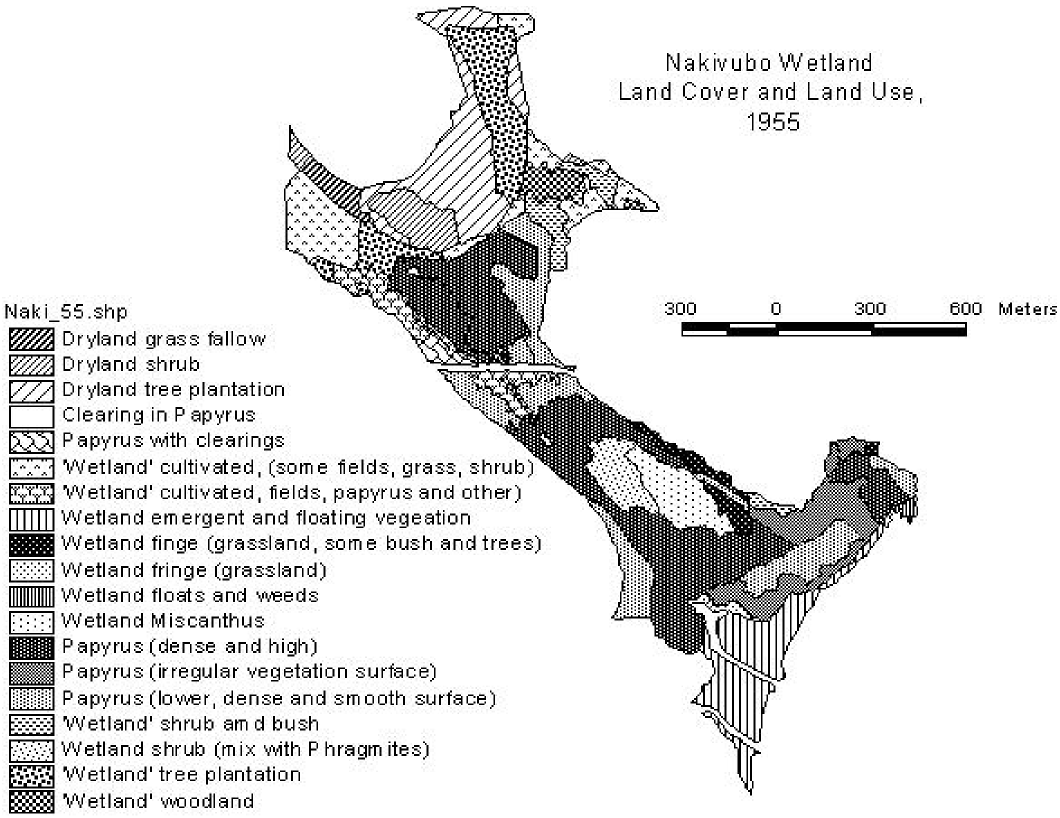

Figure 3. Nakivubo land use and land cover in 1955

been harvested, one find grassland with bushes, but no clear evidence of hydromorphic vegetation. The industrial area was already established at its present location. Papyrus vegetation can easily be recognised and is confined to an area that is not basically different form the area it occupied until beginning of the nineties. This disagrees with the common believe that large parts of the wetland were encroached upon and were converted. It is generally stated that the industrial area was built in the wetlands. One can doubt whether that is true given the evidence form the photos. Rather, one could argue that the wetland might have extended in later years due to wetter circumstances and that the wetland encompassed the industrial area. It emphasises the need for a consistent definition of wetland area. The situation in 1964 is basically the same as in 1955, only that the wetland edge to the open water of Lake Victoria retreated, especially evidenced in a retreat and widening of the inlet. In the other parts, the boundary of the papyrus vegetation seems to be rather stable. This process continued up to 1973, after which the papyrus grew back slowly.

In 1964 there was still very little encroachment (of the papyrus (!) wetland). Some little cultivation along the Nakivubo channel occurred. In 1973 this strip widened and a first larger clearing within the papyrus area is visible. Changes relate mainly to the north-western section of the papyrus vegetation, north of the railway that cuts trough the wetland. These clearing may be the result of papyrus harvesting, after which the papyrus recovers and therefore it does not represent conversion of the wetland as such. In 1988, more large clearings are visible and some evidence of former clearings, were the papyrus re-established. In 1995 considerable parts of the wetland are being cleared and converted. In addition, papyrus areas south of the railway are being affected, where the wetland is deeper. The 1999 classification indicates that the northern section is almost completely converted. The southern part seems to be less affected. The evidence seems to suggest that major changes have taken place in the last 10 to 15 years. Which such a rate of conversion, the monitoring frequency should be once per three to five years, varying with the status of the wetland.

Very striking is that the changes occur from within the papyrus area and not predominantly from the edge. Fragmentation certainly takes place, but seems to refer more to the cleared spots that the papyrus vegetation itself, until later stages of the wetland conversion. This means that a fine resolution is needed to accurately map these changes in area of papyrus vegetation. Image resolution of 20 or 30 meters might not suffice.

3.2 Wetland Boundary Delineation

The land use and land cover map of 1995 as depicted in Figure 3, distinguished between dryland and wetland. Where typical wetland vegetation, like papyrus, is found, the delineation of the wetland boundary is not difficult. The papyrus wetland areas are very flat (i.e. the vegetation surface) in contrast to the surrounding hill landscape and the y represent very homogenous areas with a characteristic texture, which makes them clearly distinguishable from surrounding land cover. Were this vegetation is not present the boundary between dryland and wetland is defined mainly on topographic characteristics. The valley bottoms are not completely flat (certainly at the edges) and the transition from the lower hill slopes to the valley bottom is a gradual one. For the 1995 photos (scale approximately 1:24000) the error margin is estimated to be 40 to 50 meters, but larger in case of dense woody vegetation. These topographic boundaries do generally not correspond to marked changes in land use and land cover. The land cover and land use information as derived from photo-interpretation is therefore not a suitable criteria for delineating wetlands. For example, in 1955 tree plantations and grassland fallow are found across the wetland boundary (see figure 3). This situation is true for the different years for which aerial photos were obtained. Advantage of these topographic boundaries is that they may be considered constant. They do not represent dynamic features.

In contrast to the above findings, figure 1 seems to suggest that wetland boundaries can be delineated using satellite imagery, probably based on land cover characteristics. In figure 4 a SPOT image of Nakivubo wetland, from 1992 is presented, with an interpretation of the image superimposed.

There is a clear contrast between the wetland and the urban environment. Where urban characteristics are less pronounced the interpretation of the wetland boundary becomes less reliable. This is also reflected in the land use and cover map presented in figure 2, which includes surrounding areas of the wetland. The interpretation of the SPOT image was done after having interpreted the aerial photos and therefore with prior knowledge. Still the wetland boundary deviates in places up to 120 meter from the boundary as derived from the 1955 aerial photos.

3.3 Fragmentation, Recognition of Land Cover Types and Spatial and Spectral Resolution

As observed on the photos of 1988 fields where the papyrus vegetation areas may measure from 10 by 10 to 30 by 30 meters. Such fields will not be visible on SPOT or Landsat images. However, generally these fields are conglomerated to constitute larger clearings typically ranging from about 0.36 to fields 1.1 ha. These latter clearing will be visible, as can also be observed in Figure 4. The error in the estimates of the total cleared papyrus vegetation is limited since isolated small clearings do not constitute more than 10% of the total cleared papyrus area. The estimate of the papyrus area is even less affected in terms of percentage because the total cleared area does not amount to more than about 20 of the papyrus area. The error will of course increase with further conversion and fragmentation of the wetland area, and with decreasing image resolution.

Figure 4 seems to suggest that the papyrus area can be reasonably well recognised, when at least the wetland boundary is known. Excluding these areas from the interpretation should prevent possible confusion with vegetation types outside the wetland. Even within the papyrus area differentiation is possible based on the spectral characteristics. Whether these indeed correspond to the different types of papyrus vegetation needs to be evaluated. The above interpretation is based on visual inspection of the image. Results with spectral classification techniques are expected to give less favourable results.

Interpretation of the aerial photos makes use of differences in tone, texture, pattern, shape and height visible in the photos. It allows establishing previous human interference providing information on land use. In papyrus areas, former clearing can be observed from particular shape and pattern characteristics. Experience indicates that photo scales down to about 1:25000 to 1:30000 allow for the identification of the relevant land cover and land use characteristics of wetlands, but it will require experienced interpreters. The information on texture, shape and pattern, referred to above is lost when using Spot or Landsat imagery. This is however partly compensated by the increased spectral resolution. Comparison of Spot with Landsat data did not seem to suggest that the additional MIR channel provides much additional information. Higher spectral resolution yet does not seem to be required. The digital camera data used for the 1999 land use and land cover mapping combines high resolution with multi-spectral information. However, it has the disadvantage of being airborne data requiring that covers only small part of the wetland per scene and therefore requires complicated geometric correction and radiometric correction due to inter scene variation in brightness level. Multi-spectral data with a resolution of about 4 to 5 meters, like IKONOS would probably be ideal.

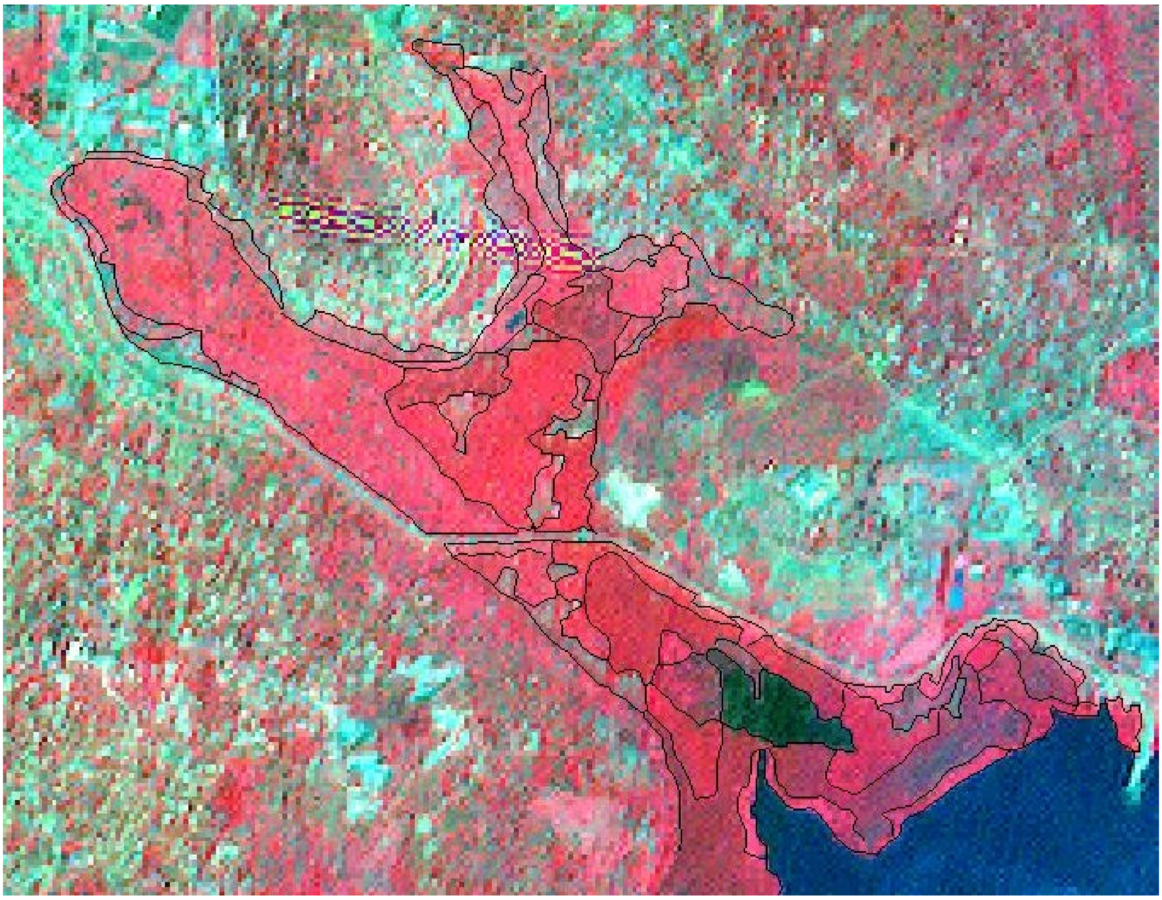

Figure 4. SPOT'92 of Nakivubo wetland with visual interpretation superimposed

4. CONCLUSIONS

This paper presented the first results of a study into the possibilities for monitoring wetlands with remote sensing. The first results are indicative rather than conclusive. This study in the end will result in a matrix indicating the suitability of a number of remote sensing techniques to measure the various wetland characteristics that are considered to be of importance for monitoring. These characteristics will refer to for example the location of the wetland boundary, wetland fragmentation, area of various land cover types within the wetland, but also rate of change wetland conversions and others. In addition, a number of aspects of the remote sensing data will be considered like cost, data provision and other. In addition, SAR data will be considered. Based on these criteria the most appropriate remote sensing technique (or combination of techniques) will be selected.

A first preliminary investigation seems to suggest that an area frame sampling approach would probably be the most appropriate for generating information at national level. Given the specific configuration of the wetland medium to high resolution data will be needed, referring to 20 m or preferably higher resolution.

The Nakivubo study indicates that major parts of what is generally considered to be the wetland were already converted in 1955. It is even doubtful whether one can speak of active conversion, since there is no evidence from the aerial photos that the area was formerly covered under papyrus. Though some drainage channels are visible, the area does not seem to suffer from naturally poorly drained conditions, which might well have facilitated the use of the wetlands.

Monitoring of wetlands like Nakivubo seems certainly feasible, but will require multi-spectral imagery with resolution of 20 meter, but preferably less.

So far no investigation into seasonal wetlands has been done. These will probably pose their own specific requirements with respect to monitoring by means of remote sensing.

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