ENHANCED LAND COVER CLASSIFICATION IN A TROPICAL KENYA LANDSCAPE

Tracy J. Baldyga, Research Assistant
Scott N. Miller, Assistant Professor
Department of Renewable Resources
Kenneth L. Driese, Research Scientist
Ramesh Sivanpillai, Assistant Research Scientist
Wyoming Geographic Information Science Center
University of Wyoming
Department 3354, 1000 University Dr.
Laramie, WY 82071
tbaldyga@uwyo.edu
snmiller@uwyo.edu
kdriese@uwyo.edu
sivan@uwyo.edu

Charles Maina Gichaba, Department Head Geography
Egerton University
PO BOX 536
Njoro, KENYA
maina_gichaba@yahoo.co.uk

ABSTRACT

Kenya's Rift Valley has been undergoing rapid land cover change for the past two decades, which has resulted in ecological and hydrological changes within the region. An effort is underway to quantify the timing and rate of these changes in an experimental watershed near the towns of Njoro and Nakuru using remote sensing and geographic information system (GIS) methods. Three Landsat TM images representing a 17-year period in which the area underwent significant land cover transition were classified. Baldyga et al. (2004) showed that vegetation diversity and temporal variability posed many challenges and resulted in large classification errors for four scenes captured during the dry season. While the distinction between forested and unforested areas was clear, capturing variability in agriculture informational classes proved difficult. Several enhancements were employed in an effort to capture this variability. Band separability analysis coupled with ancillary data indicated that 14 informational classes are distinguishable using various band combinations. Field validation was used to quantify error throughout the watershed, and uncertainty in land cover classification among vegetation types with similar spectral response was reduced relative to previous attempts to classify land cover into 10 classes. Resulting classified land cover scenes will serve as input to GIS-based models as part of a systems approach to understanding watershed dynamics. Research findings will improve historical land cover transition estimates and aid in interpreting land cover change impacts on biophysical and human dimensions.

INTRODUCTION

According to a Kenya Forests Working Group report (KFWG, 2001), the Mau Forest Complex has decreased in area by approximately 9% (340 km^2) from 1964 – 2000, with marked changes in the Likia portion of the forest where the River Njoro headwaters are located. While previous deforestation estimates were reported for the Mau Forest Complex (KFWG, 2001), a rigorous quantitative assessment of change was lacking. Baldyga et al. (2004) generated a preliminary assessment to distinguish spatial and temporal changes in forested and non-forested areas. This current study provides a more refined land cover classification scheme and serves as a baseline for future studies into land cover changes within the Mau Forest Complex.

Population growth and migration to areas deemed favorable for agriculture are a concern in tropical regions worldwide due to the resultant rapid deforestation and ecosystem fragmentation (Imbernon, 1999; Mistry, 2000; Tiffen et al., 1994). Land cover change affects hydrologic response at a watershed scale (Calder, 1993; Krhoda, 1988; Miller et al., 2002; Sharma et al., 2001). Over time, these circumstances can lead to severe consequences such as water shortages, health risks, desertification, and habitat destruction (Cirone and Duncan, 2000; King and Hood, 1999; Krhoda, 1988; Mathooko and Kariuki, 2000; Mathooko et al., 2001; Mistry, 2000; Navrud and Mungatana, 1994; Patz, 2001). With its fertile deforested uplands, the River Njoro watershed is a site where such transformations are underway.

There is an enormous benefit gained by monitoring land cover changes using remotely sensed imagery insofar as it provides information regarding areas that have little to no access as well as enables more efficient and cost-effective land cover mapping (Maingi and Marsh, 2001; Sheng et al., 1997). Remote sensing and GIS can tools provide up-to-date, as well as temporal, natural resource information related to LULCC caused by resource exploitation or renewal, available resource estimates, and how LULCC are affecting nearby areas.

Several challenges must be overcome when performing a land cover classification within a tropical region. It is a significant challenge to acquire data on days where cloud cover and water vapor are at a minimum. Consequently, anniversary date images required for temporal change detection are rare. Images are sometimes available for dates falling within one to two weeks of each other and may be suitable. Finding anniversary dates is particularly challenging during rainy season in tropical regions when cloud cover can be an almost daily occurrence.

After heavy rainfalls during a long rainy season, areas neighboring tropical forests (*i.e.* edges) may be difficult to distinguish, as they blend with other green vegetation and spatial correlation may influence accuracy along edges (Campbell, 1981). As such, boundaries may be difficult to discern except in dry season imagery. In the dry season, forested areas are more readily distinguished from non-forested areas because forested areas have a low reflectance in the visible spectrum when compared to non-forested land cover types (Lucas et al., 2004; Baldyga et al., 2004). If vegetation establishes in a deforested area, however, the distinction among vegetation types may be lost. (Maingi and Marsh, 2001; Singh, 1987; Tole, 2002).

In areas where the landscapes contain a high degree of heterogeneity, mixed pixels (*i.e.*, those with multiple land cover types in a single pixel) pose a challenge because land cover types become indistinct (Smith et al., 2003). Several challenges may arise in this case: dominant land cover type may not be most reflective or no single land cover type dominates and instead the pixel appears as a distinct and unknown land cover type. Moreover, in such landscapes spatial correlation effects of neighboring pixels with high reflectance can lead to land cover class confusion (Campbell, 1981)

Another limitation to image classification in tropical regions worldwide occurs where topographical relief renders certain areas inaccessible. Reflectance has been shown to be significantly affected in areas that exhibit a high degree of relief (Cingolani et al., 2004; Colby and Keating, 1998; Leprieur et al., 1988).

SITE DESCRIPTION

The River Njoro watershed is located Kenya's southwestern Rift Valley at 0°30' South, 35°, 20' East (Figure 1). The river itself is approximately 50 km in length with an estimated 270-km^2 contributing source area. Originating in the Eastern Mau Escarpment at approximately 3,000 m, the River Njoro winds through forested and agricultural lands before serving several urban settlements and finally terminating at 1,759 m in Lake Nakuru, a shallow soda lake typical of the Rift Valley.

Climate in the Njoro region is characterized by a trimodal precipitation pattern with long rains occurring from April – May, short rains occurring from November – December, and an additional small peak occurring in August. Mean annual rainfall measured at Njoro town center from 1949-2001 is 939.3 mm. Average annual minimum and maximum temperatures for the area range are 9° and 24° C, respectively.

Vegetation cover in the watershed ranges from 0% in areas affected by anthropogenic practices such as agriculture and livestock husbandry to 90% in upland indigenous forests that are difficult to reach due to extreme topographic relief on the eastern rift escarpment. The catchment's uplands can be characterized into three principle vegetation zones (Mathooko and Kariuki, 2000). Heavily grazed moorlands are found in the uppermost section and bordering a dense closed canopy indigenous montane forest mixed with bamboo. Continuing further downstream, tracts of intact and deforested plantations are present consisting of various *Cupressus* and *Pinus* species (Mathooko and Kariuki, 2000). Between Logomon and Egerton University, (Figure 1) there are various sized tracts of agricultural and pasture lands. The multitude of diverse vegetation found in the watershed serves a wide range of purposes including timber harvesting, medicine, human food, livestock fodder, building material, and fuel wood.

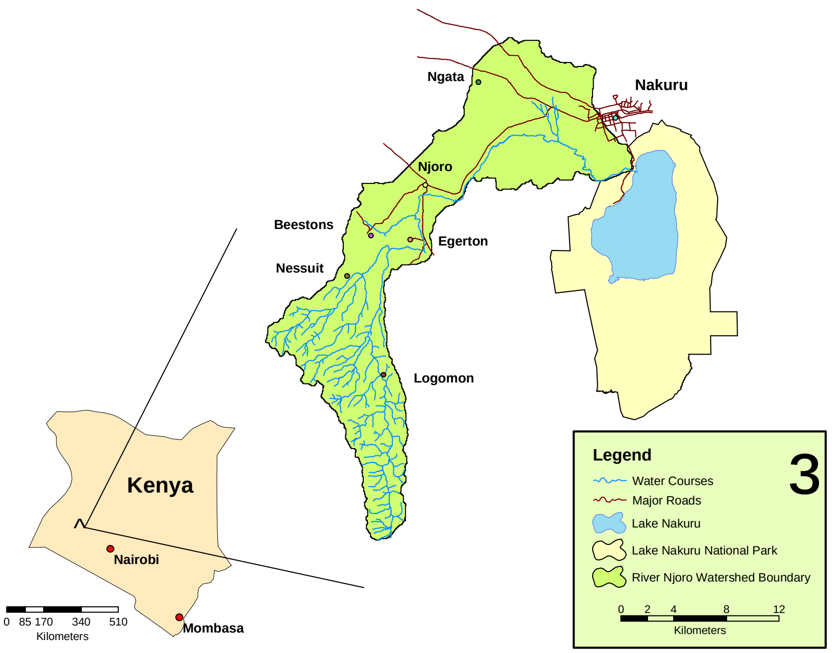

Figure 1: River Njoro watershed location in Kenya.

Soils in the region range from Humic Acrisols (Ultisols), Phaeozems (Mollisols), Andosols, Planosols (Aqualfs), Plinthosols, and Fluvisols (Fluvents) (Mainuri, 2005). Soil textures range from clay loams in the lower watershed to sandy clay loams in the plantation and indigenous forest areas at higher elevations. Topographic variation and historical volcanic activity in the area influence soil formation.

METHODS

Three Landsat scenes were selected for this study (Table 1). Every effort was made to acquire imagery that corresponded with Government of Kenya census dates as meaningful input to a separate study on population dynamics as well as available anniversary date imagery for change analysis. Landsat imagery used in this study all have 30-meter pixel resolution, considered an appropriate resolution for a subregional analysis as undertaken in this study (Campbell, 2002; Lucas et al., 2004).

Table 1: Satellite data used for this study (Baldyga, 2005).

Acquisition Date	Sensor	Path / Row	Resolution (m)
28 January 1986	Landsat 5 TM	169 / 60	30 x 30
06 February 1995	Landsat 5 TM	169 / 60	30 x 30
04 February 2003	Landsat 7 ETM+	169 / 60	30 x 30

For this study, the most critical distinction sought is between forested and non-forested areas in an effort to isolate the hydrologic response to rapid conversion of forest to small-scale subsistence farming and managed pasture. Given that the distinction in reflectance between forested and non-forested areas is greatest during the dry season, images that corresponded to a pre green-up period were chosen for this study. It has been suggested that by using dry season images there will be decreased confusion at forest edges between dense forest vegetation and small-scale agricultural plots (Campbell, 1981; Maingi and Marsh, 2001; Singh, 1987; Tole, 2002).

While numerous informational classes may be useful in modeling exercises, such as hydrology, only ten information classes were identified as spectrally or visually distinguishable (*e.g.*, large-scale agriculture patches greater than 1 km^2 are distinguished from mixed agriculture and pasture) in this study. (Table 2). Several image enhancements were employed for this study to improve accuracy assessment in comparison to results achieved by

Baldyga et al. (2004): Tasseled Cap (Huang et al., 2002; Kauth and Thomas, 1976); infrared to red band ratio (Campbell, 2002); Normalized Difference Vegetation Index (Serneels et al., 2001; Tole, 2002; Xiuwan, 2002); and Texture using a 3x3 window (Kiema, 2002).

Table 2. Land cover information classes used in River Njoro watershed.

Class Name	Class Description
Dense Vegetation	Greater than 75% tree cover and includes bamboo forests. Upland areas consist primarily of unaltered native species.
Acacia	Cover dominated by Acacia species.
Euphorbia	Cover dominated by Euphorbia species.
Plantation	Pine and Cyprus forests maintained for timber production.
Riparian	Dense vegetation falling within a 15-m stream buffer.
Urban	Greater than 30% constructed materials such as asphalt, concrete, and buildings.
Degraded	Bare rock, exposed soil, roads, gravel pits, sand harvesting, or with little to no green vegetation.
Large Agriculture	Large homogenous blocks planted and used for crop production including hay.
Mixed Ag / Pasture	Small crops for domestic consumption; typically have grazing area and small structures built using local vegetation as primary building material.
Water	Open water

A challenge confronted in this research project, while not necessarily unique to tropical regions but exacerbated by it, is distinguishing among various non-forested land cover types (Chart 1). Several nonforested, but vegetated, land cover types are often indistinguishable from one another in this study (*i.e.*, managed grasses and various agriculture types). The River Njoro watershed landscape contains land cover types at a spatial scale such that actual land cover types are indistinguishable from one another. Mixed pixels dominate the landscape in several areas and as a result, a single class consisting of managed pastures or small-scale agriculture was identified. Large-scale agriculture is distinguished by patch size and shape by the analyst.

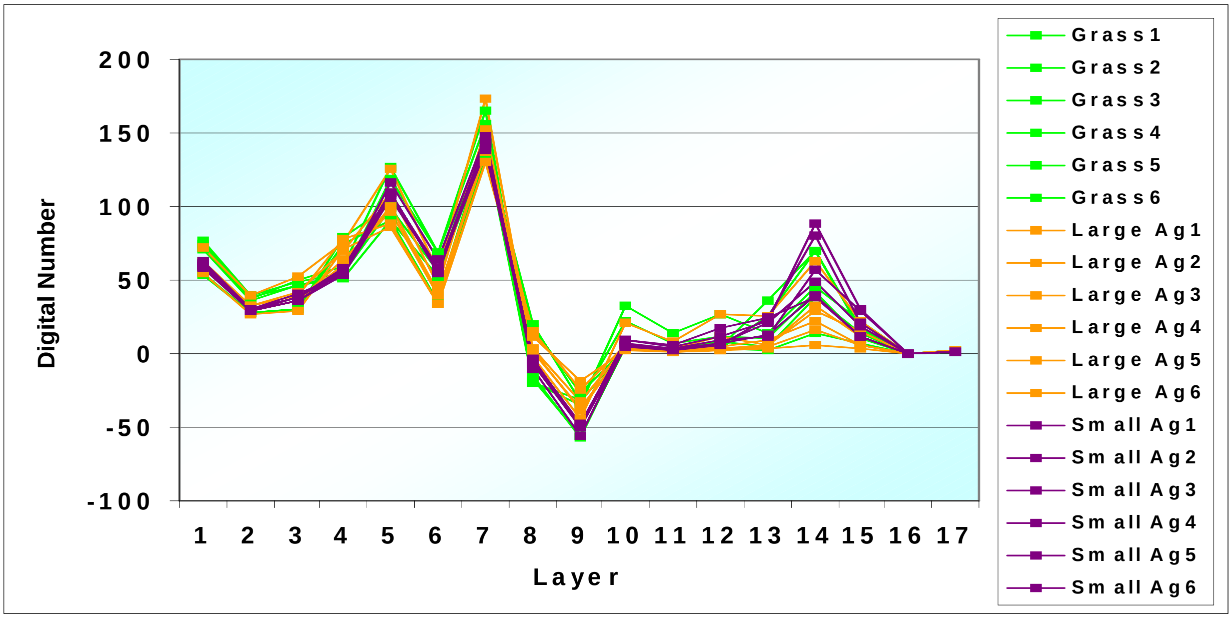

Chart 1. Grass versus agriculture spectral signatures. Digital number represents the average digital number for a training site.

RESULTS

Land cover maps were generated from three Landsat images (Table 1). For each classified image, land cover maps were generated for the entire watershed, which is 270 km2 Additional maps were generated for the uplands region where the greatest land cover changes are believed to be occurring (Figure 2, Figure 3). The upland region in this study is comprised of the area above Egerton University and is 116 km2. For each map, land cover type as a percentage of the total area was calculated (Table 3).

Data collected for classification accuracy occurred during July and August 2004. This is a flawed approach insofar as the accuracy assessment was completed on an image from February 2003, which is in the dry season. Either effort should be made to collect data on the same day as image acquisition, or, when this is impractical, within the same season. In this study, data were collected more than one year after image acquisition during the rainy season. In the River Njoro watershed land management practices change seasonally and this is evident in the low accuracy assessment values (Table 4).

$\hat{K}$ results (Table 4) indicate that at 0.41, the watershed land cover classification is a moderate representation of what is actually on the ground (0.4 – 0.8) (Congalton and Green, 1999).

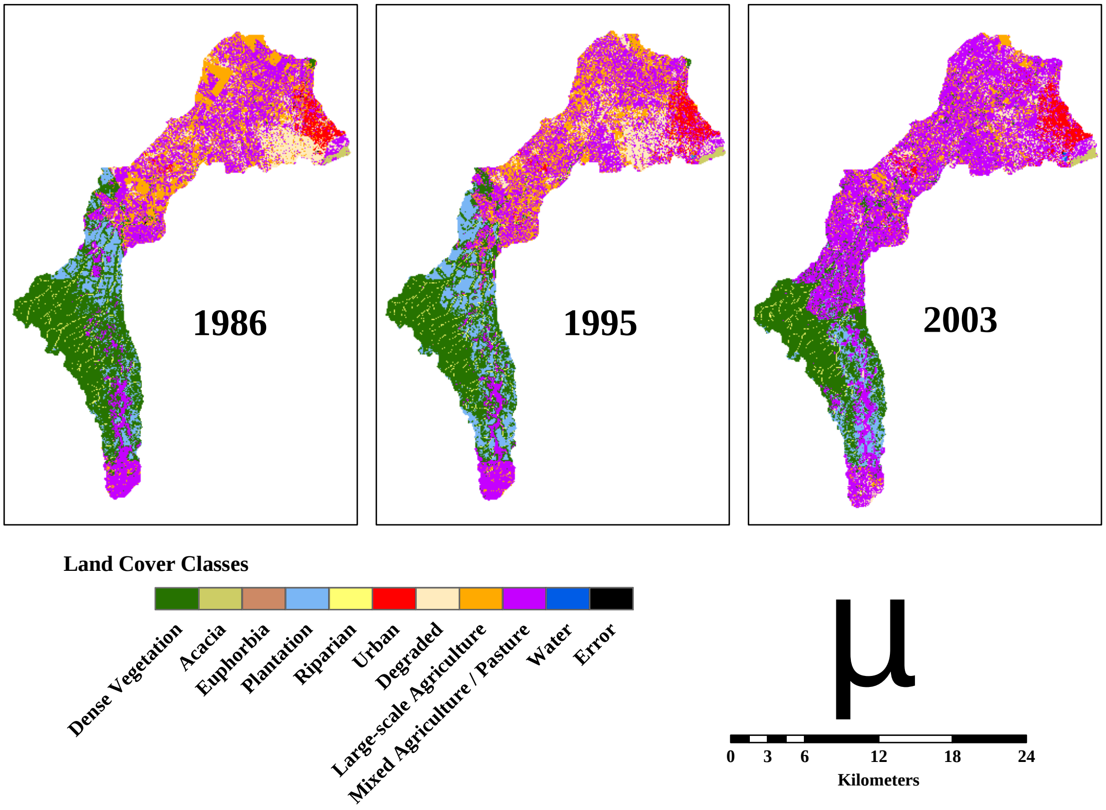

Figure 2. Land cover within the River Njoro watershed.

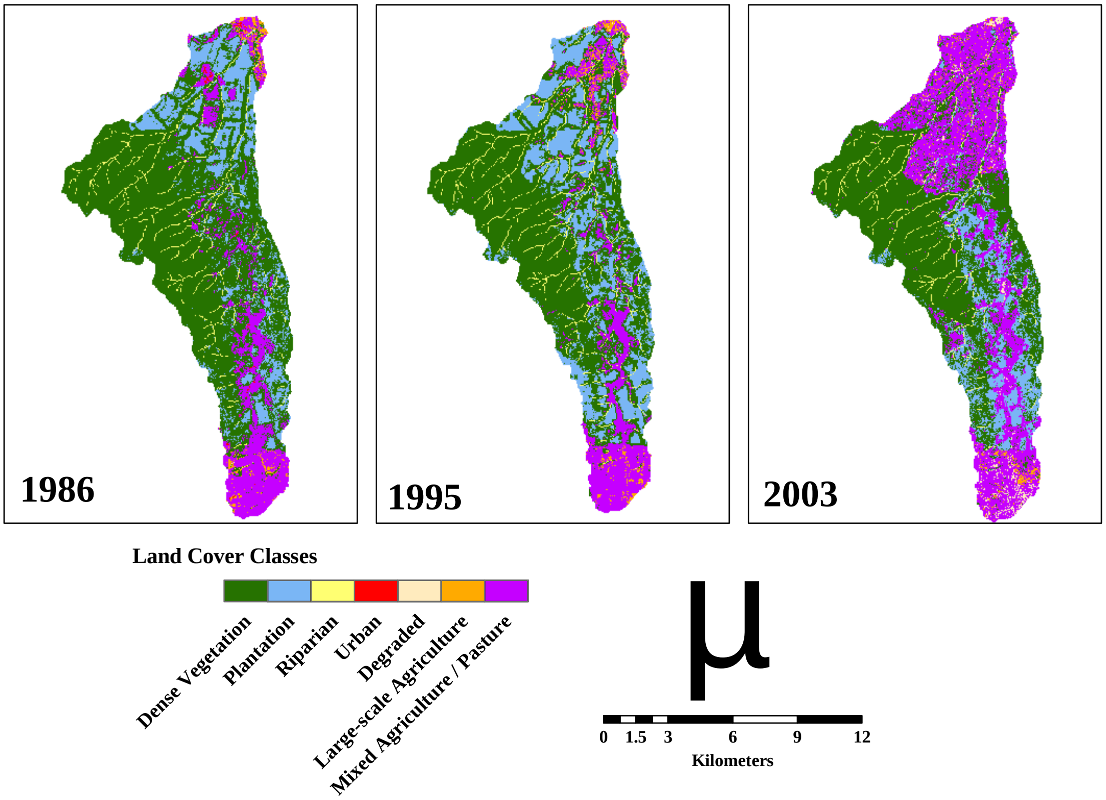

Figure 3. Land cover within the uplands region of the River Njoro watershed.

Table 3. Land cover within the River Njoro watershed. Uplands region is presented as an indicator that land cover change is occurring at a greater rate in the uplands region from dense vegetation and plantation forests to mixed agriculture/ pasture. When comparing Baldyga et al. (2004) "Bare Ground" is considered "Degraded". Baldyga et al. (2004) did not distinguish "Riparian".

	Percent of Watershed			**Percent of Uplands**			**Percent of Uplands (Baldyga et al., 2004)**	
Land Cover Class	**1986**	**1995**	**2003**	**1986**	**1995**	**2003**	**1986**	**2003**
Dense Vegetation	47	26	29	**57**	64	**22**	**35**	**24**
Acacia	0	0.5	0.5	**0**	0	**0.5**	**0**	**0**
Euphorbia	0	<0.5	<0.5	**0**	0	**<0.5**	**0**	**0**
Plantation	14	11	8	**23**	17	**6**	**22**	**13**
Riparian	3	2	1	**4**	3	**1**	**0**	**0**
Urban	0	3	2	**0**	0	**4**	**0**	**0**
Degraded	2	8	8	**0**	<0.5	**6**	**1**	**1**
Large-scale Ag	1	17	19	**2**	1	**9**	**16**	**9**
Mixed Ag / Pasture	33	33	32	**14**	15	**51**	**26**	**53**
Water	0	<0.5	<0.5	**0**	0	**<0.5**	**0**	**0**

DISCUSSION

While overall accuracy results consider maps generated in this study to be a moderate representation of actual land cover (Table 4), they are an improvement over work previously completed by Baldyga et al. (2004).

Results presented here indicate that seasonality is a significant problem when using reference data collected during the dry season. Degraded land cover is over predicted and most often confused with mixed agriculture and pasture. Recall that the images used in this study were chosen primarily to identify the differences between forested and non-forested lands and were taken in January and February, which is the driest period of the year and is usually between harvest and planting. During the dry season many farmers let their fields go to fallow, water becomes scarce and irrigation is rare, so it is not unreasonable to have a higher representation of degraded land cover in the images classified for this study. During the rainy season, those degraded areas are likely to be under cultivation or managed as pasture. Future research is needed to assess land cover accuracy using the same classification methods to classify a Landsat image from the same season in which reference data were collected.

Several data points for dense vegetation were collected in small-scale agricultural fields (Baldyga Field Photo Collection, 2004), and it is likely that the dense vegetation did not cover a large enough area to be considered as distinct and instead appear within mixed pixels classified as small-scale agriculture.

Producer’s accuracy assessment results for dense vegetation and plantation forests were low (Table 4) and somewhat unexpected because the two land cover types have distinct spectral signatures when compared to other land cover types. Low accuracy results are believed to be an error resulting from mixed pixels defined as dense vegetation in cultivated areas. Plantation forests are rare in the River Njoro watershed as evidenced by the few data points collected. Many plantation forests are no longer actively managed by the Kenya Forestry Department. Consequently, dense vegetation is growing within the stands, and reflectance in these areas may mimic the dense vegetation spectral signature more than the plantation signature. As noted in Table 4, only seven reference points were collected for plantation forest accuracy assessment. Three of those points were misclassified as dense vegetation, and one each as grass and small-scale agriculture. While plantation forests are spectrally distinct when present as large distinct homogeneous patches, too few data points were available to demonstrate the statistical validity of the methods employed for classifying plantation forests in this study.

Classifying imagery using multiple seasons may alleviate much of the error in the accuracy assessment. At present, plans are in place for classifying a rainy season image from September 2002, but are beyond the scope of the current study detailed here.

Primary land cover changes occurring (Table 3) indicate increased land cover conversion after 1995 over that which occurred between 1986 and 1995. For example, mixed agriculture / pasture increased marginally between 1986 and 1995 at both the watershed and uplands scale, while it increased by nearly 20% at the watershed level and more than doubled in the uplands.

Table 4. Accuracy assessment for 04 February 2003 Landsat image. M = Mixed Agriculture / Pasture; DV = Dense Vegetation; A = Acacia; P = Plantation; R = Riparian; U = Urban; D = Degraded; LA = Large-scale Agriculture.

		Reference Data								
		M	**DV**	**A**	**P**	**R**	**U**	**D**	**LA**	**Row Total**
Classified Data	**M**	**189**	26	1	2	4	3	15	31	**271**
	DV	8	**17**	0	3	0	0	0	0	**28**
	A	0	0	**6**	0	0	0	1	0	**7**
	P	0	1	0	**2**	1	0	0	0	**4**
	R	0	0	0	0	**2**	0	0	0	**2**
	U	1	0	0	0	1	**9**	0	2	**13**
	D	16	2	1	0	0	0	**21**	1	**41**
	LA	13	3	0	0	0	1	1	**15**	**33**
	Column Total	**227**	**49**	**8**	**7**	**8**	**13**	**38**	**49**	**399**

Producer's Accuracy	**User's Accuracy**
M = 189 / 227 = 83%	**M = 189 / 271 = 70%**
DV = 17 / 49 = 35%	**DV = 17 / 28 = 61%**
A = 6 / 8 = 75%	**A = 6 / 7 = 86%**
P = 2 / 7 = 29%	**P = 2 / 4 = 50%**
R = 2 / 8 = 25%	**R = 2 / 2 = 100%**
U = 9 / 13 = 69%	**U = 9 / 13 = 69%**
D = 21 / 38 = 55%	**D = 21 / 41 = 51%**
LA = 15 / 49 = 33%	**LA = 15 / 33 = 45%**
Overall Accuracy = 65%	**Khat = 0.41**

CONCLUSION

Results, and consequently methods used, presented here represent an improvement over previous work by Baldyga et al. (2004). Previous attempts at land cover classification resulted in only a 41% map accuracy with a $\hat{K}$ of only 0.17, indicating previous land cover map were poor representations of what is actually on the ground. Current land cover classification presented here has an overall accuracy of 65% with a $\hat{K}$ of. 0.41. From this improved land cover classification research is underway to understand and quantify error distribution.

In addition, work concluded here provides a baseline for understanding land cover within the Njoro and will be used as an anchor for future studies that explore possible land management scenarios. In particular, land cover results reported here will be linked in as part of a future study that analyzes large-scale migration of people into the watershed from surrounding regions and well as a primary input for modeling the hydrologic response to changes.

ACKNOWLEDGEMENTS

Funding for this research was provided by the Global Livestock Collaborative Research Support Program (GL CRSP) as part of the Sustainable Management of Watersheds project. The GL-CRSP is funded in part by USAID and by participating institutions under subgrant number 126-25-27. Significant field and technical support was provided by numerous faculty and scientists at Egerton and Moi Universities, Kenya.

REFERENCES

Baldyga, T.J., S.N. Miller, W.A. Shivoga, and C. Maina-Gichaba, 2004. Assessing land cover change impacts using remote sensing and hydrologic modeling. *Proceedings of the American Society for Photogrammetry and Remote Sensing Annual Meeting*, Denver, CO, May 23-28, 2004.

Baldyga, T.J., 2004. Collection of photographs, July – August 2004 field work in Upper River Njoro Watershed. Graduate Student, Renewable Resources Department, University of Wyoming, Laramie, WY.

Calder, I.R., 1993. Hydrologic effects of land-use change. Chapter 13 in *Handbook of Hydrology* (Maidment, D.R. Ed). McGraw-Hill, New York, 13.1-13.50.

Campbell, J.B., 2002. Introduction to Remote Sensing. 3d ed. The Guilford Press, New York, 621.

Campbell, J.B., 1981. Spatial correlation effects upon accuracy of supervised classification of land cover. *Photogrammetric Engineering and Remote Sensing*, 47(3):355-363.

Cingolani, A.M., D. Renison, M.R. Zak, and M.R. Cabido, 2004. Mapping vegetation in a heterogeneous mountain rangeland using Landsat data: an alternative method to define and classify land-cover units. *Remote Sensing of Environment*, 92:84-97.

Cirone, P.A. and P.B. Duncan, 2000. Integrating human health and ecological concerns in risk assessments. *Journal of Hazardous Materials*, 78:1-17.

Colby, J.D. and P.L. Keating, 1998. Land cover classification using Landsat TM imagery in the tropical highlands: The influence of anisotropic reflectance. *International Journal of Remote Sensing*, 19(8):1479-1500.

Congalton, R.G. and K. Green, 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. Lewis Publishers, Boca Raton, 137.

Huang, C., Wylie, B., Homer, C., Yang, L., and Zylstra, G., 2002. Derivation of a Tasseled cap transformation based on Landsat 7 at-satellite reflectance: International Journal of Remote Sensing, 23(8):1741-1748.

Imbernon, 1999. Pattern and development of land-use changes in Kenyan highlands since the 1950s. Agriculture, Ecosystems and Environment, 76:67-73.

Kauth, R.J. and G.S. Thomas, 1976. The Tasseled Cap – A Graphic Description of the Spectra-Temporal Development of Agriculture Crops as Seen by Landsat. In LARS: Proceedings of the Symposium on Machine Processing of Remotely Sensed Data. West Lafayette, IN. Perdue University Press, pp. 4B-41 - 4B-51.

Kenya Forests Working Group (KFWG), 2001. Excision and settlement in the Mau Forest. Report of Kenya Forest Working Group, 15 pp.

Kiema, J.B.K., 2002. Texture analysis and data fusion in the extraction of topographic objects from satellite imagery. International Journal of Remote Sensing, 23(4):767-76.

King, L.A. and V.L. Hood, 1999. Ecosystems health and sustainable communities: north and south. Ecosystem Health, 5(1):49-57.

Krhoda, G.O., 1988. The impact of resource utilization on the hydrology of the Mau Hills forest in Kenya. Mountain Research and Development, 8(2-3):193-200.

Leprieur, C.E., Durand, J.M. and Peyron, J.L., 1988. Influence of topography on forest reflectance using Landsat Thematic Mapper and digital terrain data. Photogrammetric Engineering and Remote Sensing, 54(4):491-496.

Lucas, R.M., A.A. Held, S.R. Phinn, and S. Saatchi, 2004. Tropical Forests. Chapter 5 in *remote Sensing for Natural Resource Management and Environmental Monitoring, 3d ed., Volume 4* (Ustin, S.L. Ed). John Wiley & Sons, Inc, Hoboken, New Jersey, 239-316.

Maingi, J.K. and S.E. Marsh, 2001. Assessment of environmental impacts of river basin development on the riverine forests of eastern Kenya using multi-temporal satellite data. International Journal of Remote Sensing, 22(14):2701-2729.

Mainuri, Z.G., 2005. Land use effects on the spatial distribution of soil aggregate stability within the River Njoro watershed, Kenya. MS Thesis submitted to Department of Geography, Egerton University, Kenya.

Mathooko, J.M., G.O. Morara and M. Leichtfried, 2001. The effect of different anthropogenic disturbances on benthic plant coarse particulate matter in a tropical Rift Valley stream. African Journal of Ecology, 39:310-312.

Mathooko, J.M. and S.T. Kariuki, 2000. Disturbances and species distribution of the riparian vegetation of a Rift Valley stream. African Journal of Ecology, 38:123-129.

Miller, S.N., W.G. Kepner, M.H. Mehaffey, M. Hernandez, R.C. Miller, D.C. Goodrich, K.K. Devonhold, D. T. Heggem, and W. P. Miller, 2002. Integrating landscape assessment and hydrologic modeling for land cover change analysis. Journal of the American Water Resources Association, 38(4):915-929.

Mistry, J., 2000. Savannas. Progress in Physical Geography, 24(2):273-279.

Navrud, S. and E.D. Mungatana, 1994. Environmental valuation in developing countries: the recreational value of wildlife viewing. Ecological Economics, 11:135-151.

Patz, J. A., 2001. Public health risk assessment linked to climatic and ecological change. Human and ecological risk assessment, 7(5):1317-1327.

Serneels, S., M.Y. Said and E.F. Lambin, 2001. Land cover changes around a major east African wildlife reserve: the Mara ecosystem (Kenya). International Journal of Remote Sensing, 22(17):3397-3420.

Sheng, T.C., R.E. Barrett and T.R. Mitchell, 1997. Using geographic information systems for watershed classification and rating in developing countries. Journal of Soil and Water Conservation, 55(2): 84-89.

Sharma, T., P.V. Satya Kiran, T.P. Singh, A.V. Trivedi and R.R. Navalgund, 2001. Hydrologic response of a watershed to land use changes: a remote sensing and GIS approach. International Journal of Remote Sensing, 22(11):2095-2108.

Singh, A., 1987. Spectral separability of tropical forest classes. International Journal of Remote Sensing, 8:971-979.

Smith, J.H., S.V. Stehman, J.D. Wickham, and L. Yang, 2003. Effects of landscape characteristics on land-cover class accuracy. Remote Sensing of Environment, 84:342-349.

Tiffen, M., M. Mortimore and F. Gichuki, 1994. Population growth and environmental recovery: Policy lessons from Kenya. Gatekeeper Series No 45. International Institute for Environment and Development, London.

Tole, L., 2002. An estimate of forest cover extent and change in Jamaica using Landsat MSS data. International Journal of Remote Sensing, 23(1):91-106.

Xiuwan, C., 2002. Using remote sensing and GIS to analyse land cover change and its impacts on regional sustainable development. International Journal of Remote Sensing, 23(1):107-124.