EXTRACTION AND CLASSIFICATION OF WETLAND FEATURES THROUGH FUSION OF REMOTE SENSING IMAGES IN THE OKAVANGO DELTA, BOTSWANA

K. Talukdar

Institute of Geodesy and Photogrammetry, ETH Hönggerberg, CH-8093 Zürich, Switzerland - talukdar@geod.baug.ethz.ch

Commission VII, WG VII/3

ABSTRACT:

The Okavango delta in northwestern Botswana is an extremely complex and dynamic wetland ecosystem. The spatial information on diverse wetland features of the delta is needed for hydrological modeling and water resources management. Due to large size and inaccessibility of the delta, satellite images provide the only viable means to reliably map and measure these features. For better identification and delineation of these features in the Okavango delta, efficient image analysis techniques are needed. The synergistic use of images from different sensors with varied spatial and spectral resolutions have the potential for better extraction and classification of features. This paper focuses on extraction and classification of landscape and land cover features through fusion of different resolution images acquired by Landsat 7 ETM+ and SPOT 5 HRG sensors over the Okavango delta. Both multispectral and panchromatic images from these two sensors are used. Different image fusion approaches are examined and used to increase reliability in feature interpretation. The effects of data fusion in recognition and extraction features are examined and illustrated. Thematic information extraction was carried out by means of supervised and unsupervised classification to produce landscape/land cover classes for different spatial resolution data set. The results indicate that as spatial resolution increases, high spatial frequency landscape/land cover features are extracted in increasing detail. However, spatial heterogeneity also increases with increasing spatial resolution.

1. INTRODUCTION

The spatial information on wetland features (i.e. landscape and land cover) of the Okavango delta is needed for hydrological modeling and water resources management. Wetlands are by definition lands with water-tables at or near the surface, either seasonally or permanently (Hughes, 1996). Wetlands and the issue of their management and preservation now engage the increasing attention of public. A goal is to provide better information as wetland ecosystems are influenced or exposed to environmental risks. There are a number of types and classification systems of wetlands to describe them (Anderson *et al*., 1976). They were categorised into different types and classes based broadly on hydrological, geomorphological, soil and vegetation characteristics of wetlands. There are a variety of information needs in wetland ecosystem management and landscape characterisation.

The Okavango River, which originates in central Angola, after flowing through over a thousand kilometer branching out to form the Okavango delta, one of the largest inland wetland ecosystems in the world, comprising an area between 16,000 to 22,000 km^2. The whole catchment area of the river plus the delta together known as the Okavango River Basin (Figure 1), comprises an area of nearly 429,400 km^2. The Okavango sub-basin is part of the larger Makgadikgadi basin, which covers an area of approximately 725,300 km^2 (Ashton and Neal, 2003).

The delta exhibits great variations in areal extent, spatial complexity and temporal dynamics. Due to large size and inaccessibility of the delta, satellite images provide the only viable means to reliably map and measure these features. Since the wetland is composed of heterogeneous objects it is difficult to reliably identify and characterize features from satellite images. For better identification and delineation of these features in the Okavango delta, efficient image analysis techniques are needed. The synergistic use of images from
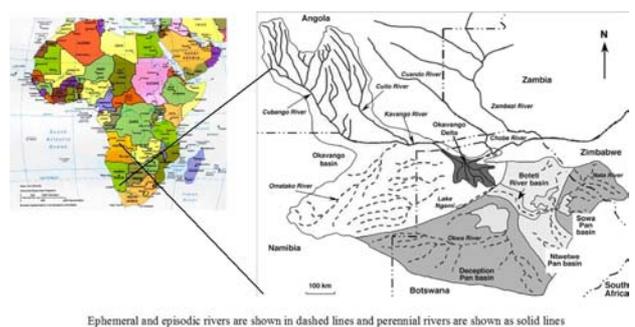
Figure 1. Location of the Okavango River Basin and the Delta, Southern Africa

different sensors with varied spatial and spectral resolutions have the potential for better extraction and classification of features. The principal aim of this study is to examine the effect of fusion of remotely sensed images from different sensors for extracting and classifying wetland features. Wetland features are represented as a collection of pixels in an image. For the

purpose of recognition, we need to describe the properties of pixels or groups of pixels.

2. THE STUDY AREA

The Okavango delta in northwestern Botswana is an extremely complex and dynamic wetland ecosystem. The increasing water demand from basin sharing countries (Angola, Namibia and Botswana) puts the resource under growing pressure and poses complex management problem. Water is a precious and important resource for all three riparian states of the basin. The demand for water is growing due to rapidly rising population and associated activities like irrigation and power generation. The Okavango delta (Figure 2), variously termed as "*the jewel*" of the Kalahari (Ross, 1987), Africa's "*Wetland Wilderness*" (Bailey, 1998) and so on. It is the last remnant of the ancient great Makgadikgadi Lake, which was formed by the Kalahari sands about three million years ago (Ross, 1987). The delta is a large alluvial fan and experience annual flooding. It consists of a series of permanent river channels, semi-permanent drainage channels, lagoons, islands and floodplains that link up and then separate again during the course of an annual flood. The delta has a very low gradient. From Mohembo to Maun with a distance of 240 km, there is roughly 1m height variation for every 4 km distance (Figure 2).
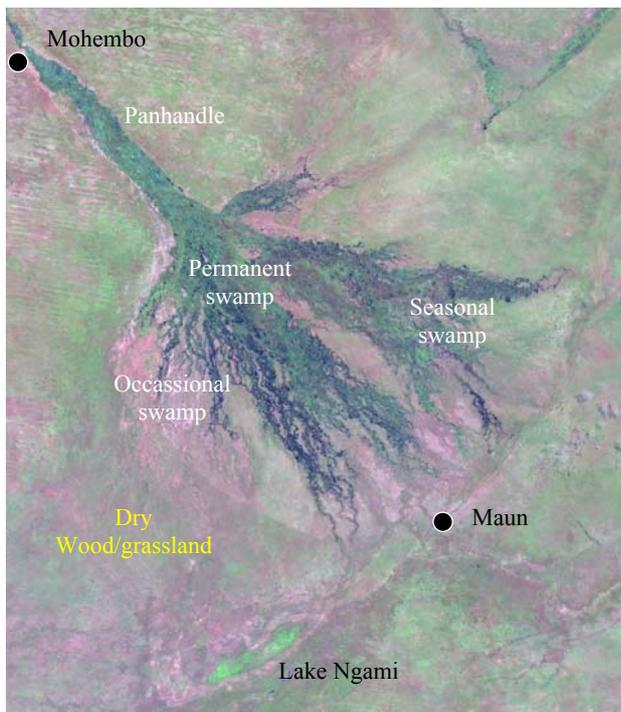
Figure 2. The Okavango delta as seen from Landsat 7 ETM+ (5,4,2 combination) image, April 2000

The Delta is located in a semi-arid region which experiences wide variations in flooding over permanent swamps, seasonal swamps and other intermittently flooded areas. The permanent swamp covers approximately 6,000 km², while the seasonal swamp varies between 4,000 and 10,000 km². Water depth in the permanent swamps averages 1.5m (UNDP, 1977), while in the seasonal swamps it is generally less than 1m (McCarthy *et al.,* 1998).

The river and the delta serve as major source of fresh water to the people of the basin area. The Okavango is one of the few large rivers in the world without notable man-made developments and that has so far remained relatively pristine.

3. DATA AND METHODS

3.1 Data

The primary data used in this study were SPOT 5 High Resolution Geometry (HRG) sensor image acquired on 12 November 2002 and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor image acquired on 28 March 2001. The other data used are 1:50,000 scale topographic maps and GPS measured ground control points. Both SPOT 5 and Landsat & images are taken during dry seasons. Figure 3 shows the scene location of SPOT 5 and Landsat 7 over the Okavango delta.

The SPOT 5 satellite was launched on May 2002 with Araine 4 rocket and put on polar sun synchronous orbit at an altitude of 832 km from earth surface, while the Landsat 7 satellite was launched on April 1999 with Delta rocket and put on polar, sun synchronous orbit at an altitude of 705 km from earth surface. Both SPOT 5 and Landsat 7 satellites orbit the earth in sun-synchronous mode at an inclination of 98.2^0 and 98^0 degree respectively.
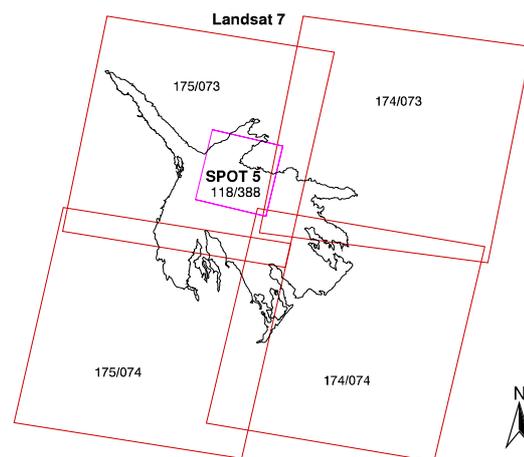
Figure 3. Landsat 7 ETM+ and SPOT 5 HRG scene location over the Okavango delta

SPOT 5 HRG sensor provides multispectral (10m resolution in band 1-3 and 20m resolution in band 4) and one panchromatic band (5m resolution) image. Each SPOT 5 HRG scene covers a ground area of 60 km x 60 km (nadir viewing). The HRG is an optical/near infrared sensor (Table 1), which is based on High Resolution Visible (*HRV*) and High Resolution Visible and Infrared Sensor (*HRVIR*). Both HRV and HRVIR are optical/near infrared *CCD* (*pushbroom*) imaging radiometers carried on *SPOT-1 to -3*, and *SPOT- 4* respectively. The two HRG instruments aboard SPOT 5 are the main imaging instruments. They provide panchromatic (black and white) imagery at a resolution of 2.5 or 5 metres and multispectral (colour) imagery at a resolution of 10 metres.

Table 1. Sensor Characteristics - Landsat 7 ETM+ and SPOT 5 HRG

Wavelength Region	Spectral Range (μm) *(with band no.)*		Spatial Resolution (m)	
	Landsat 7 ETM+	SPOT 5 HRG	ETM+	HRG
VIS Blue	0.45 - 0.515 (B1)	-	30	-
VIS Green	0.525 - 0.605 (B2)	0.50 - 0.59 (B1)	30	10
VIS Red	0.63 - 0.69 (B3)	0.61 - 0.68 (B2)	30	10
NIR	0.75 - 0.90 (B4)	0.78 - 0.89 (B3)	30	10
MIR/SWIR	1.55 - 1.75 (B5)	1.58 - 1.75 (B4)	30	20
TIR	10.40 - 12.5 (B6)	-	60	-
MIR	2.09 - 2.35 (B7)	-	30	-
PAN	0.52 - 0.90 (B8)	0.48 - 0.71	15	5

Landsat 7 ETM+ sensor provides multispectral (30m resolution in band 1-5 and 7, and 60m resolution in band 6) and one panchromatic band (15m resolution) image. Each Landsat 7 ETM+ scene covers a ground area of 185 km x 170 km. The earth observing instrument on Landsat 7, the ETM+, replicates the capabilities of the highly successful Thematic Mapper (TM) instruments on Landsats 4 and 5. The ETM+ also includes new features that make it a more versatile and efficient instrument for regional to global environmental change studies, land cover monitoring and assessment, and large area mapping. Table 1 shows the detail sensor characteristics.

3.2 Methods

Fusion of remotely sensed images obtained using different sensors need to perform carefully. All data sets to be merged needs accurate registration to one another and resampled to the same pixel size.

3.2.1 Georeferencing

The scanned topographic maps at 1:50,000 scales are geometrically rectified to the UTM projection, Zone 34 S co-ordinates. Clarke 1880 spheroid and Cape datum were used for georeferencing all data sets. On an average half pixel (i.e. 2m) accuracy is achieved in georefencing of topographic maps. The geocorrected topographic maps and a few Global Positioning System (GPS) measured ground control points (GCPs) are used for georeferencing of SPOT 5 panchromatic and multispectral images.

In case of SPOT 5 panchromatic image geometric correction, 64 well-distributed GCPs and 30 well-distributed check points are selected over the entire scene of 60 x 60 km area. RMS error for GCPs was 4.60 pixels, while for check points RMS error was 4.30 pixels. In case of SPOT 5 multispectral image geometric correction, 64 well-distributed GCPs and 30 check points are selected. RMS error for GCPs was 2.30 pixels, while for check points was 2.42 pixels. A nearest-neighbour interpolation method is used for image transformation.

Landsat 7 ETM+ panchromatic and multispectral images are registered with SPOT 5 panchromatic geocorrected image. In case of Landsat 7 ETM+ panchromatic image rectification, 127 GCPs are used, while in case of multispectral image, 126 GCPs are used. In case of panchromatic image rectification RMS error was 1.79 pixel, while in case of MS image, RMS error was 1.72 pixel. Again nearest-neighbour interpolation method is used for image transformation.

The relationship between the original pixel co-ordinates (x,y) and the transformed co-ordinates (u,v) in the new projection is specified by a pair of mapping functions:

$$u = f(x,y),$$
$$v = g(x,y), \tag{1}$$

and by an equivalent pair of inverse functions:

$$x = F(u,v),$$
$$y = G(u,v). \tag{2}$$

After geocorrection of all data sets, two test site common to all images of the delta were selected for the present study.

3.2.2 Image fusion

The radiation recorded by a sensor is dependent on, among other things, the spatial resolution of the sensor in relation to the spatial frequency of the terrain (Wulder *et al.*, 2000). Among the most important purposes of fusion of different resolution images is the production of spatially improved images suitable for classification. There are several approaches to fusion of remotely sensed images. Image fusion can be achieved at three levels, the pixel or signal level, the feature level, and the object level (Forstner, 1992; Pohl and van Genderen, 1998; Pohl, 1999). The signal level fusion techniques have been most common in remote sensing applications (Forstner, 1992).

In this study, two well-known methods based on the Brovery transformation and standardised principal components (SPC) transformation are applied to two pair of images acquired by HRG sensor onboard the SPOT 5 satellite and by ETM+ sensor onboard Landsat 7 satellite. Effects of image fusion are examined visually before classification.

3.2.3 Classification

Classification is the process of grouping of pixels or regions of the image into classes representing different ground-cover types. It chooses for each pixel a thematic class from a user-defined set. Two main digital image analysis techniques are available for the segmentation and classification of remotely-sensed, spectral data: unsupervised and supervised. In the unsupervised classification process, a computer algorithm selects a sample of pixels and clusters their radiance values

into similar spectral classes. These signatures are used by a maximum likelihood classifier to generate probability density functions and then each pixel is assigned to the probability density class it most closely resembles. The resulting classified image is assigned with landscape/land cover labels. In the supervised classification process, each pixel in an image is assigned to one of a number of classes (land cover types), by comparing the properties of the pixel with the properties of those oixels (i.e. training data) known to belong to the various classes. In essence, therefore, supervised classification forces the image classification to correspond to user-defined land-cover classes, but does not guarantee that the classes will be separable. In this study both unsupervised and supervised classification methods are used.

Three classes of wetland features are identified based on the objective of the study. They are open water, land-vegetation cover and an intermediate class, i.e. swamp with water-borne vegetation cover. The area is a complex wetland environment of marsh, swamp, channels, and shoreline. Methods to identify land and water in satellite imagery and their interface in wetlands were tested and evaluated to determine the most reliable technique. These methods include spatial image enhancement (convolution filtering), spectral enhancement (Principal component), and spectral classification (ISODATA and maximum likelihood supervised (ML) classification). The ML classifier is one of the most popular pixel-based classification method in remote sensing, in which a pixel with the maximum likelihood is classified into the corresponding landscape/landcover features. ML classifier is popular because of its robustness and simplicity.

Since the purpose of this study is to examine spatial resolution effects in extracting and classifying wetland features, it was necessary to select a proven, dependable process rather than employ a promising but experimental procedure. Accuracy assessment has been carried out through visual inspection, comparison with existing database like topographic maps, land cover maps and field knowledge.

4. RESULTS AND DISCUSSION

On an average half pixel (2m) accuracy was achieved in georefencing of 1: 50,000 scale topographic maps. This is the best possible accuracy achievable as the quality of maps were poor. In case of SPOT 5 panchromatic image, 4.6 pixel (23m) accuracy was achieved, while in case of SPOT 5 multispectral 2.3 pixel (23m) accuracy was achieved. There were tremendous problems faced during georeferencing of images as topographic maps used are very old, published between 1971 to 1989.

In case of Landsat 7 ETM+ panchromatic image, 1.8 pixel (27m) accuracy was achieved, while in case of Landsat 7 ETM+ multispectral image, 1.7 (25.5m) pixel accuracy was achieved. The results of image fusion and classification are presented in Figures 5, 6, and 7.
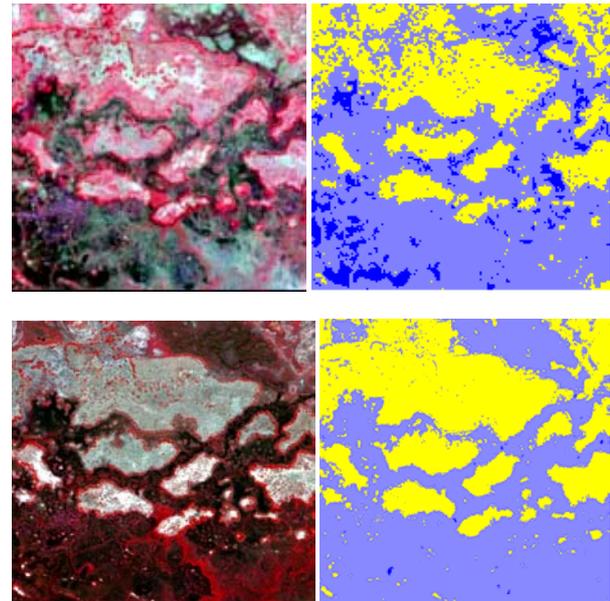
Figure 5. Upper: Left- Landsat 7 MS (30m) 4,3,2 band color composite (156 x 158 pixels), Right: 1-5 & 7 band classification result; Lower: Left- SPOT 5 XS (10m) 1,2,3 band color composite (465 x 472 pixels), Right: 1,3,4 band classification result

Figure 5 shows the results of supervised classification of Landsat 7 MS (30m) and SPOT 5 XS (10m) images. Unsupervised classification did not perform well because of the complexity of wetland features.

Table 2. Classification accuracy of SPOT 5 XS (10m) image

Class	Commission accuracy	Ommission accuracy
Open water	99.9	98.8
Swamp	93.4	97.7
Land-vegetation	98.0	94.3

Proportion of unclassified pixels = 4%
Overall accuracy = 96%
Kappa statistic = 92.6%

Overall 96% class performance was achieved for three landscape classes from SPOT 5 multispectral image classification. Table 2 shows the accuracy achieved for each of the three landscape/land cover classes along with Kappa statistic. In case of Landsat 7 multispectral image classification, overall 85% accuracy was achieved. SPOT 5 multispectral image classification results in more detail information and more sharper object boundaries than Landsat 7 multispectral image classification.

The result also shows that the best wavelength region for discriminating water from land is the near-infrared and middle-infrared regions at wavelength between 0.75 μm – 2.35 μm. Previous studies also found that land/water interface is well defined in infrared spectral bands of Landsat Thematic Mapper images (Tao *et al*., 1993; Tittley *et al*., 1994).
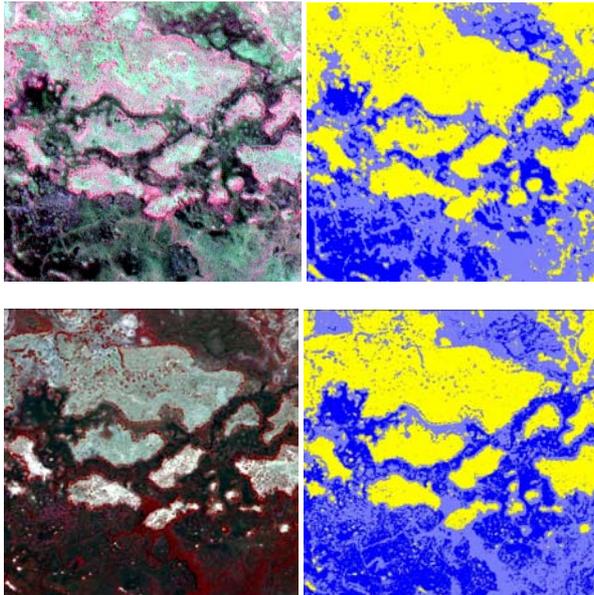
Figure 6. Upper: Left- Landsat 7 Pan (15m) and MS (30m) 4,3,2 band merge image (310 x 315 pixels); Right- classification result. Lower: Left- SPOT 5 Pan (5m) and XS (10m) 1,2,3 band merge image (929 x 943 pixels); Right- classification result.

Figure 6 shows the results of unsupervised classification of Landsat 7 ETM+ and SPOT 5 HRG merged images. Landsat 7 merged images are clustered into 5 clusters with ISODATA algorithms, then classified into three landscape/landcover classes. In case of SPOT 5 merged image, 9 clusters were generated using ISODATA algorithms, then categorise into three landscape/landcover classes. SPOT 5 merged image classification results in more detail information and more sharper object boundaries than Landsat 7 merged image classification. However, SPOT 5 merged image produces more spatial heterogeneity. Visual inspection and existing maps are used to examine the classification results.
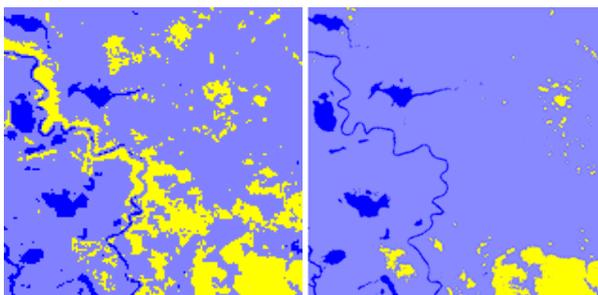
Figure 7. Left: Result of Landsat 7 merge image classification (Pan and band 4,3,2 combination); Right: Result of SPOT 5 merge image classification (Pan and band 1,2,3).

Figure 7 shows the results of supervised classification of Landsat 7 and SPOT 5 merged images for linear feature and water body feature extraction. SPOT 5 merged image provide better accuracy in extracting channels and open water bodies. Very sharp boundaries of these features can be extracted. Due to low spatial resolution, Landsat 7 merged image don't

provide detail spatial information in comparison to SPOT 5 merged image. The accuracy of classification is evaluated using visual inspection, field knowledge as well as existing map information.

5. CONCLUSIONS

Satellite remote sensing images provide a valuable tool for identification and characterisation of wetland features and related land cover types. The synergistic use of images from different sensors with varied spatial and spectral resolutions have the potential for better extraction and classification of features. Extraction and classification of landscape and land cover features from multispectral images as well as different resolution merged images of Landsat 7 ETM+ and SPOT 5 HRG sensors over the Okavango delta shows that classification accuracy and detail information content increases with increasing spatial resolution. Thematic information extraction was carried out using supervised and unsupervised classification to produce wetland landscape/ land cover classes for different spatial resolution data set. The results indicate that as spatial resolution increases, high spatial frequency landscape/land cover features are extracted in increasing detail. However, increase in spatial resolution also increases spatial heterogeneity. Further investigation need to be carried out by extracting texture features from panchromatic images and merging them with multispectral images. The segmentation and classification of texture merged image have potentiality to increase classification accuracy.

REFERENCES

Anderson, J.R., Hardy, E.E., Roach, J.T. and Witmer, R.E., 1976. A land use classification system for use with remote sensor data. U.S. Department of the Interior, U.S. Geological Survey Professional Paper 964, Washington D.C.

Ashton, P. and Neal, M., 2003. An Overview of key strategic issues in the Okavango basin. In: *Tranboundary River, Sovereignty and Development: Hydropolitical Drivers in the Okavango River Basin,* Turton, A., Ashton, P. and Cloete, E. (Eds.), AWIRU & Green Cross International, Pretoria & Geneva, pp. 31-63.

Bailey, A., 1998. *Okavango: Africa's Wetland Wilderness*. Struik Publishers (Pty) Ltd., Cape Town, SA.

Forstner, W., 1992. Fusing information in remote sensing. Invited paper, *XVII ISPRS Congress*, Washington D.C.

Hughes, F.M.R., 1996. Wetlands. In: *The Physical Geography of Africa*, Adams, W.M., Goudie, A.S. and Orme, A.R. (Eds.), Oxford University Press, Oxford, UK, pp. 267-286.

McCarthy, T.S., Cooper, G.R.J., Tyson, P.D. and Ellery, W.N., 1998. Seasonal flooding in the Okavango delta, Botswana – Recent history and future prospects. *South African Journal of Sciences* 96, pp. 25-33.

Pohl, C., 1999. Tools and methods for fusion of images of different spatial resolution. In: *International Archives of Photogrammetry and Remote Sensing*, Valladolid, Spain, Vol. 32, Part 7-4-3 W6, pp. 7-11.

Pohl, C. and van Genderen, J.L., 1998. Multisensor image fusion in remote sensing: Concepts, methods and applications. *International Journal of Remote Sensing*, 19(5), pp. 823-854.

Ross, K., 1987. *Okavango: Jewel of the Kalahari*. BBC Books, London.

Tao, Q., Lewis, A.J. and. Braud, D.H., 1993. Change detection using multi-temporal feature space with digital TM Data. In: *Proceedings of 1993 ACSM/ASPRS Annual Convention and Exposition (Volume 2),* New Orleans, Louisiana, February 15-18, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, pp. 364-373.

Tittley, B., Solomon, S.M. and Bjerkelund, C., 1994. The integration of Landsat TM, SPOT, and ERS-1 C-Band SAR for coastal studies in the MacKenzie River Delta, NWT, Canada: A preliminary assessment. *Proceedings Second Thematic Conference on Remote Sensing for Marine and Coastal Environments*, January 31-February 2, New Orleans, LA, pp. I.225-I.236.

UNDP, 1976. Investigation of the Okavango as a Primary Water Resource for Botswana. Technical Report to United Nations Food and Agricultural Organization, UNDP/FAO, BOT/71/506, 3 Vols.

Wulder, M., Niemann, K.O., and Goodenough, D.G., 2000. Local maximum filtering for the extraction of tree locations and basal area from high spatial resolution imagery. *Remote Sensing of Environment*, 73, pp.103-14.