

# Mapping land cover change of the Luvuvhu catchment, South Africa for environmental modelling

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**Abstract** Considerable land cover changes have occurred in the Luvuvhu catchment in northeastern South Africa in the past two decades. These changes are associated with human population growth and may be contributing to observed reductions in winter river baseflows and increased episodes of river drying within Kruger National Park. Six-class land cover maps of the catchment were created from 1978 (MSS) and 2005 (TM) Landsat imagery using an iterative technique. Results indicate a 1,000 km<sup>2</sup> (12%) increase in Bare Ground between 1978 and 2005, with a concomitant decrease in shrubland and indigenous forest cover. Overall classification accuracy in the 2005 image was 80%. Classification was most accurate for Water and Pine classes (100 and 92%) and least accurate for Indigenous Forest (46%), primarily due to misclassification as Shrubland.

These maps are suitable for land cover change and landscape modeling analyses, and can serve as baseline data for further research.

**Keywords** Ecology · Catchment hydrology · Sustainable development · Kruger National Park

## Introduction

Conversion of natural landscapes for agricultural and urban uses often impacts soil integrity, nutrient fluxes, and native species assemblages (Bierregaard et al. 1992; Kayombo and Lal 1993; Powers et al. 2004). Such changes can affect catchment hydrology by altering the rates of interception, infiltration, evapotranspiration, and groundwater recharge, resulting in changes in timing and amounts of surface and river runoff (Calder 1993; Miller et al. 2002; Jewitt et al. 2004). For example, several studies have demonstrated that the establishment of plantation forests in sub-tropical environments resulted in reduced baseflow (Van Lill et al. 1980; Van Wyk 1987; Lane et al. 2005) due to increased transpiration rates and subsequent reduction in groundwater recharge. Vegetation removal can result in increased baseflows if soil infiltration capacities remain intact (Brooks et al. 2003). On the other hand, if vegetation clearing is followed by land use practices that compact soils and expose them to erosion, decreased

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percolation to groundwater can result (Bruijnzeel 2004; Bonell 2004; Schulze 2000).

In semi-arid Southern Africa, where rural livelihoods are closely linked to natural resources, forest and shrubland clearing are often followed by soil-compacting activities such as plowing and livestock grazing (Cousins 1999; Shackleton et al. 2005; Higgins et al. 1999). The Luvuvhu River, located in the Limpopo Province in northeastern South Africa (Fig. 1), has undergone land cover changes since 1950s caused by forest clearing. Indigenous forests were converted to eucalyptus and pine plantations in the highlands during the 1950s and 1960s (Van der Waal 1997). Since then, forests and shrublands have also been cleared to provide fuel wood and land for small-scale agriculture and livestock grazing.

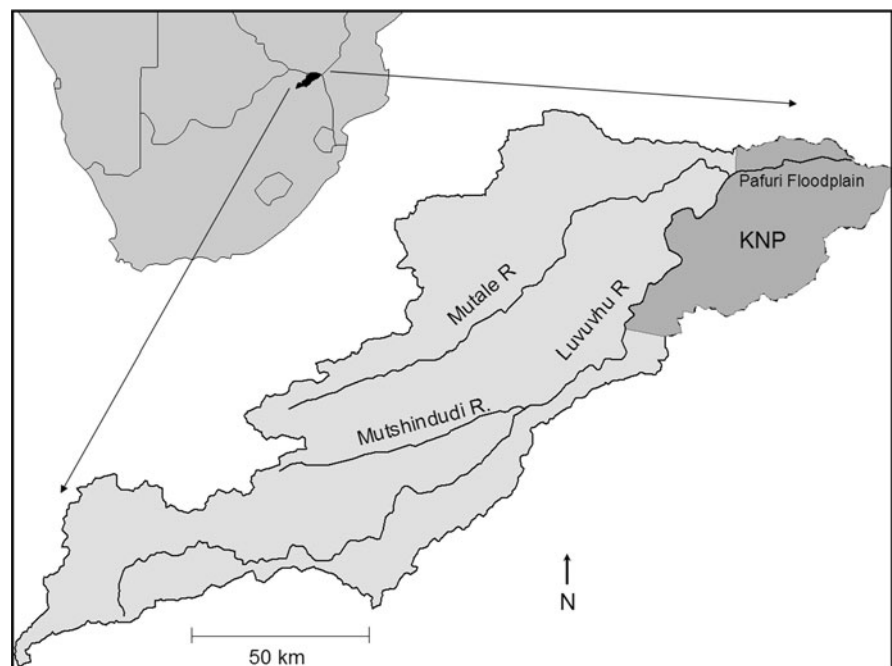
These changes in land cover have been cited as a potential cause of reduced baseflows in the Luvuvhu River (O’Keeffe and Davies 1991). Perennial before 1960, the river now ceases to flow for variable periods between August and October during most years (O’Keeffe and Davies 1991). Because aridity increases dramatically in the eastern section of the catchment, river drying poses a threat to human communities and riparian ecosystems in that region (Hope et al. 2004). Ecological degradation is a concern due to the pivotal role of baseflow in

sustaining biological communities along the river. Of particular note are potential impacts to riparian communities of high conservation value located along the terminus of the river in Kruger National Park (Tinley 1977). The importance of sustained flows in maintenance of healthy riparian communities was highlighted during a drought in the early 1990s; the river dried completely for over 10 months and resulted in massive tree mortality within the riparian zone in Kruger National Park (DWA 2004). Furthermore, many rural communities along the lower Luvuvhu and Limpopo Rivers depend heavily on instream flows for agricultural and household purposes, and the loss of perennial flow represents a threat to economic development in the region.

As demands for water increase in future years, river drying will continue to be the greatest threat to riparian and riverine communities along the Luvuvhu River in Kruger National Park (Kleynhans 1996). The causes of river drying are not completely understood, but land cover change, dams, and direct water extractions in the upper section of the catchment are cited as potential drivers (O’Keeffe and Davies 1991; Jewitt et al. 2004; Kleynhans 1996).

Hydrological models such as the Soil and Water Assessment Tool (Arnold et al. 1998) can be used for identifying the landscape factors that may be

**Fig. 1** The Luvuvhu River, located in the extreme northeastern corner of South Africa originates in the Soutpansberg Mountains, flows through Kruger National Park, and empties into the Limpopo River at the border with Mozambique and Zimbabwe



contributing towards the drying of the river (Griscom 2007; Miller et al. 2007). Several critical hydrological model parameters are derived from land cover maps (Miller et al. 2007). In the Luvuvhu Catchment, the lack of both spatial and temporal land cover data was an information gap limiting investigation into ecological and hydrological processes. We investigated the utility of using the National Land-Cover Database of South Africa (created by the CSIR) but there were a couple of barriers to using these data. First, the minimum mapping unit size and the inclusion of variable land cover classes in the 1996 CSIR map challenged effective representation of land cover variability at the catchment scale. Second, because we were seeking a comparative analysis of change over time, adopting the CSIR data would pose difficulties in creating a similar product for 1978.

Remotely sensed moderate resolution data (i.e. Landsat) are suitable for mapping the status of 1978 and 2005 land cover features within the watershed (U.S. EPA 1993; USGS 2006; Baldyga et al. 2007). Land cover maps at moderate scales enable researchers to characterize spatial distribution patterns of land cover and quantify the magnitude and the pattern of land cover changes that have occurred over time. These maps can serve as baseline data for future land cover, ecology, and watershed hydrology studies. This paper presents results from a land cover classification scheme undertaken in the Luvuvhu catchment using Landsat imagery for 1978 (MSS) and 2005 (TM). Comparisons between classification accuracies are presented as well as analyses of changes that have occurred within the study area over the 27 year interval between images.

## Description of the study area

Figure 1 shows the location of the Luvuvhu catchment in northeastern South Africa (30°E, 23°S). Elevation in the catchment ranges from 200 to 1,300 m and precipitation is determined by orographic patterns where moisture moves west from the Indian Ocean and deposits 1,200 mm to 1,500 mm/year in the forested mountain headwaters. The terrain then drops quickly into semi-arid forest and bushland which receive only 200 mm to 600 mm/year. The

subtropical climate is characterized by a distinct wet summer with frequent, intense rainstorms during November to March, and a dry winter with little precipitation from April to October. Geology is dominated by deep basaltic rock overlain with sedimentary and quartzite layers that were block-faulted to the north 150 million years ago (Brandl 2006). Soils throughout the catchment are characterized by clay-enriched lower horizons and weakly developed organic horizons (IUSS 2006). All are prone to degradation and erosion with Acrisols being the most common at higher elevations and Leptosols and Lixisols most common in the lowlands (FAO and ISRIC 2003).

Land cover in the southern highlands is dominated by exotic tree plantations of *Pinus* spp. and *Eucalyptus* spp. with some remnant and fragmented patches of indigenous forest. Large-scale citrus, mango, banana, and vegetable farms are common in the nearby Albasini foothills. In the rest of the catchment, most of the broad valley bottoms and northern highlands are dominated by small-scale agriculture and grazing lands controlled by regional chiefs of the Venda and Tsonga people. Rural settlements have been established throughout the catchment. The northern and eastern parts of the catchment are the driest and most sparsely populated. Kruger National Park, South Africa's premier ecotourism attraction, defines the eastern extremity of the catchment, where the Luvuvhu River plunges into deep canyons and empties into the Pafuri floodplain, joining the Limpopo River at the Mozambican border and flowing southeast into the Indian Ocean.

By South African standards, this is an economically poor and under-developed region, in which most people derive their subsistence from dryland maize farming, livestock, and remittances from migrant working family members ([DWAF] Department of Water Affairs and Forestry 2004). The population in the catchment has roughly doubled in the last 20 years with estimates ranging between 270,500 and 317,000 for 1985 (Kleynhans 1996; Jewitt et al. 2004) and 518,000 to 770,000 for 2003 (WRC 2001; DWAF 2004). Land cover change since 1978 is largely associated with this population growth, during which time forests and shrublands have been cleared or coppiced for the purposes of providing fuel wood, maize fields, and pasture.

## Methods

### Classification scheme

Land cover classes were identified based on a modified Anderson et al. (1976) classification system. The final land cover mapping categories were Water, Bare Ground, Shrubland, Pine Plantation, Indigenous Forest, and Eucalyptus/Fruit Orchard. Detailed descriptions of each class are listed in Table 1. Some land use classes, such as ‘Village’ and ‘Urban’ were eventually pooled with broader land cover classes such as ‘Bare Ground’ in order to deal with misclassification problems due to mixed pixels.

### Land cover mapping of 2005 image

A Landsat Thematic Mapper (TM) image (WRS2 path 169, row 76) was purchased from the Council for Scientific and Industrial Research (CSIR) in South Africa. Dry season imagery (September 15) was used to maximize the spectral distinction between indigenous vegetation and irrigated crops. This image was georectified (root mean square error <15 m) to UTM projection, zone 36S, WGS84 datum using ground control points and locations of identifiable features such as road intersections and stream segments collected during field work at locations identifiable on the image.

### Field data collection

Because no reliable land cover or land use map exists for the region, 200 circular-plots with a minimum

size of 1,000 m<sup>2</sup> were collected in the field for classification and accuracy assessment from November 28 to December 23, 2005. Matters of access prevented the collection of stratified random samples of the catchment, limiting sampling instead to the best possible coverage of the catchment from dirt and paved roads. A minimum of twenty polygons per land cover class were collected while capturing as much spectral variability as possible within each class. Areas of homogeneous land cover greater than 0.5 ha were targeted and recorded with GPS, along with buffer distances from the center of each target.

After conducting the surveys and gaining familiarity with the patterns of land use and their corresponding spectral characteristics, fifty additional land cover polygons were hand digitized within ArcMap 9.0 (ESRI 2004) to augment the number of samples per cover class. Of these 250 polygons, 125 were randomly selected as reference data and were used for analyzing the spectral characteristics of the Landsat image at those locations. Remaining polygons were used for assessing the accuracy of the classified image (Jensen 2005).

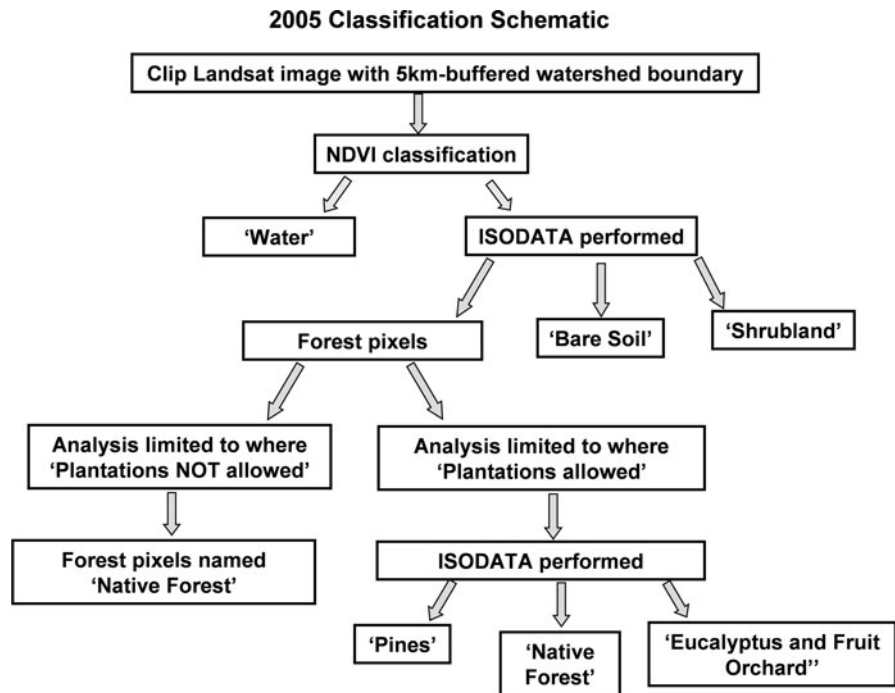
### Land cover classification

A 5 km-buffer of the catchment was used to clip the Landsat scene (bands 1–5 and 7) and a multi-stage, iterative ‘cluster-busting’ technique was used to identify the land cover classes in the study area (Jensen et al. 1987; Sivanpillai et al. 2005) (Fig. 2). In each iteration, one or two land cover classes were identified out of 50 and isolated (or masked) from the

**Table 1** Land cover class description derived from USGS 1992 National Land Cover Dataset definitions and on-ground observations in the Luvuvhu catchment

Class name	Class description
Water	Areas of open water with less than 25% vegetative cover
Bare Ground	Areas dominated by bare soil or rock with little to no “green” vegetation. If present, vegetation is very widely spaced and scrubby. Includes heavily grazed rangelands and fields used for the production of annual crops during the wet season. Also includes urban cover and can pertain to village cover when devoid of vegetation
Indigenous Forest	Areas characterized by indigenous trees greater than 6 m providing 25–100% cover
Shrubland	Areas characterized by woody vegetation with aerial stems, generally less than 6 m tall, with individuals or clumps not touching (25–100% cover). Both true shrubs and coppiced trees are included
Pine	Areas dominated by evergreen pine trees greater than 6 m tall and providing 25–100% cover
Eucalyptus/Fruit Orchards	Areas dominated by non-natural woody vegetation (25–100% cover), especially <i>Eucalyptus</i> plantations, and orchards maintained for the production of fruits, nuts, or berries. Also includes village cover when dominated by planted trees

**Fig. 2** A schematic of the methods used to classify land cover from the 2005 Landsat TM image



classified multi-spectral image. Remaining pixels were classified in the next iteration, with additional classes identified and isolated. This process was repeated until all the pixels in the image were identified with a land cover class. In addition to the standard six multi-spectral bands inherent to Landsat, a Normalized Difference Vegetation Index (NDVI) was used to minimize confusion between pixels representing water and those representing shadows cast by cliffs.

Map accuracy was evaluated by overlaying the 125 ‘verification’ polygons that were previously set aside and determining if the actual class corresponded with the mapped class. If more than half the pixels in a polygon were mapped correctly, the polygon was deemed ‘correct’. If less than half were correct, the polygon was inaccurate and the dominant category was recorded. An error matrix was produced from the accuracy assessment from which overall, producer’s, and user’s accuracies and KHAT agreement index were calculated (Congalton and Green 1999). Producer’s accuracy is a measure of how often ground characteristics are mapped correctly, whereas user’s accuracy is measure of the predictive reliability of the map. KHAT was calculated using formulas from Hudson and Ramm (1987). KHAT value ranges from +1 (total agreement) and

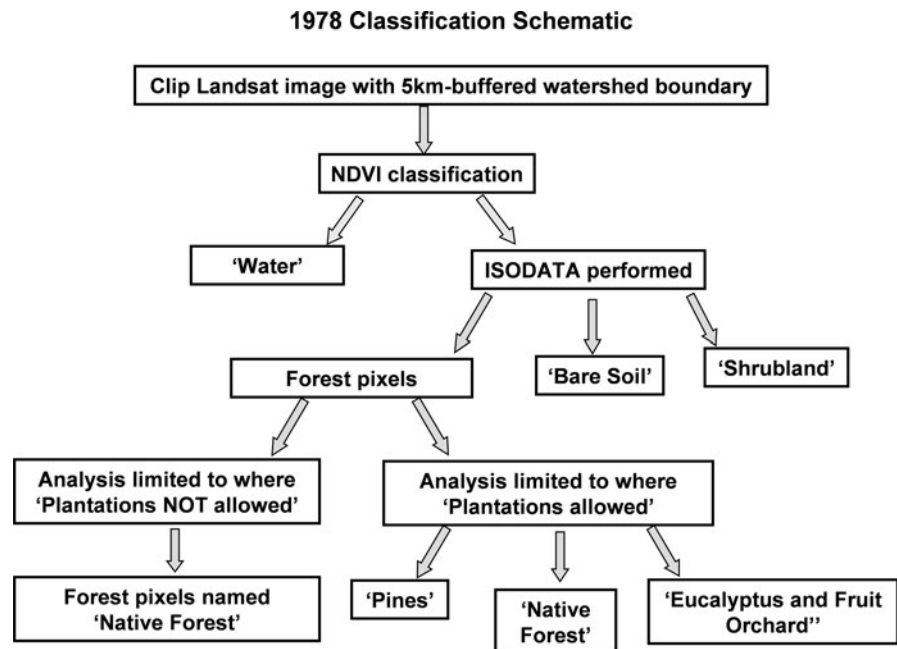
–1 (total disagreement) between the classified image and verification data. KHAT value of 0 indicates no agreement between these two datasets. It is a more stringent measure of overall accuracy which compares the classification agreement from the error matrix to the chance agreement based on row and column totals (Congalton and Green 1999).

#### Land cover mapping of 1978 image

A Landsat Multispectral Scanner (MSS) image from 1978 (path 181, row 76) was obtained from the University of Maryland’s Global Land Cover Facility (<http://glcf.umiacs.umd.edu>) and used to create a catchment land cover map with the same six classes as 2005. Dry season imagery (16 June 1978) was used to maximize the spectral distinction between indigenous and irrigated vegetation, and the image was georectified to UTM projection, zone 36S, WGS84 datum. Pixels within a 5 km-buffer from the watershed boundary were clipped from the Landsat image (Fig. 3).

Park rangers and land managers from South Africa National Parks provided information about the land cover in 1978. Landsat image was displayed on-screen and land cover features were identified on this image. Heuristic knowledge of experts familiar with

**Fig. 3** A schematic of the methods used to classify land cover from the 1978 Landsat MSS image



the land cover conditions is valuable when historic aerial photos or past land cover maps are not available (Wayman et al. 2001; Sivanpillai and Latchinsky 2007). This approach also alleviates the need to transfer spectral signatures from the recent (2005) Landsat image to the older (1978) Landsat image.

As was done with the 2005 Landsat TM image, an iterative, unsupervised classification was used to assign pixels in the Landsat MSS data to one of the six thematic classes. Supervised classification techniques were used to assign some of the clusters generated from unsupervised classification, i.e., hybrid classification (Jensen 2005). No accuracy assessment could be performed on this image due to the absence of verification data.

## Results

### Land cover maps

Figures 4 and 5 display the 2005 and 1978 land cover maps created for the Luvuvhu Catchment. The most abundant land cover type during both periods was Shrubland, which dominates the lowlands. Bare Ground and Indigenous Forest vie for second place and Eucalyptus, Fruit Orchards, Pine Plantations, and

Water collectively covered less than 10% of the catchment.

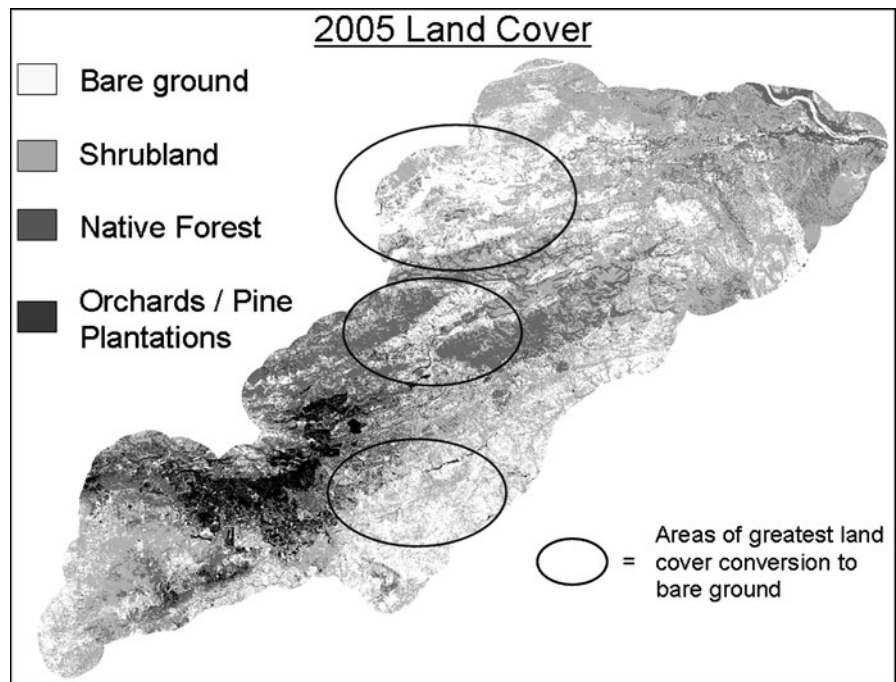
Table 2 shows the error matrix resulting from the comparison of mapped classes and reference polygons for the 2005 image (error could not be assessed for the 1978 map). Overall map accuracy across classes was 80.2% and the KHAT (Kappa statistic) was 75%. Within classes, the greatest accuracy occurred in Pine and Water. There was some confusion between Bare Ground and Shrubland categories where each was misclassified as the other. Indigenous Forest had a low producer's accuracy of 46%.

### Land cover changes between 1978 and 2005

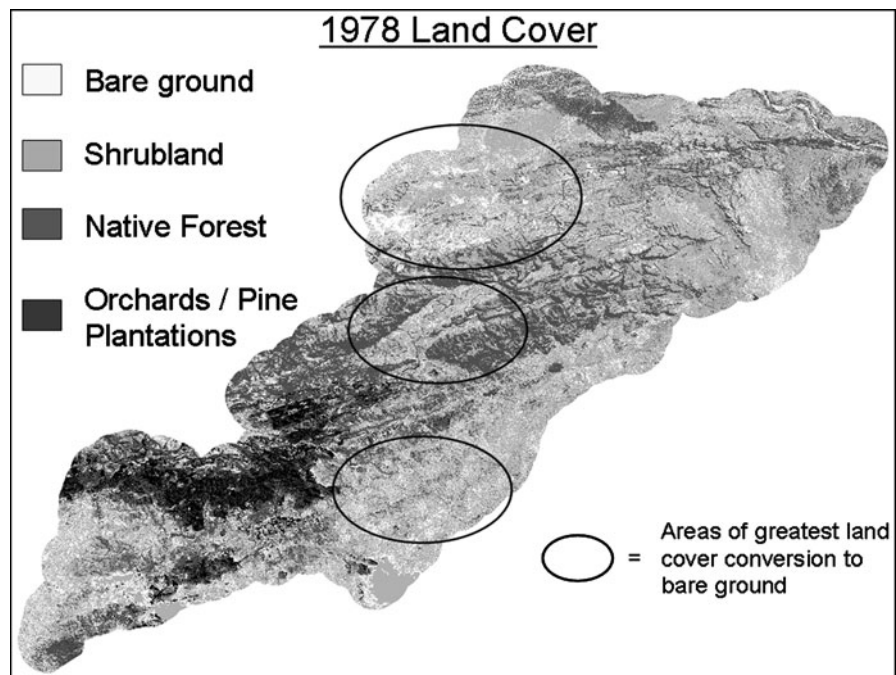
Between 1978 and 2005, Indigenous Forest and Shrubland decreased by 1,043 km<sup>2</sup>. This represents a 12% reduction in vegetative cover as Bare Ground concurrently increased by 12%. Figure 6 shows the percent change in cover for each class (the change in surface water was negligible). Eucalyptus/Fruit Orchard increased by 104 km<sup>2</sup>, and judging by the growth of irrigated agriculture visible in the Landsat image, this is thought to reflect expansion near the Levubu farm district. Pine cover decreased by 76 km<sup>2</sup>.



**Fig. 4** Land cover map of the Luvuvhu Catchment, South Africa, September 15, 2005



**Fig. 5** Land cover map of the Luvuvhu Catchment, South Africa, June 16, 1978

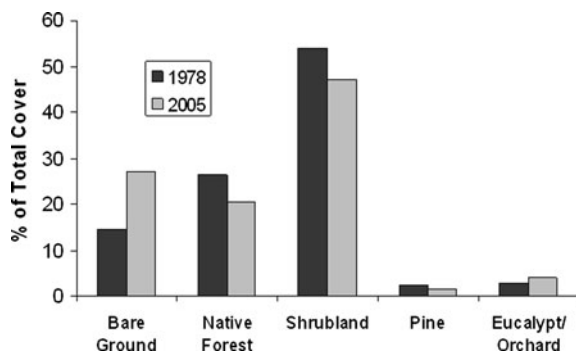


The increase in Bare Ground is most apparent in three regions of the catchment identified by circles in Figs. 4, 5. The first region is the middle and lower Mutale River valley, which undoubtedly reflects the expansion of dryland agriculture. The second is the southern lowlands of the catchment, particularly

around villages such as. Malamulele, Dzamba, and Shigalo. This appears to be from increased grazing and fuel wood gathering around burgeoning communities. The third area to see increases in Bare Ground is in the arid north. Because this region is not densely populated, the apparent increase in Bare Ground may

**Table 2** Error matrix and accuracy assessment for land cover classification of Luvuvhu Catchment, September 15, 2005

Land cover map	Reference Polygons					
	Water	Bare Ground	Indigenous Forest	Shrubland	Pine	Eucalyptus/ Fruit Orchards
Water	<b>12</b>	0	0	0	0	0
Bare Ground	0	<b>21</b>	0	6	0	0
Indigenous Forest	0	0	<b>6</b>	1	0	0
Shrubland	0	3	5	<b>22</b>	0	2
Pine	0	0	1	0	<b>12</b>	0
Eucalyptus/Fruit Orchards	0	0	1	1	1	<b>12</b>
	Overall accuracy: 80.2%			KHAT: 0.753		
	Producer's accuracy	User's accuracy				
Water	100.0	100.0				
Bare Ground	87.5	77.8				
Indigenous Forest	46.2	85.7				
Shrubland	73.3	68.8				
Pine	92.3	92.3				
Eucalyptus/Fruit Orchards	85.7	80.0				

**Fig. 6** Mapped Percent Cover by Class, Luvuvhu Catchment 1978 and 2005

not be the result of human activities; instead, the difference is more likely the product of the seasonal differences between the two images in this xeric and grass-dominated area.

## Discussion

The overall accuracy of 80.2% achieved in the 2005 land cover map is within the range (80–87%) reported in recent classifications of tropical and subtropical environments (Hudson et al. 2006; Kuplich 2006;

Yemefack et al. 2006). The resulting KHAT of 0.75 is also reasonable and on the upper end of ‘moderate agreement’ according to Landis and Koch (1977). Because of this, the final maps were deemed sufficient for the purpose of inputs to coarse-scale hydrological modelling and land cover change analyses. The iterative ‘cluster busting’ technique provides the flexibility for portioning the overall variance in the satellite data incrementally and enables the analyst to label and isolate one or two thematic classes in each step. For example in one step, the analyst can isolate pixels corresponding to the forest class and in the next iteration (or step) partition the variability within forests classes. Sivapillai and Miller (2008) used this technique to successfully map the water bodies in the Power River Basin, Wyoming, USA. Another useful step was using an NDVI enhancement to help differentiate water from shadows cast by cliffs.

In the 2005 image, the largest classification error occurred in Indigenous Forest and the producer’s accuracy measurements indicate that it was under-represented in the final map (only 46% of the ground covered by indigenous forest was correctly identified). This is primarily the result of similarities between the Shrubland and Forest classes, both



spectrally, and in the field. While conducting field work, it became apparent that many of today's shrublands are yesterday's indigenous forests that have been coppiced and thinned. The biggest clue for this trend was the observation of scattered trees (taller than 6 m) within stands of multi-stemmed shrubs. Essentially, there is a continuum between forest and shrubland types that occurred primarily in mountain foothills. This mixture of shrubs, trees, and some pasture made class designation difficult during data collection, and also caused confusion spectrally during image classification.

The other major classification error was between Shrubland and Bare Ground. This is primarily due to two factors: (1) variation in soil characteristics across the catchment and; (2) errors of consistency in class assignment during ground data collection. Much of the soil in the northern, more arid part of the catchment is very light in color. This makes it highly reflective and increases the spectral signature of the ground, even when shrubs are present. Throughout the catchment, widely scattered and coppiced shrubs which provide little ground cover are common. Because percent cover was not measured, there was a degree of uncertainty and error when assigning Bare Ground and Shrubland classes while conducting field work.

One major obstacle in remote areas of developing nations is locating historic maps or aerial photos that can serve as training and reference data. Because of the lack of validation data for the period when the 1978 image was captured, results from that classification are coarse and presumed to be less accurate than the 2005 land cover map.

One potential source of error while comparing land cover maps generated from two time periods is the response of vegetation in semi-arid environment to precipitation events. Although both Landsat images used in this study were acquired during the dry season, in the case of the 1978 image, the summer rains had subsided only 2 months prior, during which time another 3–7 cm fell across the catchment. However in the case of the 2005 image, approximately 4 months had passed since the rainy season, with almost no precipitation in the previous 2 months. Hence the conditions in 1978 would have been more favorable for grasses and forbs and less favorable in 2005, resulting in over estimation of Bare Ground in the 2005 image. However the extent

to which it could have influenced our results is limited; a closer view of numerous populated areas of the catchment in the 1978 and 2005 Landsat images confirm that shrub and tree removal was widespread during the period of interest.

Another confounding issue is comparing imagery of different resolutions and band intervals. The 2005, the 30 m image more accurately represents the heterogeneous character of the landscape compared with the 1978, 57 m image. Still, despite these drawbacks, there is value in the 1978 map. It serves as an index of the distribution of cover types, which can be used as a relative measure of the kinds of changes that have taken place in the catchment over the last 27 years, and their potential influence on hydrology within a modelling context.

## Conclusions

Observed land cover change in the Luvuvhu Catchment has the potential to impact river hydrology in complex and conflicting ways. For example, the increase in evapotranspiration caused by more fruit orchards in the Levubu farm district may be compensated by the decrease in evapotranspiration from vegetation clearing elsewhere, and could potentially result in greater river yields. However, the 12% increase in Bare Ground exhibited in this study is a probable indication of increased soil compaction, which could be a key factor in the observed reduction in baseflow. It is also highly likely that because the lower reaches of the Luvuvhu River are dependent on flows originating from the highlands, forest clearing and afforestation at high elevations have had a disproportionately large influence on ground water recharge and baseflow throughout the catchment.

The classified Landsat imagery from 1978 and 2005 reveals a reduction in vegetative cover across the Luvuvhu catchment. This pattern is thought to be primarily the result of increased agriculture, grazing, and fuel wood cutting spurred by a doubling of the population in the last 20 years. The utility of maps produced by this method can extend beyond the context of hydrological modelling into studies of sustainable development, erosion, sedimentation, deforestation, and landscape ecology.

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