UGANDAN DAMBO WETLAND CLASSIFICATION USING MULTISPECTRAL AND TOPOGRAPHIC REMOTE SENSING DATA

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ABSTRACT

The seasonally saturated dambo wetlands of Central and Southeastern Africa are likely a substantial source of methane (CH_4), an important greenhouse gas. Dambo soil, vegetative, and hydrologic characteristics vary along a gradual topographic gradient; from relatively dry uplands, to occasionally inundated margins, to more frequently inundated floors, to perennially inundated bottoms. CH_4 production presumably also varies along the gradient from uplands to bottoms, making mapping dambo topography an important first step in determining regional dambo methane production. Multispectral remote sensing data and topographic attributes were used to map upland, margin, floor, and bottom classes of dambo wetlands in a 2,200 square kilometer study area located in central Uganda. Two Système Pour l'Observacion de la Terre (SPOT) 4 multispectral scenes were acquired to coincide with the beginning and end of the January-to-March dry season in the study area. Spectral indices and spectral mixture modeling fractions were calculated for both SPOT scenes. Phenological changes occurring within each dambo class were quantified by comparing remote sensing metrics in each SPOT scene. Multispectral metrics were combined with topographic data from the Shuttle Radar Topography Mission (SRTM) using a binary decision tree (BDT) to classify the study area into upland, margin, floor, and bottom classes. Field data were used for training the classifier and assessing the accuracy of the final classification. This classification will be used to locate methane emission sampling sites within the study area as part of the first region-scale dambo methane emissions modeling project.

BACKGROUND

The anaerobic microbial decomposition of biomass that occurs in wetlands makes them the largest natural source of atmospheric CH_4. Wetlands are responsible for 20-45% of the total annual global emissions of CH_4 (Shindell et al., 2004), and CH_4 is approximately 20 times as effective a greenhouse gas as carbon dioxide (CO_2) on a molecular level (Rodhe, 1990; Faulkner, 2004). CH_4 emissions from wetlands in the tropics are among the least understood (Bartlett and Harriss, 1993), adding to the significance of this research.

"Dambo" is one of several dialectal terms used to describe the seasonally saturated, grassy, narrow depressions covering as much as 20% of the plateau regions of Central and Southern Africa (Bullock, 1992; Mäckel, 1974). While most dambo wetlands are waterlogged for at least a portion of the year, many of them dry out at the surface during the four- to six-month dry season typically found in semi-arid Africa (Acres et al., 1985). However, the "sponge-like" center of most dambos stays moist even during the dry season, sustaining the higher-density herbaceous vegetation in this zone (Mäckel, 1985). The relatively planar topography (½ – 2° slope) typical of dambo wetlands produces little hydraulic energy, which in turn facilitates soil saturation and inhibits channel formation (Acres et al., 1985; Von der Heyden, 2004).

Figure 1. Dambo cross-section

Dambo vegetation and soil types vary, but researchers have identified certain patterns characteristic of the landforms. Acres et al. (1985) used vegetation, soil type, and topography to identify three general zones within a dambo: the margin, floor, and bottom (Figure 1). The margin, at the perimeter of a dambo, is the transition zone from higher, often wooded terrain to grasslands that gently slope toward the center of the wetland (Von der Heyden, 2004). The dambo floor is a continuation of the grassland that transitions to sedges and other herbaceous plants near the bottom. At the center of the idealized dambo is the bottom, an area usually only suitable as habitat for those plants adapted to saturated soils. Because inundation varies according to these dambo zones, becoming progressively wetter from margin to bottom, distinguishing between them is essential to modeling methane emissions. The purpose of this project was to use remotely sensed information to classify dambo wetlands within a study area in Uganda, resulting in an accurate map for use in subsequent region-scale methane emissions measurement and modeling.

METHODS

This landscape classification designated each 20 meter pixel within a study area as bottom, floor, or margin, with the addition of an upland class for the surrounding terrain. The 2,200 sq. km. study area (Figure 2) was selected from a remote region of central Uganda bounded by the Mayanja and Lugogo Rivers. The study area demonstrated the topography, climate, and vegetation typical of African dambos. Additionally, the site offered a range of elevation and precipitation patterns in a relatively compact area, hopefully allowing for broader application of the methane model that will result from future research.

Field sampling of the dambo classes occurred in January and February, 2007, during one of the annual dry seasons typically experienced in the study area. The 236 sites sampled (Figure 2) during the field campaign were chosen in one of two ways. First, to capture dambo wetlands on multiple scales, a stratified random sample set was selected according to stream order. Second, samples were taken opportunely as they were observed within the study area. Two sampling techniques were also employed; one recorded the location of relatively homogeneous areas representing each of the dambo classes, and one focused on variation by measuring the extent of each class along transects running perpendicular to hydrologic flow.

Dambo classes were identified in the field according to a combination of soil, topography, and vegetation characteristics (Table 1). Bottoms were readily identified by their distinctive hummocky micro-topography and frequent inundation, margins were distinguished by sandy surface soils and slope measurements in excess of 2%, and uplands were categorized by their reddish soils according to Munsell chroma and hue. Because floors exhibited fewer unique soil or slope characteristics, they were identified by not belonging to any other class. In practice, flat, grassy terrain and the absence of hummocks were generally indicative of dambo floors.

Several sources of remotely sensed topographic and multispectral image data served as inputs to the classification (Table 2). Two four-band Système Pour l'Observacion de la Terre (SPOT) 4 satellite images, captured December 10, 2006, and February 21, 2007 (Figure 2), provided the primary inputs and set a standard spatial resolution for the classification of 20 meters. The SPOT images were also used to calculate two vegetation indices, the Normalized Difference Vegetation Index (NDVI; Rouse et al., 1973) and the Normalized Difference Infrared Index (NDII; Hunt and Rock, 1989). Endmember fractions resulting from a spectral mixture analysis (SMA; Adams et al., 1993), specifically, the percentages of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV)/soil, and shade for each SPOT pixel, provided additional vegetation-related inputs. The differences between the vegetation index and SMA values for the two SPOT scenes were also included in the classification to observe phenological changes that occurred during the dry season. To measure the spatial heterogeneity of a given variable, the classification also included the standard deviation within nine-pixel neighborhoods for each input.

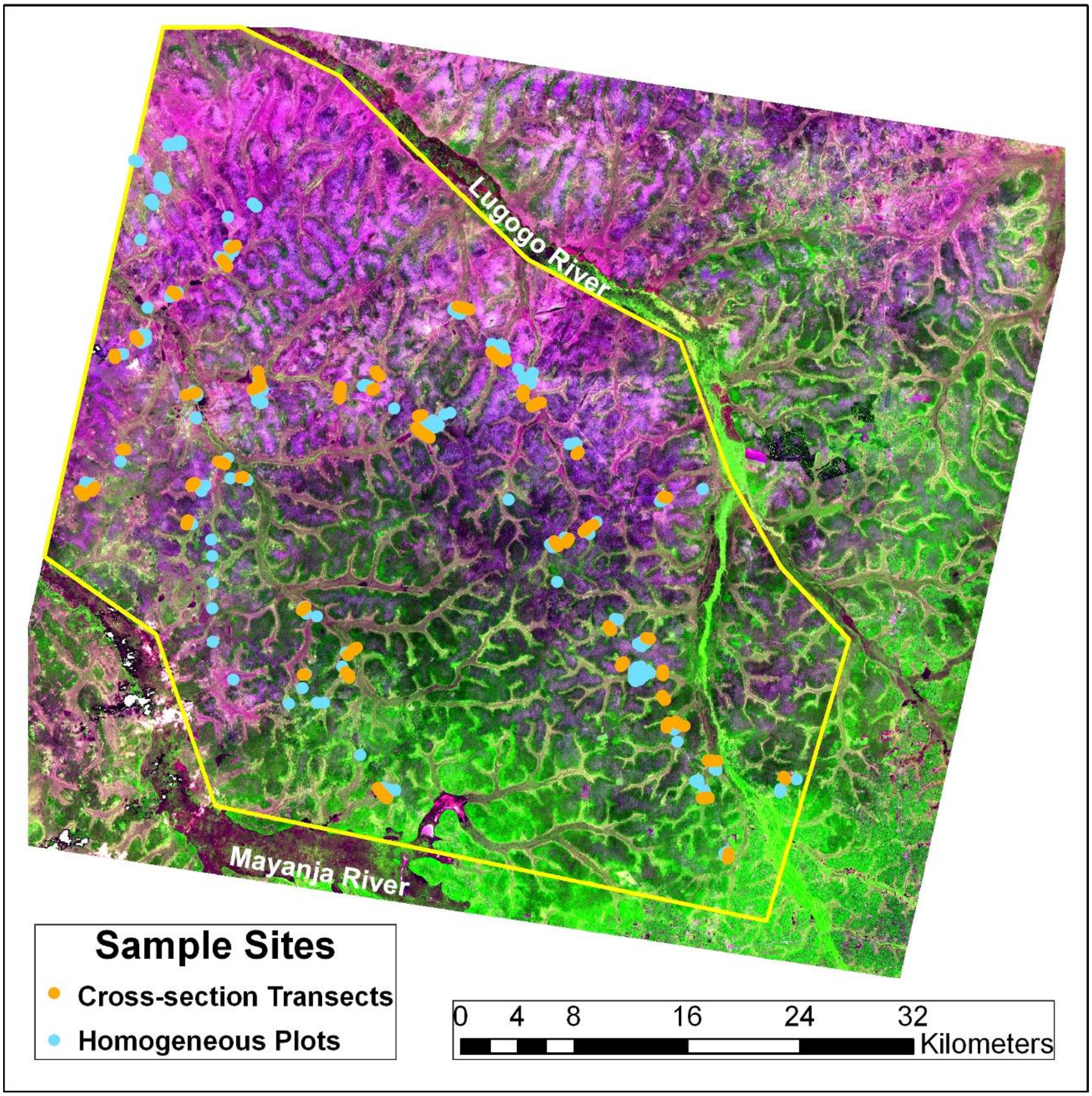

Figure 2. Study area with sample sites overlaid on the February SPOT 4 image
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Table 1. Field identification criteria

Dambo Class	Identification Criteria
Upland	Surface soil Chroma ≥ 4 and Hue ≤ 7.5 YR, or Chroma ≥ 3 and Hue ≤ 5 YR
Margin	Slope > 2%
Floor	NOT Upland, Margin, or Bottom
Bottom	Hummocky microtopography

Digital elevation model (DEM) data obtained from the Shuttle Remote Topography Mission (SRTM) provided the base topographic input for the classification. Prior to resampling, these 90-meter resolution DEM data were also used to calculate percent slope and a series of ranked relative elevation layers. Relative elevation was calculated as the rank of a given pixel within a moving window, with window sizes from 11 to 201 DEM pixels (roughly 1 km to 18 km). Inclusion of these relative elevation layers was intended to improve dambo classification by distinguishing topographic variation at multiple spatial scales.

Finally, northing and easting values from the projected coordinate system, Universal Transverse Mercator (UTM), were inputs to the classification. These coordinates were chosen to serve as a proxy for climatic gradients, particularly precipitation, which vary spatially across the study area.

The field samples for each dambo class were then randomly subdivided into training and accuracy assessment sets for the classification. As is typical for a supervised classification, the training set provided the locations for which pixel values were extracted from corresponding areas of each input variable. These extracted values were evaluated using the "tree" package (Ripley, 2006) developed for the statistical software R to construct a binary decision tree (BDT) classifier (Figure 3).

BDTs consist of a series of "nodes" and "branches," composed of classification input variables and connections, respectively. As pixels from the input layers progress through the tree, they are sorted at the nodes by comparing their value for a given variable with a threshold value established by a decision rule. They eventually arrive at a terminal node and are thereby assigned to a specific class. In the case of the dambo wetland classifier, uplands were identified exclusively by relative elevation. Slope, SPOT bands, vegetation indices, and UTM northing values were used to classify bottoms, floors, and margins.

Table 2. Classification input variables
(*denotes decision tree node)

Multispectral Inputs	Topographic Inputs
SPOT 10 Dec 06	*SRTM Elevation Data*
Band 1: green	DEM
Band 2: red	Slope*
Band 3: near infrared	Relative elevation 11
Band 4: short-wave infrared	Relative elevation 21*
SPOT 21 Feb 07	Relative elevation 31
Band 1: green	Relative elevation 41
Band 2: red	Relative elevation 51
Band 3: near infrared	Relative elevation 61
Band 4: short-wave infrared*	Relative elevation 71
Vegetation Indices	Relative elevation 81
NDVI Dec	Relative elevation 91
NDVI Feb	Relative elevation 101
NDVI difference*	Relative elevation 111
NDII Dec	Relative elevation 121
NDII Feb*	Relative elevation 131
NDII difference	Relative elevation 141
Spectral Mixture Analysis	Relative elevation 151
PV Dec	Relative elevation 161
NPV Dec	Relative elevation 171
Shade Dec	Relative elevation 181*
PV Feb	Relative elevation 191
NPV Feb	Relative elevation 201
Shade Feb	*UTM Coordinates*
PV difference	Northing*
NPV difference	Easting
Shade difference	

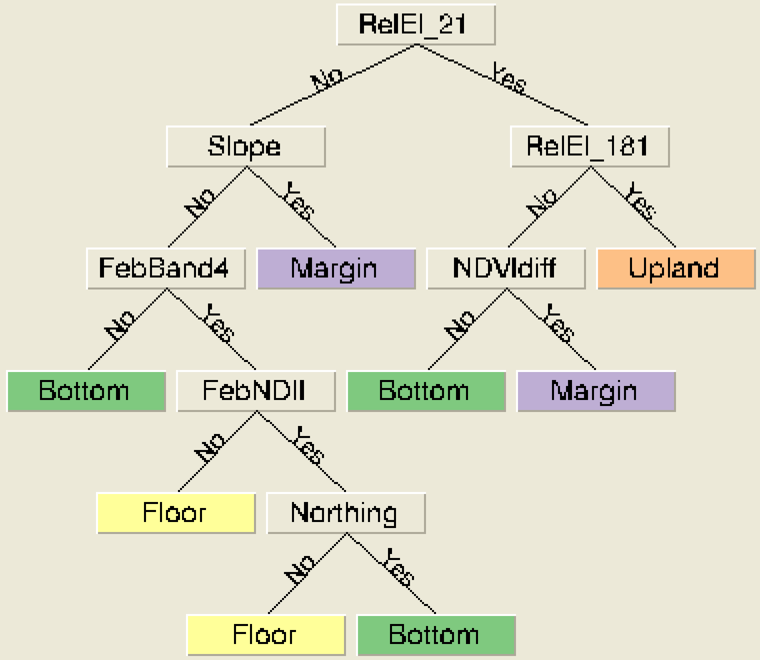

Figure 3. Binary decision tree classifier

RESULTS

The BDT classification resulted in a reasonably accurate dambo class map from a qualitative perspective (Figure 4). In general, the mapped dambo classes corresponded with the spatial patterns described in the literature and observed in the field. Bottoms were identified in the central, lowest portions of larger drainages, with floors, margins, and uplands surrounding them in succession. The classification was less accurate beyond the boundaries of the study area where field samples were not obtained. In these areas, floors and margins tended to be overclassified. Within the wider Lugogo, Towa (center left), and Mayanja River channels, bottoms were occasionally misclassified as upland or margin. In quantitative terms, the classification resulted in an overall accuracy of 75.5% and a Kappa coefficient of 0.67. Subdividing the accuracy assessment set in a confusion matrix (Table 3) revealed that uplands were the most readily identifiable class. Confusion with adjacent classes was the most common error among all of the classes.

Table 3. Pixel-level confusion matrix for BDT classification

		Ground Truth				**Producer's Accuracy**
		Bottom	*Floor*	*Margin*	*Upland*	
Classified	*Bottom*	**520**	142	88	22	67.36%
	Floor	130	**1002**	232	0	73.46%
	Margin	56	258	**1159**	294	65.59%
	Upland	0	0	102	**1396**	93.19%
User's Accuracy		73.65%	71.47%	73.31%	81.54%	

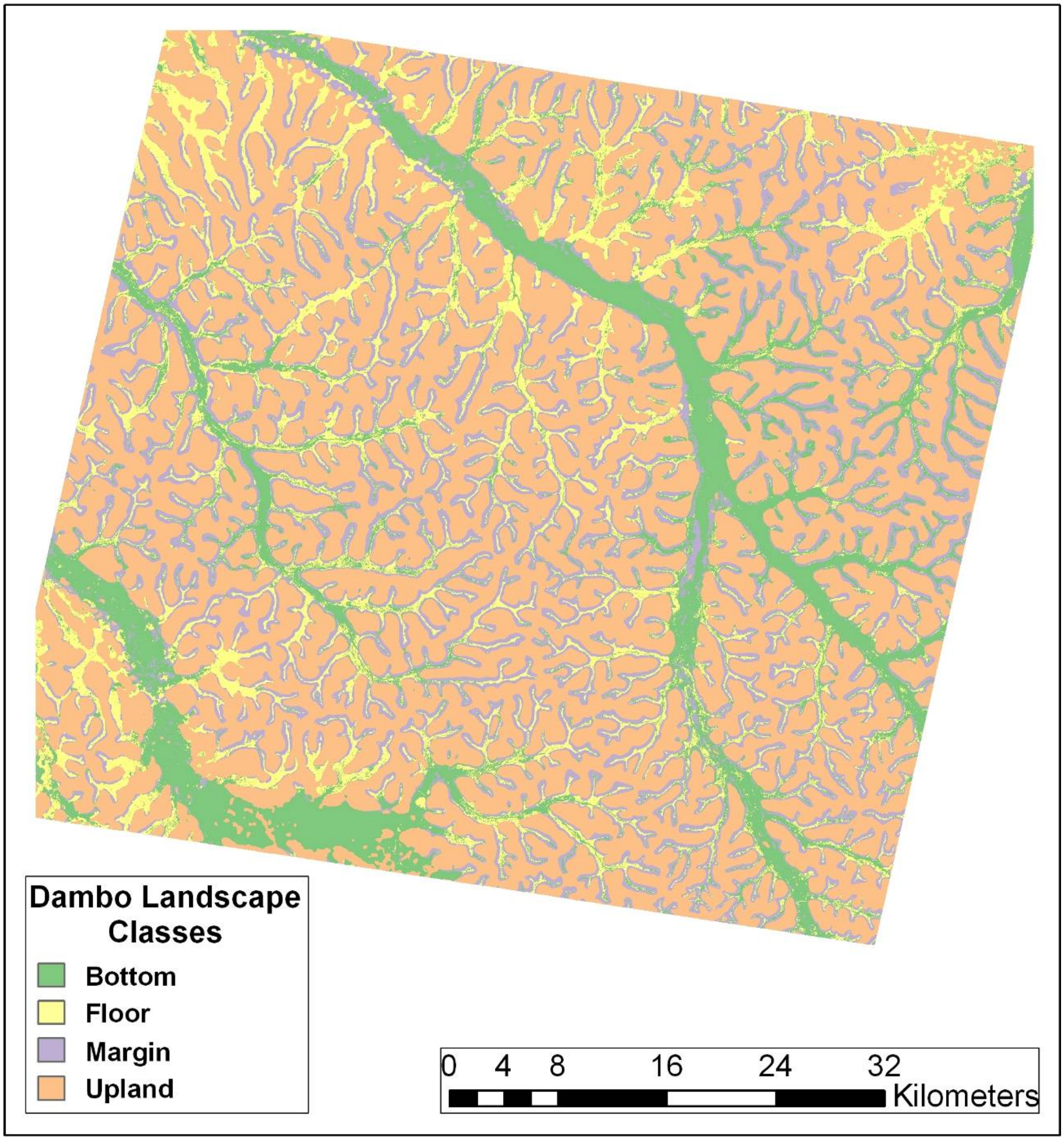

Figure 4. Dambo class map of study area

DISCUSSION

Given the relationship between topography and hydrology, it was not surprising to learn that elevation data would play a major role in this landscape classification. Uplands were identified only by elevation, with both fine- and coarse-scale relative elevation being selected for the decision tree. DEM-derived slope was used to distinguish the relatively steep margin class from the flatter bottoms and floors. Future work could benefit from the use of higher-resolution DEM data. Were these data available, the accuracy of the classification would likely increase, while the need for additional optical remote sensing inputs might decrease.

With the relatively coarse elevation data used in this study, however, vegetation-related variables served as important inputs to the classification. Drier margins were distinguished from wetter bottoms by the phenological change detected in the NDVI between December and February. Shortwave Infrared (SWIR) reflectance, the fourth band provided by SPOT 4 imagery, appears to be important for discriminating floors from bottoms, with two SWIR variables selected for the decision tree. NDII, also a measure of water content that was used to distinguish floors from bottoms, is calculated using the Near Infrared (NIR) and SWIR bands. The SWIR band may have been important because it experiences large changes in reflectance due to grass senescence. The UTM northing input's significance may be due to climatic variation within the study area. A marked latitudinal difference in green vegetation and standing water was observed while conducting field work. This variation may be linked to precipitation gradients and a general decrease in elevation moving from south to north in the study area.

The results of this first-of-its-kind classification of dambo wetlands were promising. However, the classifier did not appear to perform as well outside of the study area where no sampling occurred. Further refinement of the classifier will likely be required if it is to be applied in other areas. Due to the range of vegetation and topography found in the areas of dambo occurrence, it may not be possible to develop a universal dambo wetland classification technique. In spite of this fact, this classification delineated dambo extents within the study area accurately enough to proceed with the intended methane emissions measurement and modeling. These efforts will provide an estimate of dambo contributions to global methane emissions. In addition, this work will add to the understanding of the interplay between dambo methane production, hydroclimate, and anthropogenic land cover change.

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