ASSESSING THE IMPACT OF LAND COVER CHANGE IN KENYA USING REMOTE SENSING AND HYDROLOGIC MODELING

Tracy J. Baldyga, Research Assistant
Scott N. Miller, Assistant Professor
Department of Renewable Resources
University of Wyoming
Department 3354, 1000 University Dr.
Laramie, WY 82071
tbaldyga@uwyo.edu
snmiller@uwyo.edu
William Shivoga, Department Head Environmental and Natural Resources
Maina Gichaba, Department Head Geography
Egerton University
PO BOX 536
Njoro, KENYA
sumawa-crsp@africaonline.co.ke

ABSTRACT

Rapid land cover changes occurring in the Rift Valley of Kenya are altering the hydrologic response of critical watersheds. Four Landsat scenes from the past 18 years were used to develop a land cover classification scheme for the Njoro River watershed. These data were input to the Automated Geospatial Watershed Assessment (AGWA), a geographic information system (GIS) tool. AGWA was used to parameterize and run the Soil and Water Assessment Tool (SWAT), a hydrologic model suitable for assessing land cover change impacts on hydrologic response. The automated parameterization routines in AGWA are designed for US soil and land cover data sets and require inputs for terrain, soil, land cover, climate and rainfall. Climate, soil and terrain data were built for the watershed using historical data and field work, and classified land cover data were created using supervised and unsupervised classification and verified in the field. Techniques and methods were created to transform Kenya data sets into suitable formats for AGWA. Preliminary findings indicate the suitability of this type of analysis for watershed assessment in Kenya; changes in landscape and land use are reflected in significant changes to simulated hydrologic results.

INTRODUCTION

In developing nations where resources are scarce and increased population pressures create stress on available resources, methods are needed for examining the effects of human migration and resulting land cover changes. Understanding such effects through spatially explicit watershed modeling opens the door for monitoring and correlating environmental change with socio-economic and health changes (Cirone et al. 2000, King et al. 1999, Patz 2001, Troyer 2002). The widespread availability, and decreased cost, of remotely sensed imagery and Geographic Information Systems (GIS) allow for efficient and quantitative resource mapping and land cover change detection. This is of particular value in developing nations where trained personnel and finances are limited, or where many areas are inaccessible (Alvarez 1983, George 1998, Sheng et al. 1997). Remotely sensed imagery provides up-to-date, as well as over time, natural resource information such as land cover change caused by resource exploitation or renewal, available resource estimates, and how land cover changes are affecting surrounding areas. Such technologies can be used by developing nations to alleviate or predict resource scarcity and improve overall ability for self-sufficiency.

The primary objective in this study was to determine the suitability of the Automated Geospatial Watershed Assessment (AGWA) (Miller et al. 2002) tool in assessing hydrologic change in the River Njoro watershed, Kenya. We did not have the expectation of creating a calibrated and validated runoff prediction tool. We are trying to isolate the hydrologic signal showing response to land cover change. Our need is to have the correct magnitude and direction of change. Tasks undertaken to verify the AGWA tool suitability were threefold:

- temporal and spatial landcover change distribution assessment using remotely sensed imagery
- techniques were developed for data transformation
- used simulated hydrologic results to evaluate trends and effects of land cover change on hydrologic response

In this study particular attention was given to forested area losses, be they indigenous or plantation, through conversion to mixed small-scale agriculture and pasture.

SITE DESCRIPTION

The River Njoro watershed is located in the Rift Valley of southwestern Kenya at 0°30' South, 35°, 20' East (Figure 1). The River Njoro is approximately 50 km in length with an approximate 200 km^2 contributing area. The river originates in the Eastern Mau Escarpment at approximately 3000 masl, with its terminus at Lake Nakuru at 1,759 masl. The river flows through forested and agricultural lands before serving the towns of Njoro and Nakuru. The Lake is enclosed within the Lake Nakuru National Park. A Ramsar Site, the Park is famous for its large populations of flamingos. The area has a bimodal precipitation pattern with long rains occurring from April-May and short rains occurring from July-August. Mean annual rainfall measured at Njoro center from 1949-2001 was 939.3 mm. Average annual minimum and maximum temperatures for the area range are 9° and 24° C respectively.

In 1963 Kenya received independence from British Colonial rule. According to a report by the Kenya Forests Working Group in 2001, the Mau Forest Complex since 1964 has decreased by approximately 9% (340 km^2) due to deforestation. This study evaluates hydrologic response to land cover change in the once heavily forested upland portion of the watershed. Rapid conversion from indigenous and plantation forests to small-scale agriculture have occurred in the this upland region where agricultural conditions are favorable.

Soils in the region are Ultisols and Entisols. Soils textures range from clay loams in the lower portion of the study area to sandy clay loams in the plantation and indigenous forest areas at higher elevations.

Figure 1: Location of the Njoro watershed.

METHODS

Land Cover Change

Three Landsat TM and one Landsat TM+ scenes were selected for this study. Table 1 lists sensors and acquisition dates for the four images used. Images were selected that correspond by year with census dates for eventual

Table 1: Satellite data used.

IMAGE DATE	SENSOR	RESOLUTION
January 1986	Landsat TM	30m
March 1989	Landsat TM	30m
January 2000	Landsat TM+	30m
February 2003	Landsat TM+	30m

correlation between land cover change and human migration and population increases. Because phenological differences between wet and dry season vegetation in tropical regions can be marked, only dry season images were selected for classification (Maingi 2001). This served the purpose of distinguishing forested areas from those areas converted to mixed small-scale agriculture and pasture.

Six information classes were identified as relevant for detecting hydrologic response to land cover change in this study (Figure 2). However, only the 2003 image contains areas considered significant bare ground. An unsupervised classification using the Iterative Self-Organizing data Analysis Technique (ISODATA) available in ERDAS Imagine was performed for each of the four images separating out 50 spectral clusters. Data clusters were then assigned accordingly to one of the six informational classes. Inadequate data were available to perform a supervised classification, and the few available data did not provide any useful spectral distinctions. Land cover change is a significant factor driving hydrologic changes such as runoff volume and timing (Fohrer 2001, Maingi 2001, Miller et al. 2002, Rawls 1989). As illustrated in Table 2 land cover classification errors will produce significant differences in hydrologic response.

	Mixed Ag	Bare	Plantation	Indigenous	Grasslands
Agriculture	-16	-26	26	26	6
Mixed Ag		-10	42	42	22
Bare			51	51	32
Plantation				0	-19
Indigenous					-19

Table 2: Impact of classification error or land cover changen on curve number modeling result. Results are percent change in runoff as a function of a 2” rainfall amount.

Data Transformation

DEM Using the AGWA tool requires DEM input, which was not available for the region. Contour maps were acquired and digitized to create a 50m DEM using ArcINFO. This resolution allows AGWA to produce a suitable delineation of the watershed and subwatersheds.

Soils Soil data is a significant component to the AGWA model, however, the model only supports NRCS STATSGO and SSURGO soil data. Only FAO soil data, classifying the area as Cambisols and Acrisols in the lower and upper regions respectively, was available for the study area. Cambisols and Acrisols are classified as Ultisols and Entosols respectively in US Soil Taxonomy. This data coupled with limited soil data for texture and infiltration collected during 2003 was used to find comparable STATSGO soils. The Cambisols were assigned MUID TN120 and Acrisols were assigned MUID GA026.

Rainfall Daily rainfall totals have been collected in the town of Njoro, which lies near the outlet of the watershed, since the 1940s. These data were evaluated for consistency and completeness of their record, and a segment of the rainfall was selected for use in this study. SWAT requires daily estimates of rainfall as well as a weather generator file that describes the long-term averages for rainfall, relative humidity, and a host of other climate conditions. The data required by SWAT were available for the Njoro climate station and were used to build the required input. A period of nine years of rainfall was extracted from the long-term data for the period of 1990-1999. These data served as the primary climatic input to SWAT.

Hydrologoc Modeling

The Soil Water Assessment Tool (SWAT) (Neitesche et al 2002) component of the AGWA tool was used to simulate hydrologic response for the four land cover scenarios over a nine-year period beginning in 1990, which included El Niño in 1998. SWAT is a physically-based model operating on a daily time step. The model allows a basin to be divided into natural subwatersheds, each with a unique land cover, soil and land use combination. The model is then able to quantify the relative impact of management, soil, climate and vegetation changes for each subwatershed. As reported in Miller et al (2002), SWAT uses a modified Curve Number approach to determine rainfall excess.

RESULTS AND DISCUSSION

Land cover change

The spatial distribution of land cover change within the watershed from 1986 to 2003 is presented in Figure 2. Table 3 shows overall land cover change among the four dates. From 1986 to 1989 the landscape was relatively static with small scale changes in all informational classes. The greatest land cover changes occurred after 1989, with rapid loss in plantation forest and the conversion of forested areas into small-scale (mixed) agriculture. Additionally, several larger agricultural areas were transformed into smallholdings. By 2003 the majority of plantation forest are converted to small-scale agriculture and there is large net loss in large agricultural systems. Overall the amount of grasslands increased through time, primarily in the uppermost reaches of the watershed.

The trend in forest loss was unsurprising given the historical knowledge of the area. The Mau forest has been undergoing significant losses throughout its extent (Kenya Forest Working Group 2001). It was somewhat surprising to see rapid plantation forest losses between 2000 and 2003 in the uppermost regions of the watershed, given that the area was not converted to small-scale agriculture. We hypothesize that the plantations are not being maintained under sound agroforestry practices and are instead being transformed into more natural forests, rendering them less spectrally distinct from the indigenous forest. Thus, the increase in indigenous forest during that time period may be due to the gradual decline in plantation maintenance.

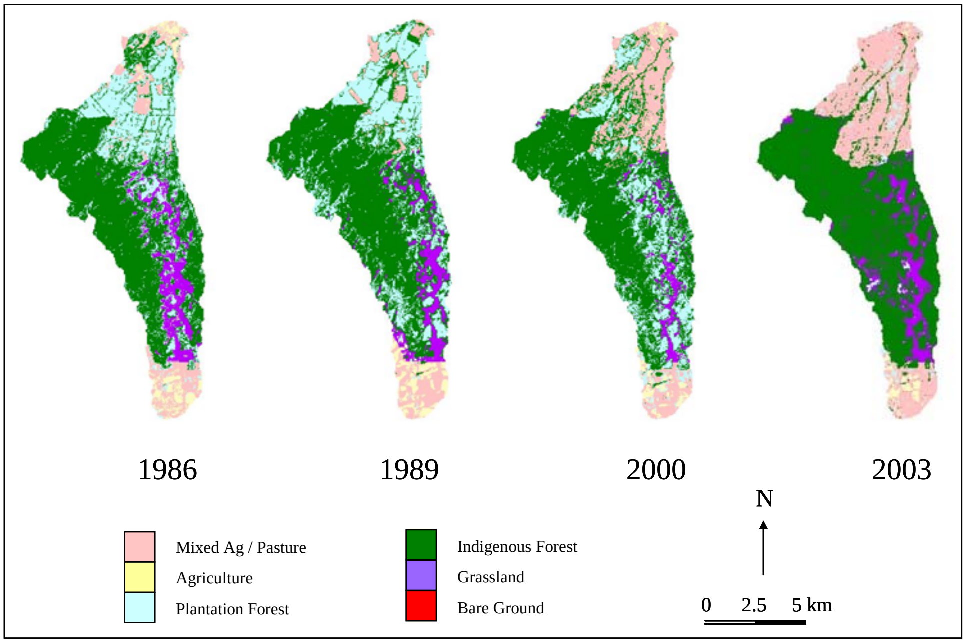

Figure 2. Unsupervised land cover classification of the upper Njoro watershed.

Large increases in smallholder agriculture is significant throughout the watershed, but are especially pronounced in the lower sections. In these areas both plantation forest and large-scale agriculture were converted into small farms as population pressure increased. There is not a significant amount of large-scale agriculture within the watershed, so most of the conversion to smallholdings took place at the expense of the plantation forests.

A preliminary accuracy assessment was performed on the 2003 image using observations taken during July 2003. Results from this assessment are presented in Table 4. The greatest source of confusion in the classified map was distinguishing indigenous and plantation forest. Plantations were often difficult to distinguish from indigenous vegetation spectrally near edges and riparian areas, as well as at lower elevations in the study area. Grasslands were distinguished only within the indigenous and plantation forest regions. Grasslands as such were not spectrally distinguishable from areas identified as mixed small-scale agriculture and pasture. However, field visits demonstrated distinct differences among vegetation cover and grazing practices between the two areas.

Table 3. Land cover change matrix for unsupervised classification data in the upper Njoro watershed.

		1989		2000		2003	
		km²	%	km²	%	km²	%
1986	AG	-0.62	-0.53	-1.89	-1.62	-2.51	-2.16
	AG MIX	-0.73	**-0.62**	10.37	**8.92**	22.47	**19.31**
	PLANT	2.11	**1.81**	-3.84	**-3.30**	-26.55	**-22.82**
	INDIG	0.72	**0.62**	0.55	**0.48**	5.67	**4.88**
	GRASS	-1.49	-1.28	-5.20	-4.47	0.61	0.53
1989	AG			-1.27	-1.09	-1.89	-1.63
	AG MIX			11.10	**9.54**	23.19	**19.94**
	PLANT			-5.94	**-5.11**	-28.65	**-24.63**
	INDIG			-0.17	**-0.14**	4.95	**4.26**
	GRASS			-3.72	-3.20	2.10	1.80
2000	AG					-0.62	-0.54
	AG MIX					12.09	**10.40**
	PLANT					-22.71	**-19.52**
	INDIG					5.12	**4.40**
	GRASS					5.81	5.00

It is recognized that the overall accuracy presented in Table 4 is relatively low (41%). However, the primary objective of this paper was to evaluate the potential for using AGWA to simulate the land cover change effects on hydrologic response. The key distinction required in the classification scheme under this objective is between forest and non-forested areas. The classification scheme was successful in making this determination. Ongoing research efforts are focused at improving classification accuracy. All remotely sensed data used in this component of the project were acquired during the dry season, and it is expected that the addition of imagery collected during the growing season will improve the classification. The 2003 field season was relatively short and the number of data points collected for the validation was inadequate to fully describe the area. Over the next year numerous site visits will enhance both the classification and the assessment of inaccuracy in the data.

Table 4. Error matrix resulting from accuracy assessment of 2003 classified land cover image.

Land Cover Class	Map Total	Number Correct	Producer's Accuracy (%)	User's Accuracy (%)
1. Agriculture	9	2	22.2	40.0
2. Bare Ground	0	0	--	--
3. Mixed Ag / Pasture	13	9	69.2	40.9
4. Indigenous Forest	8	1	11.1	25.0
5. Plantation Forest	9	4	44.4	50.0
Total:	**39**	**16**		

Overall Accuracy (%):	**41**
Overall K^ Statistics:	**0.1731**

Hydrologic Modeling

The Automated Geospatial Watershed Assessment (AGWA) tool was used to build input parameter files for the Soil and Water Assessment Tool (SWAT). Each of the four classified images was used to parameterize the watershed independently, and runoff was generated for 9 years of continuous simulation for the watershed study area. The same soil and rainfall data were used as input to each of the four simulation runs, so all changes in the runoff can be traced solely to changes in land cover following the method developed by Miller et al., 2002.

Simulated runoff results show annual runoff increases over time commensurate with increasing landscape fragmentation into small-scale agriculture and losses in forested areas. There is considerable spatial variability in the observed land cover change, and this spatial variability has implications for hydrologic modeling and assessment (Fohrer 2001, Maingi 2001, Miller et al. 2002, Rawls 1989). The change in average annual runoff at the watershed outlet is presented in Table 5. The seemingly anomalous result in Table 5 was a slight decrease in simulated runoff from 1986-1989. This decrease is due primarily to the apparent increase in forested areas and compensating loss of agricultural area during that time period.

Table 5: Percent change in annual runoff from the Njoro watershed as simulated by SWAT. Each of the four dates represents a classified land cover scene that was used to parameterize SWAT.

	1989	2000	2003
1986	-0.85	31.34	108.11
	1989	32.46	109.89
		2000	58.45

One of the primary benefits of using spatially distributed runoff models such as SWAT is the depiction of runoff as a spatially variable process. Figure 3 shows the spatial distribution in change in runoff from 1986 to 1989 and from 1986 to 2003. While increased runoff occurred in some of the subwatershed elements, other regions showed improvements in their condition. These compensating changes serve to cancel out changes in annual runoff volume at the watershed outlet. Internal variability and sensitivity to change is therefore much greater than what is observed simply by looking at the watershed outlet. Runoff simulation results imply that several areas within the watershed were responding to the land cover change to a greater degree than others. A high degree of spatial variability in runoff response was reflected in the simulation: several watershed elements showed a decline in simulated runoff, while the majority of elements indicated an increase in average annual runoff, including an overall increase at the watershed outlet.

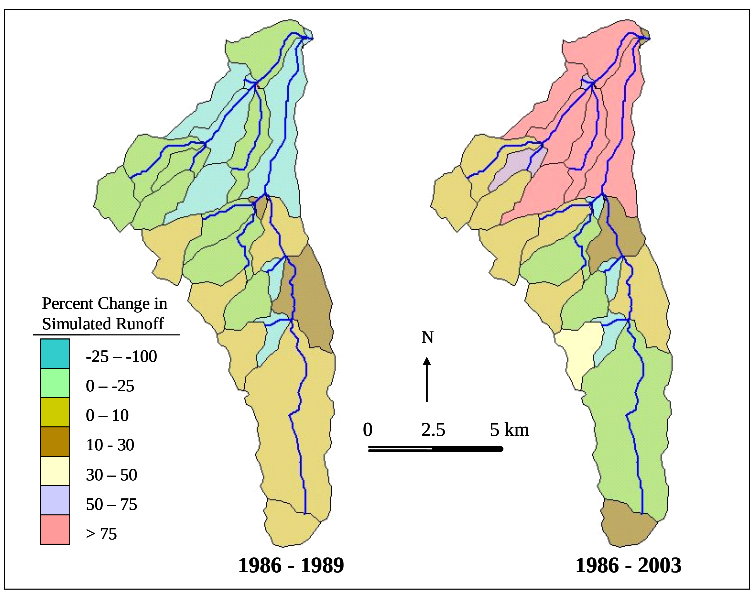

Figure 3: Spatially distributed change in simulated runoff within the Njoro watershed. Change is expressed in percent change between simulations parameterized with the 1986, 1989m and 2004 land cover scenes.

The variability in annual simulations of runoff to the watershed outlet is presented in Figure 4. In this figure the large increase in runoff on an annual basis resulting from land cover change to the 2003 data is clearly visible. Annual rainfall over the 9 years of simulation (rainfall years 1990-1998) was highly variable, resulting in highly variable simulated runoff. In general, a trend in increased percent change in runoff with increased rainfall is evident. This implies that the landscape has become more vulnerable to large-scale events. This vulnerability has significant implications for both the human and ecological concerns in the watershed. As runoff becomes more flashy and surface discharge dominates the hydrologic response, less water infiltrates and percolates to groundwater. People who are dependent on local and regional groundwater aquifers are therefore at risk.

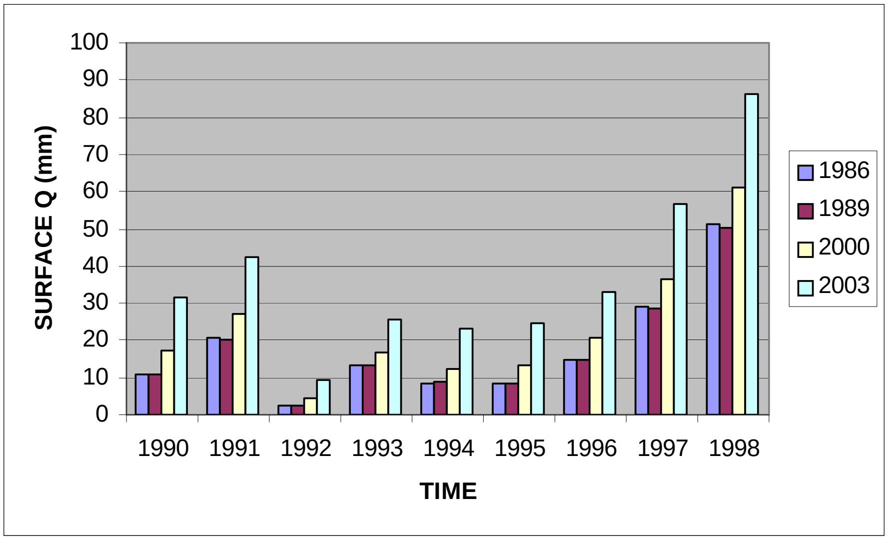

Figure 4: Annual discharge simulated for 9 years of rainfall (1990-1998) simulated by SWAT.

CONCLUSIONS

The hydrologic response of the upper Njoro watershed to land cover change over several decades was modeled using a distributed hydrologic simulation model. A classification of remotely sensed data was developed along with a preliminary accuracy assessment for scenes acquired in 1986, 1989, 2000, and 2003. These four scenes were input to the Automated Geospatial Watershed Assessment tool, which constructed input parameter files for the Soil and Water Assessment Tool, which was used to simulate surface runoff. The hydrologic response of the watershed to land cover change was successfully simulated in this environment.

Land cover change analysis shows that there was a significant loss in upland forests, primarily due to the removal of plantation forests. In addition to these losses, there was a large increase in small-scale agriculture. These changes illustrate the rapid fragmentation of the landscape over the last decade and rapid transformation of the landscape.

Hydrologic modeling results indicate that watershed hydrologic response in the Njoro watershed has been altered to favor increased average annual runoff due to land cover change during the period from 1986 to 2003. These results underscore the problems resulting from population pressures and the resultant loss of upland forests and fragmentation of the landscape into small-scale agriculture. These changes reflect an increased risk for decreased water quality, reduction in groundwater recharge and subsequent decline in the aquifer, as well as related impacts to the local ecology.

Future research will focus on improvements to the classification accuracy and model calibration. These preliminary findings are part of a long-term multi-disciplinary project (the Sustainable Management of Watersheds Collaborative Research Project) investigating the linkages among watershed hydrology, ecology, economics, and stakeholder decision making. Results from this study show that direct and powerful linkages can be expressed using a combination of remote sensing, GIS, and hydrologic modeling tools. Future efforts will focus on improving the landscape classification, acquiring primary hydrologic data to validate these efforts, and building integrated models that represent the linkages among humans, the landscape, and hydrologic and ecological changes.

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