Assessing the distribution of wetlands over wet and dry periods and land-use change on the Maputaland Coastal Plain, north-eastern KwaZulu-Natal, South Africa

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Abstract

The Maputaland Coastal Plain (north-eastern KwaZulu-Natal) hosts an array of wetlands that provide valuable ecosystem services to an increasing population and tourism demand. The apparent distribution of wetlands varies in response to periods of water surplus or drought, and over the long-term has been reduced by resource (e.g. agriculture, forestry) and infrastructure (e.g. urbanisation) development. This study used Landsat TM and ETM imagery acquired for 1992 and 2008 (dry) and Landsat ETM for 2000 (wet) along with ancillary data to 1) identify and map permanent and temporary (inland) wetlands and open water based on their spatial extent and distribution during wet and dry years; and 2) determine wetland loss from land-use changes due to cultivation, plantation and urbanisation using imagery between 1992 and 2008. In 1992 (dry) the smaller wetland extent primarily identified "permanent" groundwater-fed wetland systems, whereas for the wet year (2000) both "temporary" and "permanent" wetlands were indicated. Comparison between both dry years (1992 and 2008) indicates an 11% decrease in wetland (sedge/moist grassland) and a 7% increase in grassland distribution over time. Some areas that appear to be grassland in the dry years are actually wetland, based on the larger wetland extent (16%) in 2000. Swamp forest wetlands were difficult to map and needed the support of ancillary data. Minor expansion of urban areas (0.87%) and the change in plantation and cropland distribution also replaced some wetlands. The 2008 Landsat TM dataset classification for the entire Maputaland Coastal Plain gave an overall 80% mapping accuracy.

1. Introduction

Land-use activities such as agriculture (croplands), forestry (plantations) and water supply schemes on the Maputaland Coastal Plain (MCP) and prolonged periods of drought have reduced the availability of groundwater (Rawlins and Kelbe, 1998), which can impact the distribution of wetlands in these groundwater-dependent ecosystems (Colvin et al., 2007). The consequences are progressive landscape degradation, shrinkage and damage to remaining wetland ecosystems, increasing water scarcity and water access problems (Grundling, 2011) as well as a decrease in natural biodiversity on anthropogenically altered wetland sites (Grobler et al., 2004; Sliva, 2004).

The aeolian sands of the MCP are leached and low in nutrients, resulting in low agricultural potential (Watkeys et al., 1993), so local communities heavily rely on wetlands for their daily livelihood, especially on peat-dominated wetlands such as swamp forests (Grundling, 2000; Sliva, 2004). However, significant land-use pressures occur from both cultivation and forest plantations (Grundling et al., 1998) that affect both permanent wetlands (including swamp forests) and the temporary sedge/moist grassland wetlands on the MCP, while urbanisation impacts wetlands, for example, through infrastructure development (Cuperus et al., 1999).

Land-cover maps generated from remotely sensed imagery are used in numerous natural resource applications to assess, map and monitor the spatial distribution and pattern of land-cover classes such as open water and wetlands, as well as land-use classes like croplands, plantations or urban areas. The applications include the estimation of areal extent of various land-cover classes, land-cover change analysis and input layers for hydrological models (Stehman and Czaplewski, 1998). Wetland inventory and classification can provide information on wetland location, areal extent and wetland types within a landscape (Finlayson and van der Valk, 1995), whilst wetland assessment entails detailed evaluation of how a specific wetland or range of wetlands function by describing the ecological processes the wetland performs such as flood reduction or groundwater recharge (Smith et al., 1995; Kotze et al., 2007). Satellite sensors such as the Landsat Thematic Mapper (TM) (Zhang et al., 2011) and Landsat Enhanced Thematic Mapper (ETM+) (Baker et al., 2006) have been used in wetland vegetation mapping projects. Remote sensing methods include the use of Landsat imagery for application over regional scales because of the high cost of high resolution imagery (Jensen, 2005). However, wetlands are highly diverse ecosystems that have significant variability of physical properties. Seasonal wetlands or ephemeral features, marginal and degraded wetlands are often missed in wetland mapping procedures (Ramsey and Laine, 1997; Baker et al., 2006). However, remote sensing coupled with ancillary data sources such as a digital elevation model, vegetation and soil maps, etc., can be used to extract thematic information to characterise wetland type, extent, distribution and condition (Brooks et al., 2004; Jensen, 2005; Baker et al., 2006; Nagabhata et al., 2012).

The South African National Wetland Inventory (NWI) version 3 was incorporated in the National Freshwater Ecosystem Priority Area (NFEPA) wetland types layer (Nel et al., 2011) but some wetland areas in South Africa are still insufficiently mapped such as wetlands found in woodlands and savanna in lower altitude areas in KwaZulu-Natal, Limpopo and Mpumalanga provinces (NLC2000 Management Committee, 2008). Various wetland mapping initiatives for KwaZulu-Natal (KZN) have been created using different mapping methods and scales, including the KZN Wetland layer (Scott-Shaw and Escott, 2011), KZN Land-Cover 2005 and 2008 (GeoTerraImage, 2006; Ezemvelo KZN Wildlife, 2011). However, these datasets do not indicate whether wetland dynamics (extent and distribution) are related to seasonal and/or extreme rainfall events or whether they have well defined and relatively fixed boundaries. For example, Grundling et al. (2000) and Sliva (2004) described the nature of swamp forests on the MCP as lower-lying interdune, valley bottom areas associated with drainage lines, underlain by low-permeability sediments, which receive sustained ground- or surface-water inflow. Groundwater seepage elevates the water table sufficiently in the valley bottoms, which results in permanently wet conditions and the promotion of peat accumulation (Grobler et al., 2004; Grundling et al., 2012b). These can be described as "permanent wetlands", and have a relatively fixed boundary. On the other hand, temporary sedge/moist grassland wetlands occur on the deep sandy soil in areas where the water table fluctuations are greater; conditions which are not ideal for the development of peat. These can be referred to as "temporary wetlands", whose boundaries may appear to grow or shrink in wet or dry periods, potentially causing their area to be underestimated in periods of water shortage. During very wet years, some areas including wetlands can be temporarily inundated with pools of open water for a short period. These can be described as "temporary open water". In contrast, there are "permanent open water" areas including the Kosi Bay lake system and smaller lakes such as Lake Shengeza.

Currently, the distribution and inter-annual variability of MCP wetlands are poorly documented, but the variability of their wetted extent provides an opportunity to assess their relative permanence, hence part of their form and function. This, along with the extent of ecological change resulting from land-use change and environmental degradation is unknown. Monitoring wetland dynamics is required to inform and support management and decision making related to natural resource utilisation including access to groundwater resources by local communities, outbreak of water-borne diseases like malaria and cholera, and determination of land-use zoning and planning for sustainable resource use. Therefore, the aim of this paper was to use Landsat TM and ETM imagery along with ancillary data to 1) identify and map "permanent" and "temporary" (inland) wetlands and open water of the MCP based on their spatial extent and distribution during wet and dry years; and 2) determine wetland loss from land-use changes due to cultivation, plantations and urbanisation between 1992 and 2008.

2. The Study Area

The MCP is situated in north-eastern KwaZulu-Natal, South-Africa (Figure 1). The area covers approximately 943000ha and stretches from the Mozambique border in the north to the town of Mtunzini in the south and is bordered by the Indian Ocean on the east and the Lebombo Mountain range to the west. The MCP is characterised by sandy soils and an undulating dune landscape on a low-lying coastal plain (Momade et al., 2004). The area has a subtropical climate with hot and humid summers and mild winters (Taylor, 1991). In summer (November to March), the mean annual temperatures exceed 21ºC and the area receives 60% of the annual rainfall (Mucina and Rutherford, 2006). The maximum potential evaporation is 1900 mm per annum (Mucina and Rutherford, 2006). The study area in the northern part of the MCP is a combination of 79% unspecified or subsistence agriculture in the Tembe Tribal area (iSimangaliso Wetland Park, 2008), while 21% is protected conservation area that includes the iSimangaliso Wetland Park in the east and the Tembe Elephant Park in the west (SANBI, 2009) (Figure 1A).

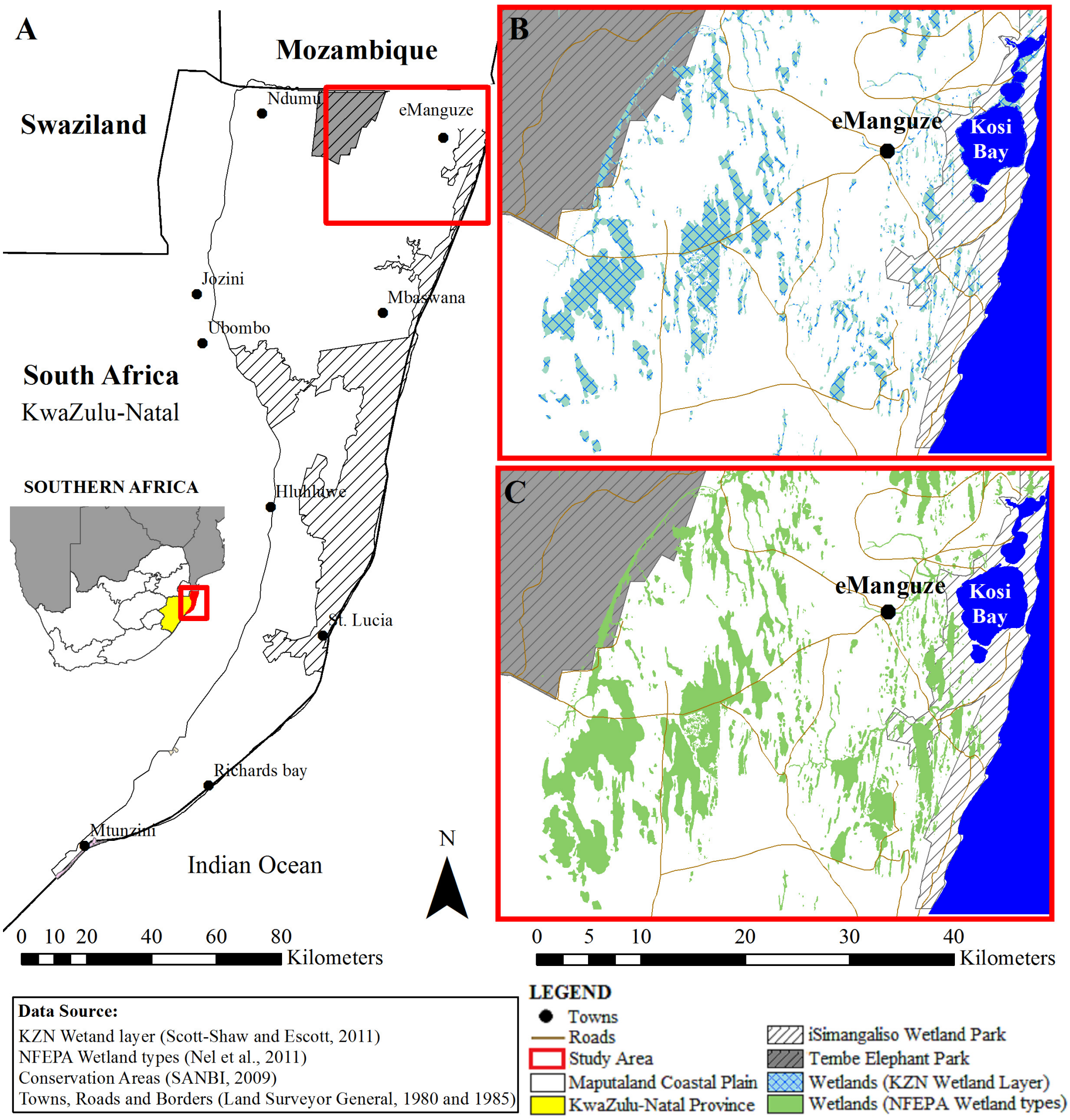

Figure 1. A) Regional map of the Maputaland Coastal Plain in South Africa and study area location. Study area indicating the KZN Wetland layer (B) and NFEPA Wetland Layer (C)

The MCP is characterised by cover sands with north-south orientated parabolic dunes on the coastal plain (Whitmore et al., 2003) and drainage systems feeding the coastal lakes such as the Kosi Bay lake system (Porat and Botha, 2008). Surface water bodies include rivers, floodplains, estuaries, pans and coastal lakes (Botha and Porat, 2007). These wetlands include peatlands, swamp forests, reed swamps, and sedge/grass wetlands (Taylor, 1991; Porat and Botha, 2008). Figure 1B indicates the subtropical freshwater wetland distribution in the study area based on the KZN Wetland layer (Scott-Shaw and Escott, 2011); Figure 1C indicates wetland types based on the NFEPA layer (Nel et al., 2011). Although the KZN Wetland layer and the NFEPA wetland type layer show the extent and distribution of wetlands, they do not indicate whether the wetlands are permanent or temporary systems.

3. Methodology

3.1. Rainfall Data

The total monthly rainfall data for the northern study area was acquired from the ARC-ISCW (2011) for the period January 1998 to December 2012 (Figure 2). The long-term rainfall indicates high summer rainfall from October to March and lower winter rainfall from April to September with average rainfall 94 mm/month (summer period) and 30 mm/month (winter period). Rainfall data were grouped monthly and annually to determine dry and wet years to facilitate satellite imagery selection. Landsat TM imagery was acquired for both 1992 and 2008 (dry), and Landsat ETM for 2000 (wet) years. The selection of 2000 (wet) was made because it was the only distinctly wet year in the period of record (Figure 2). Less than average rainfall was received from 2002 to 2012, when the average annual rainfall (586 mm) was far below the long-term average rainfall of 753 mm (measured over the previous 23 years) (Figure 2).

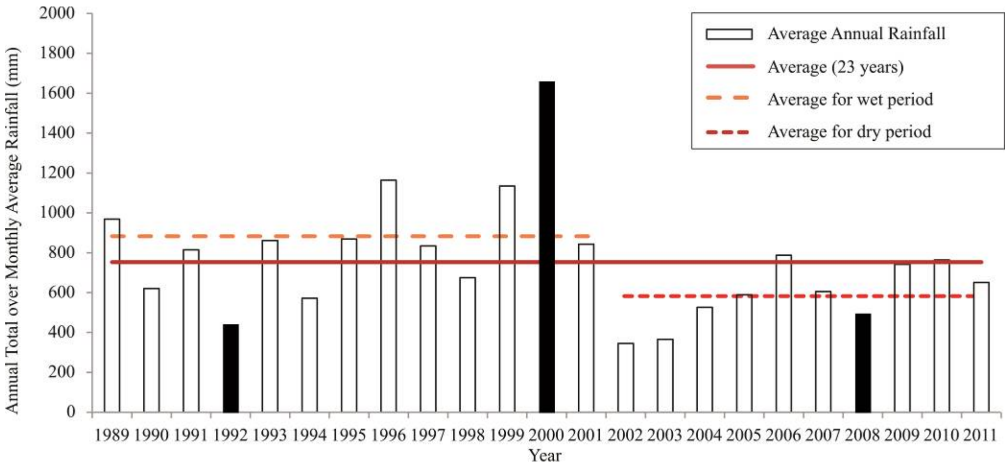

Figure 2. Average annual rainfall highlighting (in black) the wet year (2000) and dry years (1992 and 2008).

3.2. Wetland and Land-Use Mapping

3.2.1. Data Preparation

The moderate resolution Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper (ETM) data (30 m x 30 m pixel) were used to map the extent of wetlands in dry and wet years. The three assessment years (1992, 2000 and 2008) were selected from the Landsat imagery archive (USGS Global Visualization Viewer, 2010) and acquired through the former Satellite Application Centre. The decision to choose Landsat 1992 (dry year), 2000 (wet year) and 2008 (dry year) imagery was primarily made on the basis of 1) representation of wet/dry rainfall conditions; 2) availability of images with limited cloud or cloudless conditions; and 3) the images acquired were for the driest month of the requisite year (winter) (July 1992 and September 2000 and 2008).

The 1992, 2000 and 2008 Landsat images were orthorectified using the 90 m x 90 m Shuttle Radar Topography Mission (SRTM) DEM (CGIAR-CSI, 2008) and 2002 Global Land Cover network Landsat images as base maps. The orthorectification was done in the original UTM (Universal Transverse Mercator; Datum World Geodetic System 84) projection after which it was re-projected to the Geographic (Datum World Geodetic System 84) projection. Towns, roads, borders (Land Surveyor General, 1980, 1985) and conservation areas (SANBI, 2009) were sourced, and the study area boundary defined.

3.2.2. Data Processing

Landsat images for three different years (1992, 2000 and 2008) were processed by using both un-supervised classification and vegetation indices using pixel-based classifiers in ERDAS Imagine software. The land-cover maps created for the study follows the classification scheme proposed for the Standard Land-Cover Classification for South Africa (Thompson, 1996). The South African National Land-Cover 2000 Project reported that the ERDAS ISODATA clustering classification method (ERDAS, 1999; Thompson et al., 2002) using all the available Landsat TM spectral bands works the best for wetlands and for other land-cover classes applied in the National Land-Cover 2000 initiative (Van den Berg et al., 2008). Therefore, an interactive self-organised clustering procedure (ISODATA) classification with 200 classes was created. The 200 classes were interpreted and merged into 14 preliminary land-cover classes before the initial field reconnaissance to create the first draft map. A field reconnaissance trip (21-25 February 2011) was used to select training sites representative of the different classes to be mapped. Only broad wetland, vegetation and land-cover classes were mapped. At each of the 378 observation sites, descriptive information was recorded, geographical positions were determined by means of a Global Positioning System (GPS) and a colour photograph taken at some of the points. The field data were processed and a spatial layer created containing all relevant information for each specific point. Since most of the land in the study area was in conservation areas or in very remote areas, access was limited and data were therefore collected mainly along major, secondary and tertiary roads depending on the visibility from the roadside edge. The land-cover classification map was created and classification improved using 1) the knowledge gathered during the field reconnaissance to evaluate the first draft classification; and 2) interpretation and refinement based on the information from selected classes from existing ancillary datasets (Table 1). The ancillary datasets were only used as guidelines, together with known verification sites, to create areas of interest to classify the different land-cover classes. All the datasets were cut to cover the full extent of the study area. The final classification scheme used for this study (Table 2) is similar to that proposed by Thompson (1996) and GeoTerraImage (2006), with modifications of the wetlands (sedge/moist grasslands) and swamp forest classes; their classification did not distinguish swamp forest from other forest classes, and was not recognised as a wetland class. Two statistical filters were applied to the classifications. In these filters, the middle pixel of the moving window is replaced by the predefined value (mean, median or maximum) of all the pixels within the window (ERDAS Field Guide, 2008). Firstly, a 3 x 3 maximum filter was applied, to assist in the connection of isolated pixels which formed part of linear features such as rivers or inter dune wetlands. Secondly a 3 x 3 median filter was applied to filter out very small areas which otherwise create a salt and pepper effect.

Table 1. Ancillary datasets used to assist in the land-cover classification interpretation

Datasets	Reference	Purpose
Vegetation map of South Africa, Lesotho and Swaziland	SANBI (2005)	To familiarise with the distribution of subtropical freshwater wetlands and swamp forests on the coastal lowlands
Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM)	CGIAR-CSI (2008)	To determine the elevation (height above sea level)
KwaZulu-Natal (KZN) province soil and terrain unit map	Van den Berg et al. (2009)	To use the valley bottom and foot slope terrain units. These are closely associated with wetlands occurrences
National Wetland Inventory (NWI) version 3 National Freshwater Ecosystem Priority Area (NFEPA) wetland types	Nel et al. (2011)	To familiarise with the distribution of different wetland types
KZN Wetland layer	Scott-Shaw and Escott (2011)	To re-classify of the forest classes (dune, sand, swamp and riverine classes)
KZN Land-Cover 2008	Ezemvelo KZN Wildlife (2011)	To familiarise with the distribution of wetland class

Table 2. Selected land-cover classes (adapted from: Thompson, 1996; GeoTerraImage, 2006)

Class No.	Class Name	Definitions (summarised)
1	Open water	All areas of open water
2	Wetlands (Sedge/moist grassland)	All permanent, temporary fresh water and brackish wetland areas with sedge and/or moist grasslands (i.e. excludes swamp forests)
3	Urban	All urban and built-up areas, irrespective of associated populated residential, commercial or industrial use that includes some mines and quarry areas
4	Grassland	Open grassland with shrubs smaller than 50 cm high (<10% canopy closure)
7	Cultivation	Identifiable areas of commercial, scattered or clustered, small-scale, dryland or wetland cultivation associated with rural dwelling
8	Plantations	All areas of timber plantations and temporary clear-felled stands awaiting re-planting within timber plantations
14	Swamp forest wetlands	Indigenous, dense, tall trees associated with a water source (i.e. river or stream) that grow in permanent wet areas associated with footslope and valley-bottom terrain units (landscape position where wetlands are more likely to occur) with >70% canopy closure

3.2.3. Data Analysis

The wetland maps created from the 1992 (dry), 2000 (wet) and 2008 (dry) imagery were used to map the temporal character of the wetlands and open water, based on previously established definitions that include: 1) Permanent wetland: these areas are permanently saturated (DWAF, 2005), with soil that is inundated or waterlogged throughout the year, in most years (Thompson et al., 2002). The vegetation is lush green and varies from tall trees (>70% canopy closure) associated with swamp forests, to reed and sedge wetlands and discontinuous permanent wet patches in depressions in the sedge/moist grasslands. 2) Temporary wetland: this refers to seasonal wetlands characterised by saturation for three to ten months of the year, within 50 cm of the surface (DWAF, 2005). This class also includes the temporary areas where the soil close to the surface (i.e. top 50 cm) is wet for periods >2 weeks during the wet season in most years (seldom flooded or saturated at the surface for longer than a month). It can remain dry for more than a year (Thompson et al., 2002). The vegetation cover of temporary wet areas can include moist grasslands with the presence of sedge species (Pretorius, 2011). In accordance with these previously established wetland definitions, for open water the following are added: 3) Permanent open water: inland areas with open surface water such as lakes that exist in all years except the most extreme dry conditions. 4) Temporary open water: areas where open surface water occurs only seasonally or in extremely wet years. For the temporal analysis two steps were used to describe the extent and wetness types (permanent or temporary) of wetlands and open water in the MCP. Firstly, an area comparison was made between the three years by overlaying the wetland and open water layers representing the different years. A script was used to calculate the sum value for the three years with each pixel value equal to one. If the total value for the three years was 3, it was considered to be a permanent wetland or permanent open water area. If the total value for the three years was 2 or 1, it was considered to be a temporary wetland or temporary open water area. The second step made use of a simple script in ERDAS to allocate class number to create a "wetness" map that distinguishes permanent and temporary wetlands and open water.

For land-cover change analysis all three datasets were used to describe the extent of wetlands and land-use classes during the three different years (1992, 2000 and 2008). Comparative tables were completed, summarising the area and percentages of the following land-cover classes over the three assessment years. Comparison between the three mapping years (1992, 2000 and 2008) was used to quantify the change within the landscape classes from one year to the next. Finally the wetness map (permanent and temporary wetland and open water product using all three years) was compared with the 2008 land-use map to quantify the wetlands that were impacted by land-use.

3.2.4. Accuracy Assessment

The accuracy assessment analyses were done using two methods:

1) Error Matrix

The land-cover accuracy statistics were calculated using an error matrix (confusion matrix) usually represented in terms of overall, user's and producer's accuracy to compare the land-cover classes derived from satellite image classification with referenced sample points acquired in the same year (Stehman and Czaplewski, 1998; Shao and Wu, 2008). The accuracy assessment data were collected from two independent datasets, the National Alien Invasive Plant Survey (NAIPS) databases (Kotze et al., 2010) and Google Earth satellite data (Google Inc., 2011). The NAIPS database points were produced using a stratification process that includes the use of NDVI and terrain unit classes, land-cover classes and bioregion information. The survey was performed in 2008 using a fixed-wing aircraft. A digital photo was taken at each point. Each point was assigned a land cover code using an interpretation of the photo and high resolution Google Earth satellite images. Dominant land-cover class in a 100 m x 100 m area was used for the accuracy assessment database. All classification accuracies were calculated on the final filtered version of the 2008 Landsat TM classification dataset for the entire Maputaland Coastal Plain that includes the smaller study area. A total of 1753 reference points were used to calculate the overall mapping accuracy. Accuracy results included overall land-cover classification accuracy as well as omission and commission error percentages for the full 2008 classification. No field verification data or high resolution satellite images were available for the 1992 and 2000 assessment years.

2) Land Cover Change Analysis

The land-cover change analysis used the Two-date Sequence Logic Review modelling procedure (Schoeman et al., 2010) to ensure compilation of comparable and standardised land-cover class allocations, prior to any year-on-year change analyses. A uniform grid (100 m x 100 m cells) over the study area was used to compare the three assessment years using Microsoft Access 2008 software. The 100 m x 100 m cell size was selected to correspond with the minimum mapping unit associated with the Landsat datasets. The land-cover class allocated to each cell represented the spatially dominant feature within that cell, as determined from the original land-cover mapping datasets for the three years. The database calculated changes in land-cover class between the different assessment years that are likely to occur and those that are not likely to occur based on a probability list with 132 probabilities. For example, if the pixel in the first and second assessment year was water, this is not likely to be a mapping error; but if it is water in the first assessment and woodland in the second assessment, then this is likely to be a mapping error. The changes are in percentage values, indicating the percentage of the original cells that have changed to another class.

4. Results

4.1. Permanent and Temporary Wetlands and Open Water Areas

The nature of the aquifer, topography and rainfall distribution (hydrogeomorphic setting) are related to the wetland distribution and temporal character. The topography (Figure 3A) reflects the regional geological template that slopes towards the east, and is superimposed by more recent dune formations. There is also a precipitation (rainfall) gradient; the rainfall decreases from east (>820 mm) to west (680 mm) (ARC-ISCW, 2009) (Figure 3B).

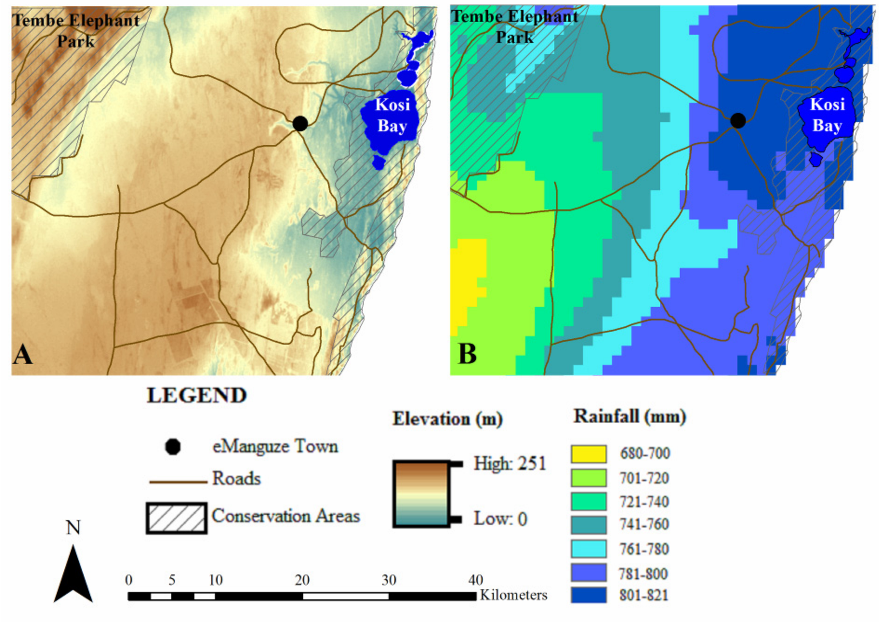

Figure 3. Elevation (A) and long-term rainfall distribution (B) of the study area.

A wetness map showing temporary and permanent wetlands and open water was created by overlaying the occurrence of swamp forest and sedge/moist grassland and open water classes for each year (1992, 2000 and 2008 shown in Figure 4A-C). Wetlands cover ~18% of the total study area. For 2000 (wettest year) this includes sedge/moist grassland (~16%) and swamp forest (~2%); open water comprises ~3% of the total study area including the Kosi Bay lake system (Table 3). The permanent wetlands (swamp forest, reed/sedge wetlands and a mosaic of discontinuous permanent wet patches in depressions within the sedge/moist grassland wetlands) comprise 15% of the total wetland and open water area, while temporary wetlands (sedge/moist grasslands) cover 72% of the total wetland and open water area (Figure 4D). The sedge/moist grassland wetlands on the uplands are flooded during large rainfall events (e.g. the floods in 2000). These wetlands can be temporarily inundated with open water during very wet years for a short period (Figure 4 D).

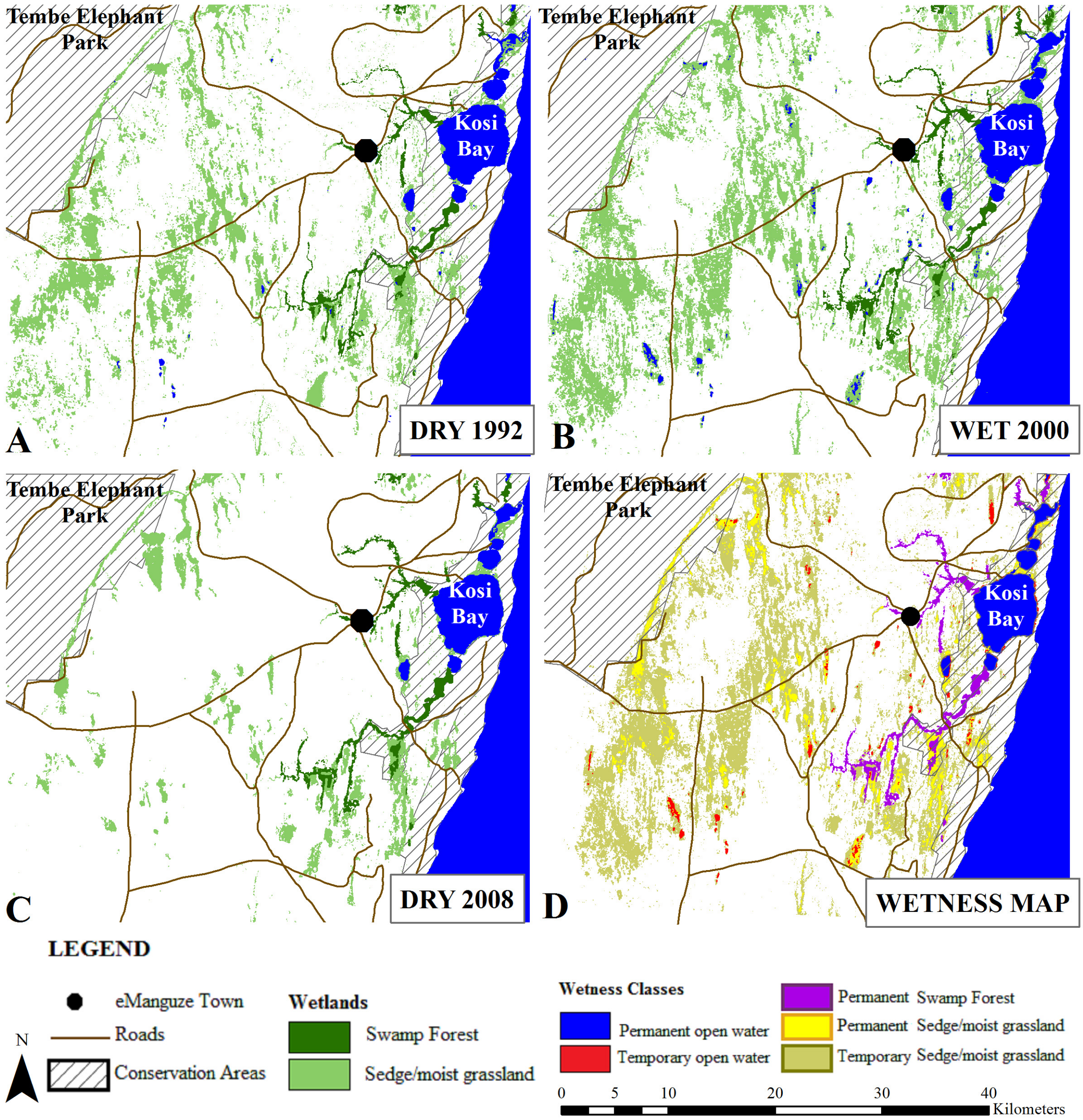

Figure 4. Wetland distribution in dry years (A and C), wet year (B) and wetness map with permanently-,temporary wetlands and open water areas (D)

Table 3. Selected land-cover class cover for 1992, 2000 and 2008 in percentage and hectares (ha)

Classes	**1992**		**2000**		**2008**	
	%	**ha**	**%**	**ha**	**%**	**ha**
Open water	2.48	4201	2.84	4781	2.34	3951
Wetlands (Sedge/moist grassland)	11.14	18845	15.97	26908	4.96	8373
Wetlands (Swamp Forest)	1.39	2352	1.58	2655	1.63	2751
Grassland	19.03	32202	16.98	28619	23.76	40089
Cultivation	17.16	29028	15.14	25523	11.12	18764
Plantations	6.96	11782	9.60	16176	8.85	14929
Urban	0.07	119	0.10	163	0.87	1472

4.2. Land-Cover Change Analysis: Wetland Loss and Land-Use Change

Figure 5 indicates the open water, grasslands, urban, cultivation and plantations classes for both dry years (1992 and 2008). These are only five of the eighteen land-cover classes mapped for the MCP. Table 3 summarises the results for open water, sedge/moist grass wetlands, swamp forests, grasslands, urban, cultivation and plantations classes mapped for all three years. Comparing the percentage area for all the land-cover classes for the entire study area in both the dry years (1992 and 2008), open water, swamp forest, plantations and urban areas all changed by less than 2.64% (Table 3). However, the plantation area (south) (Figure 5) had bare soil and clear-felled stands (areas awaiting re-planting in September 2008) that were not calculated in the plantation class for 2008. Accurate mapping of swamp forest was problematic, and the results in Table 3 shows that swamp forest cover slightly increased. However, swamp forest loss has been reported due to the slash-burn and draining of these systems for cultivation purposes (Grobler et al., 2004; Sliva, 2004). There was a slight increase in the urban and plantation classes (Table 3). In contrast, sedge/moist grassland wetlands, grasslands and cultivation areas changed considerably between dry years and between wet and dry years. The wetland (sedge/moist grassland) areas decreased from 11% in 1992 to 5% in 2008 (Table 3). The results for the wet year (2000) (Figure 4B) indicate a larger wetland extent (16%) (Table 3). Some of the areas that appear to be grassland in the dry years are actually wetland, based on the wet year image (2000). Grassland areas in dry years range from 19% (1992) to 24% (2008) (Table 3). Cultivation areas in 1992 were more (17%) than in 2000 (15%) and 2008 (11%) (Table 3). The cultivation, plantation and urban distribution pattern changed significantly from 1992 to 2008 (Figure 5A and B). Cultivated and urban areas became more prominent near the town of eManguze and the main road network instead of being dispersed throughout the landscape, while plantations spread across the study area (Figure 5B).

Results from comparing the known permanent and temporary wetland and open water areas (Figure 4D) with 2008 land-cover classes (Figure 5B) indicate that temporary sedge/moist grassland wetlands have been replaced by 883 ha of plantation. Urban development affected 96 ha of temporary and 31 ha of permanent sedge/moist grassland wetlands. Although cultivation areas were the lowest in 2008 (compared with 1992 and 2000) (Table 3), the importance of wetland utilisation for cultivation practices should not be overlooked as 4212 ha temporary sedge/most grasslands wetlands, 19 ha permanent wetlands and 37 ha temporary open water areas changed to cultivated area.

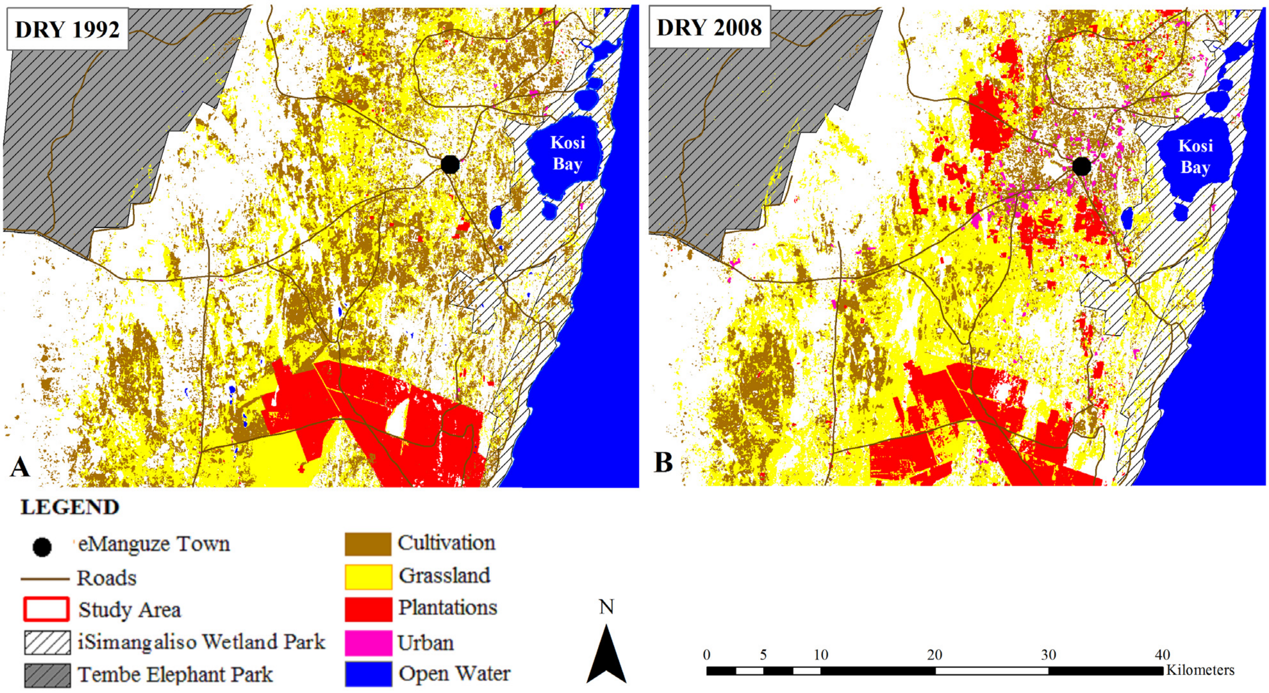

Figure 5. Comparing land-cover classification maps for the dry years 1992 (A) and 2008 (B).

5. Discussion

5.1. Permanent and Temporary Wetlands and Open Water Areas

The distribution of permanent and temporary wetlands and open water are related to the hydrological and geomorphological processes on the MCP. The upland (50-82 m.a.s.l.) has a greater proportion of temporary sedge/moist grassland wetlands; lowland areas (1-50 m.a.s.l.), where precipitation is also higher, host most of the permanent wetlands, including swamp forest, as well as some temporary wetlands and most of the permanent open water (Figure 4D). Groundwater recharge takes place when there is sufficient rainfall, while groundwater discharge occurs in low-lying areas, facilitated by the underlying regional geology that slopes towards the east. Consequently, the permanent open water areas (Kosi Bay lakes system and Lake Shengeza) which represent 2-3% of the study area, and all of the swamp forest are congruent with the high water table in the coastal region. Swamp forests covered only ~2% of the study area, and are restricted to the incised valley bottoms associated with drainage lines intercepting the regional water table that ensure permanently wet conditions. The sedge/moist grassland wetlands that occur primarily on the uplands cover ~5% of the study area and are associated with interdune-depressions and upland depressions as well as some valley bottoms. The sedge/moist grassland wetlands on the uplands are flooded during large rainfall events (e.g. the floods in 2000). In locations where the depression intercepts the water table throughout the year, it is permanently wet, but where the base is elevated relative to the water table, the wetlands are only wet during high rainfall events. The temporary sedge/moist grasslands on the upland are vital recharge areas that contribute to the regional groundwater resource (Grundling et al., 2012a), and hence may be undervalued habitat.

5.2. Land-Cover Change Analysis: Wetland Loss and Land-Use Change

The change in spatial land-use distribution from 1992 to 2008 exhibited a slight increase in urban (+1353 ha) and plantation (+3147 ha) areas and decrease in cultivation practices by 10264 ha. The increase of tourism and entrepreneurial activities near the town eManguze, close to the Mozambique border, may explain the slight increase and definite change in spatial distribution of urban, plantation and cultivation land-use classes. The 11% temporary sedge/moist grassland wetlands loss by 2008 can be directly linked to land-use change (by 883 ha plantation, 96 ha urban development and 4212 ha cultivation) that replaced these wetlands and the drop in water table resulting in the temporary wetlands that appear as grassland. The indirect impact of water abstraction (Schapers, 2012) and evapotranspiration by plantations (Grundling et al., 2012a) on wetland function and distribution is unknown and is therefore a major research need.

5.3. Accuracy Assessment

Accuracy assessment was performed using an error matrix (Table 4). Using the known verified points for the land-cover classes from an independent validated dataset (Kotze et al., 2010) against the classification data for each land-cover class (represent the pixels classified as a specific land-cover class) one can calculate the accuracy for each land-cover class and calculate the overall mapping accuracy for the dataset. The overall land-cover/wetland mapping accuracy for the entire Maputaland Coastal Plain dataset (not the smaller study area), derived from single date 2008 Landsat TM satellite imagery, was 80% (Table 4).

Table 4. Error matrix with verified points for land-cover classes (rows) versus the classified cases for each land-cover class (columns).

		Classification data										
		Water	**Wetland**	**Urban**	**Grassland**	**Cultivation**	**Plantation**	**Bare Soil**	**Swamp Forest**	**Woodland/ Savanna/ Forest**	**Total**	**Producer's Accuracy (%)**
Verified points	**Water**	**16**	1		0	1	0	0	1	0	19	84
	Wetland	1	**114**		17	4	0	0	2	12	150	76
	Urban			**0**							0	
	Grassland	0	13	2	**351**	73	7	3	3	73	525	67
	Cultivation	0	2	3	5	**92**	3	0		18	123	75
	Plantation	0	2		1	4	**45**	1		5	58	78
	Bare Soil	0	0		0	0	0	**12**		0	12	100
	Swamp Forest								**2**		2	100
	Woodland/ Savanna/Forest	0	11		28	20	12	0	21	**782**	874	89
	Total	17	143	5	402	194	67	16	29	890	1763	
	User's Accuracy (%)	94	80	0	87	47	67	75	7	88		
											Overall Accuracy (%)	**80**

High mapping confidence (75% to 100%) was obtained for land-cover classes: water, wetlands (sedge/moist grasslands), cultivation, plantation and bare soil. The urban and swamp forest classes gave unsatisfactory results because the number of independent points representing these areas were few and both classes represent small areas on the Maputaland Coastal Plain. The grassland class obtained 67% due to the overlap with cultivation practices and temporary wetlands. The woodland, savanna and other forest classes (e.g. dune forest, sand forest) were grouped because these classes were difficult to map due to the similar spectral signatures and these classes were not of concern for the study. The 80% mapping accuracy for the 2008 Maputaland dataset compares well with the NLC2000 land-cover datasets (average accuracy 48.5%) that also used Landsat imagery and a similar mapping procedure (Van den Berg et al., 2008). The same mapping technique was used for both 1992 and 2000 but no independent dataset with verified points exists for these years to calculate the mapping accuracy.

The Two-date Sequence Logic Review analysis was used to determine errors in change detection that resulted from the original land-cover mapping misclassifications. The database calculated changes in land-cover class between the different assessment years in percentage values, indicating the percentage of the original cells that have changed to another class. The highest percentage error occurred between cultivated and grassland classes (33% to 41%), between wetland and grassland classes (34%) and between bare soil and cultivation classes (26%). Ozesmi and Bauer (2002) indicated the overlap in spectral signatures between wetlands and other land-cover classes such as agricultural crops and upland forests can result in errors. The cultivation class mainly represents areas outside the swamp forests in open grassland areas and in sedge/moist grassland wetlands because cultivation activities inside the swamp forests are covered (hidden) by the tree canopy or in some instances the gardens are too small for a single pixel to be mapped as cultivation. The higher cultivation (17%) in 1992 could be that grassland areas were classed as cultivation because of the low grass cover in a dry year, similar to dry cultivated lands. Mapping of swamp forest and sedge/moist grassland wetland types indicate that Landsat classification did well in mapping the sedge/moist grassland wetland types. However, the swamp forest wetland type proved to be difficult. The resolution of the Landsat imagery (30 m) is not the optimal to map swamp forests because of their relatively narrow linear form and similar spectral signatures compared to dune forests and sand forests (Walsh, 2004), but can be used for larger sedge/moist grassland wetlands. Swamp forests could not be classified without the support from ancillary datasets, e.g. vegetation maps. Care must be given in the interpretation of swamp forest extent for the different years; it seems as if this wetland type increased, but field visits and other work indicate swamp forest loss due to cultivation practices. The advantages of using Landsat data are: 1) the images are free; 2) an archive of historic data is available for large areas of the world; 3) Landsat TM and Landsat ETM has 7 multispectral bands, with good spectral information; 4) limited image processing time is needed; and 5) it is effective in monitoring the wetland dynamics between wet and dry years and land-use change on a regional scale. SPOT imagery, in contrast, is not so readily available and has limited spectral bands.

Availability of the images for specific years can affect the classification accuracy, e.g. 1992 was the driest year early in the study period, while 2008 was chosen to represent dry conditions in the latter part of the study, although 2002 and 2003 were even drier years; however, those images were unavailable. Moreover, 2008 followed a sequence of dry years so lag effects from prior wet years were less likely. The implication of assessing the spatial patterns based on imagery from a dry year (e.g. 1992) in a relatively wet period (Figure 2) is that one would be likely to overestimate the coverage of permanent wetlands, while in extreme wet years (e.g. 2000), temporary wetlands would be overestimated. During the very wet years wetlands can be temporarily inundated with open water for a short period. The spatial scale of the sensor is the most important factor in separation of temporary open water classes with temporary wetlands in this type of wetland environment. Ramsey and Laine, (1997) reported that classifications derived from Landsat TM images provided good class separation when one class dominated more extensive areas (>1 ha), but not when mixtures of water and wetland vegetation were on the same order as the Landsat TM sensor spatial resolution (30 m). Using data over several more years, instead of only three, and images for each wet and dry season, might prove to be more successful in mapping the temporal stages and extents of wetlands and open water. The seasonality and annual rainfall of the study area need to be considered. Rainfall variability over the study area, as well as during the season, induces change in the growth and composition of vegetation and can lead to changes in the spectral signature of the land surface. The accessibility of the study areas to gather verification points for the classification were limited due to deep sandy soils, overgrown dirt roads and access entering conservation areas. This also has an implication on the accuracy of the classification.

6. Conclusion

This study has demonstrated the capability of using Landsat remote sensing imagery with ancillary datasets to establish wetland extent and permanence, as well as land-use activities (plantations, cultivation and urban classes) and its change, bearing in mind the spatial limitations of Landsat (e.g. wetlands and croplands <1 ha and cultivated fields in swamp forests will be difficult to map). The ambiguity between classes: cultivation and grassland; temporal wetland and grassland; and bare soil and cultivation need to be highlighted. These classes are closely related and driven by seasons and wet and dry periods; this is evident in the study area where abandoned gardens on temporary wetlands have become covered by grassland because of drier conditions. Similar spectral signatures of swamp forests with other forest types (dune and sand forests) as well as their relatively narrow linear form pose a problem to accurately map swamp forests; they could not be classified without the support from ancillary datasets such as vegetation maps. Urban areas, characterised by open bare soil, house structures and small croplands made class separation difficult. The combination of Landsat imagery with ancillary data show land-use activities and drought have reduced wetland extent and distribution by 11%. Wetland loss is a significant problem for the local communities that depend on them as a natural resource and illustrates the need for improved management by all stakeholders. The permanent and temporary wetland map and land-use impact assessment on wetlands can help to underline the wetland function and vulnerability and guide land-use practices that have a direct and indirect effect on them. Improvements to this method (e.g. Landsat imagery with supporting ancillary data such as maps for wetland vegetation, cultivation and urban classes from high resolution spectral and spatial resolution imagery can be applied to similar coastal areas, such as the MCP in Mozambique, supporting future research.

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