Global Livestock CRSP

Investigating the Role of Land Cover Change on the Hydrology of the River Njoro Watershed

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Rapid land cover and land use changes occurring in Kenya's Rift Valley are altering the hydrologic response in the River Njoro watershed. This watershed is a critical contributor of runoff to Lake Nakuru National Park, an internationally recognized wetlands area. Three remote sensing images were classified to determine the land cover transitions that occurred over a 17-year period from the mid-1980's through the mid-1990's. The results served as the primary land cover data set for surface runoff simulation using a GIS-based hydrologic modeling system called the Automated Geospatial Watershed Assessment (AGWA) tool. AGWA was used to generate parameter input files for the Soil and Water Assessment Tool (SWAT). SWAT is a hydrologic model suitable for assessing land cover change impacts on hydrologic response. Results show that changes have resulted in corresponding increases in surface runoff and changes to the timing and intensity of runoff. Increases in surface runoff and changes to water yield show a high degree of spatial and temporal heterogeneity that are linked to land cover and land use changes. Modeling serves an important role in land management since the time, cost, and expertise required to install, monitor, and identify problems in the field using hydrological instrumentation can be prohibitive, while lessons learned in a modeling environment can be transferred to other similar environments.

Background

Changes to the hydrologic regime, meaning the timing and amount of river flow, in the River Njoro have the potential to significantly disrupt both human and ecological systems that rely on the river. People look to the river as a primary source of drinking water and for other household, livestock, and agricultural needs. Lake Nakuru National Park relies on the river to sustain ecological services, both within the river corridor and the lake itself. Conversion of natural landscapes for agricultural and urban uses often impacts soil integrity, nutrient fluxes, and native species. Such changes can affect the surface hydrology by altering the rates of the processes that control the transformation of rainfall to runoff and groundwater. For example, several studies have demonstrated that the establishment of plantation forests in sub-tropical environments resulted in reduced river flow during dry seasons due to increased losses of water through vegetation. On the other hand, if vegetation clearing is followed by land use practices that compact soils and expose them to erosion, decreased percolation to groundwater can result.

Both anecdotal evidence and river observations suggest that the timing, duration, and overall amounts of flows in the River Njoro have changed in the last decade, coincident with significant changes in the land cover, overall deforestation of the region, and increases in agricultural and other human activities. This project seeks to determine whether the observed land cover changes can be causally linked to hydrological alterations. A hydrological modeling system was used to compare the hydrologic response of the river under the land cover characteristics observed over time.

Findings

Significant effort was put toward identifying appropriate model inputs that would adequately describe the annual fluxes of water and capture the processes that control the hydrologic response of the catchment. This effort was somewhat limited by the relatively scarce rainfall and runoff data that existed prior to the establishment of the SUMAWA project. Relatively robust records of rainfall and runoff were available for seven years to a runoff gauging station near Egerton University in Njoro. These data were used to calibrate the SWAT model for annual water yield with an emphasis on capturing the temporal variability in water yield by altering the surface conditions and the rate of rainfall as it passes into the soil profile. Results from this effort were very good relative to the available literature, with efficiencies greater than 90 percent.

Hydrologic impacts were assessed by comparing a series of model runs where the rainfall and climate data were held constant, but the vegetation cover was changed to represent the changing land cover identified by Baldyga et al. (2007). Simulated rainfall-runoff results for 1986, 1995, and 2003 land cover show increased direct surface runoff using the same rainfall as input for all simulations after model calibration.

Further analysis indicates that the greatest increase in runoff has occurred post-1995. As a function of land cover change, simulated runoff increased between 1995 and 2003 by more than 50 percent for each simulation year, with most years showing an increase by at least 60 percent. Surface runoff is that portion of rainfall that does not infiltrate into the soil and is primarily responsible for ancillary effects such as surface and stream erosion.

An analysis of the spatial distribution of percent change in surface runoff (Figure 1) shows that areas near the outlet that were plantation forests but were altered to small-scale agriculture had the greatest increase in runoff. Such increases are to be expected in areas where deforestation and agricultural intensification, significant drivers of hydrologic change at a watershed scale, are occurring simultaneously. Several significant basin scale changes can be attributed to deforestation. Annual flows generally increase in a magnitude proportional to the amount of deforestation.

This spatial analysis is particularly useful for decision support and local interpretation of effects. The simulated rainfall-runoff results for 1986, 1995, and 2003 land cover are from the outlet and represent an overall basin response whereby the areas of very high change are somewhat balanced by those areas that have not undergone significant alterations. Taking a spatially distributed approach shows those areas of greatest change clearly in Figure 1 and identifies those that need additional research and/or development focus.

Historical gauge records provide additional support for these findings. While the data are somewhat uneven, there is a shift to increased surface runoff in the uplands coupled with decreased groundwater recharge. Such observations are caused by either a dramatic shift in climate or a shift in how quickly the flow rate in the river decreases after a rainstorm. Increased average annual rainfall is not expected; reaches along the river, however, are drying up sooner and for longer periods. This is indicative of a change in the timing of runoff and the rapidity with which storm water flows recede, leaving the river dry once again.

Practical Implications

Model simulations identify land use and land cover change as significant factors in increased direct surface runoff within the River Njoro watershed uplands. This increased water yield, however, is not necessarily distributed throughout the year, nor is it necessarily distributed spatially throughout the uplands regions. Rather, the increased runoff is occurring in sub-watersheds where land cover alteration occurred over a short period.

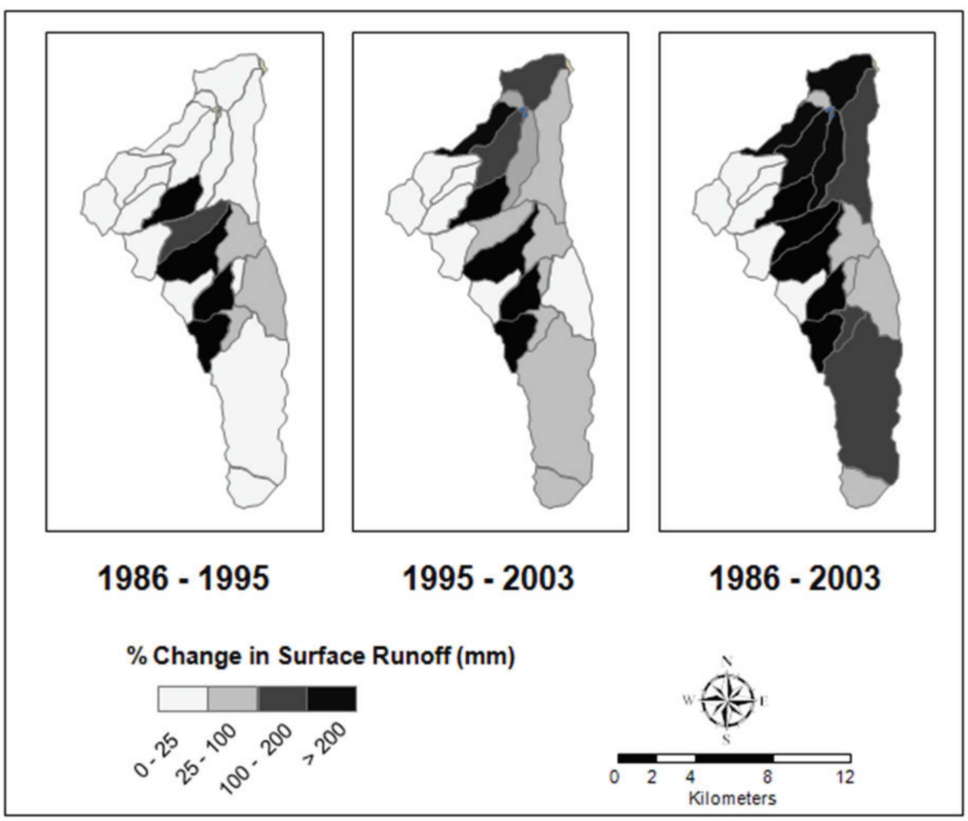

Figure 1. Spatially distributed change in runoff. The areas of greatest change are those associated with intensive transformation from forested to agricultural land cover (Baldyga et al., 2007).

Small watersheds, like that of the River Njoro, are more sensitive to short duration, high intensity rainfall events because overland flow processes drive response. Consequently, increased localized flooding will most likely occur in the absence of dense vegetation. The type of land cover change occurring in the River Njoro watershed can affect soil erosion. By converting land cover from dense vegetation to small-scale agriculture and managed grasses, the energy that raindrops put on exposed soils leads to erosion and topsoil losses.

Results from this study can be used in conjunction with the Revised Universal Soil Loss Equation (RUSLE) to locate areas in the watershed that are most susceptible to soil loss from erosion. RUSLE, like MSLE (the Modified Soil Loss Equation, see Baldyga and Holley, 2008), uses the same formula as the USLE (Universal Soil Loss Equation) but has certain improvements that make it more adequate for this research. For example, RUSLE has a time-varying approach for a soil erodibility factor, a sub-factor approach for evaluating the cover management factor, and new conservation-practice values.

Results in this study are highly suggestive that land use and land cover changes are the central drivers of hydrologic response within the River Njoro watershed. More land cover analysis is required during the period of rainfall-runoff record to establish a statistically valid link between rapid changes in land cover occurring annually and observed hydrologic response. In its current state, this modeling effort is most useful for identifying sensitive areas within the watershed, linking land cover and hydrology, and as a platform for scenario building and decision-support (Baldyga et al., 2008).

Further Reading

Baldyga, T. and F. Holley. 2008. "Introduction to SEADS: SUMAWA's Spatial Environment and Agricultural Decision Support Tool." *Research Brief 08-03-SUMAWA*. Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

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Baldyga, T.J., S.N. Miller, W.A. Shivoga, L.W. Chiuri. 2008. "Development and use of a multiple objective spatial decision support system in East African rural watershed management." *Proceedings of the American Water Resources Association Spring Specialty Conference*, 17-19 March 2008, San Mateo, CA.

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The GL-CRSP Sustainable Management of Rural Watersheds (SUMAWA) project was established in 2003 and is a multidisciplinary research effort focusing on biophysical and human-related factors governing health in the River Njoro watershed in Kenya.

The Global Livestock CRSP is comprised of multidisciplinary, collaborative projects focused on human nutrition, economic growth, environment and policy related to animal agriculture and linked by a global theme of risk in a changing environment. The program is active in East and West Africa, Central Asia and Latin America.

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