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Natural Resource Management Research Briefs

1998 - 2010

Natural Resource Management

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GLOBAL LIVESTOCK CRSP

The Economy of Change: Livelihood Diversification and Land Use Change in Simanjiro, Tanzania

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POLEYC Project

Research Brief 09-01-POLEYC March 2009

In East Africa, widespread conflict exists regarding the implications of land use practices for wildlife conservation. Among the Maasai of northern Tanzania, cultivation is increasing, and the impacts of these changes on the landscape and wildlife are still in question. The research project discussed in this brief aims to assess the impacts of cultivation on Maasai household economy, livestock mobility, and migratory wildlife movement in the Simanjiro Plains of Tanzania. Evaluation of these components of the system will promote informed conservation policy that can best balance the needs of people with those of wildlife. The goal of this particular study was to evaluate the economic role of cultivation and cash generated through the local gem trade in modern Maasai livelihoods. A household-level analysis of incomes and expenditures indicates that cultivation contributes significantly to livelihoods at the household level. Food and cash generated through cultivation not only feed families directly but also allow households to maintain herds by reducing the need to sell livestock to meet other needs. Cultivation also buffers against system shocks such as drought by generating new food quickly while herds recover. The gem trade appears to generate pulses of cash that may have important consequences for land conversion to cultivation and development at the village level.

Background

Across much of East Africa, a conflict has arisen between land users and governments and conservation agencies regarding the impacts of land use practices on the landscape, wildlife, and biodiversity in general. In northern Tanzania, the problem of balancing conservation goals with resident human needs has been debated fiercely in many areas, including the Tarangire-Manyara Ecosystem (TME). During the rainy season wildlife leave Tarangire National Park (TNP), dispersing to take advantage of widespread water resources and high quality forage in the pastoral zone (Borner 1985; Voeten 1999). The impact of cultivation on these migratory wildlife has been a concern because of the potential for cultivation to block wildlife migration corridors.

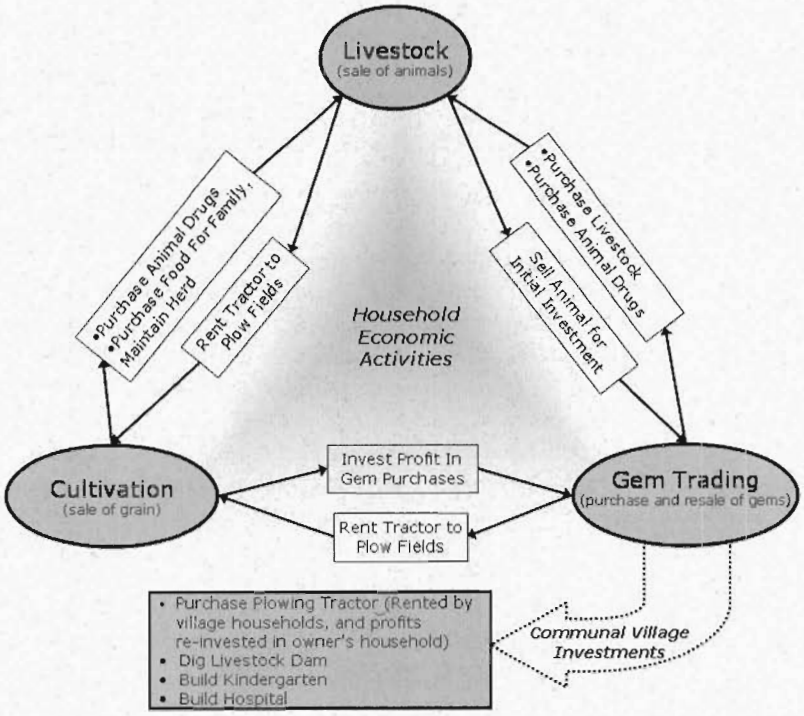
Pastoralists traditionally reduce the risks of highly variable resource availability through a multitude of adaptations (i.e. livestock movement to track forage and water availability, multi-species livestock herds, and social programs such as stock associations and wealth re-distribution). Economic diversification may further reduce vulnerability to stochastic events, such as drought, and perceived future risks (i.e. food security and land tenure changes), and compensate for or preempt changes in the ability to maintain a household through pastoralism alone. The widespread perception or recognition of increased vulnerability by Simanjiro Maasai may be a key factor in cultivation increases that continued through 2006.

The two most common means of livelihood diversification in Simanjiro at the time of data collection (2002-2003) were cultivation and gem trading. Both of these activities have the potential to substantially increase food and cash availability to participating households, thereby buffering fluctuations in the livestock sector and possibly boosting its viability (Figure 1).

The fundamental question addressed here is whether diversification into cultivation and gem trading contributed positively to household and village economies, or whether they acted as a drain on resources that could otherwise have been invested in livestock. In 2006 cultivation was banned in Simanjiro, as the area is critical to the long term survival for Tarangire National Park because it facilitates wet season dispersal and breeding for wildlife, especially wildebeest and zebra. Land conversion to small and large scale agriculture threatens the area, and a moratorium on land allocations to agriculture was issued until the area could be properly zoned. This research study and analyses were completed prior to the cultivation ban and therefore reflect the preceding state of affairs, but the results remain relevant to the Simanjiro land use dialogue.

Study area. The boundaries of the 20,000 square kilometers of TME (Tarangire-Manyara Ecosystem) are based primarily on the annual movements of migratory wildebeest. The Tarangire National Park (TNP) was

Figure 1. The economic relationship between Simanjiro's three primary income-generating activities is synergistic, each supporting the other, and all invest in household welfare. Large gem trading profits were invested in several things that benefited village communities as a whole.



established in 1970, setting aside 2,642 square kilometers and an important permanent water source, the Tarangire River, for exclusive use by regional wildlife. Lake Manyara National Park (320 square kilometers) was established in 1960. The remaining 17,000 square kilometers is comprised of the Simanjiro Plains to the east of the parks (Tarangire-Manyara Conservation Project - TMCP 2002).

The TME is classified as semi-arid with a highly variable mean annual precipitation of 600 mm (Voeten 1999). A bimodal pattern of rainfall such as that found in the TME favors pastures, woody plants, and the pastoral land use that takes maximum advantage of these resources (Ellis and Galvin 1994).

The study area consists of three Simanjiro villages: Sukuro, Loiborsoit, and Emboreet (Figure 2). The primary shift in land use in these and other surrounding villages from 1980-2006 was an increase in cultivation. Despite the questionable suitability of the TME for agricultural purposes, cultivation had become a customary Maasai land use practice by 2006.

Research hypotheses. The objective of the study described in this brief is to determine the contributions of livelihood diversification activities to Maasai households in the Simanjiro Plains of the Maasai Steppe. Several hypotheses were statistically tested based upon 2001-2003 conditions:

Hypothesis 01: Livestock herding remained the most important income-generating activity for Simanjiro households relative to cultivation and gem trading.
Hypothesis 02: Cultivation made a positive monetary contribution to household economies despite the costs incurred.
Hypothesis 03: Gem trading activities made a significant contribution to household economies despite the costs incurred.
Hypothesis 04: The acceleration of land use change in Simanjiro was due at least in part to livelihood diversification into cultivation and gem trading, and the cash was generated through these activities.

Data collection, processing and analysis. A household is defined as a male herdowner, his wives and children, plus any other dependent individuals. A boma, or settlement, consists of one or more male herdowners and their associated households. One hundred long and 107 short interviews were conducted. Inter-annual production varies widely, so two years of agricultural production data (2001-2002, 2002-2003) were collected.

Seventy bomas were stratified by village and subvillage: 31 bomas in Sukuro (33% of village, 96 total households); 28 bomas in Loiborsoit (20% of village, 65 total households); and 11 bomas in Emboreet (25% of village, 46 total households).

The relative contributions of livestock and cultivation to household incomes and expenditures were evaluated using household rank data and reported gains and losses. Household-level cost-benefit analyses were performed. Livestock numbers were converted to Tropical Livestock Units (TLUs) where one head of cattle equals 0.71 TLU, and one head of smallstock (sheep and goats) is equal to 0.17 TLU. SPSS version 15.0 for Windows (SPSS, Inc., Chicago, IL) was used for all statistical analysis. Skewed data that did not conform to a normal distribution were transformed for analysis.

Major Findings

The mean age of interviewees was 47 years of age. The mean acreage per household across villages in 2003 was 13.5 acres. Data indicate that most men begin cultivating as young adults, so that the average age of those that began

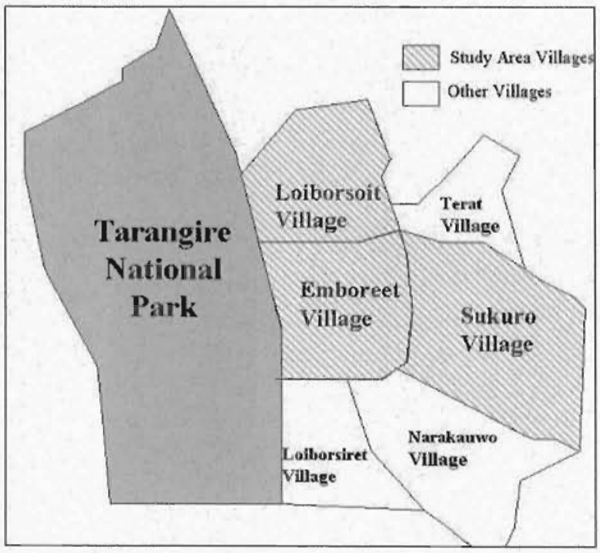
cultivating in the 1960's is now 61 and that of those men who began cultivating in the 2000's is now 33. The use of handplows has decreased over time; the use of tractors has increased.

Hypothesis 01: Livestock was ranked by a majority as the primary wet season income source, while agriculture was ranked as the primary dry season income source with livestock a close second (Table 1).
Hypothesis 02: The net cash value of agricultural production remained positive even in the poor year (2002-2003). Livestock was a more important household expense than cultivation (Table 2).
Hypothesis 03: Most households that participated in gem trading activities reported a small overall gain.
Hypothesis 04a: Households that did participate in gem trading activities applied gains from these activities to other household sectors (livestock and cultivation).
Hypothesis 04b: The few households that made large gains in gem trading often purchased tractors to plow fields.

Practical Implications

The analyses presented indicate that despite the costs of cultivation, the average household was profiting from cultivation activities both directly in the form of food produced and consumed by the family, and indirectly, in the form of cash used to purchase livestock medicines, clothing, school fees, hospital fees, and other household expenses. During the 25 years that cultivation has been actively practiced by Simanjiro Maasai, the size of plots increased, and its contribution to household food and cash availability likely grew proportionally.

Figure 2. Reference map of Tarangire National Park and nearby Maasai villages. Study area villages include Loiborsoit, Emboreet, and Sukuro villages. (not to scale).



A recent cultivation ban (2006) in some areas of Emboreet Village may present interesting implications for households residing in that area. The analyses indicate that cultivation had become an important means of subsistence for Simanjiro Maasai livelihoods since the 1980's. It is questionable as to how households will fill the void left in their incomes that was previously a buffer to the livestock sector. The inputs from cultivation sales into livestock medicines and actual livestock purchases serve as a boost to the livestock sector as a whole, not just a buffer in times of failure.

Table 1 - top. The relative importance of income activities was ranked by herdowners (n=107), where 0=No Participation, 1=Most Important, 3=Least Important. Table 2 - bottom. Additive values were calculated for the relative rankings of Livestock, Agriculture, and Supplemental Food expenditures for the wet and dry seasons. Higher values connote greater perceived contributions to household expenditures.

Relative Importance of Income Activities						
	Wet Season			Dry Season		
Rank	Livestock	Agriculture	Mining	Livestock	Agriculture	Mining
0	0.0%	0.9%	53.5%	0.90%	5.6%	54.2%
1	63.6%	35.5%	0.9%	43.9%	48.6%	5.6%
2	31.8%	61.7%	5.6%	50.5%	38.3%	8.4%
3	4.7%	1.9%	40.2%	4.7%	5.6%	31.8%

Additive Rankings of Household Expenditures			
	Wet	Dry	Average
Livestock	421	455	438
Agriculture	448	17	232
Supplemental Food	465	583	524

Further cultivation bans and controversy may leave the Maasai of Simanjiro more vulnerable to livestock sector failure in the event of a large disease outbreak, drought, or other system shock. When available, grain sales are the choice source of cash for household expenditures such as food, school fees, clothing, and hospital fees. The patterns of these expenses may change if livestock must be sold to support them. For instance, if there is no longer the presence of home-grown grain to fill either the food or cash needs of the household, households would need to sell livestock to free up cash.

Research such as that detailed in this brief is necessary to assess the impacts of cultivation on Maasai household economy, livestock mobility, and migratory wildlife movement in the Simanjiro Plains of Tanzania. Furthermore, evaluation of these components will promote and contribute to informed conservation policy that can best balance the needs of people with those of wildlife.

Further Reading

Borner, M. 1985. "The increasing isolation of Tarangire National Park." *Oryx* 19(2): 91-96.

Ellis, J. and K. Galvin. 1994. "Climate patterns and land-use practices in the dry zones of Africa." *BioScience* 44(5): 340-349.

TMCP. 2002. *Tarangire-Manyara Conservation Project Final Report: Analysis of Migratory Movements of Large Mammals and Their Interaction with Human Activities in the Tarangire Area in Tanzania As a Contribution to a Conservation and Sustainable Development Strategy*. Arusha, Tanzania: Tarangire-Manyara Conservation Project - TCMP.

Voeten, M. M. 1999. *Living with Wildlife: Coexistence of Wildlife and Livestock in an East African Savanna System.* Wageningen: Wageningen University.

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The GL-CRSP POLEYC project (Integrated Assessment of Pastoral-Wildlife Interactions in East Africa: Implications for People, Policy, Conservation and Development in East Africa) focused on the development of integrated assessments of pastoral-wildlife interactions in East Africa and the corresponding implications for people, policy, conservation and development. The Principal Investigator was David Swift at Colorado State University. Email: davesw@nrel.colostate.edu. Stacy Lynn's project, more specifically, aims to combine ecological and anthropological data to take a broad look at the impacts of land use change, primarily increased cultivation, for people and wildlife in Maasailand, Tanzania. Ms. Lynn was a student of Dr. Jim Ellis, who was, prior to his passing, Principal Investigator for the POLEYC project. Dr. Ellis's scientific achievements and mentorship capabilities inspired the Jim Ellis Mentorship Program Fellowship award.

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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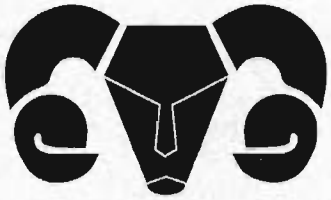

"Staying Together:" People-Wildlife Relationship in the Amboseli Ecosystem, Southern Kenya

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Jim Ellis Award Recipient 2002-2003
POLEYC Project

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The relationship of Maasai pastoralists to the wild animals with which they share land and resources has been described as "harmonious" and "tolerant." This research brief describes a study of local attitudes towards wildlife within Maasai communities of the Amboseli ecosystem. This study investigates the multiple dimensions of the relationship between pastoralists and wild animals in three Maasai group ranches in the Kajiado District of southeastern Kenya, under present conditions of demographic, cultural and socio-economic changes. Preliminary results reveal that despite a high perceived level of conflict between people and wild animals and the perceived lack of wildlife-based economic benefits, attitudes towards wild animals are generally positive, even though they are motivated by different factors, especially across age groups. The co-existence of people and wildlife in the Amboseli ecosystem is multifaceted and goes beyond assumptions that Maasai live in harmony with wildlife. Final research results will contribute a multi-layered and sensitive picture of the co-existence of humans, livestock and wild animals in the Amboseli ecosystem to guide policy-makers in smart planning and adaptive policies that integrate conservation and livelihoods.

Background

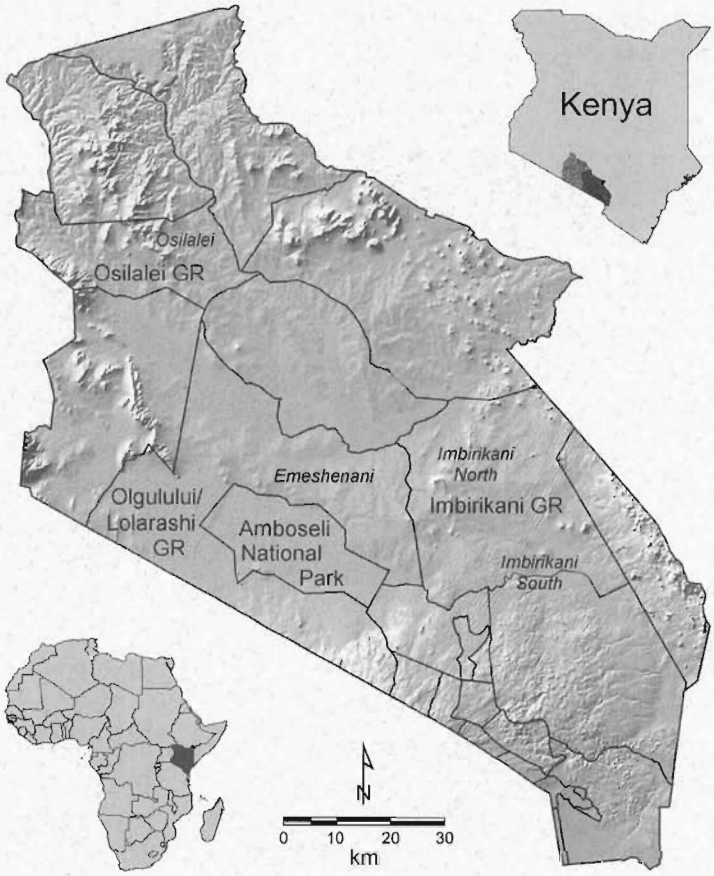
In East Africa, pastoralists and wildlife species have coexisted for 2,500 years (Collett 1987). Maasai, in particular, have been given credit for local wildlife abundances. Although the cultural role of wildlife should not be ignored, Maasai coexistence with wild animals is also due to large scales of resource exploitation, non-reliance on wild meat, and the fact that wildlife interfered mildly with the pastoral way of life. Today, Maasai areas retain greater wildlife populations than other parts of Kenya. However, these areas are undergoing rapid socioeconomic changes, which could affect the Maasai's tolerant outlook on wild animals. For instance, new types of human-wildlife conflicts that accompany land tenure and land use changes and the provision of economic benefits from community-based conservation are hypothesized to affect local attitudes towards wildlife.

Wildlife conservation in Africa depends on the cooperation of local residents (Western 1982). In the Amboseli ecosystem, where wild ungulates seasonally disperse out of Amboseli National Park (ANP) onto Maasai Group Ranches (GR), conflict remains intense, despite efforts to reduce it (Campbell et al. 1999) It is recognized that strategies aimed at improving people's willingness to live with wildlife should be based on their values and perceived problems and expectations, and not just on the assumption that economic benefits from wildlife will make them conservationists (Gibson & Marks 1995). Also, communities are heterogeneous, and Maasai society is strongly stratified by age, gender and wealth (Hodgson 2000). Ongoing economic diversification, conversion to Christianity, and formal education are contributing to an increasing diversification of ideas and ways of life within Maasai society. In this context, knowing how different people perceive costs and benefits of living with wild animals, their attitudes towards wild animals, and the factors determining such attitudes is relevant for policy-making. For the purposes of this brief, an attitude is defined as an individual's consistent tendency to respond favorably or unfavorably to a commodity, condition or event. It is thus a determinant of behavior (Taylor & Douglas 1999). Studies of attitudes are vital to research on environmental decision- and policy-making.

This project proposed to describe how local residents in Amboseli Maasai communities in southeastern Kajiado District perceive costs and benefits of living with wildlife to characterize their attitudes towards wild animals and to identify the factors that underlie those attitudes. In the Amboseli ecosystem, answering these questions is imperative at a time when crucial decisions (e.g. land privatization) are impending and when local land use changes are accelerating.

Methods. This study is a comparative survey of the attitudes of local residents towards wildlife in predominantly Maasai communities in the Amboseli ecosystem. Fieldwork is in progress in three study areas

Figure 1. Map of the study area within Kenya and in relation to the continent, including Imbirikani South, Emeshenani and Osilalei.



characterized by contrasting cultural contexts, land tenure and land use regimes, and provision of wildlife-based economic benefits. The study areas include Imbirikani South, Emeshenani and Osilalei (Figure 1).

In order to capture the demographic, socio-economic and cultural diversity within these three communities, in-depth household interviews are being conducted. In each study area, a random sample of 32 Maasai households stratified by land use was selected, and 64 people are being interviewed (n=192). A census of non-Maasai households present in the swamps area of Imbirikani was also carried out, followed by a survey of perceived costs and benefits of and attitudes towards wild animals (n=80; 27% of the non-Maasai population) of non-Maasai household heads. Additionally, to map and quantify human-wildlife conflict, records of human-wildlife conflicts are being kept by local enumerators in each study area. Existing wildlife-based benefits for the communities were determined through interviews with key informants and focus-groups.

Preliminary Findings

Non-Maasai households. Preliminary results from the non-Maasai survey show that 73.75% of the respondents were Tanzanian citizens; 26.3% were Kenyans. All the respondents were crop farmers; only 7.5% possessed livestock (poultry only). In terms of economic losses to wildlife, 62.5% of the respondents suffered crop damage between January of 2002 and January 2003, with 54.25% of the damage reported in Isinet/ Kalesirua, where no electric fence is present. For both Isinet/Kalesirua and Namelok, elephants were the wild animals most frequently reported as damaging crops (51.2%), followed by gazelles, buffaloes, eland, and baboons. Injuries of household members were rare (2.5%); no human deaths caused by wildlife were reported. The survey also showed that 25% of the households consumed meat from wild animals. This may be an underestimation, however, as respondents know this to be an illegal activity. Those who reported not eating wild meat invoked religious, cultural and health reasons. No other benefit from wildlife was mentioned because of what respondents call their "outsider" status, as many are illegal aliens from Tanzania and do not belong to the Imbirikani Group Ranches (GR), which would entitle them to wildlife-based benefits (e.g. school bursaries; financial help). Data relating to which wild species are consumed and preferred, details of wildlife-caused economic losses per study area, strategies to minimize wildlife-caused problems, perceived solutions to wildlife-caused problems, and why specific species are liked and disliked are currently being analyzed.

Maasai households. In-depth interviews were carried out in 30 Maasai households in Imbirikani South. The majority of the informants (80%) were agro-pastoralists (irrigated and/or rain fed cultivation); the others were pastoralists. Two in-depth interviews have been carried out in Emeshenani. Although no analysis has yet been carried out for Imbirikani South, the following general points stand out:

1) Attitudes towards GR subdivision (potentially determining behaviors with negative consequences for wildlife) are generally positive across all land use and age/ gender groups. The most frequently mentioned motivation is land ownership insecurity, followed by the idea that land users expect to make tourists pay for pictures of "their wild animals." 2) The most frequent problem caused by wildlife is crop damage (by elephants in Kalesirua; baboons in Namelok). 3) When there is knowledge of the local economic benefits from wildlife, it is usually incomplete and incorrect, across all land use and age/gender groups. 4) Few households acknowledged having received any benefits from wildlife; they believe that benefits remain

with few individuals (the GR leaders). 5) In the absence of benefits, when attitudes are positive, killing wildlife in retaliation or for cultural reasons (such as in the lion hunt) is considered wrong. Rather, pastoralists expect to enjoy the benefits of wildlife preservation for themselves and community members in the future. 6) Not all wild animals are considered "wild." Linguistically, Maasai categorize animals in reference to domestic animals (*inkishu*). The non-domestic ones are divided into *inguesi*, which include the predators and harmful animals (rhinoceros, elephant, hippo, buffalo, baboons), and *ilcangit*, which comprise the harmless animals (eland, giraffe, gazelles, zebra). If *ilcangit* compete for grazing, it is acceptable because "God has created them in such a way that they also need to eat." *Ilcangit* are therefore perceived more positively and are usually considered more beautiful than *inguesi*. 7) Among Maasai informants, positive attitudes towards eating wild meat cut across all groups, although its actual consumption is rare. Some wild species (ostrich) are never killed by Kisonko Maasai for cultural reasons. Furthermore, there is a strong cultural element underlying the refusal of wild meat by half of the informants.

It is clear from interview data so far that the Maasai population in Imbirikani South is enjoying few benefits at the household level, despite the provision of substantial wildlife-based economic benefits within the GR. Informants perceive that benefits are being "eaten" (or controlled) by a restricted group (e.g. the local leadership). When people have enjoyed community-wide benefits, including provision of health and schooling facilities and dams, provided through community-based conservation initiatives, few knew the origin of such benefits.

Nevertheless, despite the lack of economic benefits from wildlife in the household, attitudes towards wildlife seem, generally and without further analysis, positive, especially among representatives of older age-sets and younger generations. Attitudes are somewhat less positive among married agro-pastoralists of intermediate age. Positive attitudes seem to be driven by different factors. Older people invoked that people, livestock and wild animals have always "stayed together" because all are God's creation and "this is the way it should be." Representatives of the younger generations invoked wildlife as a "provider of foreign exchange." Almost all informants mentioned the possibility of benefiting economically from wildlife in the future.

Practical Implications

Community-based conservation philosophy rests on the premise that economic benefits from wildlife promotes positive attitudes and behaviors towards wildlife. This approach has come under fire in recent years because many of its assumptions are unwarranted (for a review, see Barrett and Arcese 1995), especially the assumption that individuals who benefit economically from wildlife will be more willing to share land and resources with wild animals, as well as to protect them as valued economic assets. Besides the fact that wild animals may also be valued for reasons that are not monetary (an aspect that is being investigated in this study), the availability of benefits does not necessarily imply that individuals will receive them, as shown here. Therefore, unless individuals in the Amboseli ecosystem receive the economic benefits to which they are entitled, the hypothesis that there is a direct relation between economic benefits and positive attitudes towards wildlife (and hence behaviors) cannot be tested.

In Imbirikani, despite not receiving benefits, attitudes towards wildlife are generally positive because of expectation of future benefits. However, under current leadership, this expectation is unlikely to be fulfilled. The ensuing frustration may actually hinder conservation objectives and compromise future attempts at reconciling people and wildlife. Attention must be paid to local governance when setting up schemes to compensate and benefit local people through wildlife-based activities, so as to ensure an equitable distribution of benefits. The changing ethnic composition of Imbirikani's population may also become an issue. Group Ranch (GR) membership is a condition for enjoying most wildlife-based economic benefits. Thus, a substantial and growing part of the population, which is non-Maasai, is currently not benefiting from wildlife, while incurring the worst costs. In addition, non-Maasai land users have introduced wild meat consumption, which may have an impact on wildlife populations. Incorporating attitudes of non-Maasai elements into community conservation planning is an important step towards the sustainable management of human-wildlife relationships on Imbirikani GRs.

The co-existence of people and wildlife in the Amboseli ecosystem is multifaceted and goes beyond assumptions that Maasai live in harmony with wildlife. In recent times, socio-economic, land tenure and land use changes, and wildlife conservation measures have introduced layers of complexity in the relationship between land users and wildlife. Efforts at reconciling wildlife and people through the development of wildlife-based enterprises and the provision of benefits to individuals are commendable. However, such efforts are useless if heterogeneity within communities is not considered and the benefits not equally distributed. Through the mismanagement of expectations and the creation of frustration, the approach may backfire and make future conservation efforts more difficult. Final research results will contribute a multi-layered and sensitive picture of the co-existence of humans, livestock and wild animals in the Amboseli ecosystem to guide policy-makers in smart planning and adaptive policies that integrate conservation and livelihoods.

Further Reading

Barrett C.B. and P. Arcese. 1995. "Are integrated conservation-development projects (ICDPs) sustainable? On the conservation of large mammals in sub-Saharan Africa." *World Development* 23:1073-1084.

Campbell, D.J., H. Gichohi, R. Reid, A. Mwangi, L. Chege and T. Sawin. 1999. "Interactions between People and Wildlife in Southeastern Kajiado District, Kenya." *LUCID Working Paper*, November 1999.

Collett, D. P. 1987. "Pastoralists and wildlife: Image and reality in Kenya Maasailand." In *Conservation in Africa: People, Policies and Practice*, ed. D. Anderson and R. Grove. Cambridge: Cambridge UP, 149-167.

Gibson, C. C. and S. A. Marks. 1995. "Transforming rural hunters into conservationists: An assessment of community-based wildlife management programs in Africa." *World Development* 23: 941-957.

Hodgson, D. 2001. "Pastoralism, Patriarchy and History Among Maasai in Tanganyika, 1890-1940." In *Rethinking Pastoralism in Africa,* ed. D. Hodgson and J. Currey. Athens: Ohio UP, 97-120.

Taylor, J. G. and A. J. Douglas. 1999. "Diversifying natural resources value measurements: The Trinity River Study." *Society and Natural Resources* 12: 315-336.

Western, D. 1982. "Amboseli National Park: Enlisting landowners to conserve migratory wildlife." *Ambio* 11(5): 302-308.

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Gross Fecal Pollution of a Rural Watershed in Kenya: Research Identifying Cattle as a Major Source in the River Njoro Watershed

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Sustainable Management of Rural Watersheds Project

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Elevated levels of fecal pollution in surface water pose significant health risks for humans as well as livestock, and degrade aquatic ecosystems. This brief presents preliminary findings on pollution research in the River Njoro Watershed and explores actions to reduce gross pollution found throughout. We conducted an extensive survey and launched a year-long program to measure fecal coliform bacteria in river water to quantify pollution levels across the watershed, pinpoint problem areas and identify major sources. Genetic methods were applied to track fecal sources and test for Cryptosporidium spp., *a water-borne pathogen causing severe diarrhea in young, old, and immuno-compromised human and cattle populations. A common pattern of fecal pollution peaking in August, significantly higher levels detected when cattle were present at a site, and widespread detection of cow fecal genetic markers, point to livestock, in particular cattle, as the most likely cause of gross fecal pollution and probable source of* Cryptosporidium *risk in the Njoro Watershed. Elimination of the widespread practice of in-river livestock watering through provision of watering troughs would quickly reduce gross levels of fecal pollution, bringing immediate health benefits for humans, livestock, and ecosystems. Tackling the complex web of human-livestock-animal, resident-migratory, and rural-urban combinations of sources and actors contributing fecal pollution in this and similar rural watersheds throughout Kenya requires a long-term multi-pronged engagement process of joint local community and government action.*

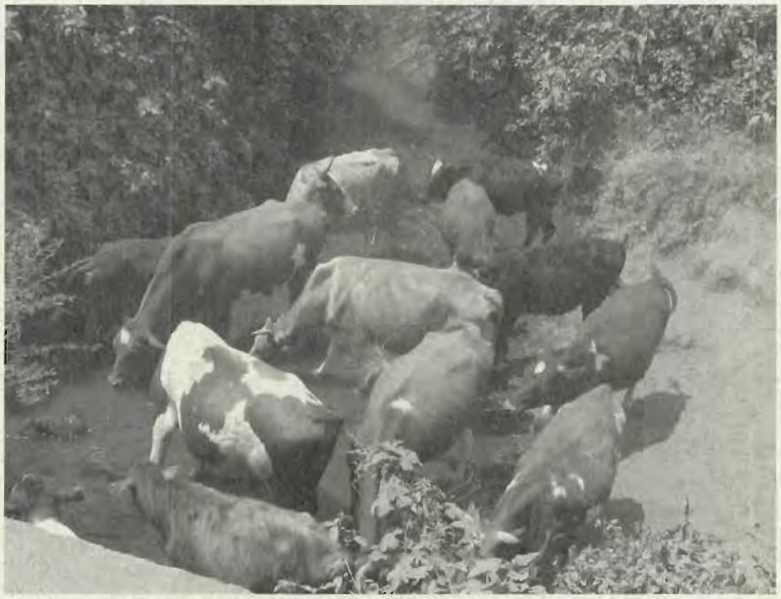
Background

Historically, the earliest concerns with water pollution have been with the transmission of pathogenic diseases, such as typhoid. When large amounts of excreta from humans, livestock, or wildlife are allowed to enter a water system, environmental exposure to and spread of infectious enteric pathogens increases for humans, animals and wildlife, while the organic matter and nutrients (nitrogen and phosphorous) in excreta degrade aquatic environments, causing algal growth, reduced oxygen levels and eutrophic conditions. Fecal water pollution and the increased exposure to water-borne infectious pathogens have immediate negative health and economic consequences in Kenya, especially for marginalized communities where clean water is acutely scarce, improved water supply coverage low, health services strained or out-of-reach, and livestock assets an important component of livelihoods.

At about 3000 msl (meters above sea level) in the eastern Mau Escarpment, the River Njoro descends through high elevation indigenous forest and pasture down through agricultural and urban lands into the Rift Valley, passing along the city of Nakuru, and terminating at Lake Nakuru (1750 msl). The 50 km river and 280 km^2 watershed are an important source of surface and groundwater supplies for growing domestic, industrial, commercial, livestock, irrigation, and environmental water requirements in and around the watershed. Massai herdsmen move their livestock into the watershed for grazing and watering during the dry season. Dramatic increases in small-scale agriculture and livestock populations in the upper watershed have been documented, with numbers of cattle and sheep rising by over 250% and 200%, respectively, in the last five years (GL-CRSP, 2005).

Research to assess the magnitude, extent, and causes of fecal pollution in the Njoro Watershed was initiated in 2004 as part of the Sustainable Management of Watersheds (SUMAWA) project. SUMAWA is demonstrating a science-based approach to rural watershed management that tackles degraded water quality and declining quantity problems facing watershed residents, stakeholders, water resources users, and resource managers. Community outreach early in the project revealed scarcity of clean water, river water pollution, water-borne diseases, and animal health as priority concerns among watershed residents dependent on river flow for some or all of their human and livestock water requirements (Jenkins, et al., 2004).

Dr. Marion Jenkins, US Co-PI, University of California, Davis, working with Dr. Charles Maina-Gichaba at Egerton University, began with an extensive field survey of the River Njoro stream network and adjacent land use to inventory potential fecal pollution sources. Thirty-



Cattle watering at open access points along the River Njoro stream network are a common sight throughout the watershed. Photo by Sian Mooney.

eight public access watering points where domestic water supplies are collected, livestock watered, and other activities occur, and numerous other non-point and point sources of potential fecal pollution were identified. A year-long monitoring program along the length of the main River Njoro and Little Shuru tributary was launched in October 2005. UC Davis environmental engineering PhD student Sangam Tiwari provided technical training and oversight for students and technicians at Egerton University, who were trained and equipped to collect water samples, record site activities, and measure fecal coliform concentrations in labs at Egerton University. Following a baseline assessment, 15 sites were selected for monthly monitoring, including 3 un- or least disturbed sites and 12 watering points.

Fecal coliform bacteria is the most common standard microbiological indicator of fecal contamination from human, livestock, or other warm-blooded animals in environmental water samples, but it is unable to distinguish between these sources and unable to accurately identify if human fecal pollution, the most dangerous for human health, is present. Given these weaknesses, a variety of new microbial source tracking and pathogen detection methods have emerged in the last 10 years to improve scientific ability to identify sources of fecal pollution in watersheds (Simpson, et al., 2002). The overwhelming number of non-point direct (in-river, i.e., at watering points) and diffuse (land-based) human and animal source activities potentially contributing fecal contamination along any given section of the River Njoro makes it difficult to establish which activities, locations, and fecal source activities should be prioritized in developing an abatement program. New gene-based qPCR TaqMan detection methods (Kildare, et al., 2007), developed at UC Davis and elsewhere to identify specific pathogenic species and track or fingerprint fecal organisms by their animal or human source, were used to help identify priority sources and risks. To our knowledge, this is the first time a gene-based fecal source tracking method has been applied in a developing country. With the help of Dr. Stefan Wuertz, at UC Davis, we tested five established fecal source marker assays designed to detect universal, cow-specific, and human-specific 16s rRNA Bacteroidales (a gut organism excreted in the feces of warm-blooded animals) against Kenya fecal samples of known origin to establish assay validity in Kenya. We then used the validated TaqMan assays and another designed to detect *Cryptosporidium spp.*, a water-borne pathogen harmful to humans and livestock, on a subset of river water samples.

Research Findings

High levels of fecal water pollution occur throughout the watershed. Out of 162 water samples collected monthly along the river from October 2006 through September 2006, fecal coliform levels in just three met the surface water pollution threshold of 200 cfu/100 ml considered acceptable for human contact or use as a raw water source by the US EPA. River water averaged 8,000 cfu/100 ml of fecal coliforms across all sites during the year. Fecal concentrations at watering points in the upper watershed were lower than those in rest of the watershed but still always exceeded 200 cfu. Contamination levels at watering points in middle reaches exceeded 10,000 cfu/100 ml 30% of the time, and at lower watershed watering points, 65% of the time. Fecal loading throughout the watershed has persistent and cumulative effects on water quality, reaching particularly elevated levels in the lower watershed just prior to entering Lake Nakuru National Park.

Incidents of gross pollution exceeding 100,000 cfu/100 ml occurred at 10 of the 15 monitored locations. These occurred periodically during the dry season at several sites in the upper watershed and were associated with the presence of large herds of Massai cattle watering at the time of sample collection. Gross pollution was also evident nearly everywhere in the watershed during August, the wet season month when effective rainfall and runoff are historically greatest.

We compared mean log 10 fecal coliform concentrations for river water samples grouped according to types of activity occurring at the site at the time of sample collection and found statistically significant differences in the quality of

water when cows were present compared to no activity or non-cow activity present. A more than four-fold increase in mean fecal contamination at sites with cow activity (n=34 was measured compared to sites with no activity (n=45) (18,501 vs. 4,075 cfu/100 ml). At sites with non-cow activity (including human and other animals; n=71), the concentration was half of that with cow activity (9,715 versus 18,501 cfu/100ml).

Cow fecal genetic markers were detected at 10 of 12 locations tested in Fall 2005, including at the highest and lowest points. Four sites in the middle and lower watershed tested positive for human genetic markers. Reliability of the genetic results for the Njoro watershed was estimated to be 100% for positive and 81-91% for negative detections. Genetic source tracking evidence supports the fecal coliform findings which point to cows and the practice of in-river watering and river access as the most widespread likely cause of gross fecal contamination in the Njoro Watershed. These include the large spikes measured at sites when cows were present and the spikes seen across the watershed during the late wet season peak runoff month of August, the most likely cause for the latter being the transport of accumulated still moist cattle fecal deposits in contributing areas along the river's 38 known watering sites during major rainfall-runoff events.

Among negative impacts of widespread contamination of water by cattle is the spread of Cryptosporidiosis, a zoonotic waterborne fecal-oral disease transmitted between humans and cattle, cattle and other animals including wildlife, and between humans and other animals. Cattle are a known major environmental reservoir for this gastrointestinal disease, a leading cause of mortality among AIDS patients, and a recognized cause of childhood and calf diarrhea disease. *Cryptosporidium spp.* was measured with a new gene probe (Miller et al., 2006) able to detect one occyst, a dose sufficient to cause illness in immuno-compromised populations. Genetic markers were found in 50 mL river samples from 10 out of the 12 locations, detected 80% of the time with cow and 30% with human fecal markers. While not definitive, the genetic detection results are strong evidence of the likelihood that this and other waterborne zoonotic pathogens are present in the Njoro watershed at potentially significant concentrations dangerous to health.

Practical Implications

In the Njoro watershed, livestock small-holders have few options but the river for watering their cattle and other livestock. Moving cattle from home to the river each day is the only way livestock are watered. During the dry season, Maasai herdsmen bring their cattle and livestock into the watershed to feed and water at the river for extended periods, notably along the lower Little Shuru tributary. Pathways to and from river watering sites tend to be littered with cow pats, while adjacent riparian areas are attractive grazing spots. Watershed studies of cattle behavior, fecal loading rates, and deposition patterns elsewhere (Tate, et al., 2003) show cattle produce 40-60 kg of fecal matter per day (compared to 0.3-0.5 kg for humans and smaller amounts for other livestock) and are more likely to defecate in and around watering points, preferred food sources, and shade trees.

Eliminating the extensive practice of cattle watering in, and access to, the River Njoro is the single most effect action likely to reduce gross fecal pollution in the Njoro Watershed. Expansion of improved water supplies and construction of off-river watering troughs for cattle and other livestock, with attention to controlling and managing fecal deposits at these sites, are key actions to explore. Successful local models for managing livestock watering facilities in environmentally and financially sustainable ways will need to be developed. Reducing direct and indirect mass loading of cattle excreta to the stream network will also reduce organic, nitrogen and phosphorous pollution for downstream ecosystems in Lake Nakuru.

Engaging communities across the watershed to analyze underlying conditions which lead poorer agricultural and peri-urban households to use the river to water cattle and livestock is crucial in gaining community support and identifying workable solutions. These are thought to include the widespread lack of access to improved water sources in the upper and middle watershed for livestock and domestic needs, frequent rationing and shortages of improved water supplies in the middle and lower watershed, and high prices charged for improved water sold at some kiosks compared to private connections. The Njoro Watershed Water Resource Users Association, a community-based institution supported by SUMAWA, provides a platform for dialogue among communities, livestock-owning households, Massai representatives, water resource managers, water service providers, and agricultural extension agents about fecal pollution problems and mutually beneficial solutions.

Further research is recommended to verify and investigate the extent of *Crytosporidium* contamination of river water and ascertain the prevalence of Cryptosporidosis among neonatal cattle and human populations, and the extent to which cattle health and productivity are impacted by drinking heavily polluted river water in watersheds like the Njoro. Education and extension services to help small livestock owners recognize and prevent the spread of *cryptosporidium* from feces of infected neonatal cattle, a major transmission pathway, and the development of and education on low cost water filtration treatment methods are activities that address the impacts of gross fecal pollution on the human health of large numbers of watershed households who use dangerously polluted river water for their domestic water supplies. (GL-CRSP, 2005).

Further Reading

GL-CRSP. 2005. "Sustainable Management of Rural Watersheds." *Global Livestock CRSP 2005 Annual Report.* Davis, California: GL-CRSP University of California, Davis.

Jenkins, M.W., F.K. Lelo, L. W. Chiuri, et al. 2004. "Community perceptions and priorities for managing water and environmental resources in the River Njoro Watershed in Kenya." *Proceedings 2004 Conference on Water Resources Planning and Management.* June 27-July 1, 2004, Salt Lake City, UT. Arlington, VA: EWRI of ASCE.

Kildare, B. J., C. M. Leutenegger, B. S. McSwain, D. Bambic, V. B. Rajal1, and S. Wuertz. 2007. "16S rRNA-Based Assays for Quantitative Detection of Universal, Human-, Cow-, and Dog-Specific Fecal Bacteroidales: A Bayesian Approach." *Water Research* 41 (16): 3701-3715.

Miller, W.A., I.A. Gardner, E.R. Atwill, C.M. Leuteneggar., M.A. Miller, et al. 2006. "Evaluation of methods for improved detection of *Cryptosporidium spp.* in mussels (*Mytilus californianus*)." *Journal of Microbiological Methods* 65: 367-379.

Simpson, J.M., D. J. Reasoner, and J. W. Santo Domingo. 2002. "Microbial source tracking: state of the science." *Environment, Science and Technology* 36: 5279-5288.

Tate, K.W., E.R. Atwill, N.K. McDougald and M.R. George. 2003. "Spatial and temporal patterns of cattle feces deposition on annual rangeland watersheds." *Range Management* 56: 432–438.

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The GL-CRSP Sustainable Management of Rural Watersheds (SUMAWA) project was established in 2003 and is a multi-disciplinary research effort focusing on biophysical and human-related factors governing health in the River Njoro watershed in Kenya. Dr. Marion Jenkins, University of California, Davis serves as the project's Co-PI. Email: mwjenkins@ucdavis.edu.

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 Africa, Central Asia and Latin America.

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Design by Susan L. Johnson

GLOBAL LIVESTOCK CRSP

Point-of-Use Treatment Options for Improving Household Water Quality Among Rural Populations in the River Njoro Watershed, Kenya

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Rural access to improved water supplies in Kenya stands at 46%. Consequences are apparent in the River Njoro watershed, where a majority of households fetch and use polluted river water for some or all of their domestic water needs, suffering high rates of diarrhea, typhoid, and other water-borne diseases. Responding to expressed needs for improving water quality in the watershed, the SUMAWA Project launched work to develop low-cost water treatment for household use. This brief reports findings from screening six point-of-use (POU) water treatment technologies applicable in developing countries. Operating characteristics, performance, costs, procurement, and local sustainability were reviewed and suitability of use with river water by households in the Njoro watershed was assessed. Intermittent slow-sand filtration (known as the "BioSand Filter" or BSF), ceramic clay filtration ("Filtron" pot), and chlorine disinfection were identified as suitable. Among these, the BSF was selected as most promising for application development in the Njoro watershed on the basis of robust design, easy of use, no recurrent costs, high flow rate, and ability to treat highly turbid river water. A program to develop and trial the BSF for use by high-risk households to treat polluted River Njoro water was launched in 2006 jointly with the Nakuru District Ministry of Health's Public Health Division, and Civil and Environmental Engineering Departments of UC Davis and Egerton University. As the program wraps up, results and practical learning will be shared in upcoming research briefs.

Background

The River Njoro watershed, located in Nakuru and Molo Districts near Nakuru Municipality, is typical of many productive parts of rural Kenya that have and continue to undergo population growth and subsequent land use change. Unmanaged water and land resource impacts and inadequate development of public services result in severe negative consequences for human and ecosystem health and well-being. During participatory rural appraisal in 2003-04, undertaken by the SUMAWA Project, watershed communities identified poor domestic water quality, human and livestock diseases due to consumption of polluted river water, and water scarcity among priority problems.

Various water quality investigations confirmed the river's unsuitability for ingestion or human contact (Jenkins, 2008). Turbidity levels of 125 NTU and fecal coliform levels of 8 x 10^3 cfu/100 ml, averaged over time and space along the river, greatly exceed the World Health Organization (WHO) recommended turbidity of 5 NTU and fecal coliform concentration of under 10 cfu/100 mL for unimproved drinking water, and the US EPA fecal coliform level of 200 cfu/100 ml for safe human contact. Genetic evidence for the presence of the zoonotic water-borne fecal-oral pathogen *Cryptosporidium* spp., known to cause severe diarrhea in very young, old and immuno-compromised human and cattle populations, was found in 78% of tested water samples taken from sites throughout the river.

A SUMAWA survey revealed the majority of households within the watershed depend on River Njoro water for some or all of their water needs. Those with access to improved sources at home or in their neighborhood, such as roof rainwater catchments, kiosks selling borehole water by the jerry can (3-5 Ksh/20 liters), community-operated taps, and in rare cases, piped water connections, must still use the river in times of rationing, shortage, in-operation and other common causes of non-availability (GLCRSP 2005). At the 38 public access river watering points identified along the River Njoro, activities include: livestock watering, domestic water collection, washing laundry, children bathing, washing bicycles and cars, washing produce for sale in the market, and commercial collection of water for distribution and sale or for productive activities such as construction and drilling. Discharges of untreated and poorly treated wastewater from small and medium-size sewerage, canning, dairy and other commercial operations located along the river can make up a significant portion of the stream flow in the middle and lower sections of the river during the dry season.

A review of registered cases at government clinics found diarrhea diseases and typhoid to be endemic in the watershed, concentrated in neighborhoods and communities with the poorest water supply and sanitation conditions (GLCRSP, 2005). Diarrhea reported among children under five, in a 2-week

prevalence survey of households using river water, ranged from 19 to 11% across the watershed and showed a clear link with lack of safe water for drinking. Diarrhea rates of 22% were seen among children in homes using river water for drinking, compared to diarrhea rates of 9%, 8% and 13% among children in homes who, while using river water for other domestic needs, used piped water, roof-collected rainwater and borehole water, respectively, specifically for drinking. Bacterial river water quality (fecal coliform counts) measured at watering and monitoring sites along the river, 2-week child diarrhea prevalence among river-using households, and water supply and sanitation conditions across the watershed (Table 1), illustrate the important need for safer water supply for household health in the Njoro watershed.

Water treatment in the home at the point of use, known as point-of-use (POU) treatment, has received a great deal of attention as a potential way to rapidly and affordably improve the water quality and quality of life for the 1.1 billion people living in developing countries who do not have ready access to a safe improved water supply (Sobsey, 2002). A decentralized approach to improved water supply, focused at the household level, may be both more environmentally sustainable and operationally feasible than centralized systems in rural areas of developing countries like Kenya. A variety of low-cost POU methods for use in developing countries has emerged based on 1) filtration techniques (slow sand, ceramic of various kinds, and filters made from local materials such as burned rice husks or cloth), 2) chemical disinfection (including chlorine, generally in the form of sodium hypochlorite), 3) solar disinfection or disinfection by ultraviolet (UV) light, 4) bone-char (to remove fluoride), and 5) chemical flocculation (using products like Alum, Moringa seeds, or chemicals). In places like the United States, more "advanced" treatment methods such as reverse osmosis membranes are used in homes but are inappropriate in Kenya because they require electricity. Health impact trials in developing countries of POU technologies have shown diarrhea diseases reductions of 30% (Fewtrell, et al., 2005).

Through an in-depth literature review POU options were identified and evaluated against a list of performance and implementation considerations (Tiwari, 2006). Design and operating characteristics and advantages and disadvantages were then compiled for each POU option in the context of treating river water in homes of Njoro watershed residents. The goal was to select the most suitable option for further development, local adaptation, and eventual household trials in the Njoro watershed.

Major Findings

The most appropriate, acceptable and feasible POU methods for a given context will vary with the variety of situations encountered in less developed countries. POU technologies must be selected, tested, adapted and promoted on the basis of satisfying local water safety issues, cultural issues, cost issues and water demand (volume) issues. Many considerations must be taken into account when choosing an appropriate POU household drinking water treatment system for a particular local context and target population in a developing country. First are water quality considerations for developing an effective treatment regime. Major ones include: 1) pathogen removal, 2) turbidity reduction and 3) flow rate or size of batch (volume treated) for batch processes. Secondary water quality considerations include: 1) residual disinfection capability/ possibility of recontamination, 2) removal of organics, 3) removal of potentially harmful inorganic constituents such as arsenic, lead and fluoride and 4) finished water odor, taste and color. Non-water quality considerations are equally important and include such things as: 1) ease of

Table 1. Median fecal coliform in river water, diarrhea cases and water supply/sanitation conditions by zone and community in the River Njoro Watershed.

Watershed Zone & Communities	Fecal Coliform Median Count /100 ml (5 - 95 percentile)	Child Diarrhea 2-week incidence (Jun 2004)	Household Water Supply, Sanitation, and Poverty Conditions
Upper Catchment: Nessuit Area	2,457 (289-57,511)	19%	No improved water supplies; 35% no latrine; poverty highest; dispersed agricultural community
Upper Middle: Beeston, Mwigito, Njokerio	9,593 (3,978-201,389)	15%	Limited availability of improved water supplies; 98% have latrine or toilet; rapid un-planned peri-urban growth
Middle: Njoro Town, Rumwe	6,912 (1,750-67,639)	13%	Improved supplies available but cost a barrier and interruptions common; 98% have latrine or toilet
Lower Middle: Piave, Ngata, Ingabor	4,855 (936–53,556)	Unavailable	Improved supplies available but cost and distance a barrier; 98% have sanitation
Lower Catchment: Mogoon, Baruri, Kaptembwa, Ronda	31,608 (4,793–385,000)	11%	Improved supplies available but cost and distance a barrier; 100% have sanitation; higher incomes and greater employment opportunities, with slum-like living conditions in some neighborhoods

use, 2) cost (both initial investment and periodic costs), 3) practical considerations such as availability of power supply, proximity to water source and local availability of materials and services and 4) social acceptability of the system. Secondary non-water quality considerations include: 1) maintenance requirements and 2) durability/ longevity of the system.

Low cost POU options identified for consideration included: 1) intermittently operated slow-sand filters, known as the BioSand filter (BSF), 2) clay pot filters with silver treatment, known as "Filtron" filters, 3) ceramic candle filters, with or without silver treatment, manufactured by a wide range of companies in Europe, India and Latin America, 4) chemical disinfection using sodium hypochlorite liquid, sold in Kenya under the brand "WaterGuard" and "AguaGuard," 5) SODIS, simple passive solar disinfection, requiring clear 1 liter plastic bottles (PET) placed in the sun for 6 or more hours, and 6) combined chemical coagulation-flocculation and disinfection powder, sold in packets under the brand name PUR[1]. Ceramic candles, BSF, and chemical treatment and disinfection are now commercially available in many developing countries, including in Kenya. BSF and Filtron filters can be manufacturer locally as cottage industries, requiring some capital investment and specialized equipment.

Practical Implications

After reviewing the literature with particular attention to performance relative to river water characteristics, and issues of local access to consumables and products, volume and flow rate, and ease of use, the BSF, Filtron, and chlorine disinfection using WaterGuard were selected for further consideration as potentially suitable in the context of needs and situation of high-risk communities within the Njoro watershed. These three methods encompass POU technologies with extremely low capital cost ($5-25) and no to low recurrent costs (0 to $1.00/month), good potential for local production or procurement, general ease of use, and long-term sustainability within the Njoro watershed. Unique reasons for selecting the BSF and chlorine included: local availability of materials and technology to produce them or to purchase key inputs; possibility of high throughput for the large volumes of river water needing treatment for drinking and other domestic needs in some households; and effective removal of pathogenic organisms such as protozoa, in the case of BSF, and high viral and bacterial destruction with formation of a residual in the case of chlorine.

Candle filters are also potentially appropriate for drinking purposes but only for better off households, due to higher capital and recurring costs associated with regular candle replacement. They have also been extensively tested elsewhere. The technology to produce Filtron filters, a much cheaper version of candle filters, is not yet available in Kenya, making these difficult to manufacture for the moment. They also have low throughput and are suitable for treating drinking water volumes only. PUR was not explored further because of high costs given monetary constraints of poor households, limited local availability, and difficulties of use. River Njoro water tends to be high in turbidity thus SODIS was not a viable POU option. Chlorine was eliminated as a stand alone treatment, given large seasonal variations in river water turbidity and the implications for correct chlorine dosage, but retained as a complementary supplemental treatment, given its local availability, high effectiveness especially on bacteria and viruses, ease of use and very low cost. Thus, intermittently operated slow sand filtration, the BSF, despite some disadvantages, provides the most appropriate and suitable option likely to meet water quality improvement needs of poor agricultural and peri-urban households using river water for drinking and other purposes in the Njoro watershed.

Dr. David Manz of University of Calgary, Alberta, first proposed the BSF by adapting the traditional slow sand filter for intermittent household use by raising the under drainpipe to 5 cm above the sand to maintain a saturated system (Palmateer, et al., 1999). While the original container design was plastic, most ISSF units promoted and in use in developing countries are constructed of concrete using local materials at a commercial cost of US $15-25 per filter. The BSF is designed to hold 20 liters in the upper portion of the container above the sand and the depth of sand was chosen to have sufficient pore space to hold 20 liters, the volume of a jerry can, when sitting idle. Once set up, the filter has proven to be easily operated and maintained by the household in other settings for many years without additional costs.

For poor populations in developing countries who lack access to improved water supplies like those in the Njoro Watershed, the BSF has several key advantages over other POU methods, including: (1) robust design, unlike the ceramic filters such as the Filtron which can break easily; (2) no recurring costs, as required by chemical treatment and no regular replacement costs, such as with ceramic candle filters; (3) simple operation and maintenance easily mastered by the household; (4) relatively high flowrate, 3-60 L/hr, as compared to the ceramic Filtron and candle filters which have flow rates of 1-2 L/hr and 0.3-0.8 L/hr, respectively; (5) tolerates highly turbid waters, > 100 NTU, at levels for which chlorine and SODIS become ineffective; (6) locally available construction materials and skills making this technology sustainable within isolated communities; and (7) affordable to the poor. A survey by CAWST in 2005 revealed 80,000 concrete BSF units in use in over 36 countries.

[1]PUR is a commercial product manufactured by Proctor & Gamble, sold in Kenya at a subsidized price of 10 Ksh per packet, enough to treat 10 liters of water.

Having identified the BSF as the most promising option for improving the quality of river water used in homes in the Njoro, Dr. Jenkins designed a three-phase research program to develop and adapt the technology for local production and eventual testing in actual homes and brought UC Davis Environmental Engineer Sangam Tiwari into the SUMAWA Project to undertake the work for her PhD. Phase one, consisting of bench-scale laboratory testing at UC Davis to explore design and operating improvements for the BSF, was followed by phase two, local production and confirmatory pilot scale testing at Egerton University using river Njoro water. Phase three, the final test of applicability, proposed a six-month household trail of filters in volunteer homes of high-risk river-using households. To secure a successful and sustainable program, a memorandum of understanding between the SUMAWA Project and the Nakuru District Ministry of Health's Public Health team was signed and collaboration from Dr. Saenyi of the Civil and Environmental Engineering Department and his staff and students at Egerton University secured to work collaboratively to carry forward the three phases of work. The BSF research program is nearing completion. Development and trail results and findings will soon be shared in future research briefs.

Further Reading

Fewtrell, L., R. Kaufmann, D. Kay, W. Enanoria, L. Haller, and J. Colford. 2005. "Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis." *The Lancet Infectious Diseases* 5: 42-5.

GLCRSP. 2005. "Sustainable Management of Rural Watersheds: Biophysical, Livestock and Human Interactions in the River Njoro Watershed, Kenya". *2004-2005 Annual Report.* Davis, California: Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Jenkins, M. 2008. "Gross Fecal Pollution of a Rural Watershed in Kenya: Research Identifying Cattle as a Major Source in the Njoro Watershed." *Research Brief 07-01-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Palmateer, G., D. Manz, A. Jurkovic, R. McInnis, S. Unger, K. K. Kwan and B. J. Dudka. 1999. "Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter." *Environmental Toxicology* 14: 217-225.

Sobsey, M.D. 2002. *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply.* Geneva, Switzerland: The World Health Organization.

Tiwari, S. 2006. "Development and Trial of Point-of-Use Treatment Systems to Improve Drinking Water Quality in High Risk Communities of the River Njoro Watershed, Kenya." Jim Ellis Mentorship Program for Graduate Students Proposal. Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

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GLOBAL LIVESTOCK CRSP

Introduction to SEADS: SUMAWA's Spatial Environment and Agricultural Decision Support Tool

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Sustainable Management of Rural Watersheds (SUMAWA) Project

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The Global Livestock CRSP Sustainable Management of Rural Watersheds (SUMAWA) project has successfully investigated how land management decisions can be compared across multiple stakeholder groups with competing interests in the River Njoro watershed, Kenya via the use of the Spatial Environment and Agricultural Decision Support tool (SEADS). SEADS not only assists in evaluating an array of land use possibilities, but creates an arena for stakeholders and policy makers to communicate with one another as part of the decision making process. In an area such as the River Njoro watershed, where a long-established human interface has strongly influenced environmental processes, a tool like SEADS can increase the effectiveness of the decision making process at both local stakeholder/community and larger policy levels. SEADS is based on multiple criteria decision analysis (MCDA) methods and supports a number of modeled data including those from the Soil and Water Assessment Tool (SWAT), the Modified Soil Loss Equation (MSLE), and total gross margin for crops and livestock. This brief introduces SEADS and provides an overview of the tools used as part of the spatial decision support system implemented in the River Njoro watershed.

Background

DSS and SDSS. A Decision Support System (DSS) is a computerized system that supports organization decision-making activities. Information may be collected from a number of sources including raw data, interviews, or models and entered into the software-based DSS to help identify and solve problems, compare results, and make decisions. More specifically, a Spatial Decision Support System (SDSS) is a DSS used to provide guidance in making spatial or locational decisions.

As part of the SUMAWA project, the Spatial Environment and Agricultural Decision Support tool (SEADS) was developed to address water resources issues from multiple stakeholder groups in the River Njoro watershed. SEADS is intended to guide policy makers on implementing land management policies that are both environmentally and economically sound, while also acceptable to stakeholders, thereby increasing the likelihood of adoption.

SEADS allows users to integrate spatial and non-spatial data for improved decision-making (Figure 1). These data are generated using models such as the Soil and Water Assessment Tool (SWAT), the Modified Soil Loss Equation (MSLE), and spreadsheet calculations of total gross margin for crops and livestock under potential land use alternatives. All of these data can be generated using a Geographic Information System (GIS) and imported directly into SEADS. Users may also choose to integrate additional data into SEADS from other models or tools. Components currently linked to SEADS are described in the following sections.

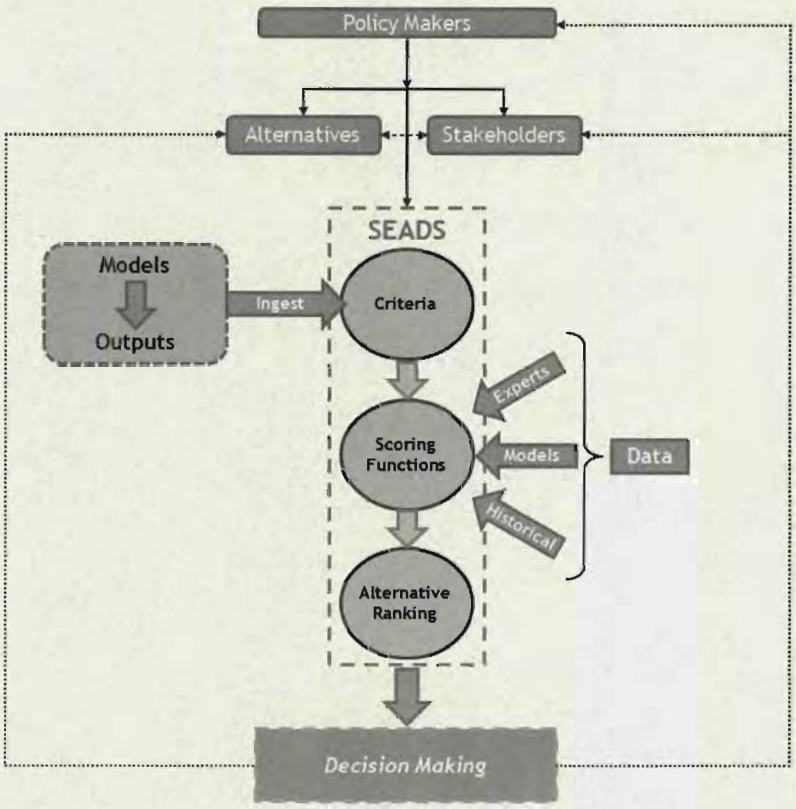
SEADS Components

Multiple Criteria Decision Analysis (MCDA). SEADS uses scoring functions and alternative ranking algorithms derived from the Facilitator, which is an open source generic multiple objective decision analysis tool that uses a hierarchical decision making structure (Heilman et al., 2002). Four scoring functions are used in the SEADS model to mathematically transform raw data with varying measurement scales into scores on a zero to one dimensionless scale, which allow criteria to be directly compared (Figure 2; Wymore, 1988; Yakowitz et al., 1992a, 1992b).

SEADS ranks alternatives by calculating the best and worst possible scores for each alternative using all possible weight combinations for criteria, while maintaining the criteria importance order as specified according to stakeholder preferences (Heilman et al., 2002; Yakowitz, 1996; Yakowitz et al., 1993). A significant advantage of this method is that it does not require decision makers to assign numerical weights to the criteria.

Geographic Information System (GIS). SEADS is built to operate on a GIS platform. Geographic Information Systems are information systems used for the capture, storage, manipulation, and visualization - in the form of

Figure 1. SEADS has the ability to integrate both spatial and non-spatial data, thereby contributing to the decision-making process at the stakeholder and policy levels.



maps, graphs, charts, and reports - of spatially referenced geographic data. GIS can also incorporate and reference non-spatial data through their database capabilities, adding to their popularity as management tools. For example, land use maps generated in a GIS are used in models such as SWAT to generate information about the impact of land use management. This information can then be transferred into a decision support tool, such as SEADS, to aid in the decision making process.

Soil and Water Assessment Tool (SWAT). SWAT is an important part of the SUMAWA project's prototype SDSS, SEADS, as it allows various hydrologic processes to be simulated in a watershed. Originally developed for the USDA Agricultural Research Service (ARS), the SWAT watershed scale model is designed "to predict the impact of land management practices on water, sediment and agricultural chemical yields in complex watersheds with varying soils, land use and management conditions over long periods of time" (Neitsch et al., 2005).

SWAT is physically based, uses readily available inputs, does not require large investments of time or money, and enables users to study long-term impacts of land use change. It has been modified and improved over time to account for changes in agricultural trends and production.

Based on the principle that water balance is the driving force behind everything that happens in the watershed (Neitsch et al., 2005), SWAT has two divisions of simulation that help predict the movement of pesticides and sediments or nutrients: the land phase and the water or routing phase that account for all the movement of water in the hydrologic cycle.

Modified Soil Loss Equation (MSLE). The Modified Soil Loss Equation (MSLE) is used to determine erosion caused by rainfall and runoff and is employed as part of SWAT. It is an empirically based soil erosion model founded on the Universal Soil Loss Equation (USLE); however, it is more versatile in developing nations where land use may not be based on cropping systems because it accounts for Vegetation Management systems (efforts used to mitigate erosion processes). Such systems include rangelands and forests. MSLE may be used at multiple scales from plot level to hill slope scale for predicting average annual soil erosion rates. Like SWAT, MSLE may be used in ungaged catchments where characteristics of the landscape are understood.

Soil erosion prediction is an important aspect of land use management, especially in agricultural areas, for several reasons. Soil losses can result in nutrient depletion and can lead to increased amounts of organic and inorganic matter in water. Such losses can also contribute to alterations in water balance within a watershed through depositional processes. (Neitsch et al., 2005). MSLE can be used to predict how a particular land use decision may impact soil loss, which is an indicator of soil erosion.

Practical Implications

The SUMAWA Spatial Environment and Agricultural Decision Support tool, SEADS, evaluates how well land use alternatives meet stakeholder's preferences using interactive and comprehensive methods to analyze the effects of various land use decisions. It is not designed to select the optimal land use for an area, but it identifies how well land use alternatives address stakeholder concerns. SEADS can guide policy makers on implementing land management policies that are both environmentally and

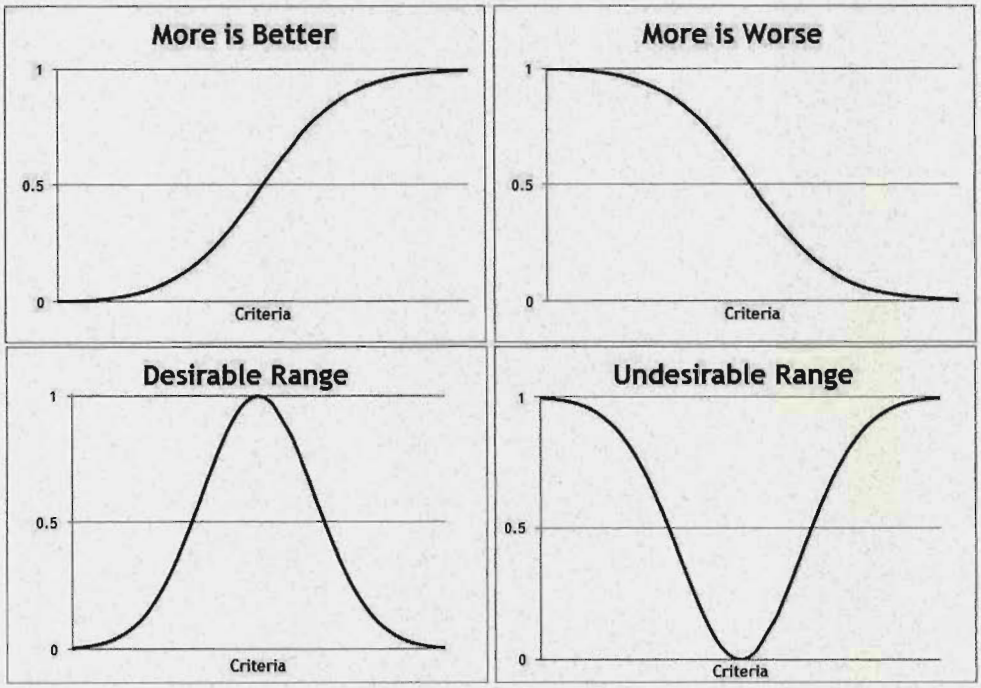


Figure 2. Four basic shapes of scoring functions to be used in the SEADS. Each criterion in SEADS is defined based on one of these four basic functions.

economically sound, while also acceptable to stakeholders, which increases the likelihood of adoption. Information is turned into knowledge by using interlinked and up-to-date models that account for biophysical and economic factors important to any complex watershed.

The SUMAWA prototype Spatial Decsion Support System SEADS has been used in the River Njoro watershed to develop a comparative framework whereby all parties, including local community stakeholders and more regional and national policy makers, can be involved in the decision making processes of future land use in a rapidly changing ecosystem.

Further Reading

Baldyga, Tracy. 2008. "Land Cover and Land Use Change in the Njoro Watershed, Kenya: A Threat to Human and Ecosystem Health." *Research Brief 08-04-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Baldyga, Tracy. 2008. "Spatial Decision Support System: An Integrated Approach to Assessing and Managing Natural Resources." *Research Brief 08-05-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Heilman, P., G. Davis, P. Lawrence, J.L. Hatfield, and J. Huddleston. 2002. "The Facilitator: An open source effort to support multi-objective decision making." Proceedings of the 1st Biennial Meeting of the International Environmental Modelling and Software Society. 3:253-258.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, and J.R. Williams. 2005. "Soil and Water Assessment Tool: Theoretical Documentation." Temple: Agricultural Research Service and Texas Agricultural Experiment Station. http://www.brc.tamus.edu/swat/doc.html.

Wymore, A.W. 1988. "Structuring system design decisions." Proceedings of International Conference on Systems Science and Engineering, July 25-28, 1988, Beijing, China.

Yakowitz, D.S., L.J. Lane, J.J. Stone, P. Heilman, and R. Reddy. 1992a. "A decision support systems for water quality modeling." ASCE Water Resources Planning & Management, Proceedings of the Water Resources Sessions/ Water Forum. August, Baltimore, Maryland. 188-193.

Yakowitz, D.S., L.J. Lane, J.J. Stone, P. Heilman, R. Reddy, and B. Imam. 1992b. "Evaluating land management effects on water quality using multi-objective analysis within a decision system." First International Conference on Groundwater Ecology, April, Tampa, Florida. 365-373.

Yakowitz, D.S. 1996. "Computing multi-attribute value measurement ranges under a hierarchy of the criteria." International Symposium on Analytic Hierarchy / Network Process. July, Vancouver, Canada.

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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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GLOBAL LIVESTOCK CRSP

Land Cover and Land Use Change in the Njoro Watershed, Kenya: A Threat to Human and Ecosystem Health

Tracy Baldyga, University of Wyoming
Sustainable Management of Rural Watersheds (SUMAWA) Project

Research Brief 08-04-SUMAWA November 2008

The River Njoro watershed and surrounding areas have undergone rapid changes in land cover and land use during the past two decades. In an effort to quantify these changes, and as part of the SUMAWA project, satellite images were acquired from January 28, 1986, February 6, 1995, and February 4, 2003. These satellite images were used to determine both the amount of overall land cover change as well as provide insight regarding the types of land use changes, representing the first quantitative assessment of land cover and land use change in the region. Results showed that significant changes in land cover and land use have occurred within the region as a whole and, more specifically, at an alarming rate in the uplands where the River Njoro headwaters are located on the escarpment. Results generated from this research have proven invaluable for all components of the SUMAWA project. Land cover and land use maps are primary inputs for the Soil and Water Assessment Tool (SWAT), the hydrological model currently employed in the SUMAWA project. Furthermore, as the project has developed and undertaken the task of building a spatial decision support system (SDSS) for rural watershed assessment and planning, the land cover and land use maps provided a basis for developing alternative land use scenarios. Finally, as part of the land cover and land use change mapping, a large-scale map was generated from these data and now sits in Lake Nakuru National Park where the River Njoro enters the park and helps tell the story of this rapidly changing landscape.

Background

In 2001, the Kenya Forest Working Group released a report indicating that deforestation was an ongoing critical threat to Kenya's five water towers: the Aberdare Range, Mt. Kenya, Mt. Elgon, the Mau Forest Complex, and the Cherangani Hills. These assessments, while an important step in identifying the problem of deforestation, fail to offer a rigorous quantitative assessment of temporal land cover and land use changes. The study detailed in this brief focuses on the River Njoro watershed, which finds its headwaters in the Mau Forest Complex on top of the rift escarpment.

From the available Landsat TM and ETM+ satellite images, it was clear that significant changes occurred in the Mau Forest after 1995. Local community members reported that significant changes in water availability had also occurred since that time. In 2003 and 2004, Participatory Rural Appraisal meetings were held as part of the SUMAWA project, and community members were able to express how changes in water resources within the watershed were affecting their lives. Within the community, people believe that the rapid and significant changes that have occurred in the uplands are the root cause of the water resources scarcity in the watershed. This coincides with the commonly accepted principal in hydrological science that when vegetation is removed from a landscape, the flow of water over the surface is modified and, in general, increases.

To this end, SUMAWA team members decided to examine in more detail the land cover and land use changes occurring within the Nakuru District, which would then allow for further examination of the linkages between land cover and flows in the River Njoro. For classifying the satellite images, two field campaigns were conducted in Nakuru District. During these field campaigns, data were collected on vegetation and land use. The areas were photographed, and GPS coordinates were used to combine these data with the satellite imagery, which resulted in the first quantitative land cover maps of the area. Using knowledge of the landscape at the time (2003 – 2004), team members were then able to use the older satellite images to make historical maps of the region.

Major Findings

Nine vegetation classes were identified as discernible for the land cover mapping: small-scale agriculture and pasture, basalt vegetation, dense vegetation, plantation forests, exposed non-vegetated areas, urban, large-scale agriculture, water, and algae blooms in Lake Nakuru. Results showed significant changes in land cover after 1995 (Table 1). Land cover changes were particularly notable in the upland regions (Table 1; Figures 1a and 1b). Throughout the region, the land cover change that generates the most concern is the decrease in dense

Table 1. Land cover as a percentage of total area for three years at multiple scales: Nakuru District, Njoro Watershed, and the Njoro Uplands

	Nakuru District			Njoro Watershed			Njoro Uplands		
Land Cover Class	**1986**	**1995**	**2003**	**1986**	**1995**	**2003**	**1986**	**1995**	**2003**
Mixed small agriculture/ pasture	34.4	36.7	50.6	32.1	32.5	51.2	14.8	14.4	33.4
Dense vegetation	32.5	31.8	25.5	30.9	27.8	23.6	67.1	60.0	49.8
Plantation forests	4.6	6.1	4.7	7.8	10.8	6.1	16.6	23.3	13.6
Large-scale agriculture	18.8	15.8	7.2	18.7	17.4	9.3	1.2	2.2	1.5
Exposed	7.1	7.1	9.5	8.0	8.4	6.1	0.2	0.1	1.6
Urban	0.3	0.4	0.5	2.5	3.1	3.7	0	0	0.01
Water	0.7	0.6	0.7	0	0	0	0	0	0
Algae bloom	0	0	trace	0	0	0	0	0	0

vegetation (e.g., indigenous forest and riparian vegetation) and plantation forests along with the concurrent increase in mixed small-scale agriculture and pasture. Additionally, the study found that the changes occurred predominantly after 1995 and over a short period.

Governmental and institutional arrangements regarding land tenure within Kenya after independence spurred large-scale land use and land cover changes. In particular, plantation forests in the once forested uplands region around the River Njoro watershed were removed and converted to small-scale agriculture. Census records indicate that population in the Nakuru district nearly doubled from 270,912 in 1979 to 413,698 in 1999. Population increases were greatest after 1989. Between 1979 and 1989, the recorded population only increased by approximately 15,000, with the additional population increases occurring between 1989 and 1999.

Practical Implications

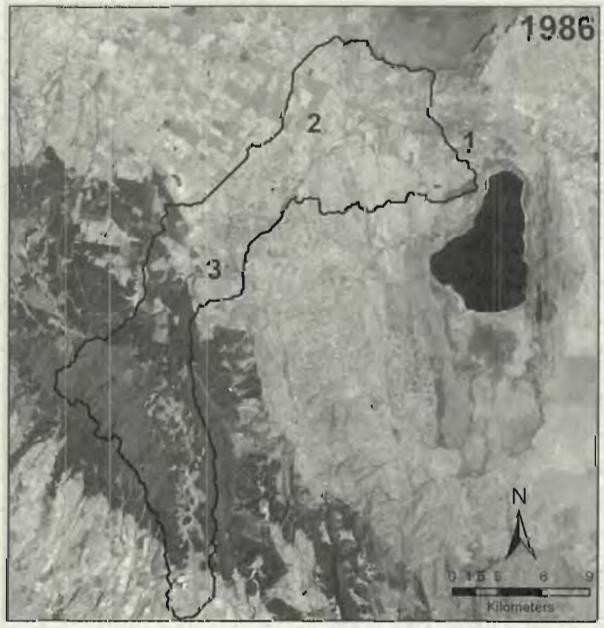
While changes in land cover and land use can have many and various deleterious effects, the changes in hydrological response and implications of land use change on soil erosion are critical to address. When vegetation on the landscape changes, there is the potential to change the way water flows across the landscape, as well as the amount retained in the soil. Under conditions such as dense forest, overland flow is slow, and water infiltrates the soil.

When vegetation is removed, water flows more freely across the landscape and does not have an opportunity to infiltrate the soil. The result is a change in the timing and amount of runoff to the river. "Flashier" flows are also increased, as water rushes from the landscape into the river channel.

Consistent with the hypothesis that changes in the watershed are associated with upland vegetation changes, floods and high flows have increased in recent years within the River Njoro watershed. The impact land cover changes are having on soil erosion is an additional concern. At Lake Nakuru National Park, reports indicate that sediment yields from the river to the lake are worsening.

There are two main contributing factors to the recent increase in sediment yields. First, with less dense vegetation to provide land cover, there are increased opportunities for rainfall to detach soil particles, which are then transported via overland flow processes to the river and, ultimately, the lake. In 2003, an algae bloom appeared marking a new event for the lake. It is likely that this bloom appeared as

Figure 1a. River Njoro Land Use and Land Cover, 1986. 1: The city of Nakuru, Kenya. 2: The Njoro watershed near Ngata. 3: The River Njoro headwaters in the uplands of Kenya. See Figure 1b (following page) for more detailed images.



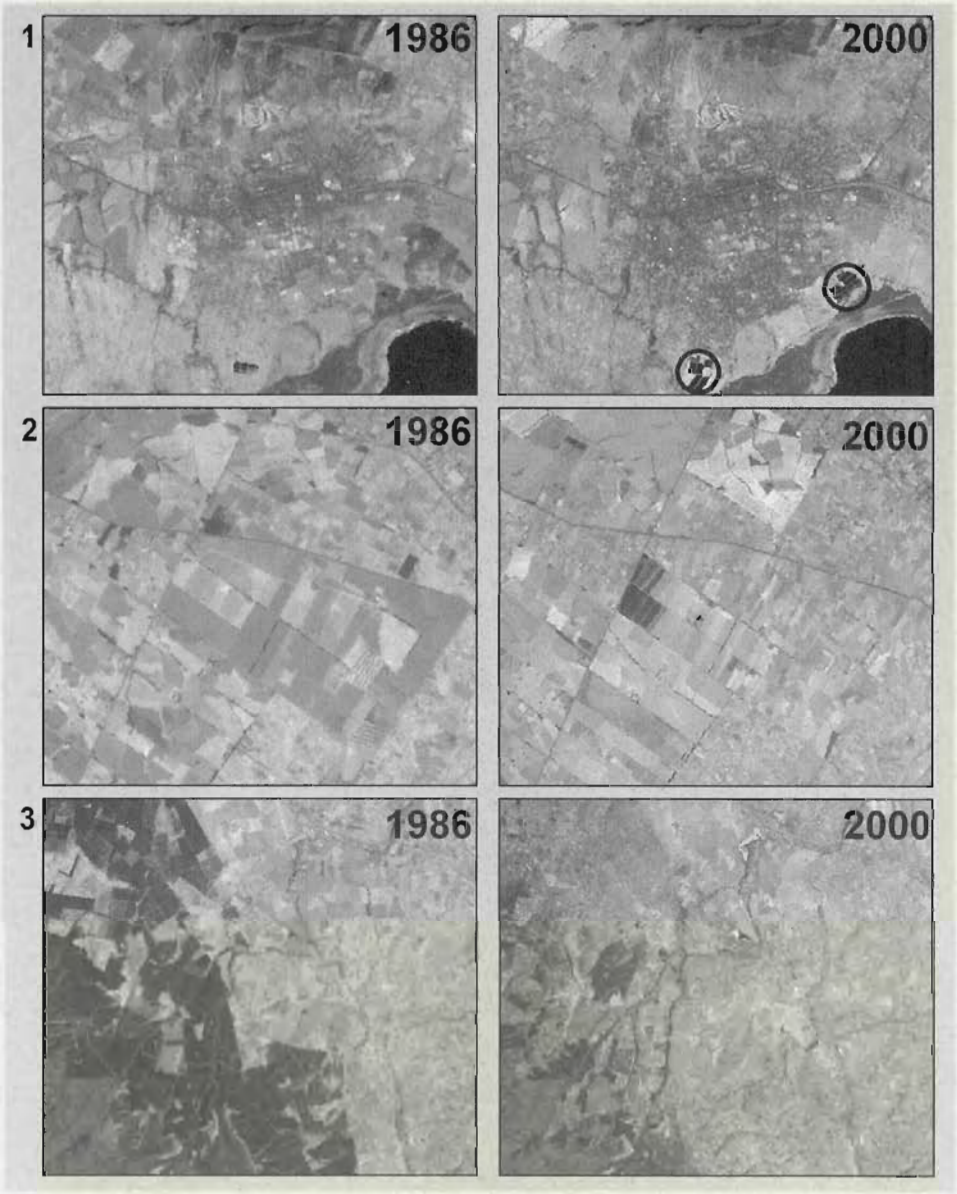


Figure 1b. Examples of River Njoro Land Use and Land Cover Change, 1986-2000. 1: Nakuru, Kenya's fourth largest city, grew substantially between 1986 and 2000. In this image, the city center pixels appear darker. Also note increased sewerage ponds (circled). 2: Subdivision of large-scale agricultural lands into small-scale agricultural plots is ongoing in this area of the watershed, near Ngata. 3: In the uplands, where the River Njoro headwaters are located, conversion of plantation and native forests to small-scale agriculture is ongoing. Such disturbances in the upper watershed are of particular concern, as they lead to changes in the river response such as flash floods followed by prolonged dry periods.

a result of agricultural run-off from an increased number of small-scale farms that replaced existing vegetation in the watershed uplands or increased effluent from the surrounding area. The appearance of the algae bloom is a sign of eutrophication, which indicates a lack of oxygen in the lake. In turn, this has severe implications for water quality in the lake and can negatively impact fish, bird and animal populations. Second, as soil transport (erosion) increases in the River Njoro watershed, large quantities of pesticides and fertilizers are potentially carried along with the soil thereby contaminating domestic and livestock water sources.

In short, the land cover and land use changes occurring in the watershed are not only alarming due to the impact on biodiversity and ecological services but also pose a significant challenge to improving both human and watershed health.

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.

Baldyga, T.J., S.N. Miller, K.L. Driese, and C.M. Gichaba. 2007. "Land cover change assessment within Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46(1): 46-54.

Baldyga, T.J. 2005. "Assessing land cover change impacts using remote sensing and hydrologic modeling." Master's Thesis, University of Wyoming. 188 pp.

Kenya Forests Working Group. 2001. "Excision and settlement in the Mau Forest." Report of Kenya Forest Working Group, Nairobi, Kenya, 15 pp.

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GLOBAL LIVESTOCK CRSP

Spatial Decision Support System : An Integrated Approach to Assessing and Managing Natural Resources

Tracy Baldyga, University of Wyoming
Sustainable Management of Rural Watersheds (SUMAWA) Project

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Increased awareness of the complex interactions among humans, their environment, and potential land management decisions has created a demand for integrated multidisciplinary decision support tools within a spatial framework. A prototype of a spatial decision support system (SDSS) that incorporates biophysical and economic models into a single user interface, known as the Spatial Environment and Agricultural Decision Support tool (SEADS), has been implemented within the River Njoro watershed. Spatial and nonspatial data are integrated into a spatially and temporally distributed modeling structure, where complex interactions can be studied through scenario building at watershed and subwatershed scales. Using SEADS, the Sustainable Management of Rural Watersheds (SUMAWA) project has successfully examined how land management decisions can be compared across multiple stakeholder groups with competing interests. From the user's perspective, SEADS provides an environment where policy makers and stakeholders can gain greater understanding of the complexities involved in land management decision making. Through increased knowledge of the system, policy makers and stakeholders are able to make more informed and, ultimately, more appropriate long-term land management decisions.

Background

Encompassing the River Njoro watershed, the Lake Nakuru region geo-ecosystem demonstrates a series of complex interactions where a long-established human interface strongly influences environmental processes. The goal of sustainable development is to meet the current needs of society without compromising the ability of future generations to also meet their needs, and it encompasses interlinked economic, ecological and community imperatives. To further this goal, a spatial decision support system (SDSS) was proposed as part of the Sustainable Management of Rural Watersheds (SUMAWA) project. The SUMAWA prototype SDSS, known as the Spatial Environment and Agricultural Decision Support tool (SEADS), not only allows researchers to develop land and water use scenarios but will also encourage and facilitate stakeholder participation for setting criteria and selecting acceptable management scenarios.

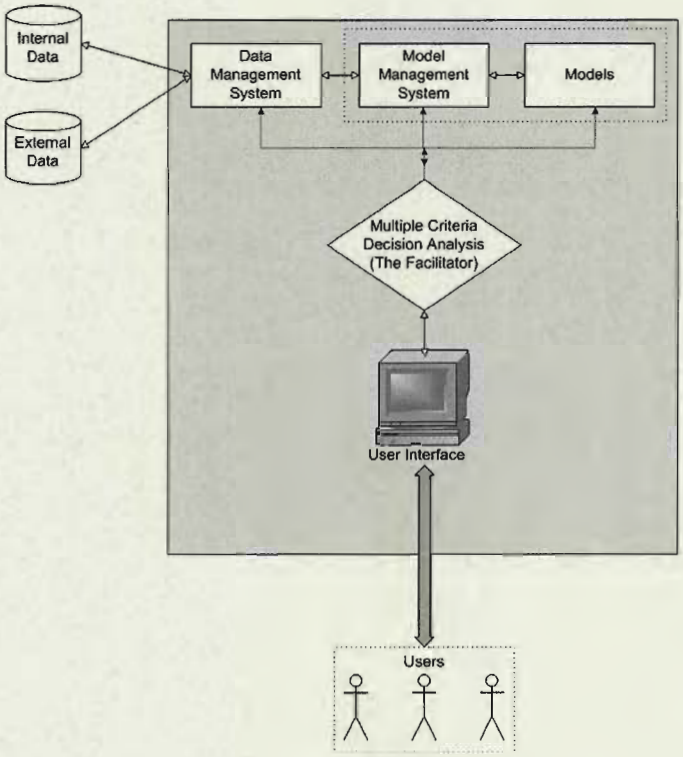
The application of the SDSS is illustrated as follows. Within one of the four River Njoro watershed Water Resources User groups, a plan may emerge to set aside areas for communal grazing while simultaneously closing off other areas. After interactively selecting the area for land use change on a map of the watershed, models and tools that are part of SEADS (the Soil and Water Assessment Tool (SWAT), the Modified Universal Soil Loss Equation (MSLE), and economic indicators) are parameterized and run using information related to the new land use map. Examples of criteria generated by these models and used in the SDSS are water quality and quantity, land cover, fertilizer and pesticide applications, and crop types. These new model outputs can then be compared for feasibility and appropriateness with ranked criteria identified through participatory methods. This new proposed land use can be compared to the current land use, as well as any number of additional alternatives proposed by stakeholder groups. Project researchers are presently working to implement the system in a single ArcGIS interface that will generate several output formats (maps, graphs, charts, and reports) that are meaningful for the various stakeholders involved (Figure 1).

Preliminary Findings

For testing the prototype, simulated stakeholder groups were developed that represent the multiple land management interests SUMAWA researchers have identified over the past several years. These groups represent interests in agriculture, conservation and industry. Various land cover scenarios have been developed for research at symposia (Baldyga et al., 2008; Baldyga et al., 2007a; Baldyga et al., 2007b).

SUMAWA researchers developed land use scenarios involving various types of soil conservation and cropping systems that are appropriate for the area from both biophysical and social perspectives. Within SEADS, criteria are converted to a dimensionless index that allows direct comparison among seemingly disparate

Figure 1. SDSS proposed for use on the SUMAWA project. Source: Baldyga et al., 2008.



criteria. This is accomplished using four simple scoring functions (Figure 2). SEADS does not require stakeholders to assign weights to the criteria. Instead, the criteria ranking assigned by stakeholders is used to calculate the maximum and minimum score for each alternative as constrained by stakeholder ranking, thus removing difficulties a decision maker may face when asked to assign a quantitative importance weight to each criterion. After stakeholder ranking, land use scenarios are ranked from best to worst for each set of identified preferences. This allows land managers to see where groups may be overlapping in preferences and also to examine the differences that can guide further land use scenario development. Ultimately, there is potential for SEADS to convene various stakeholders and facilitate more equitable land management decision-making.

Practical Implications

During fall of 2008, the SDSS was showcased in several venues throughout Africa: the East Africa ESRI User Group Annual Meeting (Kampala, Uganda), AfricaGIS 2007 (Ouagadougou, Burkina Faso) and many government and non-government settings in Kenya (Egerton University faculty and students, World Wildlife Fund for Nature, Kenya Wildlife Service, the Rift Valley Water Resources Management Authority, and local Water Resources User Groups in the River Njoro). The practical application of SEADS was immediately perceived by all the groups. Individual groups suggested applications of the tool for their respective purposes, and these suggestions are being used to further guide SEADS development. SUMAWA expects the final SDSS to be implemented in an ArcGIS interface by the fall of 2008.

The merits of simple GIS and participatory mapping efforts have been widely heralded as the next step in development practices, yet there is a noted lack of GIS applications – such as SDSS – that have the true potential to be stakeholder driven. Development of the SDSS puts the SUMAWA team at the forefront of natural resource management science.

Several DSS and SDSS have been designed and implemented with varying degrees of success in African countries. An SDSS was recently implemented in Niger for the Inner Niger Delta that successfully incorporated economics, ecology and water management but was based solely on policy without stakeholder input (Zwarts et al., 2006). In Kenya, at least two Spatial Decision Support System projects were developed in recent years. In 2003, researchers at the Regional Centre for Mapping of Resources for Development (RCMRD)

Figure 2. Four basic shapes of scoring functions to be used in the proposed SDSS. Each criterion in the SDSS is defined based on one of these four basic functions.

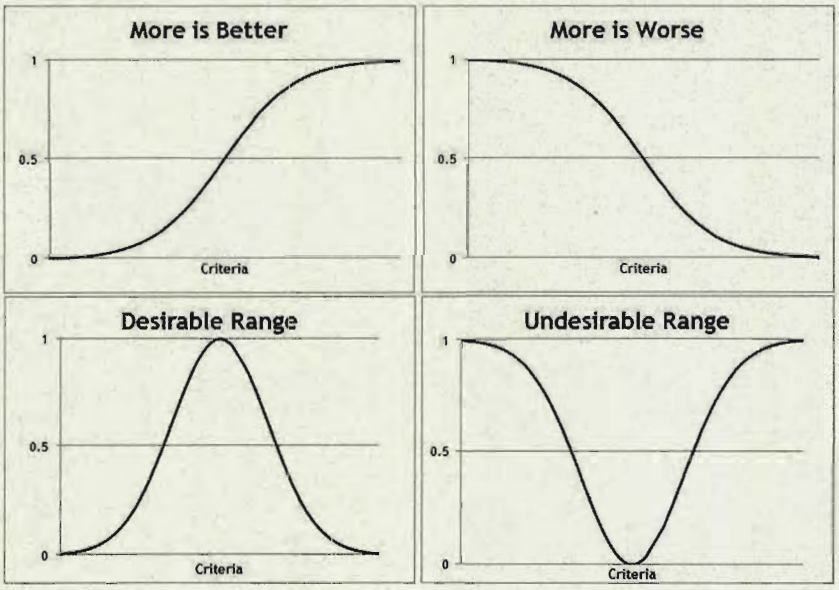


Table 1a-f. Land use alternative scenarios for the upper River Njoro watershed and the watershed location within Kenya. Scenarios were designed to broadly assess impacts of large-scale land management decisions, not actual management decisions. Source: Baldyga et al., 2008.

Table 1a. Current Scenario	
Land Cover Land Use	*Area (Ha)*
Grass	1483.47
Dense Vegetation	5806.89
Plantation Forest	1583.82
Urban	1.17
Degraded	181.71
Small-Grain Crops	706.32
Maize	740.7
Maize-Bean Intercropping	1126.08

Table 1b. Forest Incursions	
Land Cover Land Use	*Area (Ha)*
Grass	2083.41
Dense Vegetation	4487.13
Plantation Forest	135
Urban	1.17
Degraded	181.71
Small-Grain Crops	706.32
Maize	1285.2
Maize-Bean Intercropping	2750.22

Table 1c. All small-scale agriculture as maize	
Land Cover Land Use	*Area (Ha)*
Grass	1483.47
Dense Vegetation	5806.89
Plantation Forest	1583.82
Urban	1.17
Degraded	181.71
Small-Grain Crops	706.32
Maize	1866.78

Table 1d. Contour cropping	
Land Cover Land Use	*Area (Ha)*
Grass	1483.47
Dense Vegetation	5806.89
Plantation Forest	1583.82
Urban	1.17
Degraded	181.71
Contoured Small-Grain Crops	706.32
Contoured Maize	740.7
Contoured Maize-Bean Intercropping	1126.08

Table 1e. Forests converted to small-scale mixed agriculture	
Land Cover Land Use	*Area (Ha)*
Grass	1717.83
Urban	1.17
Degraded	181.71
Small-Grain Crops	706.32
Maize	3601.8
Maize-Bean Intercropping	5421.33

Table 1f. Forests converted to maize	
Land Cover Land Use	*Area (Ha)*
Grass	1717.83
Dense Vegetation	5615.46
Plantation Forest	1540.89
Urban	1.17
Degraded	181.71
Small-Grain Crops	706.32
Maize	740.7
Maize-Bean Intercropping	1126.08

put together what they identified as an SDSS in the Njoro watershed, but it lacked any analysis methods and relied only on standard GIS functionality (Agatsiva and Oroda, 2003). A second and highly successful SDSS was designed and implemented in the Kusa and Koru areas in Kenya (Ochola and Kerkides, 2004). Their spatial decision support system was integrative and interactive in scope and focused on land quality assessments for agricultural purposes specifically.

SUMAWA, on the other hand, is developing an SDSS that is watershed management-based and has the potential to facilitate land use planning efforts throughout East Africa from a stakeholder driven perspective. SUMAWA is making a significant contribution to SDSS research by developing improved methods for integrating and analyzing unstructured data, such as stakeholders' views of natural resources, with structured data from biophysical and economic models.

Issues such as tropical deforestation and overgrazing are receiving a great deal of attention in the public forum as significant factors in decreased ecological function and biodiversity, soil losses, and negatively impacted rural livelihoods. At the same time, there is a call to include more stakeholder input from the village to the national level in making land use planning decisions (World Commission on Dams, 2000). As computer hardware and spatial datasets are becoming more available and accessible, SDSS tools are more commonplace in natural resources management. Globally, there is a strong push to develop these integrated tools for natural resource management, a movement reinforced by the enthusiastic reception of SEADS within U.S. venues and government agencies. SUMAWA's SDSS will enable communities and policy makers to make more informed decisions to work toward a more sustainable future.

Further Reading

Agatsiva, J. and A. Oroda, 2003. "Remote sensing and GIS in the development of a decision support system for sustainable management of the drylands of eastern Africa: A case of the Kenyan drylands." *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 34 (6/W6): 42-49.

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.

Baldyga, T.J., S.N. Miller, W.A. Shivoga, and 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*, San Mateo, CA, March 17-19, 2008.

Baldyga, T.J. S.N. Miller, W.A. Shivoga, F. Lelo, G. Paige, and S. Mooney. 2007a. "Development of a participatory spatial decision support system for East African rural planning." Paper and presentation at *AfricaGIS 2007*, Ouagadougou, Burkina Faso, September 17-21, 2007.

Baldyga, T.J., S.N. Miller, W.A. Shivoga, F. Lelo, G. Paige, and S. Mooney. 2007b. "Rural planning in East Africa using a participatory spatial decision support system." Paper and presentation planned for *The East Africa ESRI User Group Conference*, Kampala, Uganda, September 13-14, 2007.

Ochola, W.O. and P. Kerkides, 2004. "An integrated indicator-based spatial decision support system for land quality assessment in Kenya." *Computers and Electronics in Agriculture* 45 (1-3): 3 – 26.

World Commission on Dams, 2000. "Report of the World Commission on Dams, 16 November 2000." http://www.dams.org//docs/report/wcdreport.pdf.

Zwarts, L., P. van Beukerling, B. Koné, E. Wymenga, and D. Taylor, 2006. "The economic and ecological effects of water management choices in Upper Niger River: Development of decision support methods." *Water Resources Development* 22(1):135 – 156.

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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.

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GLOBAL LIVESTOCK CRSP

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

Scott Miller, University of Wyoming
Sustainable Management of Rural Watersheds (SUMAWA) Project

Research Brief 08-06-SUMAWA November 2008

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.

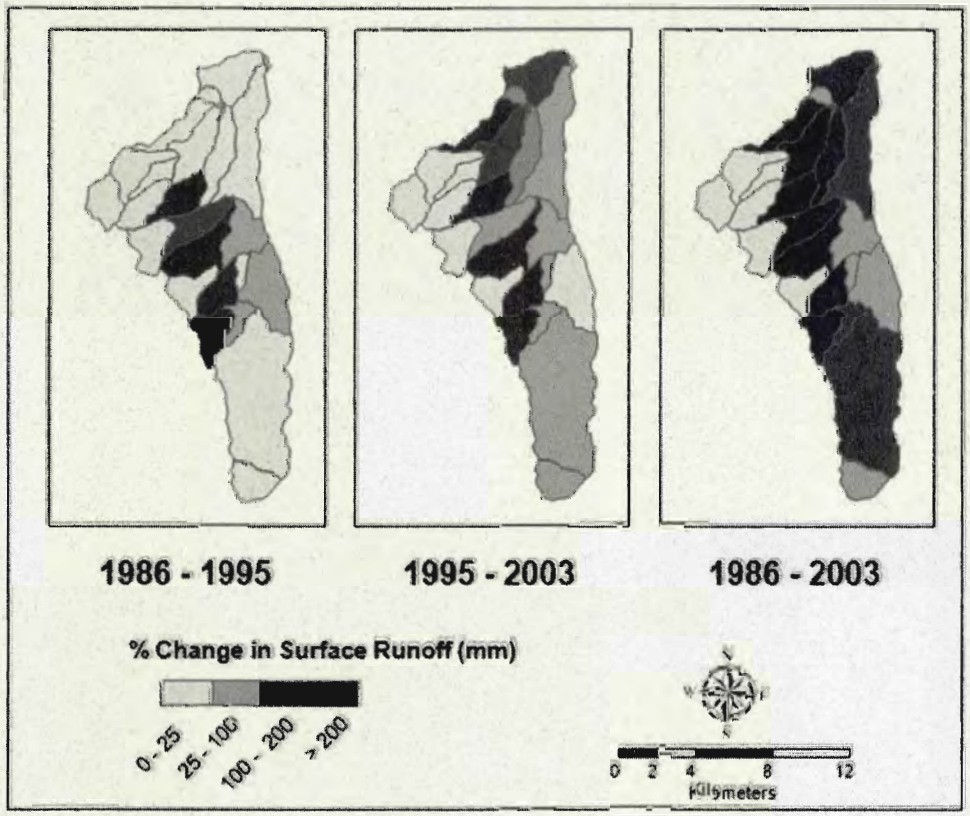

Figure 1. Spatially distributed change in runoff. The areas of greatest change are those associated with intensive transformation from forested to agricultural land cover (Baldyga et al., 2007).

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.

Baldyga, T.J., S.N. Miller, K.L. Driese, and C. Maina Gichaba, 2007. "Land cover change assessment within Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46 (1): 46-54.

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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GLOBAL LIVESTOCK CRSP

Exploring Uncertainty in Decision Support Systems for Land-Use Management

Tracy Baker, International Water Management Institute
Sustainable Management of Rural Watersheds Project

Research Brief 09-01-SUMAWA April 2009

Underlying all decision support systems are criteria scoring and decision rules. A multi-objective decision support tool known as the Spatial Environment and Agricultural Decision Support (SEADS) tool was developed by SUMAWA team members to be used by land managers and scientists in the identification of appropriate and desirable decisions for landscape management in settings where a variety of multiple competing interests exist. The SEADS toolkit passes observational and model data through mathematical equations termed "scoring functions" that establish a score for various potential land use options; these scores can be used to support decisions made on the ground. As part of the SEADS development, an uncertainty analysis was carried out to determine the degree to which these scoring functions affect the final score, therefore analyzing the extent to which SEADS outcomes may be improperly influenced by functions. Seven methods were used to parameterize three scoring functions that are part of SEADS. Results indicate that parameterization (the programming of the model) disproportionately influenced model outcomes when utilizing the SEADS scoring method. Further research is currently underway to assess the extent to which the model is sensitive to this parameterization. It is therefore important to understand that models like SEADS are intended to be tools that provide decision makers with an additional layer of information for land-use management. Using modeled data must be tempered with rigorous scientific research. In the end, it is the people and not the models that have to make the decisions.

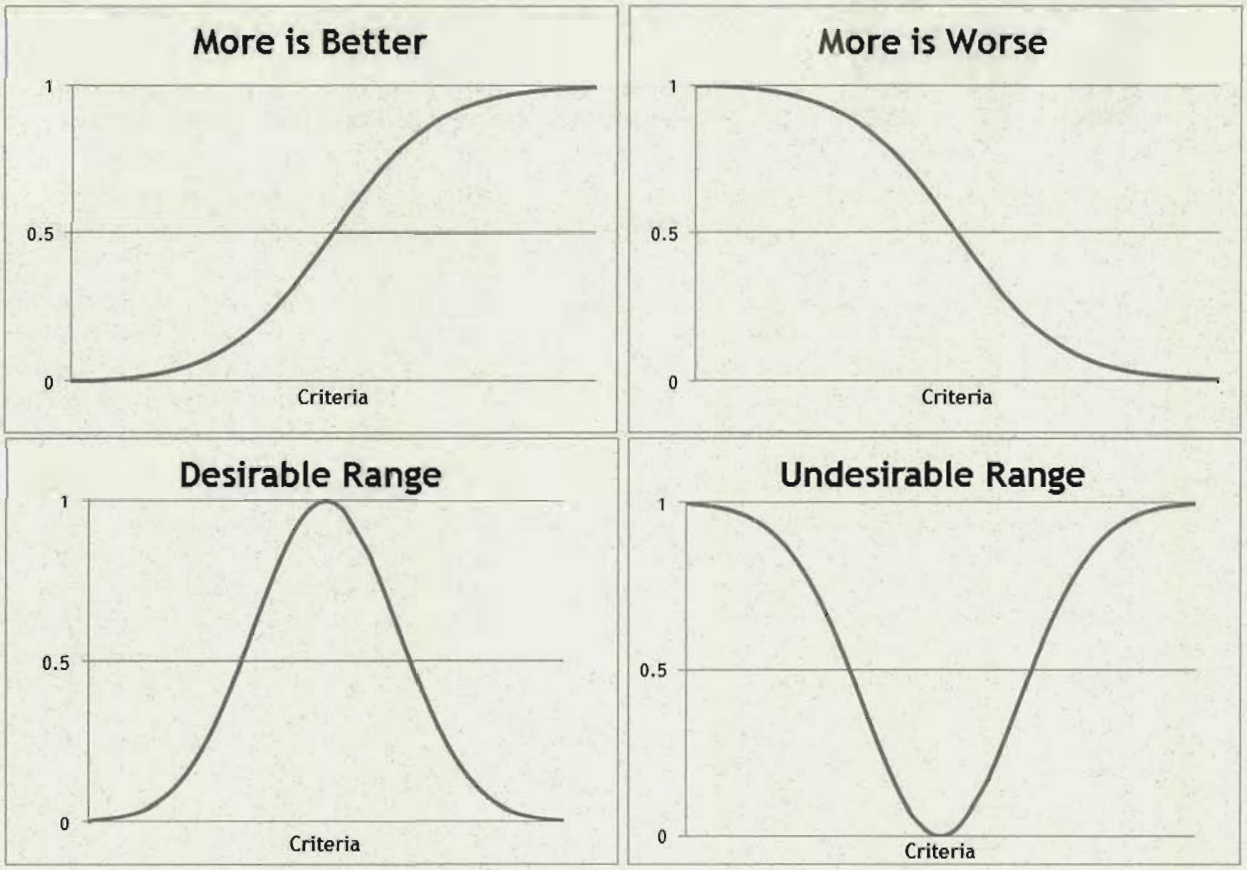
Background

This research analyzes the impact of uncertainty in parameterizing the decision rules for a spatially explicit multi-objective decision support system recently developed for use in Kenya. This system is designed to work as a mechanism to facilitate non-governmental entity participation in water resources decision-making. The Spatial Environment and Agricultural Decision Support tool (SEADS) was developed to assist land use managers in watershed-scale decision-making by integrating biophysical, economic, and social factors in a spatial decision-making space (Baldyga, 2008; Baldyga and Holley, 2008). SEADS incorporates decision rules from the Facilitator decision support system (Heilman et al., 2002) and capitalizes on readily available data sets and models, with the Soil and Water Assessment Tool (SWAT) (Arnold and Allen, 1996), embedded within the Automated Geospatial Watershed Assessment tool (Miller et al., 2007), being the principal hydrologic model.

SEADS is designed as a multi-criteria decision support tool tailored to address a class of problems with inherent conflicting objectives involving a set of evaluated alternatives. The tool identifies the highest score relative to the stated objectives in the management process, which are statements that describe a landscape system's desired end state, such as sustainable ecosystem services and productive agriculture. Criteria are used as measures of a given alternative's outcomes in meeting objectives. Erosion rates, for example, are measures of both long-term sustainability and productive agricultural systems. Users identify alternatives, which are options that deviate from the baseline condition, such as land use changes, different crop choices, or land management changes. A properly functioning decision support system ranks the relative suitability of alternatives for the desired outcome by measuring and scoring various criteria. Throughout the decision making process, there may be one or many stakeholders, and they may be comprised of groups or individuals who are considered to be affected by the decision making outcomes.

Decision support systems must employ some function for ranking alternatives, and these functions often require users to assign importance weights to criteria. SEADS uses a modified Analytical Hierarchy Process that does not require decision makers to specify numerical weights to determine criteria importance, but is instead based on how the users rank relative the importance of the criteria. This approach does not seek to find the "best" solution to a problem, but rather to determine one that is most acceptable to decision makers based on their

Figure 1. Four scoring functions used in the SEADS tool that transform observed or model data into scores for use in decision-making.



interpretation of the most critical factors leading to their desired outcome. Each data set that is used to determine an alternative's score must pass through a scoring function that transforms the data from its original value into a unitless score from 0-1. This allows criterion with differing measurement scales to be directly compared.

Developing scoring functions used in SEADS (Figure 1) requires that the user set minimum and maximum allowable values for each criterion. This may be in several ways: expert opinion of a system, historical data, legal regulations, or simulated data. The minimum and maximum values impact how the transformed score is calculated, which can ultimately propagate through the entire decision making process. Scant attention has been paid to the uncertainty introduced into the decision making process resulting from the use of these scoring functions. This project addressed this research gap to identify and then limit the uncertainty that is built into SEADS in the decision making process.

Preliminary Findings

Five alternative land use scenarios for the River Njoro watershed uplands were generated in ArcGIS 9.2 using land cover maps developed by the SUMAWA project and presented in Baldyga et al. (2007) (Table 1). These alternatives were created to broadly assess the relative impact of management decisions and do not necessarily reflect actual land use alternatives for consideration by stakeholders in the region. Current land use is based on a 2003 land cover map developed for the watershed. Alternative 1 represents small-scale agriculture incursions into the upland forest from the southwest based on trends noted since 1995. Alternatives 2 and 4 characterize drastic land use changes to 100% maize and small-scale agriculture and pasture, respectively. Alternative 3 is the current land use, but with contour cropping implemented in small-scale agricultural areas as a soil conservation measure.

Table 1. Descriptions for alternative land use management options tested for this study.

Land Use Alternative	Description
Current	Current land use based on 2003 land cover map (Baldyga et al., 2007).
Alternative 1	Forest incursions into the uplands.
Alternative 2	All small-scale agriculture is converted to 100% maize.
Alternative 3	Current land use with agricultural areas employing contour farming.
Alternative 4	Densely vegetated areas converted to small-scale maize-bean intercropping and pasture.

*Table 2. Alternative rankings for five land use scenarios based on the preference order: 1) Water Yield, 2) Groundwater yield, and 3) Sediment Yield. These rankings change depending on which of the seven methods used to parameterize the scoring functions was selected; * and ** denote equally ranked alternatives.*

Ranking	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6	Method 7
1	Current*	Alternative 4	Current*	Alternative 1	Alternative 3	Alternative 1*	Alternative 2*
2	Alternative 2*	Current*	Alternative 1*	Alternative 2	Current	Alternative 3*	Alternative 3*
3	Alternative 3*	Alternative 3*	Alternative 2*	Current	Alternative 2	Current	Current**
4	Alternative 4*	Alternative 2	Alternative 3*	Alternative 3	Alternative 4	Alternative 2**	Alternative 1**
5	Alternative 1	Alternative 1	Alternative 4	Alternative 4	Alternative 1	Alternative 4**	Alternative 4

SEADS allows users to define each criterion based on four scoring functions, or decision rules, in the form of curves: more is better, more is worse, desirable range, and undesirable range (Figure 1; Yakowitz et al., 1992). Scoring functions normalize quantitative or qualitative raw data for individual decision criteria into dimensionless scores on a 0 to 1 scale, relative to the minimum and maximum allowable values selected for each criterion. By expressing decision variables in this common dimensionless scale, comparisons among variables with varying scales are possible.

For this research, three criteria from the SEADS tool are analyzed: groundwater yield, sediment yield, and water yield. These criteria reflect important issues in the watershed and use default scoring functions in SEADS. All three criteria are SWAT outputs and for the purpose of this analysis are considered on an annual basis. These criteria reflect three separate concerns that have been reported by stakeholders within the River Njoro watershed.

Parameterizing the SEADS scoring functions requires setting minimum and maximum values for the appropriate curve. Aside from legal constraints that define guidelines for setting minimum or maximum allowable values, there are no steadfast rules for how these are set. In this analysis, SWAT outputs are used to set these values. The goal in analyzing the potential impact of uncertainty on SEADS scoring functions was to capture hydrologic model output variation within a typical 20-year land use management window.

Many hydrologic model simulations were run to define the expected range of values using a Monte Carlo simulation method, and researchers used seven different strategies to define the shapes of the scoring functions from these data. All of these scoring functions would be acceptable strategies for the use in SEADS based on decision support literature. If the shape of the scoring function were unimportant, one would expect to see no variability in the rankings of the different alternatives after being passed through the different simulations.

Once the assortment of potential scoring functions were set, the SWAT model was run using the alternative land use options outlined in Table 1. Results from the model were fed into the scoring functions, and the resultant scores were compared with one another. Identical weather characteristics were fed into all model runs to isolate their outputs to reflect the magnitude and direction of change under different land uses independent of weather variability. Table 2 shows how the ranking order changed significantly as a function of the method used to create the scoring functions. This table illustrates that the way in which the scoring functions are set has the potential to significantly alter the selection of a land use alternative for a given objective. Comparing Methods 2 and 4, for example, shows that the relative rankings of all the various land use options were different. In this case, the highest ranked land use alternative for Method 2 became the lowest ranked, while the lowest ranked became the highest. This finding is particularly troublesome because the data that were fed into the scoring functions were exactly the same for each method, with the only change being how the minimum and maximum values for these scoring functions were set.

Practical Implications

Uncertainty in scoring functions used in the SEADS tool was addressed by this research. SEADS allows for analyzing trade-offs between land use alternatives, potential impacts on the natural environment, and differing land management preferences among decision makers. Five alternative land use scenarios were developed, and three decision criteria in SEADS were analyzed: groundwater recharge, water yield, sediment yield. The purpose of this study was to quantify the uncertainty in decision making resulting from the way in which scoring functions are set within the SEADS tool.

Although this study only analyzed five land use alternatives and three criteria ranked using a single preference order, any number of objectives and land use alternatives can be

proposed and compared. Given the impact of uncertainty on the total scores presented in this analysis, it is pertinent to consider uncertainty with all scoring functions selected in the SEADS tool, or any similar decision support strategies, to assure that decision makers are being given the best available knowledge.

Further research is currently underway to assess the extent to which the model is sensitive to this parameterization. It is therefore important to understand that models like SEADS are intended to be tools that provide decision makers with an additional layer of information for land use management. Using modeled data must be tempered with rigorous scientific research. In the end, it is the people and not the models that have to make the decisions.

Further Reading

Arnold, J.G. and P.M. Allen. 1996. "Estimating hydrologic budgets for three Illinois watersheds." *Journal of Hydrology* 176: 57-77.

Baldyga, T. 2008. "Spatial Decision Support System: An Integrated Approach to Assessing and Managing Natural Resources." *Research Brief 08-05-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Baldyga, T. and F. Holley. 2008. "The SUMAWA Prototype Spatial Decision Support System and Its Tools: An Overview." *Research Brief 08-03-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Baldyga, T.J., S.N. Miller, K.L. Driese, and C.M. Gichaba. 2007. "Assessing land cover change in Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46(1): 46-54.

Heilman, P., G. Davis, P. Lawrence, J.L. Hatfield, J. Huddleston. 2002. "The Facilitator: An open source effort to support multi-objective decision making." *Proceedings of the 1st Biennial Meeting of the International Environmental Modelling and Software Society.* 3: 253-258.

Miller, S.N., D.J. Semmens, D.C. Goodrich, M. Hernandez, R.C. Miller, W.G. Kepner, and D.P. Guertin. 2007. "The Automated Geospatial Assessment Tool." *Environmental Modelling and Software* 22:365–367.

Yakowitz, D.S., L.J. Lane, J.J. Stone, P. Heilman, and R. Reddy. 1992a. "A decision support systems for water quality modeling." *Proceedings of the Water Resources Sessions/Water Forum*, August 1992, Baltimore, MD: ASCE Water Resources Planning & Management, 188-193.

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Edited by Franklin Holley & Susan L. Johnson

GLOBAL LIVESTOCK CRSP

Disaggregating Human Population for Improved Land Use Management

Tracy Baker, International Water Management Institute
Sustainable Management of Rural Watersheds Project

Research Brief 09-02-SUMAWA April 2009

Understanding the spatial distribution of a population across a landscape is important in land use planning. In developing nations, where resources are limited, such information can facilitate more efficient decision-making and resource allocations. This brief examines three methods for better understanding the distribution of human population within a natural boundary based on available census data: simple areal weighting, binary dasymetric mapping, and global regression. The study area is a rapidly changing watershed located in Kenya's Rift Valley. Variation in population estimates (ranging from 59,000 to over 150,000) resulting from different interpolation techniques underscores the importance of developing additional methods for spatially distributing population for improved land management. Census data alone are not sufficient to accomplish this task. Results indicated that appropriate methods for determining the correct spatial distribution of human population are essential and would be beneficial in land use management to better serve those most affected by the decisions. More specific to the Nakuru district, this knowledge will allow land managers to target areas for conservation measures where people are actually living. It also allows managers to discover areas where access to ecological services may be more diminished due to population pressure and puts the focus towards resource allocation solutions in areas where it is most needed.

Background

Humans derive a host of benefits from the natural environment: food, climate regulation, clean water and air, soil nutrient cycling, and fiber to name a few. Collectively, these benefits are known as ecosystem services. As human populations continue to increase, ecosystem services management and resource accessibility is coming to the forefront of applied research in natural resource management. To this end, understanding the size and distribution of human populations across landscapes is essential. Census data are used by governments to allocate financial resources, though these data may misrepresent true distribution and, ultimately, resource access of people.

It is now commonplace to use Geographic Information Systems (GIS) tools and models to more accurately represent complex spatial relationships on landscapes. GIS are readily available and affordable, and their usage is both practical and encouraged given the many freely accessible data that can be used in spatial analysis. Having access to such tools and data has the potential to increase stakeholders' ability to identify and target ecosystem services that are at risk as well as those who are dependent upon such services. For developing nations, where economic resources for assessing landscapes are scarce, there is a particular need to make use of available data and tools. Methods that maximize information gained from inexpensive or freely available spatial data sets describing natural resources and human population distribution are needed.

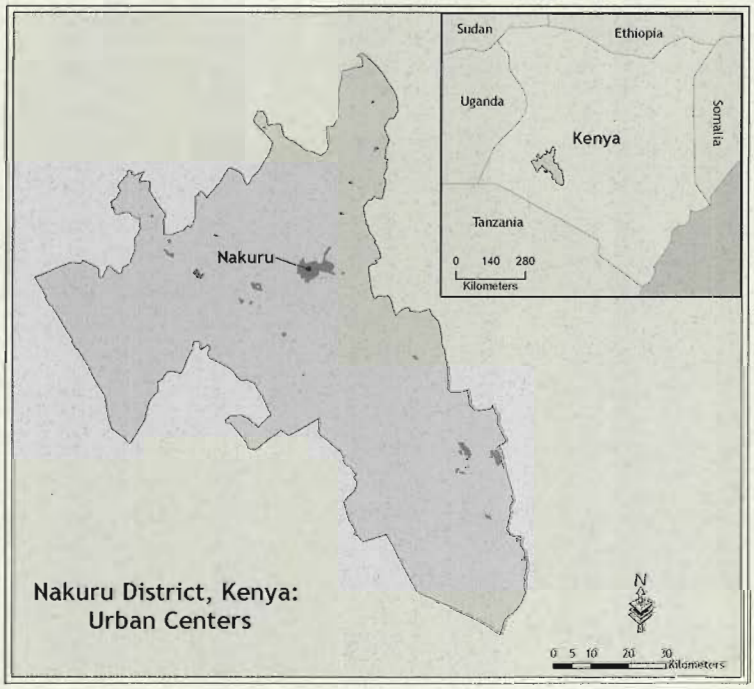
Census data are the primary sources of human population data. They are, however, often available at scales that are inadequate for land use management, which may occur on a farm or in a village and do not adequately represent human population variation within the census boundary. Census boundaries are not always drawn in relation to the numbers of people they represent but are often geopolitical boundaries that may be drawn and redrawn as political climates warrant (Crampton 2004). Analyses based solely on such data may produce erroneous information about the population and its distribution on a landscape (Monmonier 1996).

This study explores the benefits and drawbacks of three methods for mapping human population density: simple area weighting, binary dasymetric mapping, and global regression. All analyses are carried out using freely available data for disaggregating population within a natural watershed boundary in Kenya, with a primary goal to provide a resource for improved resources planning and decision-making.

Preliminary Findings

The Nakuru administrative district, Rift Valley, Kenya was used as the study area because it encompasses the River Njoro watershed, site of the SUMAWA (Sustainable Management of Rural Watersheds) project. Within the district there is one large urban centre, Nakuru town, and several smaller urbanized areas (Figure 1). Agricultural

Figure 1. Nakuru is the largest urban centre within the Nakuru district as well as Kenya's fourth largest city. Throughout the district, there are several other smaller urban areas, all highlighted in dark grey.



and livestock activities are the primary livelihoods within the district, evidenced by the majority of land cover falling into agriculture, which accounts for 4315 km^2 of the 7558 km^2 study area (Baldyga et al. 2007). Within the Nakuru district lies one of Kenya's five water towers: the Mau Forest. This area has undergone many changes since Kenya's independence from British rule in 1963. Many large-scale farms and plantations still exist, although several have been subdivided and are now classified as small-scale subsistence agriculture. Human population in the district is estimated to have increased from 522,709 in 1979 to 1,186,703 in 1999 (Central Bureau of Statistics-CBS 1981, CBS 2001).

Widely varying human population counts have been discussed for the River Njoro watershed, ranging from 250,000 to 700,000. Such discrepancies likely result from using census data at multiple administrative levels without regard to populated and unpopulated areas within the actual watershed boundary. In addition, there have been significant changes in the census unit boundaries between census enumerations, further confounding efforts to identify those residing strictly within the watershed itself.

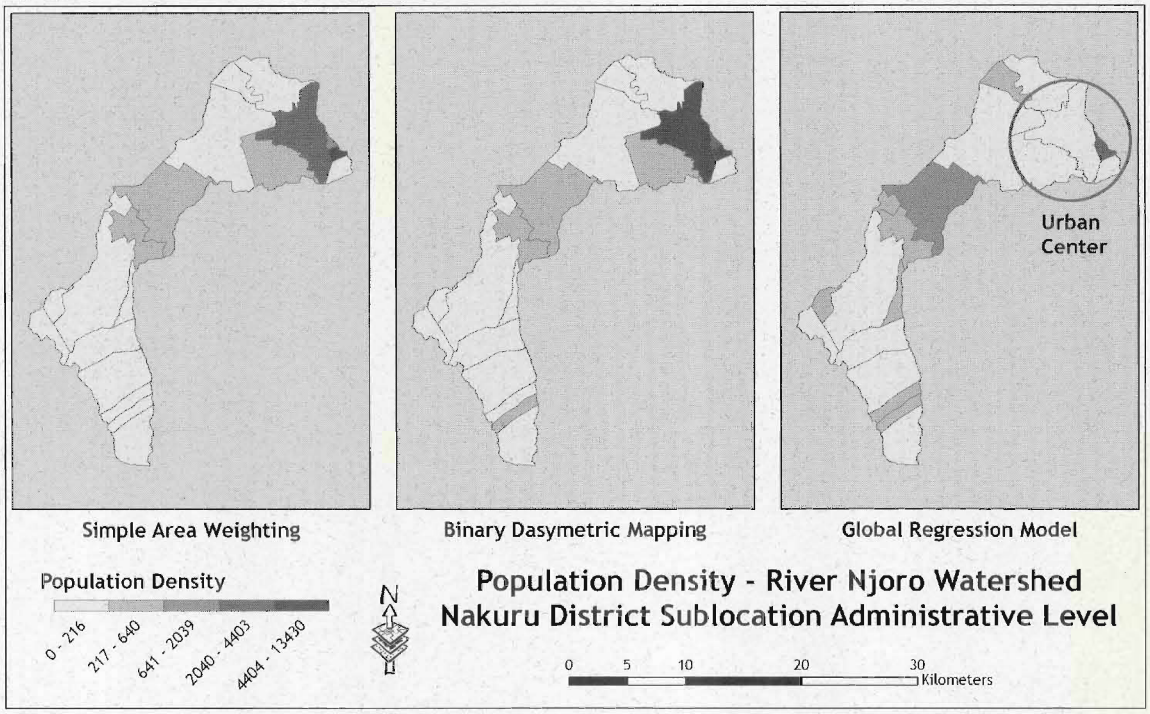
Simple area weighting is used as a baseline for representing population within the watershed for the present study. This method bases population on the area of overlap between a given administrative/census boundary (location, a medium-scale unit or sublocation, a fine-scale unit) and the watershed. It is defined by assigning people into the watershed based on the proportion of the watershed that falls within the census boundary.

Two techniques were used to refine the results given by simple area weighting. First, binary dasymetric mapping is a technique that distinguishes uninhabited areas within an areal unit and redistributes the population only within the populated areas; in this way the total population remains the same but the population density changes throughout the study area. This technique relies on field knowledge in order to identify those areas that are not inhabited and GIS to define those areas within the census boundaries.

While binary dasymetric mapping gives a better representation of where people are actually living, it still does not account for people living in greater densities based on land use. To account for the impact of land use on population density, a global regression model is used. This model identifies relationships between land cover and population density; for example, agriculture zones are less densely settled than urban zones. Fieldwork and remote sensing techniques are used to establish these relationships. A final population density map of detailed census blocks within the study area (Figure 2) illustrates that from the watershed center to the headwaters in the south, population density calculations based on binary dasymetric mapping and global regression analyses in several census areas are greater than those where simple areal weighting was used. There are also marked differences between binary dasymetric mapping and global regression modeling. When employing a global regression model, several sublocations in critical headwaters areas are illustrated to have population densities that are several times greater than those calculated using binary dasymetric mapping. Conversely, the model fails to identify many people living in dense urban centers, and is thus unsuitable for use in that setting, where people may in fact be more evenly distributed.

Simple areal weighting yielded a total population within the Njoro watershed of 146,915, with a 4.5% difference (154,774) in population calculated using binary dasymetric mapping. While the total population difference appears small, more striking differences are noted when analyzing population density both within the watershed and in the greater study area. Urban areas, such as Baruti and Njoro show little variation in population density between the two methods. Their population densities are calculated as 249 persons/km^2 and 391 persons/km^2, respectively, using simple areal weighting. Using the binary dasymetric

Figure 2. Final population density maps of the River Njoro watershed using three different mapping methods. Urban centers are highlighted in the Global Regression Model results and are considered inaccurate.



method, population densities of 251 persons/km^2 and 391 persons/km^2, respectively were calculated. In locations where a greater proportion of land is considered uninhabited, differences in population density are naturally much greater when comparing the two methods. For example, using simple area weighting and binary dasymetric mapping, the population density for Njoro is as 365 persons/km^2 and 362 persons/km^2, respectively. However, when applying the global regression model, which accounts for land use in the area, a population density of 666 persons/km^2 is calculated. In many instances, the global regression model produced markedly different results from the other two methods (59,000 people), with most of the discrepancy within the urbanized areas.

Researchers found that all three methods produced much lower population estimates within the watershed than previous reports; however, the model results also implied that many areas have much higher human population densities than presumed. Important to management, the models differed in the distribution of people with significant differences in estimates of population density. Population densities in the forested upper watershed show the greatest difference among methods (urban centers not withstanding), which was noticeable at a range of spatial scales. Such variations in population density could potentially lead to different decisions for land management or resource allocation. Importantly, these results indicate that even high-performing models have limitations, which must be taken into account as part of the analysis.

Practical Implications

In this study, it was clear that changes in scale and spatial distribution fundamentally change population density estimates and, consequently, total population estimates. Results indicated that appropriate methods for determining the correct spatial distribution of human population are essential and would be beneficial in land use management to better serve those most affected by the decisions. More specific to the Nakuru district, this knowledge will allow land managers to target areas for conservation measures where people are actually living. It also allows managers to discover areas where access to ecological services may be more diminished due to population pressure and puts the focus towards resource allocation solutions in areas where it is most needed.

Methods presented in this research brief can be carried out using freely available data sets, such as Africover (FAO 2000) and human census data. The results serve as a call to work with and refine the available data to develop additional methods that facilitate improved and targeted decision-making. Population density estimation alone cannot account for where people obtain their resources (such as water or fuel wood), but it refines the process of identifying areas of potential interest. This analysis could be extended by analyzing patterns of resources extraction and producing opportunity maps to incorporate with land management decision-making and alternative land use scenario design.

Further Reading

Baldyga, T.J., S.N. Miller, K.L. Driese, and C.M. Gichaba. 2007. "Assessing land cover change in Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46: 46-54.

Central Bureau of Statistics, Ministry of Finance and Planning (CBS). 1981. *1979 Population and Housing Census: Volume 1.* Census, Nairobi: Kenya Government.

Central Bureau of Statistics, Ministry of Finance and Planning (CBS). 2001. "Population Distribution by Administrative Areas and Urban Centres." In *1999 Population and Housing Census: Counting our People for Development: Volume 1.* Census, Nairobi: Kenya Government.

Crampton, J.W. 2004. "GIS and geographic governance: Reconstructing the choropleth map." *Cartographica* 39(1): 41-53.

Food and Agriculture Organization of the United Nations (FAO). 2000. "Africover Multipurpose Land Cover Databases for Kenya." Available from: http://www.africover.org. Accessed July 2008.

Monmonier, M. 1996. *How to Lie with Maps.* Chicago: University of Chicago.

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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 Principal Investigator for SUMAWA is Dr. Patterson Semenye. Email: semenye@sumawa.or.ke.

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Edited by Franklin Holley & Susan L. Johnson

GLOBAL LIVESTOCK CRSP

Medicinal Plants of the Ogiek Community in the Upper Watershed of River Njoro

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Research Brief 09-03-SUMAWA April 2009

This research brief presents findings on gendered knowledge of medicinal plants among the Ogiek community of River Njoro watershed that shows that both men and women of various ages know and use medicinal plants found within the watershed. A total of 94 plants were found to be used by the community to treat various diseases. The plants included trees, shrubs, herbs and grasses, which are found along riverbanks, in open uncultivated fields, and in the forest. Men mentioned more plants than women, but women are responsible for the collecting, preparing and administering of the drugs. The older men and women know more plants than the younger people. Medicinal plants are threatened to extinction mainly due to habitat destruction for cultivation and indiscriminate vegetation clearing for charcoal burning. Participatory three-dimensional mapping showed that women are able to identify plants found mainly along the river and in open fields as opposed to men who locate plants deep in the forest. This is due to gendered responsibilities in the community. Men and women showed interest in being involved in conservation interventions, such as establishing tree nurseries and botanical garden, and are willing to contribute labor and other materials needed for the interventions.

Background

Medicinal plants play a great role in meeting health needs of rural communities, and in Kenya, 75-90 % of local communities depend on medicinal plants as the dominant health care systems. Knowledge of these plants is threatened to extinction, for it is passed on orally from one generation to another and is influenced by culture change due to development. Habitat destruction leads to diminished numbers of medicinal plants in people's surroundings, thus affecting their access to traditional treatments. Indigenous communities are the most affected, as they depend on the plants for their main source of medical care. The Ogiek of the upper River Njoro watershed, Kenya, are part of an indigenous community who utilize the forest as their source of livelihood, for they are hunters and gatherers. The community used to live in the forest and obtained food and other needs from it; however, they have now settled elsewhere and are practicing agriculture, as forest policy in Kenya does not allow people to settle in the forest. The Ogiek community depends on medicinal plants to meet their health needs. Not only do they believe that the plants are effective against most common diseases, but modern health services are limited in the area.

The eastern Mau catchment where the River Njoro originates has undergone excessive vegetation clearing for agriculture and charcoal burning. Such reduced forest resources have negatively affected the Ogiek community. There has also been ethnic interaction between the Ogiek and other communities, and other settlers in the area are influencing the culture of the indigenous peoples. The knowledge of medicinal plants, which is mainly in the minds of the elderly, is threatened, as this knowledge is not passed down to younger Ogiek generations. Documentation of traditional medicinal knowledge is imperative for the future generations.

Participatory three-dimensional modeling provides the local community with an opportunity to transpose their mental maps on to a graph that can be used to address many issues of ownership, conflict, and development as people discuss the locations of various features in their area. Furthermore, gender influences medicinal plant knowledge, use, and conservation, since men and women are charged with different responsibilities in the Ogiek society. This study aimed to document the medicinal plants and gendered knowledge, which is important for gender equity and inter-generational involvement in conservation of medicinal plants and the biodiversity of the catchment area in general.

Preliminary Findings

From the data obtained through a questionnaire responded to by 60 men and 60 women, 72% of men and 70% of women cited that they prefer traditional health services where medicinal plants are the backbone. Men mentioned more plants than women with the mean number of 8.08 for men and 6.35 for women. There was high consistency in the diseases a plant is

Women mapping in the Upper River Njoro Watershed. In this study, women and men mapped separately. Women showed location of plants mainly found in open fields and along the river, where they frequently visit in search of water and firewood. Photo by Carrie Chitty.

believed to cure as indicated by both men and women respondents. Such agreement was observed in the following plants: *Cucumis ficifolius* (Sweet melon of the wolf) used to treat malaria, *Urtica massaica* (Stinging nettle) for kidney problem, *Rhus natalensis* (Dessert date) for constipation, *Dombeya goetzenii* (Forest Dombeya) for stomach complications, *Cyathula cylindrical* (Hookweed) for malaria, *Olea europea spp. Africana* (African wild olive) for eye infections, *Plectranthus barbatus* (Fasle boldo) for stomach complications, *Toddalia asiatica* (Orange climber) for fever, *Schifflera volkensii* (Schefflera) for chest pains and *Gomphocarpus physocarpus* (Balloon cotton bush) for tooth ache.

Medicinal plant knowledge is passed on orally from the elderly to the younger generations by going to the field to collect plants and by preparing the plants in presence of the young people. Mothers and grandmothers show young girls while fetching water and firewood, whereas fathers and grandfathers show young boys as they herd their cattle.

Medicinal plants are believed to be effective against most diseases affecting the community. Some diseases, however, including pneumonia in children, cerebral malaria, ulcers, cancer, brucellosis and tuberculosis, affect both men and women and need modern medicine to treat. These diseases have no known medicinal cures, or those known have proven to be ineffective. Most of these medicinal plants are found growing in the wild; however, few have been domesticated, such as *Dombeya goetzenii* (Forest Dombeya), *Cotyledon barbeyi* (Hoary navelwort) and *Olea europea spp. Africana* (African wild olive). Roots, leaves, bark and flowers are the plants parts that are most commonly used.

The community expressed concern for the diminishing numbers of medicinal plants, blaming indiscriminate vegetation clearing and unsustainable harvesting techniques such as excessive debarking. Some species of medicinal value are threatened to extinction such as *Engleromyces goetzei* (Bamboo parasite - see photo), and *Cucumis ficifolius* (Sweet melon of the wolf). Men and women indicated that there are few traditional conservation management systems, and those that do exist are no longer being employed, thus more plants may be threatened by extinction. Participants also reported that medicinal plant knowledge has eroded in the community. Reasons given for such knowledge loss included: presence of modern health facilities, in-accessibility of some medicinal plants, and the influence of Christianity.

In the three-dimensional model of the watershed, men and women indicated useful locations where they obtain their medicinal plants. Researchers provided the participants with a blank model and asked them to show where the features are in the area using pins and threads of various colors. The vegetation along riverbanks, open fields and the forest include plants of medicinal value.

In the mapping exercise, 30 men and 30 women between 17-78 years were involved. Men and women mapped separately. The plants mapped in the model are those most commonly used in the community; men mapped 26, and women mapped 31 plants. Women located plants in open fields and along the river, where they frequently visit in search of water and firewood. Men showed plants deep in the forest because that is where they go hunting and grazing and use the plants while in the forest.

Dry Engleromyces goetzei *is a parasitic plant that grows on bamboo plant. It is used in the community to treat malaria and headache. Photo by Eunice Ngari.*

Both men and women indicated that there is need to conserve the remaining medicinal plants for future generations. They showed their efforts and interests in being involved in any conservation intervention aimed at protecting the medicinal plants' habitats as well as the plants themselves. They community proposed establishing tree nurseries where they would collect the plants' seeds and seedlings from the forest, nurture the trees, and later plant them in a botanical garden, in riparian zone, or in their farms.

Practical Implications

The results of the study are useful to many end users, both in the community and other outsiders. It shows that men and women of various ages value medicinal plants and have knowledge of and access to alternative medical treatment. The future generation of the Ogiek community will now have a reference for their medicinal plants and their uses. This means that even with the introduction of model medical services in the area, the people can have an alternative and supplemental source of medication. This is particularly useful to the community since the health centre is only one in the area, and some people live far away from the centre.

Carrying out gender-differentiated research is important to understand the community responsibilities and gender involvement in development activities. This study therefore shows that both men and women are stakeholders in conservation practices of the watershed. While men would like to conserve forest for other reasons such as source of honey, grazing fields and medicinal plants, women indicated that riparian zones also need to be conserved for medicinal plants and firewood. This means that by involving both men and women, its is possible to conserve the catchment area of River Njoro as well as the riparian zone, which in turn would increase the river flow, as well as protect other watershed resources. The results provide a basis for gender mainstreaming in all conservation practices in the watershed, for some activities are better carried out by women than by men.

From the results of the study, a list of trees to be included in on-farm tree planting can also be obtained. This means trees can be domesticated for medicinal purposes as well as provide other benefits, such as wind protection and erosion prevention on-farm.

The participatory three-dimensional model allowed the Ogiek community to transpose their mental knowledge of their surroundings to a graphical representation of the watershed. The resulting map can be used by the community to inform policy makers of the issues and problems affecting the community, as well as the solutions proposed by the community. For example, in the upper watershed, few social amenities are available as compared to other regions in the watershed. The Ogiek can use the model to demonstrate their ancestral land and where they obtain various resources.

The study is also useful to scholars, as it provides a basis for further research in bio-assay tests to determine the efficacy of the plants against certain human diseases. Perhaps leading to the development of more modern medical treatments obtained from the plant extracts.

Further Reading

Bussmann, R.W. 2006. "Ethnobotany of the Samburu of Mount Nyiru, South Turkana, Kenya." *Journal of Ethnobiology and Ethnomedicine* 2:35.

Teklenaymanot, T. and M. Giday, M. 2007. "Ethnobotanical study of medicinal plants used by people in Zegie Peninsula, Northwestern Ethiopia." *Journal of Ethnobiology and Ethnomedicine* 3:12.

Willmer, A. and J. Ketzis. 1998. "Participatory gender resource mapping: A case study in a rural community in Honduras." *PLA Notes* 33: 17-22.

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GLOBAL LIVESTOCK CRSP

Modeling Tool to Assess Economic Consequences of Changing Farming Systems for Resource-Poor Small Farmers in the Upper Njoro River Watershed, Kenya

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Research Brief 09-04-SUMAWA April 2009

A modeling tool applying net present value economic analysis was developed to estimate long-term economic returns to labor and land for smallholder cropping systems in the upper River Njoro watershed. Production expenditures and income over a 15 year time horizon, for a typical farm household cultivating 2.5 hectares of maize-bean intercrop, pyrethrum, and potato mix were characterized based on field work. Results (2003 values) indicate annual net present value returns to land under the current system average Ksh 3,488/acre ($46/acre), and net farm income to the household averages Ksh 25,646 ($342) per year. Net returns are particularly sensitive to maize yield and price, cost of seeds, and the discount rate. The tool can be adapted to evaluate the economic consequences to farmers of adopting alternative agronomic practices and cropping systems. Estimated changes in farm income can be quantified and used to assess whether economic incentives are necessary as part of efforts to investigate improved environmental land management and development programs in the Njoro watershed. Farmer field trials, research experiments, and pricing information provide the agronomic and economic data to characterize proposed new practices such as agroforesty, riparian tree planting, set-aside, and soil conservation in the model. Such agro-economically grounded quantitative estimates of smallholder income and cash flow impacts and sensitivity from adoption of natural resource management and conservation practices provide a critical input to the process of developing locally successful environmental land and water management programs in threatened resources systems such as the Njoro watershed.

Background

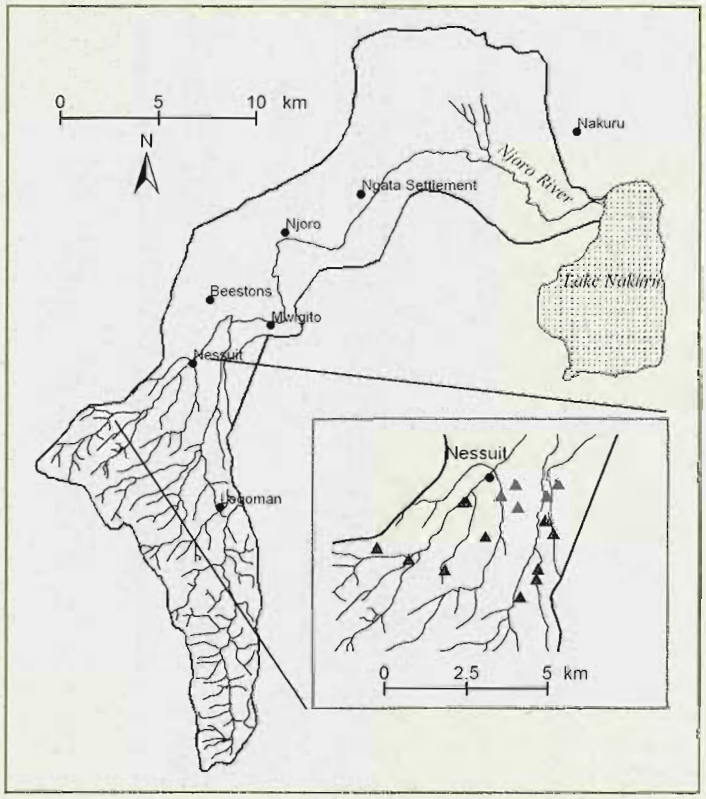
The Sustainable Management of Rural Watersheds (SUMAWA) project is focused on improving watershed health and livelihood security within the River Njoro watershed. Typical of many previously forested areas of Kenya, the watershed has been progressively settled and deforested, with the latest large-scale phase triggered by the declassification of significant portions of the Mau Forest in the early 1990's. The upper catchment of the Njoro watershed has come under cultivation by in-migration of settlers to clear-cut areas. Observed changes in the river's hydrologic regime and degraded downstream water quality have alarmed researchers and stakeholders, focusing attention on relationships between upland land use and water supply.

Participatory rural appraisals and scientific investigations by stakeholders and project researchers identified agroforestry as a promising approach to counter soil and forest resource degradation as well as declining watershed services within the watershed. Adoption of agroforestry, however, represents a change from existing cultivation practices and is likely to alter the economic circumstances of watershed farmers. Tree-planting can entail significant economic risks for resource-poor farmers (Mercer 2004). SUMAWA project researchers at the University of California, Davis and Boise State University developed a simple spreadsheet modeling tool to investigate changes in long term economic returns to watershed farmers of adopting new cropping systems and practices on their land in support of broader efforts to evaluate environmental management approaches such as agroforestry.

The model applies a net present value (NPV) approach. NPV analysis computes the projected economic costs and benefits of a prescribed cropping system over multiple cropping seasons. A comparison of the NPV of alternative cropping systems as well as year-by-year costs and returns can help determine whether proposed changes would be more or less profitable and economically sustainable for farmers, compared to their current system. While NPV analysis does not account for the complex socio-cultural issues, nor all of the risks that influence small farmer behavior, it is useful in preliminary analyses of improved environmental management impacts on smallholder agriculture in the Njoro watershed.

In the NPV modeling tool, cropping system economics are modeled for 15 years beyond "year zero," the baseline when most data were collected, and to which future costs and returns are discounted. If the NPV exceeds zero, the system generates profits over the analysis horizon considered. Conversely, where NPV is less than zero,

Map of the watershed showing the locations of the 15 households of the in-depth study and general project area.



invested funds are lost because the costs of inputs outweigh the value of returns. The modeling analysis also shows revenues and costs over time to identify any potential short term cash flow barriers to adopting new systems. Where access to credit is difficult and working capital minimal, a positive NPV may not be sufficient to encourage the adoption of a new cropping system because, despite an overall positive NPV, it is possible for producers to experience loses in individual years.

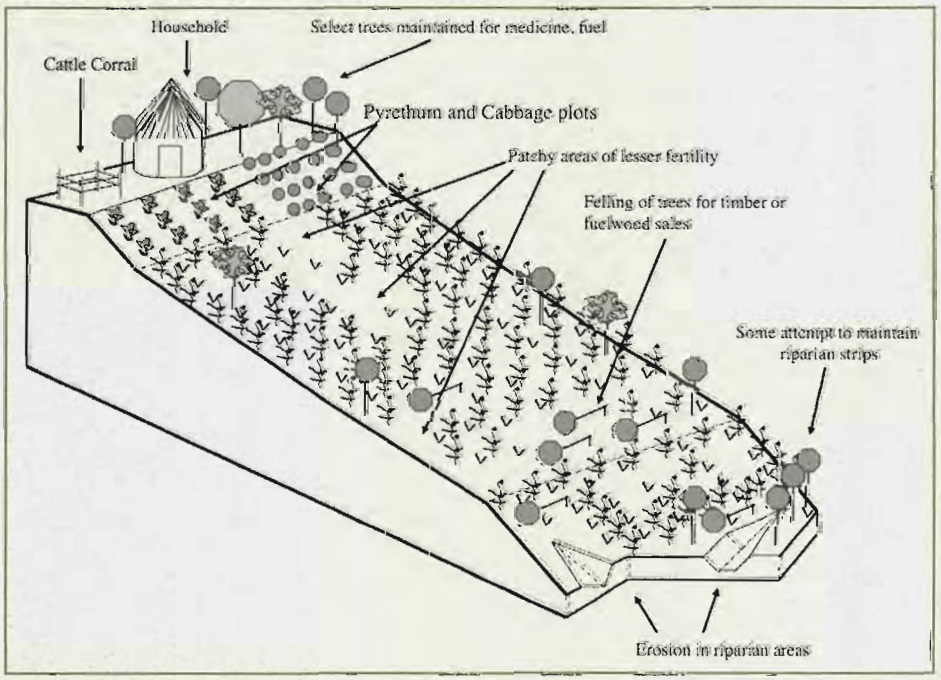
The NPV modeling tool uses multiple, interlinked Microsoft Excel spreadsheets. Generalized input and output quantities and prices are calculated for the farming system and adjusted each year to reflect annual changes in production practices. A real discount rate (inflation-adjusted cost of capital) based on actual values for Kenya of 17.08 percent per annum is applied in formulas to discount computed future year net revenue streams. Model formulas and input cells are structured, input values set, and then NPV of the characterized cropping system is computed.

Major Findings

In 2003, an in-depth study of 15 farm households was undertaken to identify predominant farming system characteristics within the upper catchment of the River Njoro watershed. Farmers described their input use and production as well as how much time they spent to complete basic agricultural tasks such as tillage, planting, weeding, harvesting, and post-harvest activities. Attention was paid to the division of tasks performed by different members of the household, especially those differentiated by gender and age, and those undertaken by hired labor. Costs and prices were recorded with information about sources, quantity, frequency and timing of other agricultural inputs and outputs.

Weighted mean data were then used to construct the archetypical crop production system of farm households in the upper catchment area. Average 2003 homestead size was approximately 2.5 hectares with another 0.1 hectares devoted to family housing and home gardens (Figure 1). Mean farm household size was six, including extended family members. Based on these characteristics, the NPV spreadsheet model was constructed assuming a cropped farm area of 2.5

Figure 1. A typical farm layout in the upper River Njoro watershed (Krupnik and Jenkins 2006).



hectares, with 75 percent planted to a maize-bean intercrop, 12.5 percent to the cash crop pyrethrum (an insecticide), and the remainder to potatoes. Although important to households' health, self-consumed home gardens and animal products have been excluded from the current NPV model formulation but could, with additional effort, be considered in future work. Krupnik and Jenkins (2006) provide a detailed description of farm and household dynamics.

*Table 1. Sensitivity to yield and price variations of NPV returns to land for the upper River Njoro watershed cropping system. kg = kilogram; ha = hectare; Ksh = 2003 Kenyan Shilling (US$1.00 = Ksh 75 in 2003). * Standard deviation of maize and bean yields derived from data reported in SUMAWA Project 2004 survey of households residing in the upper watershed.*

Maize yield kg/ha	Bean Yield Kg/ha	Maize price Ksh/kg	Annual NPV income Ksh/ ac-yr (US $)	Notes
3,113	775	12	5,978 (80)	Maize & Bean yield + 1 std dev.
3,113	452	12	5,016 (67)	Maize yield + 1 std dev.*
2,086	775	12	4,450 (59)	Bean yield + 1 std dev.*
2,086	452	16	4,420 (59)	+ 4 Ksh/kg in maize price
2,086	**452**	**12**	**3,488 (46)**	**Average maize & bean yield, and maize price**
2,086	452	8	2,556 (34)	- 4 Ksh/kg in maize price
2,086	129	12	2,526 (33)	Bean yield - 1 std dev. *
1,059	452	12	1,960 (26)	Maize yiel - 1 std dev. *
1,059	129	12	997 (13)	Maize & Bean yield - 1 std dev.

Total net present value (2003 values) generated by the current small-holder cropping system over 15 years is Ksh 323,042 ($4,307), providing an annual average net return of Ksh 3,488 per acre ($46) and a household income (return to family labor) of Ksh 25,646 ($342) after factoring out family labor costs. This household income is similar to Kenya's 2003 gross national product (GNP) per capita of US $340 (FAO/GIEWS 2003), but supports six people. Households also engage in additional on and off farm activities, however, cropping income accounts for the greater portion of household income. NPV results suggest farming households in the upper watershed subsist well below the already low Kenyan GNP per capita. Estimated inter-annual variation in net crop income under the current system varies considerably but generates positive cash flow in every year, an important concern for poor small-holder households and those without access to credit.

Maize intercropped with bean, the dominant crop grown by watershed farmers, is of paramount importance to the economic viability of the current farming system. NPV sensitivity to varying maize yield, bean yield and maize price are examined and presented in Table 1. Reductions (within one standard deviation of observed data) in maize and bean yields and fluctuations in maize price have significant effects on farm income in the current cropping system; annual NPV returns could be as low as Ksh 997 (US $13) or as high as Ksh 5,978 ($80) per acre for some households in the project area.

Practical Implications

NPV modeling analysis of the existing upper River Njoro watershed cropping system provides a basis for comparative economic evaluations of farmer adoption of new practices like agroforestry among small-holders in the River Njoro watershed. To this end, three common trees (*Ficus thonningii, Grevillea robusta, Polyscuas fulva*) preferred by watershed farmers for their agroforestry benefits have been considered. Based on a comprehensive literature review, *G. robusta*, a medium size tree that is noted for rapid establishment in riverine and highland habitats, was selected for further agronomic and economic evaluation. The net present value (NPV) modeling tool can be adapted to examine how the addition of an agroforestry enterprise using G. robusta to produce fodder and green manure within the existing small-holder maize-bean cropping system, would affect the amount and stability of small-holder household crop incomes in the watershed. NPV modeling has yet to be conducted on agroforestry management using this species. Nonetheless, significant experimental work has been conducted assessing the agroecological potential (enhanced yield, production of secondary farm products and erosion control) and tradeoffs (increased competition for soil nutrients, water and light) associated with G. robusta-maize intercrops, hedgerows, and related systems in Kenya (Muchiri et al. 2002), to allow adapting the model to examine agroforestry variants and their cash flow and income effects within the current cropping system.

The NPV sensitivity analysis indicates small reductions in maize yields and prices have significant negative effects on already meager household crop income in the current cropping system. In this initial characterization, potential future declines in soil fertility were ignored but could be included by altering crop yield parameters over time. It may be possible that less reliance on maize, mal-adapted to the higher elevations of the Njoro watershed, and greater crop diversification including agroforestry, wheat, and vegetables, could stabilize household incomes, especially under potential declining yields.

Beyond agroforestry, applications for the model include evaluation of the farm income and cash flow impacts of adopting various proposed soil conservation practices and of efforts to restore riparian buffer zones on watershed farmers' lands adjacent to the stream network. For the later, the model provides an estimate of the magnitude and duration of economic incentives to compensate farmers who restore riparian zones on their lands. Such agro-economically grounded quantitative estimates of small holder income and cash flow impacts and sensitivity from adoption of natural resource management and conservation practices provide a critical input to the process of developing locally successful environmental land and water management programs in threatened resources systems such as the Njoro watershed.

Further Reading

FAO/GIEWS. 2003. "Africa Report-Kenya." Food and Agriculture Organization of the United Nations and Global Information and Early Warning System on Food and Agriculture. 1: 28. (Online). http://www.fao.org/docrep/005/y9304e/y9304e28.htm. Accessed August 8 2005.

Krupnik, T.J. and M. Jenkins. 2006. "Linking farmer, forest and watershed: Agricultural systems and natural resources management along the upper Njoro River, Kenya." In University of California International and Area Studies Digital Collection. (Online). http://repositories.cdlib.org/uciaspubs/articles/3.

Muchiri, M., T. Pukkala, and J. Miina. 2002. "Optimizing the management of maize-*Gravellia robusta* fields in Kenya." Agroforestry Systems 56(1): 13-25.

Vosti, S. A., J. Witcover, J. Gockowski, T. Tomich, C. Carpentier, M. Faminow, S. Oliveira, and C. Diaw. 2000. "Working group on economic and social indicators: Report on methods for the ASB best bet matrix." Alternatives to Slash and Burn Agriculture Programme (ASB). Nairobi, Kenya.

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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 Principal Investigator is Dr. Patterson Semenye. Email: semenye@sumawa.or.ke. Dr. Jenkins is the project's US Co-PI. Email: mwjenkins@ucdavis.edu.

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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GLOBAL LIVESTOCK CRSP

Sustaining Lake Levels in Lake Nakuru, Kenya: Development of a Water Balance Model for Decision Making

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Research Brief 09-05-SUMAWA April 2009

Fluctuations in Lake Nakuru's water level, particularly since the mid-1980s have been a source of significant concern for the sustainability of the lake's unique ecosystem. To improve collective understanding of lake level fluctuation and drying, and to explore impacts of regional population growth, increasing water extraction, and land use changes, a preliminary water balance model of the lake was developed and initial analyses undertaken. Direct rainfall is the largest inflow to the lake, followed by tributary discharges and groundwater seepage. The lake's hydrologic balance appears to have changed substantially since the 1970's, with the proportion of water entering the lake rapidly as surface water - rather than perennially as groundwater - having increased, causing lake level and salinity to fluctuate more rapidly. This change is linked to an apparent increase since the 1970's in surface water runoff at the expense of groundwater recharge in the lake's River Njoro and other upstream watersheds. A declining groundwater table has the greatest negative impact on the sustainability of lake levels. The present situation calls for major efforts to improve hydro-meteorological monitoring and data management for the greater Lake Nakuru area with a priority on groundwater monitoring and institutionalization of these activities as essential governance rather than as piecemeal, short-lived projects.

Background

Lake Nakuru, located in Lake Nakuru National Park, at 1,759 meters elevation in the Eastern Rift Valley in Kenya is a broad, shallow, endorheic (no surface outlets) saline lake formed at the bottom of its closed catchment. Its unique ecosystem is internationally recognized for the diversity and density of its wetland birds, including the lesser flamingo, and large mammal wildlife that inhabit the surrounding Lake Nakuru National Park managed by the Kenya Wildlife Service (KWS). A prolonged lake drying period and falling water levels from the mid-1980's through 1996, and associated increases in water salinity, culminated with the lake completely drying in 1995 and 1996. Most bird life disappeared and tourism greatly diminished. Lake levels rebounded following extreme El Niño-driven flooding in 1997 and 1998; flamingos returned in 2000 but fewer than before. Such negative effects on the lake's unique birdlife cause concern for KWS and biologists and directly translate into economic losses from reduced tourism.

Of the three perennial rivers in the lake's catchment, the River Njoro drains the highest and wettest western side that rises to the Eastern Mau Escarpment, providing an important source of year-round surface inflow to the lake and recharge to the regional groundwater basin. The Njoro watershed, like much of the catchment, continues to experience the regional pressures of population growth, land use change, increasing rates of surface and groundwater extraction, and upland deforestation that has accelerated in recent decades (Baldyga et al. 2007).

Water balance modeling is commonly used as the first scientific step to understand the hydrological behavior of systems and impacts of water resource, climatic, and regional development changes. Water inputs consist of direct rainfall over the lake's surface, and surface water and groundwater inflows, while outputs consist of evaporation from the lake's surface and groundwater outflows.

Major surface water discharges into Lake Nakuru include several rivers, a perennial spring, and a sewage plant effluent. The lake has no surface outflow. An important portion of the rain falling over Lake Nakuru's catchment infiltrates to groundwater over the land or from its rivers before it reaches the lake (McCall 1957). Groundwater acts as a reservoir from which water seeps into (or out of) Lake Nakuru through the lake's bed sediments, in response to the difference in elevation head between the lake's surface level and the surrounding groundwater table.

Deforestation since the 1970's, along with increased surface and groundwater extraction, pollution, and land sub-division for small scale agriculture and population growth, continues to impact the Lake Nakuru region. Ongoing deforestation in the Njoro watershed is increasing surface water runoff at the expense of groundwater recharge, thereby increasing the proportion of rainfall water moving rapidly through the hydrologic cycle as runoff. Increased flash flooding and reduced groundwater replenishment result. Increased

water extractions compound these effects, reducing already diminished stream flow during dry seasons and lowering groundwater levels further. Little is known, however, about the magnitude of water table declines or how regional trends are impacting the regional groundwater system. In constructing a preliminary water balance model of Lake Nakuru to gain insight into the sustainability of lake levels, several important questions emerge and are addressed in the following section.

Preliminary Findings

What long-term historic monitoring data are available for developing a water balance model of Lake Nakuru? An exhaustive inventory and assessment of available historic monitoring records and lake-related data was undertaken. Climate data at the lake were more abundant and extensive than hydrologic data, but both contained significant quality problems. Evaluation of flow data for the seven surface and sub-surface inflow gauging stations to Lake Nakuru found that monitoring for most was initiated and pursued in the 1990's for relatively short periods only and that a significant portion of the recorded values are missing (11% to 60%), while station records of the two rivers with the largest contributing drainage to Lake Nakuru could not be found at all. The only long-term station record is for the Ngosur River mouth (1948-2000; 89% complete). Groundwater in the area has never been monitored and the lake's sediment hydraulic properties have never been reported. Less reliable reports of the water table around the lake on three past occasions were obtained. Lake geometry is available for 1960s conditions, at which time a depth-salinity relationship was also developed (Vareschi 1982). Lake level monitoring data from 1956 though 2002 were obtained with some limitations: missing and unreliable values appear for the period 1977-1994 and 2000-present while several anomalous values appear elsewhere; the gauge datum has not been measured since the early 1970's and is likely to have been affected by lake sedimentation.

While there is no historical period for which a complete set of time-series observations for water balance modeling of the lake's hydrologic system was found, two periods of data were identified for which a preliminary water balance model could be constructed and initial calibration and validation undertaken (McCord 2007).

What are the relative contributions of each hydrologic component to Lake Nakuru's water balance and water levels, particularly that of River Njoro surface inflows? A monthly water balance model of the lake was constructed and simulated using the best available rainfall, evaporation, surface inflow, and groundwater level data as input. Monthly inputs of surface water, groundwater, and rainfall, and monthly evaporation losses were developed. The water balance model was calibrated to the period January 1958 – September 1976 by minimizing the error between simulated (model estimated) and observed lake levels.

Results indicate that direct rainfall is by far the largest source of water to the lake, followed by tributary inflows and then groundwater seepage. Groundwater, however, can be the dominant source in dry periods and has served historically to stabilize lake levels in those periods. The flashiness of several rivers that discharge into the lake was inadequately characterized in this preliminary effort, but appears important for explaining the more rapid rates of lake rising and drying behavior observed in the historic record than predicted by the model over the calibration period (Figure 1).

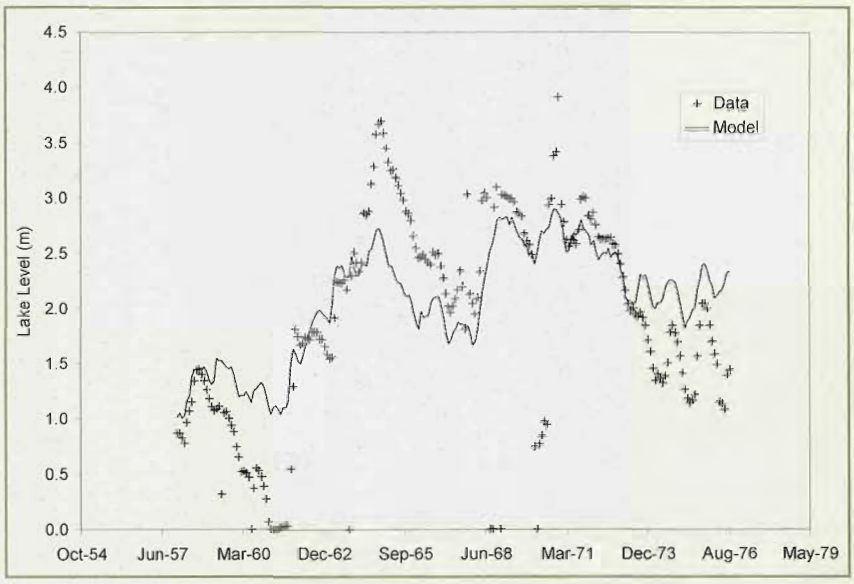
A validation test, where model performance is evaluated on an independent data set, was run for the period January 1994 – December 1999. This test revealed that significant changes in the lake's hydrology have occurred since the calibration period. To explore changes since the 1970s, model sensitivity and lake level response time analyses were undertaken.

What role does the surrounding groundwater basin play in sustaining Lake Nakuru water levels? Despite its small volume, the contribution of groundwater seepage to the lake's water balance is unique and appears particularly important historically for dampening the effects of extreme rainfall fluctuations on lake levels. Water moves into or out of the lake from and to the surrounding local groundwater basin depending on which level is higher. When high rainfall and runoff cause a rapid rise in lake level, the rate of groundwater seepage diminishes and may even reverse, causing water losses to increase. Lake levels tend to stabilize again at close to the long-term surrounding local groundwater table, as long it remains above the lake bottom.

An analysis of how quickly lake levels respond to changes in net rainfall (direct rainfall – evaporation over the lake surface) was undertaken. Response time in the relatively dry 1972-1976 period was compared to the relatively wet 1994-1998 period. In the earlier period, lake levels fluctuated less and more slowly with about a one-month lag in response to net rainfall changes. In the more recent period, lake levels responded directly to net rainfall with no apparent lag time. Furthermore, levels remained relatively steady in the 1970s despite low net rainfall but remained generally low in the 1990s period despite high net rainfall.

A long-term lowering of groundwater levels, starting in the 1970s and accelerating, is suspected. Increasing numbers of new boreholes installed starting in the 1960's provides some evidence to support this hypothesis. Sensitivity analysis explored potential effects: a lower groundwater level (three meters below the 1957 fixed groundwater level

Figure 1. Lake Nakuru water balance model calibration results comparing observed lake levels to model predicted levels over the January 1958 to September 1976 calibration period.

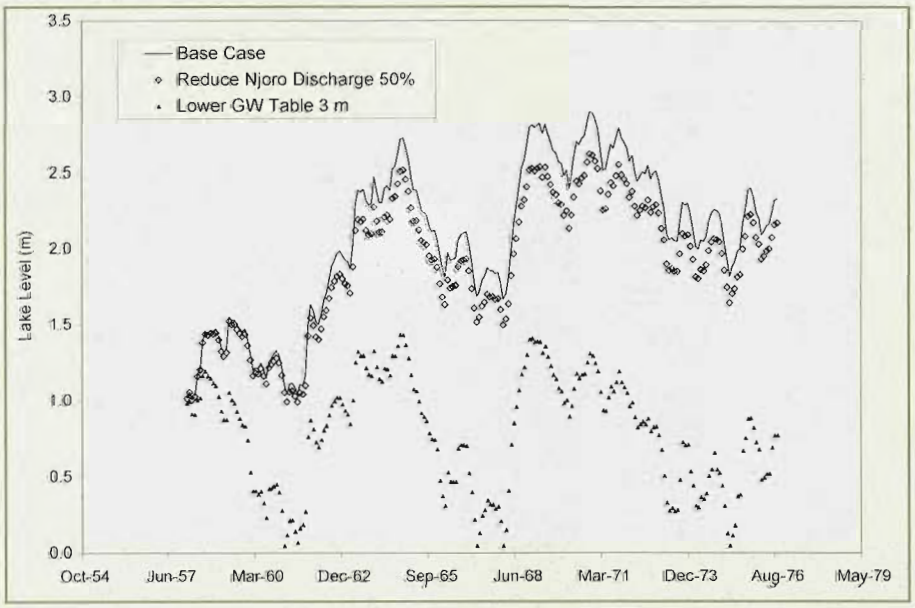


of 1,762 meters assumed in the calibration run) caused lake drying and the predicted mean lake depth over the calibration period to drop by 62%, or more than a meter (Figure 2).

What effects do population growth and land use changes in the Njoro watershed have on the sustainability of water levels in Lake Nakuru? Runoff from the Njoro watershed makes a disproportionately larger contribution to the lake than its drainage area would suggest because it drains the wettest portion of the lake's catchment. Lake level sensitivity to halving the volume of River Njoro discharge into the lake, holding all other assumptions constant, shows levels would drop by about 17 centimeters over the calibration period, much smaller than the drop predicted from a reduction in the groundwater table (Figure 2). The historic flashiness and complex stream-aquifer interactions of the lower River Njoro could not be characterized due to lack of systematic station recording. Recent changes in the River Njoro's hydrologic regime from deforestation, land use change, and increasing water abstractions affect the monthly distribution pattern of runoff and groundwater replenishment processes. These changes are likely to negatively impact lake levels, even if the total annual discharge volume remains the same.

What gaps and limitations in hydro-meteorological monitoring data, and other critical data need to be addressed in order to improve the scientific understanding of Lake Nakuru's water balance and water level fluctuations? Lack of long-term monitoring data and uncertainty in the quality of very limited records on surface discharges constrained the ability to match the historic record of lake levels in this initial effort. Major gaps and important limitations in the existence and quality of monitoring data were identified: 1) very short and sporadic stream gauging records for the major streams and rivers flowing into the lake largely do not overlap with lake level data; 2) the groundwater table around the lake has not been recorded; 3) monitoring and record keeping since 1970 have been highly problematic; 4) stream gauge data collection has been irregular and erratic since 2000; 5) a high degree of inaccuracy and unreliability of available records for a number of the climatic and streamflow stations; and 6) lack of lake geometry and sediment hydraulic properties and changes over time in light of increasing upstream sediment erosion to the lake (McCord 2007).

Figure 2. Predicted sensitivity of Lake Nakuru levels to a modeled reduction in a) the groundwater table, and b) the River Njoro discharge volume, over the January 1958 to September 1976 model calibration period.



Practical Implications

This preliminary modeling work identified the critical role of groundwater in sustaining and stabilizing lake levels, storing water when surface water discharges to the lake are high, and seeping back to the lake in drier periods. Groundwater functions to support long-term lake levels in this way as long as the local water table remains sufficiently high (above the lake bed bottom). Investment in a comprehensive regional and near-lake groundwater-monitoring program, accompanied by field and modeling studies to develop a greater scientific understanding of groundwater behavior in the Nakuru region and greater Rift Valley (where other lakes are likely to be similarly affected by groundwater levels) should be a government priority. Such investment is justified not only for the sustainability of ecosystems like Lake Nakuru's, but also for the long-term sustainability of local water supplies, a majority of which have and continue to draw from groundwater. As part of a groundwater-monitoring program, the Government of Kenya's Water Resources Management Authority (WRMA) needs to enforce the legal requirement of air lines in well construction permits. Some recently installed regional wells have not included air lines, precluding the ability to measure groundwater levels. The 2002 Water Act imposes a volumetric tax on groundwater extractions which is collected by WRMA. These funds would seem a viable source of investment for sustaining a regional, long-term, seasonal groundwater monitoring program.

Collecting and managing high quality, continuous, long-term hydrological and meteorological monitoring data for common use is imperative for a water budget analysis. This research highlighted countless significant cases where better data would have saved time and increased confidence in the data. Recommendations for improving hydrologic and climatologic monitoring to improve understanding of the lake's water balance and development of the water balance model include: 1) Investigate river gauging stations and records to assess and revise preliminary discharge factors used to represent ungauged inflows in the model; 2) Rehabilitate, upgrade and re-calibrate stream flow stage gauges on major inflows; 3) Monitor and record sewage discharges to address pollutant concerns and estimate local aquifer seepage; 4) Generate a detailed depth map of Lake Nakuru, compare to the 1960s map and measure sediment bed properties; and 5) Invest in long-term station gauge maintenance, calibration, and regular data quality assessment and archival record management systems (McCord 2007).

Further Reading

Baldyga, T.J., S.N. Miller, K.L. Driese, and C.M. Gichaba. 2007. "Assessing land cover change in Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46(1): 46-54.

McCall, G.J.H. 1957. "Geology and groundwater conditions in the Nakuru Area." Technical Report No. 3. Hydraulic Branch, Ministry of Works, British Colonial of Kenya.

McCord, S. 2007. "Technical Memorandum: Task 2 – Lake Nakuru Water Budget." Technical Report: SUMAWA/NJORO WATER projects.

Versachi, E. 1982. "The ecology of Lake Nakuru (Kenya). III. Abiotic factors and primary production." *Oecologia* 55(1): 81-101.

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The GL-CRSP Sustainable Management of Rural Watersheds (SUMAWA) project was established in 2003 and is a multi-disciplinary research effort focusing on biophysical and human-related factors governing health in the River Njoro watershed in Kenya. The research conducted for this brief is part of the NJORO WATER (Water and Sanitation in the Njoro Watershed) project, which supplements SUMAWA with scientific analysis and modeling of SUMAWA data sets. Dr. Marion Jenkins serves as Principal Investigator for NJORO WATER. Email: mwjenkins@ucdavis.edu.

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GLOBAL LIVESTOCK CRSP

The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya

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Unsafe drinking and domestic water is a major community and public health concern in the River Njoro watershed. Low-cost household water treatment was identified as an intervention to address the problem, and the BioSand filter (BSF) was selected as the most sustainable and appropriate technology to develop for river-using households in the Njoro watershed. This brief summarizes results of a three-phase research program to develop and adapt the BioSand filter for local production and use, and test its effectiveness, acceptability, and health impacts with the population segment using river water for domestic and drinking in the Njoro and similar areas. Laboratory experiments showed sand grain size, residence time, and hydraulic loading rate have significant effects on the microbiological removal performance of the BSF. By adapting these design and operating parameters to better match local water source characteristics prior to local commercialization, performance can be significantly improved. In a six-month trial of the adapted local filter design with 30 rural and peri-urban households in the Njoro watershed, average removal performance matched controlled laboratory performance for indicator bacteria and viruses. The filters also demonstrated a very high level of user satisfaction and good evidence of commercial demand.

Background

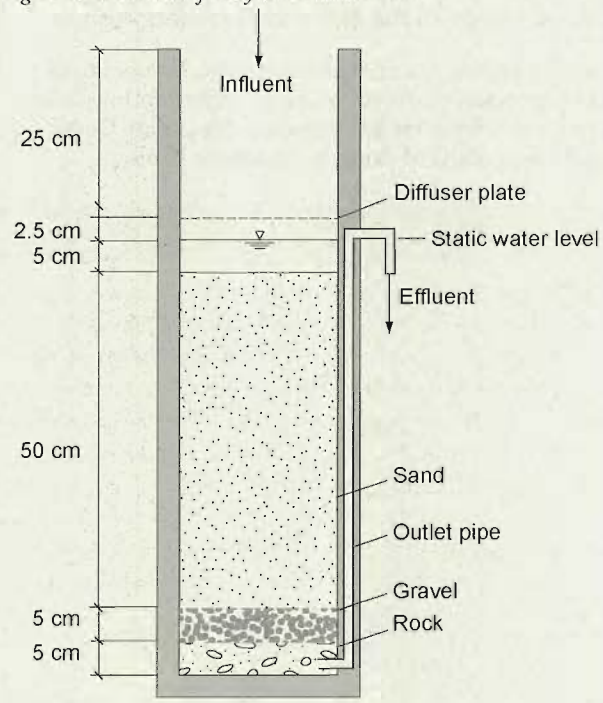
Access to safe, clean, and reliable domestic water supplies is unavailable for many households in the Njoro watershed, and emerged early in the SUMAWA project as a major community priority. The situation is similar across many rural and peri-urban communities in Kenya, where, according to the World Health Organization, less than half of households in 2004 had an improved water supply source within 15 minutes of home. Agricultural households are disproportionately affected, as they are located in dispersed and often remote communities where providing public water service is often prohibitively expensive. Consequently, over half of the households in the Njoro watershed fetch water for drinking and domestic use directly from watering points along the highly polluted River Njoro and Little Shuru Tributary, where domestic livestock are watered and many other domestic and small commercial water needs are met. Early investigations revealed recurrent outbreaks of typhoid and high rates of childhood diarrhea associated with drinking river water in the area.

To address the water-borne disease burden, low cost point-of-use (POU) household water treatment was identified as an intervention to improve domestic water quality for the population segment that depends on open polluted water sources. Review and screening of available technologies identified the BioSand filter (BSF) as best suited to conditions in the Njoro watershed (Tiwari and Jenkins 2008). A program to evaluate, adapt, and field test the BSF for use by high-risk households to treat polluted River water was launched in 2006 with the Nakuru District Ministry of Health's Public Health Division and the Civil and Environmental Engineering Departments of University of California, Davis (UCD) and Egerton University (EU).

The BSF is a slow sand filter modified to operate intermittently at household level, treating one 20-liter batch at a time. It is composed of a container, made of either plastic or concrete, which contains five centimeters (cm) of rock, five cm of gravel and a column of 50-60 cm of sand (Figure 1). Polluted water is poured into the top, flows down through the sand column by gravity and out the exit pipe where the treated water is collected. The BSF was selected for development application in the Njoro watershed on the basis of its robust design, ease of use, no recurring costs, low capital cost, high flow rate, and potential to treat turbid water.

Starting in 2006 under Phase I development, design and operating factors were tested in controlled laboratory experiments at UCD to evaluate and optimize the BSF's ability to remove bacteria, viruses and turbidity. Two different sand sizes, fine (0.17 millimeters-mm) and coarse (0.52 mm), and three maximum head space levels (10, 20 and 30 cm above the sand surface), were tested under both long (mean: 16 hours) and short (mean: five hours) batch residence time operation. Insights from Phase I research on filter design and operation were applied in the next phase of confirmatory testing at Egerton University (EU) labs in Kenya using locally constructed filters operated with River Njoro

Figure 1. Schematic of Kenyan BioSand Filter



water. Filter performance with different local sands and sizes was compared: processed fine (0.15 mm) sand from Kisumu (commercial granitic river sand), processed coarse (0.30 mm) Kisumu sand, and processed coarse (0.30 mm) locally mined porous volcanic pumice sand from the Njoro watershed. Other tests were also conducted to adapt best design and operating guidelines to local conditions.

Results from development testing at EU provided the basis for finalizing standards for commercial design, local construction, and household operation of the BSF for the last phase of field-testing undertaken in 2007. Final validation consisted of a six-month randomized controlled behavioral trial of the filters by households living in the upper and middle Njoro watershed who met a high risk profile for child diarrhea disease from drinking untreated river water established in earlier assessments. Of the 59 qualifying households enrolled in the trail, 30 were randomly assigned to receive and use the BSF. The remainder continued their normal water use practices. Filter performance in BSF households and drinking water quality in all 59 households were monitored monthly and BSF and control households compared. BSF users' perceptions, attitudes, and usage and maintenance practices were collected at three points during the trial. All households were given the opportunity to purchase the filter at a reduced price or have it removed at the end of the trial.

Major Findings

The BSF ability to remove bacteria, virus, and turbidity in water was evaluated in filter influent and effluent samples. Key findings from each research phase (I, II, and III) are presented in the following sections.

Phase I: Experimentation to Optimize Filter Design and Operation. Operating the filter with a pause of 12 to 24 hours (long residence time) between treatment of successive batches of water significantly improved the removal of bacteria, viruses and turbidity, irrespective of sand size or head level compared to no pause between successive batches (short residence time). Fecal coliform bacteria removal was significantly better for fine sand filters (+0.16 to 0.30 $\log_{10}$) and for lower head filters (+0.10 to 0.29 $\log_{10}$), independently of each other, under both long and short residence time operation, with the positive effects produced by fine sand and lower heads enhanced under long compared to short residence time operation. Fine sand and lower head also produced higher virus removals; however, the effects were considerably smaller (+0.05 to 0.10 $\log_{10}$) than those for bacteria and observed only under short residence time operation. Fine sand size resulted in slightly decreased turbidity removal under long residence time operation (-1.7% points) but showed no effect under short operation, while reducing head to 10 cm from 30 cm resulted in improved turbidity removal only under short residence time operation (+4.3% points). Irrespective of the filter's design configuration, Sacramento River water turbidity (spiked with raw sewage and MS2 coliphage - a virus that is parasitic and reproduces itself in bacteria), which ranged from five to 59 NTU (nephelometric turbidity unit to measure turbidity) over Phase I experiments, was always reduced to below three NTU under short residence time operation and to two NTU or below under long residence time operation, translating to average long and short operation turbidity reductions of 91% and 87%, respectively. Mean performance for the best BSF configuration (fine sand, 10 cm head) under long residence time operation and the worst configuration (coarse sand, 30 cm head) under short residence time operation is compared in Table 1.

Phase II: Confirmatory Testing of Local Filter Construction Materials and River Njoro Water. Testing at EU in Njoro, Kenya on the effects of local sand type and size was conducted for long (24-hour) residence time operation with the standard 30 cm head configuration. Results confirmed Phase I findings of significant improvement in bacterial removal by fine over coarse sand (1.30 $\log_{10}$ or 95% vs. 0.91 $\log_{10}$ or 88%), but found no significant difference between coarse Kisumu and coarse porous volcanic Njoro sand (0.91 $\log_{10}$ or 88% vs. 0.97 $\log_{10}$ or 89%). Turbidity and MS2 coliphage removals were not statistically different for the three sand configurations. Viral removal in the fine Kisumu sand filter averaged 0.81 log (84.5%), comparable to Phase I results for the same sand size under long residence time operation. River Njoro water is very turbid; levels averaged 133 NTU during lab

testing. Turbidity removal in the Kenyan BSF filters was much worse than in Phase I at UCD, averaging only 39.3%, and filter effluent was never below 23.3 NTU. Analysis of the chemical composition of River Njoro water revealed its extreme chemical softness compared to surface waters globally; softness can reduce the BSF biofilm's ability to attract and remove suspended particles. When River Njoro water's hardness was artificially raised by calcium carbonate addition and filter performance re-tested, effluent turbidity was reduced to below five NTU, confirming the negative influence of Njoro water's extreme softness on BSF Njoro River turbidity removal. The fine Kisumu sand filters demonstrated comparable fecal coliform removal under eight and 24-hour pause time in further testing. Switching between highly turbid and polluted river water to cleaner and clear borehole groundwater in filter operation resulted in degraded groundwater quality and led to the decision to limit BSF operation to river water for Phase III.

Phase III: In-home BSF Performance and Drinking Water Improvement. Based on Phase I and II findings, fine Kisumu sand and a 30 cm head space container were selected for field validation in river-using households. BSF trial households were advised to only treat river water in the BSF, to allow eight hours of pause between batches for a maximum of 60 liters (three batches) treated per day, and to use water from the overnight batch (morning collection) for drinking. Local volcanic sand was too coarse to produce fine size sand, and the cost and complexity of chemical additives to raise hardness prohibitive for households to sustain. The standard 30 cm head space design, which handles a maximum of 20 liters, was selected because it retains full flexibility to operate the filter with higher or lower head by simply reducing the batch volume. Table 2 compares the performance from each phase of BSF development and testing, for the standardized fine sand 30 cm head filter design configuration. Over the six months of monitoring, fecal coliform and turbidity removal in the 30 household-operated BioSand filters (95% and 43%, respectively) was comparable to results obtained under controlled EU laboratory testing with River Njoro water (Table 2). Across trial homes, the bacterial quality of BSF treated river-sourced drinking water was greatly improved (average 39/100 ml) compared to control homes' untreated river-sourced drinking water (average 504/100 ml) and found to be comparable to that of public borehole groundwater-sourced drinking water (average 29/100 ml) in homes that occassionally used this improved source for drinking.

Table 1. Comparison of average performance of best (fine sand, 10 cm head, long operation) and worst (coarse sand, 30 cm head, short operation) filter design configuration and operation (CI – Confidence Interval).

Performance Outcome	Best	Worst	Difference: Mean (95% CIs)
Fecal Coliform removed (Log_{10})	1.83	1.08	0.75 (0.52, 0.97)
MS2 Coliphage Removed (Log_{10})	0.68	0.25	0.44 (0.20, 0.67)
Turbidity Removed (%)	92.4	86.4	6.0 points (2.5, 9.6)

Although the BSF did a relatively poor job of clarifying river water, BSF users considered the treated water to be better aesthetically than untreated water. Specifically, 97% reported better taste, 83% reported better smell, and 75% reported better appearance. Intervention households were able to easily incorporate BSF water treatment into daily routines, reported more than enough clean water production, and recommended the BSF to friends and neighbors. At the termination of the trial, 69% of control households and 90% of intervention households purchased the BSF at the reduced offer price (US $4.86 vs. US $22.91 commercial price).

Over half the trial households used rainwater and river water interchangeably as water sources in their BSF. This mixing did not degrade the quality of BSF effluent, and collected rainwater quality was improved through BSF treatment. BSF households reported a variety of health and non-health benefits from using the BSF, which motivated high levels of observed user satisfaction and post-trial purchase.

Table 2. Mean and standard deviation of BioSand filter performance under long operation for the fine sand 30 cm hydraulic head design configuration. [1]Operated with moderately turbid and hard Sacramento River water collected at West Sacramento City's Intake and spiked with raw sewage and MS2 virus coliphages.[2]Operated with highly turbid and extremely soft River Njoro water collected at Mary Joy and spiked with MS2 virus coliphages. [3]Operated with highly turbid and extremely soft River Njoro water collected at various water points by households.

Filter Performance		Three Phases of BSF Development and Testing		
Outcome	Indicator Measure	UC Davis Lab Experiment [1] (3 Filters)	Egerton U. Lab Testing [2] (2 Filters)	Household Trial [3] (30 Filters)
Bacteria Removal	Mean Log Fecal Coliforms removed (percent equivalent)	1.51 ± 0.36 (96.1%)	1.30 ± 0.40 (95.0%)	1.30 ± 0.95 (95.0%)
Virus Removal	Mean Log MS2 virus coliphages removed (percent equivalent)	0.81 ± 0.35 (84.5%)	0.81 ± (84.5%)	not tested
Turbidity Removal	Percent of NTU of Turbidity removed	88.5 %	39.3 %	43.2 %

Practical Implications

This research has demonstrated the Kenyan BSF design (Figure 1) significantly improves the microbial quality and safety of contaminated river and collected rainwater for drinking and domestic needs when operated by Kenyan households who depend on polluted surface sources and unsanitary collection and storage of roof-harvested rainwater. The standardized design and simple construction process are suitable for local commercial production by artisan masons in the Njoro and similar communities where access to improved sources is inadequate or lacking. Users found the BSF easy to operate and maintain and experienced a range of health and non-health consumer benefits (including reduced incidence of diarrhea and less time spent treating contaminated water), allowing households to quickly take up and sustain the practice of treating their river water. These findings provide strong justification for development investment to widely promote and market commercial Kenyan BioSand filters to at-risk rural segments in the Njoro and similar watersheds in Kenya.

The research also demonstrates the value of local investigative lab testing and adapting the BSF design and operating guidelines to accommodate differences in the turbidity and chemical composition of local waters, and household water switching behavior. Poorer households lacking improved water supplies often depend on relatively turbid and contaminated surface or shallow well water. The BSF was able to perform well for microbial removal under high turbidity conditions, but was shown to perform poorly in removing turbidity when the source water was chemically soft, without pre-treatment with a coagulant or source of artificial hardness, which make filter operation more costly and complicated for households. While the BSF greatly improved the safety of river and rainwater, by removing 95% of bacteria and 84% of viruses, a post-filtration disinfection step by pasteurization or chlorination (with cheap, widely available products like WaterGuard or AquaGuard, in Kenya) is recommended to guarantee safety.

Further Reading

Sobsey, M.D., C.E. Stauber, L.M. Casanova, J.M. Brown, and M.A. Elliott. 2008. "Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world." *Environmental Science and Technology* 42(12): 4261-4267.

Tiwari, S.K. and M.W. Jenkins. 2008. "Point-of-Use Treatment Options for Improving Household Water Quality Among Rural Populations in the River Njoro Watershed, Kenya." *Research Brief 08-02-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Tiwari, S.K. 2008. *Development and Implementation of Household Level Intermittent Slow Sand Filters for Rural Areas to Mitigate Water-Related Diseases.* PhD diss., Department of Civil and Environmental Engineering, University of California, Davis.

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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 research conducted for this brief is part of the POU WID (Development and Marketing of Point-of-Use Household Filters for Drinking Water Improvement) project, which supplements SUMAWA with scientific investigations on the implementations of BioSand filters for improved drinking water in the River Njoro watershed, Kenya. Dr. Marion Jenkins serves as Principal Investigator for POU WID. Email: mwjenkins@ucdavis.edu.

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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GLOBAL LIVESTOCK CRSP

Hydrologic Modeling of the Downstream Impacts of Land Use Change in the Mau Forest

Scott N. Miller, University of Wyoming
Sustainable Management of Rural Watersheds Project

Research Brief 09-07-SUMAWA April 2009

A significant portion of the forest within the upper Njoro River drainage basin was converted to agriculture between 1995 and 2003. This portion of the watershed lies within the Mau Forest, a significant water tower in Kenya that supplies both surface runoff and groundwater recharge within the Rift Valley. The Njoro River is a key contributor to Lake Nakuru National Park, which provides a host of ecological and economic services to the region. Previous research in the upper portion of the basin has identified deforestation as significantly altering the hydrologic regime of the river, but was limited to a local analysis where relatively rich data were available. In this research project, a hydrologic model was used to identify how the changes in the upper part of the watershed would be manifest in changes to the amount, timing, and apportionment of water both in terms of the riverine discharge and groundwater recharge. Findings show that the overall amount of water delivered to the river terminus (Lake Nakuru) was relatively unchanged, while the ratio of surface flow to groundwater recharge was significantly changed, that the timing of water flow was altered, and that the number of low flow days increased. These findings have implications for both human and ecological stability in the region, and are intended to provide guidance to planners tasked with watershed management and community development.

Background

Prior to a change in policy regarding forest management that took place in the early 2000's, the upper portion of the Njoro River watershed, located in the Rift Valley of Kenya (Figure 1) was dominated by mixed forest with some grassy areas and agriculture in the extreme upper portion of the watershed. Plantation forests dominated the lower reaches of the forested area, while the upper and steeper sections were indigenous forests. Previous research by SUMAWA has quantified the extent of the conversion of these forests to small-scale agriculture (Baldyga et al., 2007); the watershed changed from a dominant forested region (>80% forested) to a mixed-use region with 63% forested. This transition has resulted in changes to the hydrology of the upper watershed, primarily through changes in the timing and amount of surface runoff. Previous efforts at understanding and modeling the hydrological system in the Njoro River focused on the upper watershed because of the relatively rich historical data set that allowed for a better quantification and calibration of the effects. This research extends previous work by simulating runoff and groundwater recharge throughout the entire basin as it extends to Lake Nakuru at its terminus.

Lake Nakuru is an important economic and ecologic site within the Rift Valley. The Lake itself is highly dependent on both surface water discharge from the Njoro and other small rivers and groundwater influx from the regional water table. There is concern that changes in runoff, both in terms of timing and amount, will negatively affect the lake by changing water quality (especially sediment loading) and volume. Furthermore, if the rate of groundwater recharge to the regional aquifer is reduced, there is the increased potential for lake instability. In addition to these ecological effects, changes in hydrology have potential serious consequences for humans reliant on both groundwater and surface water. People within the Njoro watershed rely on both surface and groundwater for domestic and animal use. Groundwater reserves are particularly important for human use because they have higher water quality and reduced pathogen loadings, with the notable trade-off of being higher in fluoride, which increases the risk of fluorosis (a health condition hindering tooth development, generally in young children). However, people rely on surface discharge as well for both household use and for stock watering throughout the year, and if the timing of river discharges is altered or flows are significantly reduced during the dry season, this places additional stress on these families due to lowered access and reduced water quality.

Major Findings

A hydrologic model was built for the entire Njoro watershed that drains the Mau Forest water tower and empties into Lake Nakuru (Figure 1). The Soil and Water Assessment Tool (SWAT) was used to simulate

Table 1. Average annual values for hydrologic characteristics simulated using the SWAT hydrologic model with implications for human consumption.

Category	Water Yield	Surface Runoff	Groundwater Recharge
1995 Vegetation	148	108	127
2003 Vegetation	151	118	118
Change from 1995-2003 (mm)	+3	+10	-9
Change from 1995-2003 (%)	+2	+9	-7
Change from 1995-2203 in water available for domestic water use, assuming 150 liters per day per person	+15,000	+50,000	-44,509

hydrologic processes within the Automated Geospatial Watershed Assessment (AGWA; Miller et al., 2007) model. AGWA has a Geographic Information System (GIS)-driven interface that allows the user to calibrate and optimize the model by changing the ways in which rainfall-runoff ratios are calculated. The model was calibrated using historical data collected at a runoff station located halfway down the watershed and land cover and soils data constructed by SUMAWA researchers. Researchers investigated changes to the hydrology of the River by looking at simulated changes in the amounts and timing of evapotranspiration, surface runoff, groundwater recharge, and total water yield delivered on a daily basis for 12 years. These results were evaluated both at the outlet of the River and spatially within the watershed using GIS.

The net effect of land cover conversion was an overall slight increase in water yield, expressed as the total discharge from the outlet of the river resulting from both surface runoff and river flow supported by water migrating to the river from the soil, which occurs when the soil is relatively well saturated. While the overall effect on water yield was relatively small (an increase from 148 mm/yr to 151 mm/yr), the proportion of water yield resulting from surface runoff increased significantly at the expense of soil water and subsurface flow. Surface runoff increased by 9% while lateral flow was reduced by approximately 2%. The increase in surface water was offset by a commensurate decline in groundwater recharge (Table 1), which declined by 7%. These changes are the result of two factors: 1) declines in evapotranspiration due to the reduction in forest cover, and 2) a higher proportion of rainfall being converted into surface runoff instead of infiltrating into the soil and migrating to the regional aquifer. This effect is well documented throughout the scientific literature, and these results are reasonable given the SUMAWA experience in hydrologic modeling of the upper watershed. The implications, however, are very important.

The spatial distribution of changes in surface runoff and groundwater recharge are nearly mirror images of one another. Inspecting Figure 1 reveals that the upper-middle part of the watershed experienced the highest rate of change in surface runoff due to the conversion of forest to agriculture, while the uppermost and middle reaches of the watershed were relatively stable. The greatest increase (40-50%) occurred where plantation forests had previously been present; as Baldyga et al. (2007) showed; almost the entire plantation forest was harvested, while the indigenous forest remained more or less intact, though subject to small incursions.

Practical Implications

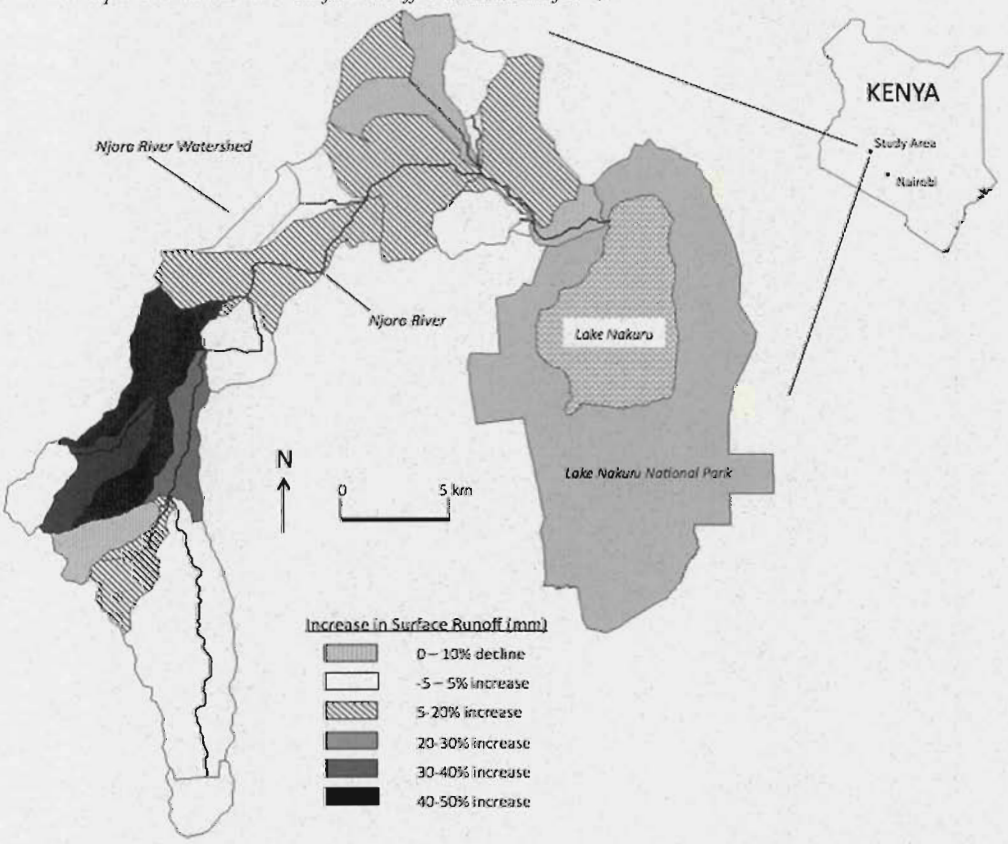
Humans rely on water for a range of household, animal husbandry, and industrial uses. People within the watershed source their water from both surface and groundwater withdrawal points. There is a trade-off involved in the sourcing of water: groundwater costs more but has higher water quality and lower risk of pathogens and water-borne disease. The groundwater within and around the watershed is, however, relatively high in fluoride, which is undesirable due to potential health concerns regarding the human acquisition of fluorosis. Changes in the apportionment of water have direct implications for human water use; there is a shift from rainfall being recharged into the regional aquifer and converted into direct surface runoff. This has the net effect of reducing groundwater reserves and impacting borehole function. In fact, several boreholes within the watershed have gone dry in recent years, to the point where Egerton University (located in the middle portion of the watershed) has commissioned a task force to respond to a water availability crisis on the campus due to declining borehole function.

Table 1 illustrates the shift in allocations of surface and groundwater recharge with an estimated associated impact

on water availability for human use. It is very challenging to identify the minimum human requirements for domestic water consumption. The World Health Organization (WHO) identifies a minimum standard of 15 liters per person per day, but this is strictly for consumption and sanitation. More reasonable estimates for domestic use that include cooking, cleaning, and other household duties range from 100-200 liters per person per day as a minimum. In Table 1, water is converted from units of mm to liters and then divided by 150 liters per person per day to determine the number of people impacted by the change in hydrology. The overall net effect is an increase in water availability due to increases surface runoff and a decline in groundwater availability. However, the amount of water actually available to humans via surface runoff is actually much lower due to the high variability in runoff throughout the year; much of the runoff pulses through the watershed in response to high rainfall events and quickly is lost to the lake. A more stable and reliable source of water throughout the year is groundwater supported by recharge, but the model identifies a net decline of water availability via recharge. Note that these numbers are relatively rough estimates of annual averages and are better used to identify trends and magnitude in change, and do not precisely identify gains or losses.

Ecological effects are primarily negative with this kind of shift in water delivery. While Lake Nakuru relies on river flow to periodically increase its volume, especially in high rainfall years, the shift to surface runoff has several outcomes on the lake that are undesirable from an ecological perspective. First, surface runoff is associated with higher erosion and sediment delivery, and the park has identified siltation and sediment transport as issues of serious concern for lake sustainability. While the researchers did not simulate erosion prediction in this effort, increases in surface runoff are linked to increased surface erosion and loss of topsoil and long-term sustainability. Surface runoff, especially in areas with low vegetation cover, results in concentrated flow and increased sediment transport, resulting in higher sediment delivery rates downstream and reduced water quality. Second, surface runoff is more rapid than flow supported by groundwater and/or soil moisture release, and downstream runoff from these flows tend to be much flashier. A shift to a flashier system impacts the temporal distribution of flow by increasing runoff during the rainy season but reducing it during the dry season, when ecosystems are particularly stressed. Thus, the net effect can be an increase or negligible change in total runoff on an annual basis while the system is put under stress due to a shift in the timing of the delivery of water.

Figure 1. Spatially distributed change in surface runoff in the Njoro River watershed resulting from land cover change (primarily conversion of forest to agriculture) from 1995-2003 simulated with a hydrologic model. (Note that much of the watershed experienced increases in surface runoff in exceedence of 5%).



Further Reading

Baldyga, T. 2008. "Land Cover and Land Use Change in the Njoro Watershed, Kenya: A Threat to Human and Ecosystem Health." *Research Brief 08-04-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Baldyga, T.J., S.N. Miller, K.L. Driese, and C.M. Gichaba. 2007. "Assessing land cover change in Kenya's Mau Forest region using remotely sensed data." *African Journal of Ecology* 46: 46-54.

Gleik, P. 2006. "Basic water requirements for human activities: Meeting basic needs." *International Water* 21(2): 83-92.

Miller, S. 2008. "Investigating the Role of Land Cover Change on the Hydrology of the River Njoro Watershed." *Research Brief 08-06-SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis.

Miller, S.N., D.J. Semmens, D.C. Goodrich, M. Hernandez, R.C. Miller, W.G. Kepner, and D.P. Guertin. 2007. "The Automated Geospatial Assessment Tool." *Environmental Modelling and Software* 22: 365–367.

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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 Principal Investigators for SUMAWA are Dr. Scott Miller (Email: snmiller@uwyo.edu) and Dr. Patterson Semenye (Email: semenye@sumawa.or.ke).

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GLOBAL LIVESTOCK CRSP

The Potential for Culture of Nile Tilapia and African Catfish in the River Njoro Watershed

David Liti, Moi University
Sustainable Management of Rural Watersheds Project

Research Brief 09-08-SUMAWA April 2009

Aquaculture systems have the benefit of being highly intensive with demonstrated economic returns. Aquaculture can be an efficient strategy for economical land use and serve as an alternative means of livelihood for rural communities. Consequently, fish farming can play a major role in environmental conservation and restoration programs by reducing extensive land use. However, regional variability in climate, soils, and water quality are limiting constraints on aquaculture success. This study was conducted to assess the potential for culture of two warm water fish species, Nile tilapia (Oreocromis niloticus, Linnaeus) and African catfish (Clarias gariepinus, Burchell) at the high altitudes of the River Njoro watershed. Growth performance of Nile tilapia and African catfish were evaluated for 180 days in ponds fertilized with organic manure and stocked at a rate of two fish per square meter for tilapia, and 0.5 fish per square meter for catfish. Results from this study demonstrated remarkable growth in Nile tilapia but poor growth and condition in African catfish. After several attempts, African catfish eggs fertilized for the study failed to hatch, most probably due to low temperatures and the poor water quality of the Njoro River. These results demonstrate the feasibility of Nile tilapia culture at high altitudes of the watershed, while African catfish culture was limited by poor growth performance and seed availability. The farming of Nile tilapia is therefore recommended in the Njoro River watershed as a potential alternative livelihood strategy to intensive agriculture.

Background

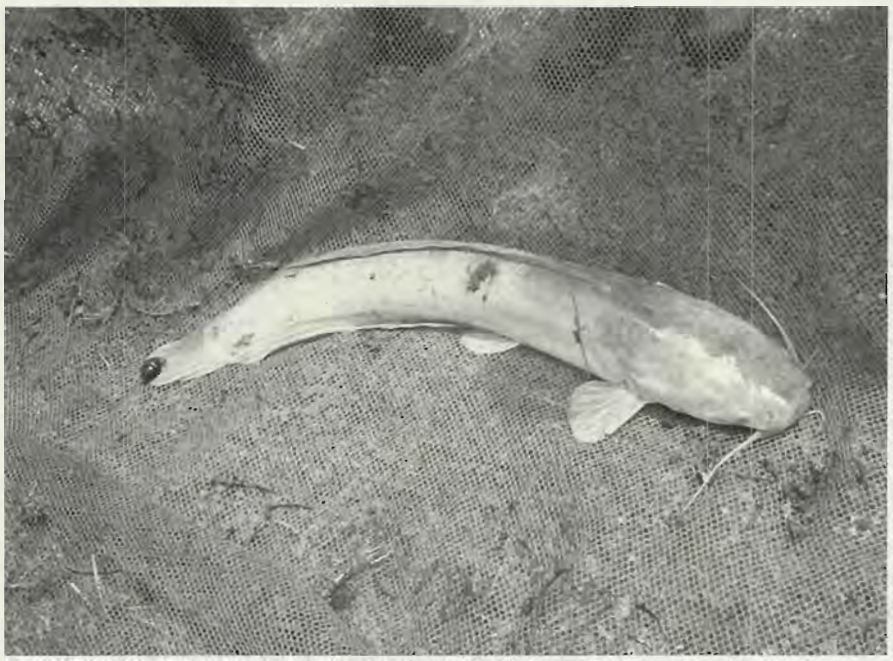
Kenya's economy is heavily reliant on agriculture with a clear need for improved sustainable agricultural development. Aquaculture systems have the benefit of being highly intensive with demonstrated economic returns. Aquaculture can be an efficient strategy for economical land use and serve as an alternative means of livelihood for rural communities. Consequently, fish farming can play a major role in environmental conservation and restoration programs by reducing extensive land use. However, regional variability in climate, soils, and water quality are limiting constraints on aquaculture success. This study explores the feasibility of intensive small-scale pond aquaculture for Nile tilapia *(Oreocromis niloticus, Linnaeus)* and African catfish *(Clarias gariepinus, Burchell)* at the high altitudes of Njoro river watershed where aquaculture has not previously been attempted.

Nile tilapia is one of the most important species among the commercially farmed tilapias in Africa and is widely farmed in Kenya. The species has favorable attributes for aquaculture and is highly attractive to consumers. This species of tilapia breeds readily in captivity, which can lead to overpopulation of fish ponds within a few months after stocking. The African catfish is co-cultured with Nile tilapia to increase fish yields and also to reduce fingerling recruitment from Nile tilapia in fishponds. However, unlike tilapia, the African catfish does not breed in captivity, and therefore seed availability can be a major problem in the culture of the species.

The success and propagation of culture stocks is not only governed by the biological characteristics of the target species but also by the local environmental factors. High altitudes, for example, are characterized by low temperatures, which may in turn adversely affect the rate of natural food production, growth, and the breeding performance of culture species. Therefore, for successful propagation of fish within a fishpond, it is important to understand the characteristics of the fish and the biotic and abiotic parameters of pond system. The present study was initiated by the SUMAWA project to evaluate the potential for culture of the two warm water species at high altitudes of Njoro River watershed.

Preliminary Findings

Four ponds, each measuring 300m^2 were constructed at Egerton University and conditioned for three weeks before stocking. The ponds were fertilized with organic manure and co-stocked with Nile tilapia and African catfish at rates of two and 0.5 fish per square meter, respectively. There was no artificial feed supplementation during the course of the experiment. The trials took six



*African catfish (*C. gariepinus*) pulled from a SUMAWA pond. The water quality parameters in the River Njoro watershed made it difficult to culture the African catfish in ponds at high altitudes. No eggs from this species hatched, indicating that attempts to get the fish to spawn were unsuccessful. Photo by David Liti.*

months during which growth performance and pond water quality changes were monitored. Artificial spawning was conducted with Nile tilapia using mature fish, which were purchased from Sagana Aquaculture Center.

The two culture species are presented in the photos, while fish growth data are presented in Table 1. From the photos, the good condition of Nile tilapia on the one hand (bottom), and the poor condition of African catfish (above) after six months of pond culture are clearly apparent. The range in weight (200-280g) for the males of Nile tilapia presents a reasonably good growth performance given that most of the fish reached 250g, a suitable size for food fish.

A clearly marked sexual growth dimorphism (difference in form within a species) between the female and male Nile tilapia was observed in the study; the growth of males was double that of females. Differential growth in the species has been attributed to the prolific breeding in the female. However, given the low prevailing temperatures in SUMAWA ponds, the breeding activity in the current study would be much reduced. Thus, the sexual growth differences between the male and female Nile tilapia may have a genetic basis. Several attempts to induce spawning in African catfish were not successful, as the eggs failed to hatch. This was attributed to low temperatures and unfavorable water quality from the Njoro River.

*Nile tilapia (*O. niloticus*) taken from a SUMAWA pond. Efforts to raise Nile tilapia were more successful owing to the lower impact of cool temperatures on fish development in this species. The range in weight between 200 and 280g for the males presents a reasonably good growth performance (250g is considered a suitable size for food fish). Photo by David Liti.*

Table 1. Fish growth and water quality data from SUMAWA ponds.

Nile tilapia *(Oreochromis niloticus L.)*				
	Males	**Females**	**Size Range**	
Stocking weight (g)	20	20	**Males**	**Females**
Mean Harvest weight (g)	240.2±31.6	105.1±15.1	200-240g	80-120g
Growth rate	1.2±0.08	0.5±0.07		
Growth ratio	2.1	1.0		
African catfish *(Clarias gariepinus B.)*				
	Males	**Females**	**Size Range**	
Stocking weight (g)	15	15	50-80g	
Harvest weight (g)	77.7±6	76.8±8		
Growth rate	0.34±0.03	0.34±0.02		
Growth ratio	1.1	1.0		
Water Quality Parameters				
	Mean	**Range**	**Recommended**	
Temperature	19.4± 2.3	16-24	25-30	
Dissolved oxygen (mgl-1)	0.43± 0.25	0.09-0.96	>3	
pH	7.3± 0.34	6.7-7.3	6.5-9.0	
Alkalinity(mg CaCO3 l-1)	75 5	70-85	100-150	
Ammonia (mgl-1)	0.01	0-0.01	<1.0	
Nitrite (mgl-1)	0.01	0.01-0.02	-	

For pond water quality, temperature and dissolved oxygen (DO) are the two most important parameters that control fish growth (Table 1). In the Njoro ponds, temperature was sub-optimal (mean 19.4, and range16-24°C) for Nile tilapia, who's growth is optimized at (25-30°C). During periods of pond heating on sunny days, most of the heat was confined to the topmost water strata and insulated from penetrating the whole water column by a brief thermal structure that was established daily between 10.00 and 16.00 hours. The net effect was maintenance of water temperature below the optimum range for both species. Except during the periods of mixing, DO occurred at levels which would not adversely affect fish growth. It was concluded that temperature was solely responsible for the poor performance of African catfish, and that this species was more prone to adverse affects of low temperature when compared to Nile tilapia.

Practical Implications

Interactions with stakeholders in the River Njoro watershed have shown support for the development of aquaculture as an alternative livelihood strategy to agriculture in the region. SUMAWA scientists and collaborators from the Kenya Fisheries Department have used research fishponds as training and outreach facilities for local stakeholders, and have generated considerable interest in aquaculture among watershed communities. Furthermore, there is an apparent local market for fish, though further assessments on the economics of fish marketing and profitability of small-scale aquaculture in the region are recommended. The future success of pond aquaculture in the watershed, however, is hindered by the relatively cool temperatures of the region. While initial concerns regarding water quality, specifically dissolved oxygen levels, were allayed by this research, study attempts to raise African catfish *(C. gariepinus)* to market size were unsuccessful. Efforts to raise Nile tilapia *(O. niloticus)* males, on the other hand, were more successful owing to the lower impact of cool temperatures on fish development in this species, while females were markedly smaller. In conclusion, this study has succeeded in identifying the preliminary barriers and opportunities to fish farming in the River Njoro watershed, and has provided a baseline for further inquiry into the mechanisms for generating a sustainable aquaculture program with the potential to enhance rural livelihoods within the River Njoro watershed.

Further Reading

Boyd, C.E. 1991. *Water Quality in Ponds for Aquaculture.* Alabama Agricultural Experiment Station, Auburn, Alabama, pp. 482.

Lin, C. K. and J. S. Diana. 1995. "Co- culture of catfish (Clarias macrocephalus x C. gariepinus) and tilapia (Oreochromis niloticus) in ponds." *Aquatic Living Resources* 8(4): 449-454.

Msiska, O.V. 1988. "Preliminary studies on the performance of *Oreochromis shiranus* Chilwae in ponds with reference to water quality and temperature." In: *The second ISTA. International Centre of the Living Aquatic Resources Management (ICLARM) Conference Proceedings 15.* (Eds.) R.S.V. Pullin, T. Bhukaswan, K. Tonguthai and J.L. Maclean, Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Philippines.

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GLOBAL LIVESTOCK CRSP

Livestock Production Systems and Environmental Interactions: Producer Response to Climate and Market Changes in the River Njoro Watershed, Kenya

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Sustainable Management of Rural Watersheds Project

Research Brief 09-09-SUMAWA April 2009

In developing countries, the past two decades have witnessed changes in market structure, climate and demographic characteristics resulting in fast growth in the demand for livestock products and increasing dependence on livestock for sustainable livelihood systems. In response, there have been rapid land use and land cover changes, characterized by expansion of agricultural systems and a decline in farm sizes. As markets change, producers respond through different adaptive capacities. Producers endowed with more livelihood assets: financial, natural, social and physical, are more capable of responding to and benefiting from these changes. This study consisted of two components: characterizing livestock producers in the River Njoro watershed in order to determine the factors that influence the selection of livestock production systems; and assessing the socioeconomic status of producers in the study area, with the objective of monitoring adaptation based on the following key attributes: livestock stocking rates, feeding systems, herd structure and farm size. Study results identified three primary production systems: Intensive highly diversified and commercial systems; Semi-intensive subsistence systems; and Extensive semi-commercial systems, with an overall trend towards more intensive systems. From the socio-economic surveys it was found that 30% of producers adapted production systems to increase productivity due to a shortage of pasture, and 15% due to increasing demand for livestock products, while 22% cited changes in land tenure as the critical factor to production system change, drawing attention to land tenure issues in the watershed. When producers gain greater property rights through allocation of title deeds, they are more inclined to invest in long-term livestock structures and engage in more intensive systems, a potentially positive feedback loop for improving livelihoods in the region, given proper management and governance and/or community oversight of production systems.

Background

The River Njoro watershed is about 300 square kilometers, located within Nakuru District, Kenya. Livestock production is an important economic activity to approximately 80% of the watershed population through its contribution to livelihoods, agricultural production and ecological services. Many farmers in the watershed integrate crop and livestock production on farms averaging 7.8 hectares in size. There are, however, many landless livestock producers within the Njoro region, and most of the livestock production in the watershed depends on communal resources such as water and grazing land.

Despite their contributions to food production, livestock are (directly and indirectly) responsible for causing negative ecological impacts, such as water pollution and soil erosion. The River Njoro watershed has experienced rapid land use and land cover changes in the past two decades (Baldyga, 2007). These changes correspond with rapid changes in consumption patterns and rates of urbanization, leading to increased demand for livestock products. In response to these changes, which include a decline in farm sizes caused by population pressure, producers have adjusted their agricultural systems over time. These systems determine the influence of livestock on watershed resources. Overall degradation of communal land resources is a matter of serious concern in the River Njoro watershed. In the study area, farm animals graze openly along the road reserves, the riparian zones, and other public fields without any controls on resource use or consideration of permissible stocking rates. This phenomenon has led to increased land degradation and pressure on natural resources. Livestock grazing along riparian zones leads to soil compaction, which in turn results in reduced infiltration, increased runoff and erosion, and increased deposition of sediments and nutrients to water bodies.

The lack of oversight on livestock grazing in rural areas like the River Njoro watershed threatens to undermine communal ecological resources and requires intervention, whether public or communal, to enforce more sustainable livestock management practices. This brief presents the results of a study designed to identify the major livestock production systems and changes taking place in these systems in the River Njoro watershed, in order to better understand the constraints and opportunities of each system, and to identify interventions targeting production and management improvements along with ecological safeguards.

Preliminary Findings

A baseline survey conducted by the Sustainable Management of Rural Watersheds (SUMAWA) project in 2004 was repeated in 2007 to identify different production systems and to assess the socioeconomic status of producers and farming practices within the study area, with the objective of monitoring changes in households based on the following key attributes: livestock stocking rates, feeding systems, herd structure and farm sizes. The study identified three major livestock production systems: 1) Intensive highly diversified commercial systems; 2) Intensive subsistence systems; and 3) Extensive semi-commercial systems.

Production System Characterization. Intensive-highly diversified commercial systems constituted 34.7% of the sample. Producers in this cluster were spread over three zones in the watershed with Njoro, Nessuit and Ngata having 50.0%, 21.4% and 28.6% of the households respectively. Producers in this system are generally older and displayed the highest level of risk management through involvement in several enterprises (diversification), self-production of farm fodder, and use of purchased concentrates. The zero grazing and semi-zero grazing units in this system are considered more efficient as these farms had the highest milk output per head. In addition, these producers had a higher commercialization index (measured by proxy: the proportion of marketed milk output). On average, they have a higher level of education and greater access to credit. Due to the higher degree of commercialization, these producers had the highest household incomes. On average, they are located closer to markets, good roads and water sources.

The second cluster is comprised of semi-intensive subsistence systems. Producers in this cluster are found mainly in the lower watershed (Ngata and part of Njoro) and constitute the lowest number of households, 19.0%. It is characterized by younger farmers with a higher level of education that enables them to be more involved in off-farm activities (e.g. salaried employment). Producers in this category have greater access to credit and extension services, mainly due to greater social status and influence. However, producers within this system have the lowest number of livestock holdings on semi-zero grazing units, and have little experience in livestock keeping. Their commercialization index is low, indicating that most of their production is for home consumption. Their degree of diversification is also very low and they do not produce fodder on their farms. They therefore depend on grazing their own pastures, and cut and curry fodder from communal areas such as riparian zones and roadsides.

The final cluster, extensive semi-commercial systems, contains the highest number of households (46.3%) spread evenly over the entire watershed. The majority of producers in this category are found in Ngata (41.1%) while the rest are distributed between Njoro (39.3%) and Nessuit (19.6 %). In general, these producers have a relatively higher number of livestock holdings, but a moderate level of market orientation. They keep a mixture of cross breeds and local cattle breeds. Only a few produce fodder, and they have several production constraints, including access to credit and extension services. These producers have been keeping livestock for the longest period of time, and are ranked lowest in the utilization of concentrates.

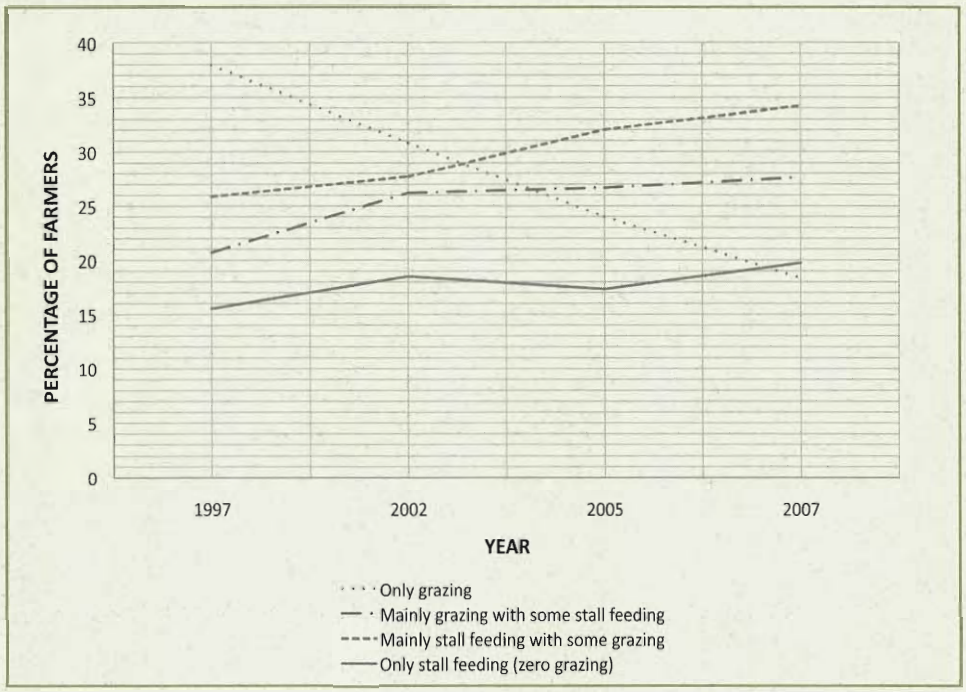
Changing Systems. A comparison of livestock production systems in 1997 and 2007 indicates that producers have been changing systems for a number of reasons. Faced with a shortage of pasture (30%) and increasing demand for livestock products, 15% of farmers reported changing management to increase productivity/output. Of the surveyed farmers, 22% cited changes in land tenure as critical factors in shifting production systems. Institutions that govern property rights play key roles in shaping agricultural producers' choice of production practices, outputs and, hence food security and poverty alleviation. Producers with high tenure insecurity tend to look for practices that give returns in the short run instead of engaging in more long-term investments. When producers gain more property rights through allocation of title deeds, they are more inclined to invest in long-term livestock structures and engage in more intensive production systems.

A previous SUMAWA study (Baldyga, 2005), revealed substantial changes in land cover between 1986 and 2003. Furthermore, as in many other areas of East Africa, the greater Nakuru district has been facing variability in rainfall, both in terms of quantity, predictability and distribution (Baldyga et al. 2007), with increasing runoff corresponding to changes in land cover. These changes have had drastic implications on farming systems as well, with more intensive systems emerging over time (Figure 1).

As previously noted there has been a shift from extensive methods of livestock feeding to more intensive methods. The percentage of farmers using pure *zero grazing* and *stall-feeding with some grazing* has been increasing rapidly since 1997. On the other hand, those utilizing systems based on *pure grazing* have declined within the same 10-year period from 37.9% to 19.7%. The semi-intensive methods of livestock feeding: mainly *grazing with some stall-feeding* and *stall-feeding with some grazing* has also been increasing at a steady rate. These changes have positive implications for the resource base supporting production (see Steinfeld et al. 2006). Due to the increase in the number of farmers using only stall-feeding, there is a tendency to have more

on-farm production of fodder and increased use of concentrates. Semi-intensive producers also tend to favor crop and livestock integration, and are better able to manage soil fertility through manure applications and planting of nitrogen-fixing fodder. In addition, these producers have the opportunity to benefit from the marketing and use of on-farm products such as for biogas production from manure, an alternative fuel source to strained firewood and charcoal supplies. The level of efficiency among these producers is generally high, due to the necessary utilization of varied resources within a smaller-scale intensified system.

Figure 1. Changes in livestock feeding systems, 1997 - 2007.



The size of the farm also plays an important role on the type of system adopted by producers. In the watershed, there has been a decline in the size of household farms over time. Findings indicate that the average land holding declined by 6.4% between 2004 and 2007, from 8.33 hectares to 7.8 hectares. This may be attributed to increased population growth and changing land ownership, though further investigation to fully understand the factors influencing dwindling farm size is required.

In addition to intensification, producers in the River Njoro watershed have adapted by developing various production strategies. These include selling livestock at the onset of the dry season to minimize herd loss to drought and take advantage of weight gain due to quality forage, renting of grazing land to ensure adequate livestock nutrition, and purchasing fodder to further enhance livestock diet.

Support services: extension, credit, and veterinary. Livestock support services play an important role in determining the quality of animals. Surveys indicate that there has been a slight increase in producers who access extension and credit facilities. Most of the farmers accessing credit use it for household development and business purposes other than direct investment in agriculture. The authors assume that due to the mutually interchangeable nature of credit within the household, there are some indirect benefits to agriculture from enhanced credit access, as agriculture is the primary livelihood activity in the area.

Practical Implications

Characterizing livestock producers in the watershed is critical to understand the constraints and opportunities that exist within each livestock production system, thereby allowing for appropriate development of policy recommendations specific to each system. Understanding these production systems is also synonymous to understanding the possible environmental impact of livestock, as the systems define how livestock interact with the environment.

The majority of producers analyzed by this study fall into the *extensive semi-commercial* category. For these farmers, policies should target improving access to credit and extension services by encouraging farmers to form Common Interest Groups (CIGs), which would enable them to better access to services. The government of Kenya through the National Agricultural and Livestock Extension Programme (NALEP) is currently channeling extension services to farmers through such groups. Banking and non-banking financial institutions are also using the group lending approach (GLA) to reach out the rural producers. Producers in extensive systems should also be encouraged to participate in communal participatory resource management programs, such as the Water Resource Users Association (WRUA) developed by SUMAWA, as their stocking rates are high, and can have potentially harmful effects on the natural resource base. Because of the strong link between security of land tenure and greater investment in long-term activities that benefit natural resources, government and associations within the watershed should make land tenure security a major focus of future programs and policy. Farmers involved in intensive production

systems, on the other hand, are more market oriented, and require policies improving physical and financial infrastructure that enable increased market access and participation on a larger scale. Another major challenge for livestock producers is responding to natural variability through adjustments in production decisions. These decisions are influenced by a number of factors, some of which households have little or no control over. By better understanding the circumstances of producers and the reasoning influencing their decision-making, government and development agencies are better able to create an enabling policy environment that allows flexibility for producer response with minimal environment impact.

Producers are responding to climate variability and market changes by adjusting production systems through a reduction in herd sizes and expansion in production of monogastric livestock, especially broilers. As these systems employ a larger percentage of concentrates and off-farm inputs, demand for raw materials for the production of livestock feeds, such as maize is also increasing. The recent dramatic global fluctuation in prices for concentrates and the local shift in demand will make local market prices difficult to predict and monogastric production quite challenging, reinforcing the need to strengthen production systems and provide support networks or producers like the SUMAWA Watershed Resource User Associations.

Further Reading

Baldyga, T. J. 2005. "Assessing Land Cover Impacts in Kenya's Njoro River Watershed using Remote Sensing and Hydrological Modeling." Unpublished Msc. Thesis, Department of Renewable Resources, University of Wyoming.

Baldyga T.J., S.N. Miller, C.M. Gichaba, and W. Shivoga. 2007. "Suitability of the Automated Geospatial Watershed Assessment (AGWA) Tool in Assessing Hydrologic Response and Land Cover Change in River Watershed, Kenya." *Egerton Journal of Science and Technology* VII(1).

Galvin, K.A., R.B. Boone, N.M. Smith and S.J. Lynn. 2001. Impacts of climate variability on east African pastoralists: Linking social science and remote sensing. *Climate Research* 19:161-172.

Mburu, L. M., J.W. Wakhungu, and W.G. Kang'ethe. 2007. "Characterization of Smallholder Dairy Production Systems for Livestock Improvement in Kenya highlands." *Livestock Research for Rural Development* 19(8).

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. deHaan. 2006. *Livestock's Long Shadow: Environmental Issues and Options.* Rome: Food and Agriculture Organization of the United Nations (FAO).

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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, livestock and human-related factors. The Project Principal Investigators are Dr. Scott Miller (snmiller@uwyo.edu) and Professor William Shivoga (shivoga@sumawa.or.ke). Ms. Njeri Muhia (njeriwamuhia@yahoo.com) serves as the CO-PI for Socio-Economics Component.

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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Edited by David Wolking & Susan L. Johnson

GLOBAL LIVESTOCK CRSP

Community Environmental Interventions in the River Njoro Watershed, Kenya

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Sustainable Management of Rural Watersheds Project

Research Brief 10-01-SUMAWA January 2010

The continued expansion of the human population has resulted in changes in land use and ever increasing demand for resources, which has further degraded land and water resources in the River Njoro watershed, Kenya. Because public funding and technical inputs are limited, widespread efforts to better manage rural watersheds in developing countries will depend on the integration of the ecological and social sciences to develop adaptive capabilities, enthusiasm, and ecological knowledge of the local stakeholders to set goals, identify problems, and organise sustainable solutions for their own projects. In the River Njoro watershed, human settlement, deforestation, and unregulated agriculture have been a threat to livelihoods of the people, institutions, livestock, and wildlife. At the backdrop of these negative impacts, the SUMAWA project initiated community interventions implemented through the Njoro Water Resource Users Association (NJOWRUA), a community environmental "vigilance" and sensitization group, to aid in better management of the environment, and deal with the degradation issues. SUMAWA interventions included: a water trough system providing clean water for 3,775 head of cattle, 1,508 calves, and 841 shoats on a daily basis to reduce direct pollution of the river by livestock; a village tree nursery and school-greening program providing 70,000 tree seedlings ranging from exotic to indigenous species at eight tree nurseries owned and operated by NJOWRUA and local schools; and a pilot mushroom cultivation project offering households an alternative source of income through 40 gardens. Evaluation results on the interventions indicate that the SUMAWA water troughs have had a positive impact on overall watershed health, household labour allocation, and sustainability, while there is a strong community sense of ownership over the tree nurseries and school-greening programs, and considerable community support for the mushroom cultivation enterprise. In conclusion, SUMAWA interventions have been successfully integrated into and adopted throughout the watershed, largely due to SUMAWA's early investments in capacity strengthening and development of NJOWRUA.

Background

The River Njoro watershed, within Kenya's Rift Valley Province supports the livelihoods of over 300,000 people primarily through crop and livestock production for resident mixed farmers, and migrations of pastoralists and their livestock into the watershed during the dry season. The watershed also provides important environmental services through the River Njoro, which flows into Lake Nakuru, a Ramsar site and bird sanctuary hosting up to a million flamingos depending on the season. However, the ability of this watershed to continue providing these important services has been threatened by several factors.

Through multidisciplinary research undertaken by the Sustainable Management of Rural Watersheds (SUMAWA) project team, deforestation, changes in land use, and gross pollution from livestock and human activities were identified as some of the causes of environmental degradation in the watershed. The forest cover (dense vegetation and plantation forests) for example, was found to have declined from 38.7% to 29.7 % between 1986 and 2003 (Baker, 2008). The decline in forest cover was accompanied by an increase in mixed small-scale agriculture from 32.1% to 51.2% over the same period (Baker, 2008). Gross pollution linked to human and livestock activity was also identified at several points along the River Njoro. Jenkins reported in 2008 that the levels of coliform bacteria exceeded 100,000 cfu/100mls at hot spots of livestock watering.

These SUMAWA findings, among others, elevated the importance of introducing interventions designed to mitigate the negative impacts of human and livestock activity on the watershed environment. In response, SUMAWA initiated a participatory approach involving the watershed community. Interventions supported by SUMAWA included a community environmental greening program, water troughs for livestock and domestic water outlets, and a mushroom production pilot enterprise. All SUMAWA project interventions were implemented through the SUMAWA facilitated and supported Njoro Water Resource Users Association (NJOWRUA), a community environmental "vigilance" and sensitization group. This research brief provides an overview of the SUMAWA/NJOWRUA interventions, along with an evaluation of their success, and lessons learned.

Findings

Evaluations of the interventions were conducted in March of 2009. Criteria used to conduct the evaluations were based on original project objectives, and the sustainability of each intervention. Additional details on the criteria and evaluation methodology may be obtained from the authors.

Evaluation of the water trough intervention. Based on SUMAWA project research linking water pollution with the presence of livestock and human activities on the river, this intervention aimed at drawing these activities away from the river and riverbanks. Two water troughs were constructed in the upper watershed (Nessuit), an area associated with greater livestock activity. The objective was to reduce direct pollution of the river by livestock through deposition of faecal matter and trampling on the riverbanks (Figure 1). From the evaluation it emerged that this intervention has had a positive impact on watershed health, household labour allocation, and overall sustainability. Prior to the intervention, the streams were used for in-stream livestock watering and domestic water drawing, causing gross pollution (Jenkins, 2008). Because Nessuit is located upstream, this pollution affected not only people living in the upper watershed, but also downstream water resource users. The construction of water troughs minimized faecal deposition into the River from Nessuit water users, while also availing less polluted water to people and livestock (Figure 2). Results indicate that approximately 3,775 head of cattle, 1,508 calves and 841 shoats were brought to the water troughs daily during the time of monitoring, which coincided with the peak dry season. Water use at the troughs was estimated at 70,000 liters of water per day for livestock (Holter and Urban, 1992), and 35,000 liters of water per day for human use.

There are some outstanding issues regarding the use of the troughs, however. Resident livestock producers in Nessuit reported disallowing use of the troughs by the migratory Maasai pastoralists and their livestock, indicating that their animals could contract diseases from Maasai animals. As the Maasai constitute a significant water resource user group, especially during the dry season, it is expected that their inability to access the troughs will result in continued in-stream watering, which the troughs were intended to prevent. Greater attention to resolving this conflict is required to encourage sustainable upper watershed water use among these groups.

Evaluation of the environmental greening program. Based on SUMAWA research demonstrating the impact of land use change and deforestation on the watershed, an environmental greening program was implemented to boost reforestation efforts. The environmental greening program involved distribution of seedlings among seven primary schools and one secondary school within the watershed. The schools were also facilitated with fencing material to enhance protection of the young tree seedlings. In total, 7,885 and 2,000 seedlings were distributed and planted in 2007 and 2008, respectively. Evaluation results reveal that there has been an increase in tree cover in the schools involved in the program ranging from 10% to 60%. There was also a reported sense of belonging and ownership, as all the school children involved in the program planted trees they called their own. In addition, involving the school children was associated with a multiplier effect throughout the watershed, as children spread the message of reforestation beyond the confines of the school compounds. The greening program was a reportedly popular intervention due to the introduction of incentives: the top two schools encouraging greening were awarded desktop computers in recognition of their efforts.

Because gross deforestation also diminished the natural biodiversity of the watershed, the greening program was designed to encourage planting several varieties of trees,

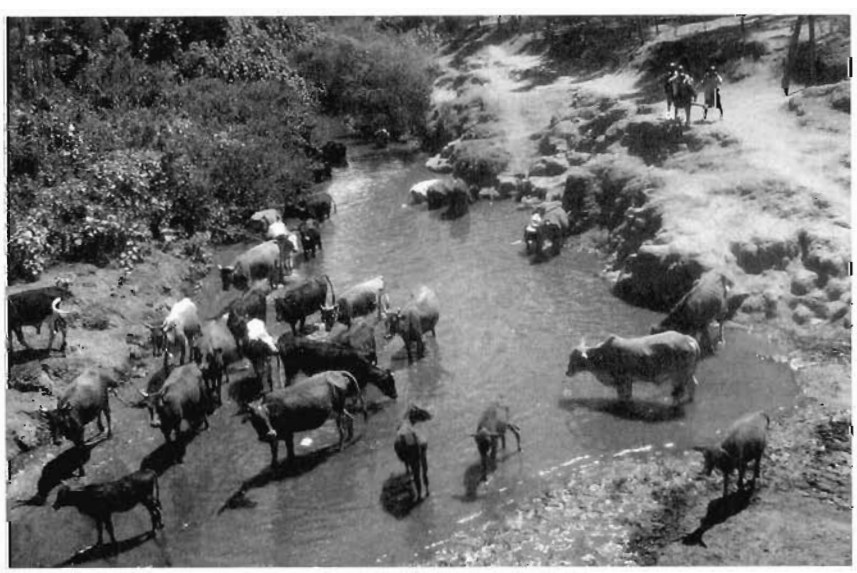

Figure 1. A depiction of the River Njoro mixed livestock and human use situation in the upper watershed before the SUMAWA water trough intervention (Figure 2). Fecal deposition into the River Njoro by in-stream livestock watering has contributed to water quality deterioration for both upstream and downstream water users. Photo by Daniel Kyalo.

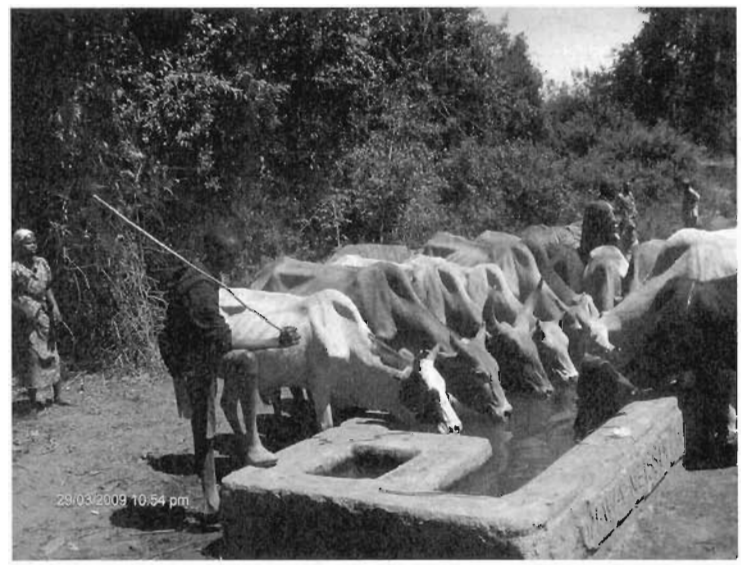

Figure 2. Livestock are brought to water at one of the two SUMAWA water troughs constructed in the upper River Njoro watershed. The SUMAWA water troughs help prevent water contamination and riverbank erosion, both major contributors to water quality degradation in the River Njoro. Interventions like these are helping local water resource users to take ownership of watershed rehabilitation through capacity building and an improved understanding of watershed management. Photo by Daniel Kyalo.

including indigenous species Red stinkwood *(Prunus africana)*, Brown olive *(Olea africana)* and Dombeya *(Dombeya torrida)*. Planting of commercial trees like Rose gum *(Eucalyptus grandis)*, Cypress *(Cupressus lusitanica)*, Whistling pine *(Casuarina equisetifolia)* and Pine *(Pinus patula)* has also been encouraged based on these species' commercial potential as timber species; it is expected that increasing commercial timber species will reduce the harvesting of indigenous stands for use in construction and fuelwood.

Evaluation of community tree nurseries. Further addressing watershed deforestation, SUMAWA initiated efforts encouraging sustainable farm forestry as a prerequisite for ecological restoration. To achieve this, SUMAWA focused on the strengthening of local institutions and capacity building for rural communities through tree planting, and the operation of village tree nurseries on a permanent basis. Eight tree nurseries were established within the watershed, owned and operated by the NJOWRUA community groups. Technical support and equipment was provided by SUMAWA, while the group members participated through provision of land and labour. As of April 2009, over 70,000 tree seedlings were ready for transplant during the long rains, with a variety of trees ranging from indigenous to commercial species.

Evaluation of the mushroom production program. Mushroom production is a non-land based production system that can offer households an alternative source of income, without necessarily putting pressure on natural resources. A pilot project was developed by SUMAWA in Njoro town, as a capacity building initiative of the NJOWRUA Njoro Chapter. Evaluation results indicate that during the first production cycle, approximately 12 kilograms of mushrooms were produced, about 40% of the potential production from the 40 pilot gardens. No mushrooms were allocated for marketing, as growers opted to consume the harvest. In the second growth phase, no mushrooms were produced due to poor germination caused by a water shortage. Despite this setback however, members remain supportive of the project, treating the setbacks as learning costs. Evaluation results suggest that considerable income generating potential remains for this intervention, if growers are able to surmount production obstacles and market the mushrooms.

Practical Implications

Several important lessons were drawn from the SUMAWA project interventions, which can be used to improve similar interventions replicated within the watershed or in other areas experiencing similar conditions. Due to the participatory nature of the SUMAWA approach, watershed users reported a strong sense of ownership and commitment regarding the interventions.

Community members at Nessuit where the water troughs were constructed, for example, have taken ownership of the troughs, protecting them from intrusion and maintaining their efficient operation. The use of an appropriate and inexpensive technology was also considered very important for the continuity and sustainability of the troughs, especially at the community level. Both of the SUMAWA water troughs use gravity flow systems, which are simple and inexpensive to maintain requiring no external assistance, as they do not rely on external power sources for water movement.

With the school greening programs, it was encouraging to observe the enthusiasm and accountability demonstrated by program participants. This attachment is expected to enhance protection of trees culminating in higher survival rates. In some schools, seedlings and transplants were protected from suffocation by weeds, and from livestock browsing through the incorporation of feed crops. These

developments indicate that the program enjoys considerable support from stakeholders, a testament to the successful educational and outreach component of SUMAWA. Expansion of this program is expected to encourage an increase in tree cover, an important step towards restoring the degraded environment.

At the community level, the SUMAWA greening program experience suggests that the performance of the tree nurseries is better when groups are smaller, due to strong group organization, peer-to-peer encouragement, and commitment. In larger groups on the other hand, there are often no clear rules to coordinate the groups, and members were reportedly less committed, especially when the benefits are group/community based, and do not accrue directly to individual members.

The success of the SUMAWA interventions is largely attributed to the participation and support of the local watershed resource user association NJOWRUA. The strong relationship between SUMAWA and NJOWRUA, encouraged since the inception of the project, enabled SUMAWA to understand stakeholder needs and develop interventions with their participation and input. Together with considerable attention to capacity building at the local and community levels, SUMAWA has enabled NJOWRUA to continue the successful management of these interventions, along with the development of additional interventions independent of SUMAWA, if provided the necessary resources. In conclusion, SUMAWA's support of capacity building in the area has encouraged the sustainability of its project interventions and improved the management of the watershed.

Further Reading

Baker (Baldyga), T.J. 2008. "Land Cover and Land Use Change in the Njoro Watershed, Kenya: A Threat to Human and Ecosystem Health." *Research Brief 08-04-SUMAWA.* Global Livestock Collaborative Research Support Program, University of California—Davis, Davis, CA.

Holter, J.B., and W.E. Urban Jr. 1992. "Water partitioning and intake prediction in dry and lactating Holstein cows." *Journal of Dairy Sciences* 75(6): 1472-1479.

Jenkins M.W. 2008. "Gross Fecal Pollution of a Rural Watershed in Kenya: Research Identifying Cattle as a Major Source in the River Njoro Watershed." *Research Brief 08-01-SUMAWA.* Global Livestock Collaborative Research Support Program, University of California—Davis, Davis, 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 Principal Investigator for SUMAWA is Dr. Patterson Semenye. Email: semenye@semco.co.ke.

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GLOBAL LIVESTOCK CRSP

Health and Non-Health Impacts of the BioSand Filter for Rural Kenya

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Sustainable Management of Rural Watersheds Project

Research Brief 10-02-SUMAWA January 2010

In the final phase of development of the BioSand Filter (BSF) in the River Njoro watershed under the GL-CRSP funded Sustainable Management of Rural Watersheds (SUMAWA) and Point-of-Use Women in Development (POU WID) projects, a randomized controlled household trial of the filter's impact on child diarrhea diseases was undertaken with 59 households meeting a high risk profile for child diarrhea from drinking river water. The BioSand filter (BSF) is a low cost locally produced household water treatment technology appropriate for permanent populations who use polluted surface water, rain, or shallow wells for their water supplies. Practices, perceptions, and attitudes of trial users regarding the filter were also evaluated during and at the end of the trial. Key health and behavioral findings on the filter's impacts and acceptability include a 54% reduction in child diarrhea disease, meaningful improvements in the aesthetic qualities of drinking and domestic water important to users, and identification of a range of positive features and consumer benefits of the BSF for treating household water in the watershed. These findings provide the basis for moving forward with a commercial approach to the local production, marketing, and sales of the BioSand filter to target rural populations in Kenya using unimproved water sources.

Background

The BioSand filter (BSF) is a household-scale slow sand filter that has been modified for intermittent operation to treat drinking and domestic water in developing countries in households lacking access to improved safe water supplies. The third and final phase of research and development for application of the BSF in the Njoro River watershed, Kenya under the GL-CRSP funded Sustainable Management of Rural Watersheds (SUMAWA) and Point-of-Use Women in Development (POU WID) projects involved a household trial to evaluate in-home filter performance, water quality improvements, health impacts on diarrhea disease, and filter usage, maintenance, perceptions, and acceptability by the target population. This brief presents the health impact and behavioral and perception findings from the household trial undertaken in 2007. Previous briefs (Tiwari and Jenkins, 2008; Jenkins et al., 2009) provide justification and background on household water treatment and technology selection in the Njoro River watershed, and report filter microbial and turbidity removal performance from design enhancement testing undertaken during the initial laboratory, field-based, and in-home trial phases.

Households meeting a high-risk profile for water-borne child diarrhea disease from drinking untreated river water and having stable residence for the next 12 months (once installed, moving the BSF is very difficult) were recruited from 11 high diarrhea endemic communities in the middle and upper Njoro River watershed. High risk characteristics, identified from earlier diarrhea disease prevalence studies, include using river water as a primary or secondary drinking water source, having a monthly income below Ksh 4,000 (USD 65, 2006) for the upper and Ksh 6,000 (USD 97, 2006) for middle watershed areas; living in thatched roof homes with mud floors; living near the river; mother having less than an eighth grade education, and children under five years of age in the household.

Sixty eligible households were enrolled in the trial, stratified by river watering point, and randomly assigned to either intervention (BSF user) or control (continued normal water use practices) groups within the strata. Upon random assignment, one control household dropped out. The remaining 30 BSF and 29 control households completed the six-month trial. Seven-day longitudinal prevalence of diarrhea among children and adults was monitored once a month for six months in addition to microbial and turbidity measurements on filter performance and drinking water. Two rounds of a user perception survey were administered, in the third and fifth months of the trial, and in-depth interviews conducted with a subset of users after the trial ended.

Findings

All 30 households were satisfied with the BSF, with all 15 upper and 13 of 15 middle watershed households being very satisfied during the second perception survey. The reason for satisfaction by over half of the mothers was that the BSF "provided enough clean water for the

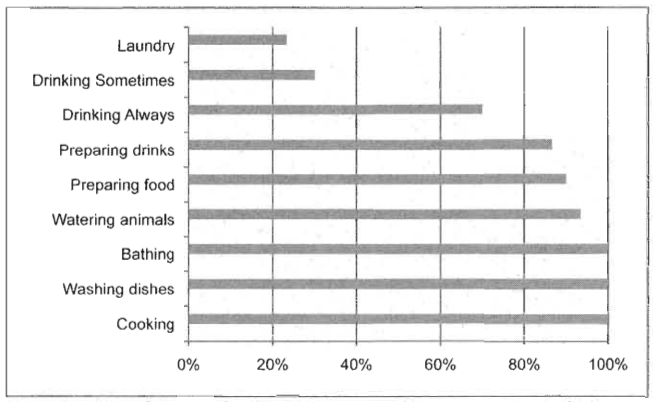


Figure 1. Use of BioSand Filter (BSF) treated water among trial households in the Njoro River watershed, Kenya.

entire household." Other reasons included: "providing safer drinking water," "cleans the water effectively," "cost effective," and "BSF works without any problems."

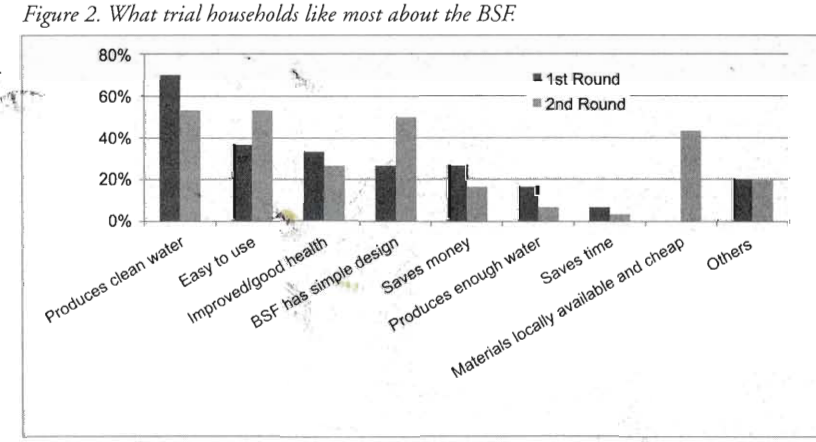
Few problems were encountered during the trial, clogging being the most common reported by two users. In each case, trained local BSF technicians were called to demonstrate to the mother the wet harrowing method of filter maintenance to restore flow rates. While reported by just one mother, BSF technicians observed mold growing on the wood filter lids due to lack of air space and high humidity in the container. Users identified three problems which would make it difficult to continue using the BSF: slow flow rate (n=9), problems with taste (n=5), and cloudiness (n=1), suggesting some experience and concern for these issues.

Generally, the locally trained BSF technicians were able to convey correct usage and maintenance procedures to users through one initial and one or more follow-up visits to test for and correct misunderstandings. Educating and empowering new users to sustain and correctly use and maintain filters via in-home demonstration and visits is a crucial component for sustained uptake. Key areas of mis-operation, which needed addressing in follow-up visits included: never blocking the filter outlet, even during filter maintenance; cautioning against excessive maintenance (wet harrowing) of the filter and avoiding all use of the term "cleaning" to refer to this de-clogging activity; during wet harrowing, avoiding penetration of the sand surface beyond the depth of one's fingernails to minimize disturbance to the biological layer and loss of sand; and avoiding the use of borehole water in the filter. Some BSF technicians and the households they trained initially misunderstood filter maintenance to be a cleaning activity, and were penetrating the sand layer of the filter, scrubbing the slimy biologically active film off of sand grains at regular weekly intervals.

The BSF has the ability to remove turbidity and absorb and remove a large variety of contaminants through a combination of biological and mechanical mechanisms. BSF treated water was perceived by nearly all mothers to be better along four important dimensions of taste (93%, 100%), smell (77%, 90%), appearance (67%, 87%), and color (43%, 90%) than their previous water in the first and second rounds of the trial, respectively. Perceptions of improved quality on each dimension increased in the second round (August) during the heavy rains when River Njoro water is seriously degraded by human and animal fecal contamination (see Jenkins, 2008), possibly making comparison more notable. Alternatively, quality may have actually improved as the BSF's biological system matures over time. No households perceived any dimension of quality to be worse for BSF treated water, while the balance indicated no change.

All BSF households reported either always or sometimes using filter water for drinking. More households in the upper watershed (12: always; three: sometimes) used the treated water for drinking than in the mid-watershed (nine: always; six: sometimes) where households had access to borehole and rainwater, safer sources recommended for drinking when accessible. Figure 1 shows all BSF trial households used filtered water for a wide range of other domestic purposes, including bathing, watering animals, and even laundry, for an average daily use of 53 liters of BSF treated water. The BSF is unique among low cost household water treatment options in its ability to treat up to 60 liters a day. All households indicated the filter produced enough water for their needs, with two middle watershed households qualifying this finding with the exception: "if not used for clothes washing". Those using BSF treated river water for laundry generally had some access to stored rainwater or borehole water for drinking and cooking.

Figure 2. What trial households like most about the BSF.



BSF users were asked what they liked about the BSF (Figure 2). Production of clean water, easy to use, simple design, and locally available and cheap materials (for construction, operation and maintenance) dominated as valued attributes of the BSF. There was a marked difference between the upper and middle watershed population. Cheap/locally available materials, simple design, and easy to use where the most important attributes of upper watershed users comprised of poorer, less educated, more rurally dispersed agricultural households dominated by the Ogiek, Kalenjin, and Kipsigi ethnic groups. In contrast, middle watershed users, living in and around Njoro town, who tended to be somewhat more educated, less poor, and from the majority Kikuyu ethnic group, sited cleaner water, improved/good health, and money savings (don't buy water, reduced health care expenses) as the most important attributes of the BSF. River water is visibly more contaminated in the middle watershed where several alternative improved sources (borehole kiosks) are available but distance, in-operation, long lines, and purchase cost are significant barriers to use for high risk households. Other positively perceived attributes of the BSF included: no need to boil water, use of clean water to wash utensils, use of clean water for cooking, provision of clean water to neighbors, availability of cool water, availability of clean water for laundry, improved taste of water, the reception of more visitors inquiring about BSF, and the ability to keep busy (the BSF did not interrupt daily chores).

By the second round survey, 100% of users had recommended the BSF to neighbors "because it is effective", "increases equity between neighbors", "because neighbors want it", and "so they stop asking for theirs", suggesting that high interest and demand for the BSF has already been generated in these communities.

Positive effects on social relationships generated by the BSF were reported by 29 users in the first round and all 30 users in the second round. These included: improved relationships with family, friends, and neighbors (11), sharing filtered water with neighbors/friends (eight), new friends (seven), others want the BSF (13), and people admire the BSF (12). The first three were more prevalent in the middle watershed while the last two in the upper watershed.

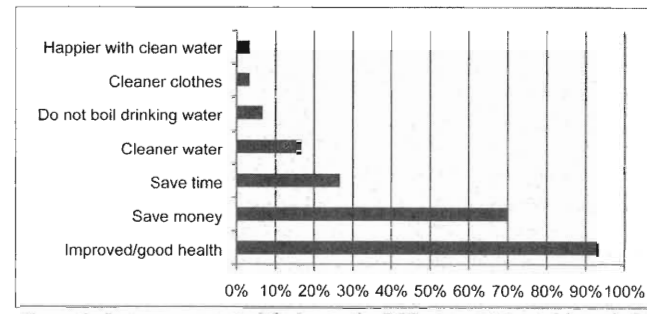
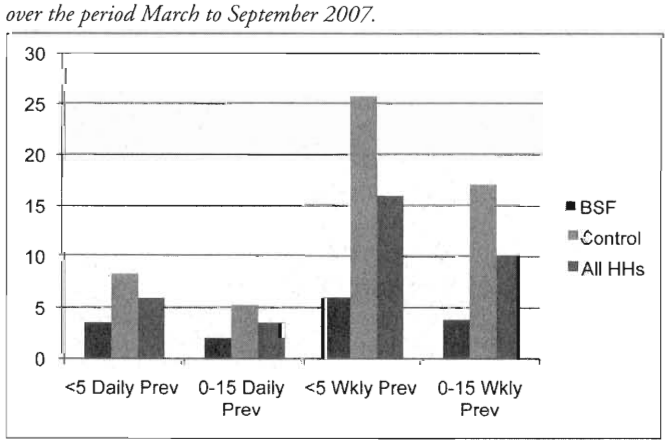


Figure 3. Improvements in life due to the BSF among 30 trial households.

Changes due to the BSF reported by users included: the saving of time, money (less medical expenses, drinking water not purchased, no fuel necessary for boiling, no chemicals necessary for treatment), improved/good health, cleaner water, plenty of water, no need for additional treatment, cleaner clothes, get clean water easily, drink more water, give neighbors filtered water, and the ability to heat rather than boil water. Savings of time and money dominated in the first round, while saving of time and provision of cleaner water dominated in the second round. The most important improvements (Figure 3) show improved/good health dominated in both the upper and lower watershed.

Perception of improved health is consistent with the diarrhea health impact findings (Figure 4) indicating a large reduction in child diarrhea prevalence in BSF households compared to controls over the trial. Applying statistical analysis to control for age effects on diarrhea, clustering of diarrhea at the household level, and repeated child measures, the relative risk ratio of child (0-15 years) diarrhea in BSF households compared to controls was 0.46, translating into a 54% risk reduction. BSF effect on child diarrhea was greater in the upper watershed (77% risk reduction) where households lacked access to improved water sources, thus drinking river water more often than in the middle watershed, where households were more likely to drink safer borehole and rainwater.

Figure 4. Daily and weekly prevalence (percentage of observed days and weeks with diarrhea) of children for the subset of under five years (< 5) and all children (zero to 15 years) by group from the 59 trial households over the period March to September 2007.



Practical Implications

The combination of health and non-health benefits from the BSF perceived by users and verified in the trial provide a strong basis for generating sustained uptake and use of the filter among high risk poor rural and agricultural households who lack access to improved water supplies in Kenya. The private benefits and

positive attributes perceived by upper and middle watershed mothers offer content for promotional and marketing messages for a commercial approach to local filter production, distribution, and sales among target population segments. The filter can be produced locally in Kenya and sold for a profit at a price of USD 25 per unit, with no recurring costs and the potential to last for many years. Of the 59 trial households, including controls, 79% of them purchased the BSF at the end of the trial at the discounted price of USD 4.63.

The ability of the BSF to provide treated clean water for nearly all domestic water needs, including animal watering, appears to be a highly valued attribute and likely to enhance the range of health and well-being benefits beyond those limited to drinking water quality. Ease of use, simple design, and self-maintenance are also clearly important consumer attributes that can assist in promotion and uptake.

Locally trained BSF technicians played a critical role in the success of the BSF during the trial and in user satisfaction and sustained uptake. They were selected from among masons and all men, but many have since left leaving lack of local BSF service support and expertise in some communities. We successfully showed that local resident women can be trained to be successful BSF technicians and should therefore be recruited for this position as they are much less likely to leave in search of jobs.

Further Reading

Jenkins, M.W. 2008. "Gross Fecal Pollution of a Rural Watershed in Kenya: Research Identifying Cattle as a Major Source in the River Njoro Watershed." *Research Brief 08-01 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

Jenkins, M.W. 2010. "Diarrhea Disease Control as Part of Watershed Management in Kenya: The SUMAWA Project Experience." *Research Brief 10-03 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA. Submitted.

Jenkins, M.W., S.K. Tiwari, J. Darby, D. Nyakash, W. Saenyi, and K. Langenbach. 2009. "The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya." *Research Brief 09-06 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

Tiwari, S.K., and M.W. Jenkins. 2008. "Point-Of-Use Treatment Options for Improving Household Water Quality Among Rural Populations in the River Njoro Watershed, Kenya." *Research Brief 08-02 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

Tiwari, S.K., W.P. Schmidt, J. Darby, Z.G. Kariuki, and M.W. Jenkins. 2009. "Intermittent slow sand filtration for preventing diarrhoea among children in Kenyan households using unimproved water sources: randomized controlled trial." *Tropical Medicine & International Health* 14(11): 1374–1382.

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GLOBAL LIVESTOCK CRSP

Diarrhea Disease Control as Part of Watershed Management in Kenya: The SUMAWA Project Experience

Marion W. Jenkins, University of California, Davis

Sustainable Management of Rural Watersheds (SUMAWA) Project

Research Brief 10-03-SUMAWA January 2010

Community outreach in Kenya's River Njoro watershed under the GL-CRSP Sustainable Management of Rural Watersheds (SUMAWA) project identified scarcity of clean water, river pollution, and water-borne diseases as priority concerns of residents. Using the watershed as a unifying framework for problem analysis and stakeholder action planning, SUMAWA launched efforts in 2003 to document patterns and causes of water-related human diseases in the watershed, in order to design a targeted appropriate public health intervention to reduce disease burdens. Researchers employed a three step approach in collaboration with front line public health personnel in the Ministry of Health to apply local expertise, information in existing medical information systems, and simple methods to identify and map hot spots of diarrhea diseases and typhoid in the River Njoro watershed. Patterns of diarrhea illness illustrate how the differential disease burden caused by poor water supply conditions disproportionately affects children in agricultural, less educated and poorer households located farther from safe water supplies. In response, a point-of-use water treatment intervention was launched to provide high-risk populations with improved water supplies at the household level. The process demonstrates how local resources can be mobilized with limited outside guidance within a watershed management approach, to identify and implement appropriate local interventions to reduce disease burdens for the highest risk groups.

Background

Diarrhea disease, associated with lack of safe water supplies, poor environmental sanitation, and inadequate personal and domestic hygiene practices, persists as the second killer of children in developing countries (UNICEF/WHO, 2009). Kenya is no different. In 2006, only 49% of rural households in Kenya had access to an improved water source. In the River Njoro watershed under the SUMAWA project, participatory rural appraisal highlighted water-borne diseases as a priority problem in all four zones of the watershed. Addressing this concern required developing a good understanding of the water-borne disease burden, affected groups, and dominant risk practices in order to develop effective disease control interventions for the watershed.

SUMAWA's diarrhea and water-borne disease investigation began by reaching out to clinical and public health staff at the three government health facilities which serve the upper (Nessuit Dispensary), middle (Njoro Health Center) and lower (Kapkures Health Center in Baruti) areas of the watershed. We sought and gained approval to collaborate on a diarrhea disease assessment and control initiative from district medical superiors in Nakuru. Kenya's health system includes Public Health Officers and Technicians responsible for environmental health protection, outreach and enforcement, including maintaining and promoting sanitary conditions in public places (e.g. markets and food providers), as well as in the home. Attached to health centers and dispensaries, public health staff are field-based, devoting much of their time to conducting visits and investigations in the communities they cover, and are intimately familiar with community conditions, health problems, and community leaders. Working with public health personnel was a natural choice for collaboration on water-borne and water-related disease prevention in the Njoro watershed. Public health personnel comprise the second largest professional group in Kenya's health system after nurses, covering the population at a rate of 20.1 per 100,000, and can be found in some of the most remote parts of Kenya and the Njoro watershed.

Using simple methods and locally available resources, our investigation into diarrhea and other water-borne diseases in the watershed consisted of the following core activities:

- *Step 1.* Compilation and analysis of all clinical cases of water-borne diseases reported in the case registries at each of the three health facilities, including age, sex, residence location, and diagnosis of each case over the preceding five years.

- *Step 2.* Field investigation and mapping of watershed "hot" spots of disease, defined as residence locations with the greatest number of cases in clinical case registers from Step 1. Field

visits to each hot spot location were conducted with the responsible Public Health Technician to collect GPS location, investigate and map access to safe water supplies, water usage practices, and observe and collect information on environmental and domestic sanitation, housing, and household and poverty characteristics that might be associated with increased diarrhea disease transmission. Early in the project, domestic use of river water was identified as a potential risk factor and information was gathered on whether river water consumption was practiced in each hot spot.

- *Step 3.* Cross-sectional survey of diarrhea disease prevalence rates, and water, sanitation, and hygiene practices of households collecting water at 38 public access river watering points along the river's length. During the survey, every third person arriving to collect river water was interviewed, and his or her home was visited.

The above work was undertaken jointly in stages with watershed public health personnel from 2003-2005. A clear consistent picture of diarrhea and water-related disease hot spots associated with the practice of drinking polluted River Njoro water emerged from the three-step investigation. Key outputs included a list of the residential neighborhoods or pockets in which the practice of drinking untreated river water was prevalent, along with a simple profile of households engaged in this practice.

Findings

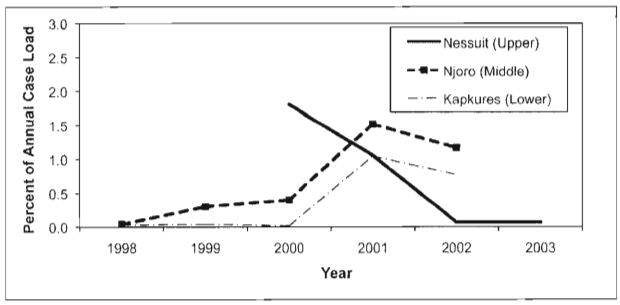
Clinical case register data for 1998-2002/3 from the three watershed health facilities is summarized in Table 1 and plotted as percent of the annual case load in Figures 1 and 2. Diarrhea and typhoid were substantial problems in the watershed. Diarrhea accounted for 5 to 6% of case load in the Nessuit area, 2 to 3% in the Njoro area, and 3 to 4% in the lower watershed (Kaptembwa and Baruti areas). Typhoid presented a case load below 0.5% except during the 2000-2002 epidemic (Figure 2).

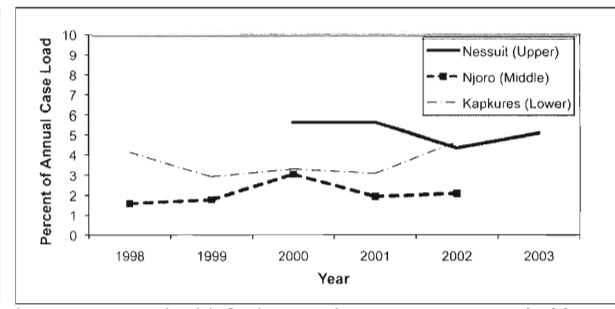
The two diseases also affect different age groups. From 56% (Njoro) to 79% (Nessuit) of diarrhea cases were in children under the age of five years (Table 1). Adults aged 20 to 40 make up a notably greater fraction of diarrhea cases in the middle and lower watershed than among the highly dispersed isolated rural agricultural population of the upper watershed. The two lower clinics serve a growing HIV/AIDS population in these more urbanized denser areas of the watershed, including the slums of Nakuru Municipality, which run along the lowest river reach. The typhoid epidemic appears to have started in the Nessuit zone, peaking there in 2000, and spreading downstream, peaking a year later in the middle and lower watershed. Typhoid is deadlier and more debilitating than diarrhea, spread by food, milk, water, and person-to-person contact with asymptomatic carriers. Typhoid appears to strike females and young adults to a greater degree than males and other ages (Table 1). Typhoid characteristics in Nessuit and Njoro were similar, but differed in the lower watershed where prevalence peaks occurred for children under five years and young adults.

By collating case residence for diarrhea and typhoid from clinical case registers, we identified watershed locations having the greatest number of diarrhea and typhoid cases in each clinic's service area. For the most part, the top 10 hot spots for diarrhea were also the top locations for typhoid in each zone, accounting for 64% (Njoro) to

Table 1. Diarrhea and typhoid cases treated at the Government of Kenya Nessuit Dispensary (2000-2003), Njoro Health Center (1998-2002), and Kapkures Health Centre (1998-2002) in the River Njoro watershed.

Case Statistics	Nessuit Dispensary (Upper)	Njoro Health Center (Middle)	Kapkures Health Center (Lower)
Est. Population Service Area	6-10,000	25-30,000	30-45,000
Typhoid Cases			
Avg. number per year	22	59	31
Mean Age in years	28.81	28.13	20.8
Modal Age(s) in years	30	30	0 to 4 & 20 to 24
Median Age in years	28	27.5	21
Female (%)	63.6	60.4	59.6
Under 5 years (%)	3.5	5	19.7
Diarrhea Cases			
Avg. number per year	228	271	312
Mean Age in years	6.1	11.2	8.14
Modal Age(s) in years	0 to 2	0 to 2.5	0 to 2
Median Age in years	1.45	2.90	1.7
Female (%)	49.1	47.5	50
Under 2 years (%)	68	45.0	56
Under 5 years (%)	79	55.7	67.8
20 to 40 years (%)	7	16.0	14.4
Over 40 years (%)	3.3	4.2	2.1





Figures 1 and 2. Typhoid cases (left), and diarrhea cases (right) at the three government health facilities in the River Njoro watershed between 1998 and 2003, expressed as a percent of total case load.

93% (Kapkures) of all diarrhea cases in a zone. Mapping and field investigations of the top 10 residence locations revealed the primary risk condition in the middle and upper watershed for the high diarrhea burden was lack of reliable and affordable access to improved water supplies, leading to households using untreated river water for domestic and drinking consumption. An independent study of fecal pollution sources and contamination levels in river water (see Jenkins, 2008) showed extremely high levels of fecal pollution throughout the river. Risk conditions for diarrhea diseases in the lower watershed were considerably different. Improved water supplies were generally available although quantities were limited by rationing. River water was so grossly polluted that it was considered aesthetically unfit for drinking by residents. However, poverty, over crowding, tenancy, poor drainage and flooding, uncollected garbage and animal waste, contributed to a highly unsanitary environment typical of a poorly served urban slum in lower watershed hot spots.

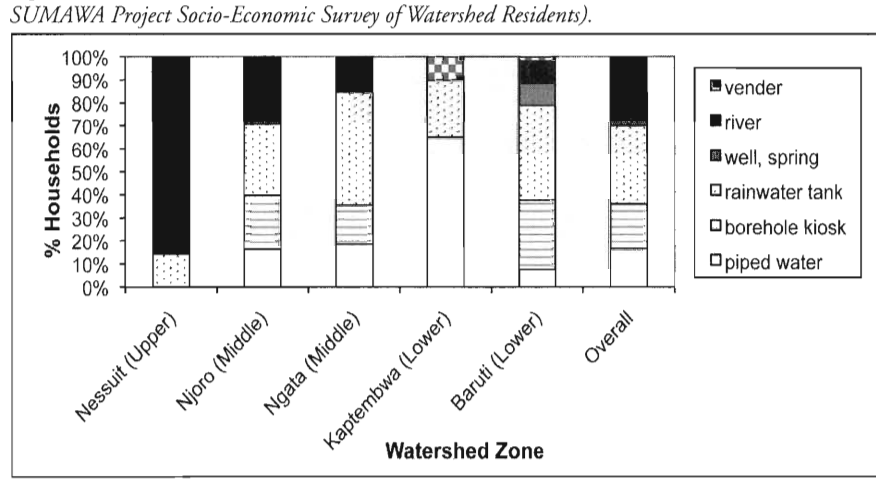
A separate socio-economic survey of watershed residents by the SUMAWA project confirmed river water was used for drinking largely in the upper and middle watershed (Figure 3). The portion of households drinking river water increases as one ascends the watershed, reaching 85% in the upper Nessuit zone. Piped water, borehole kiosks, and roof harvested rainwater provide safe alternatives to river water, to varying degrees below Nessuit.

Step 3, the cross-sectional survey of river using households confirmed wide-spread drinking of untreated river water in the upper Nessuit area, and in some middle watershed population pockets. Diarrhea among children under five years in river using households in the preceding two weeks, showed a clear trend from 19% at the top to 11% at the bottom of the watershed. Further, child diarrhea rates of 22% were observed in homes drinking river water compared to rates of 9%, 8%, and 13% in homes that, while using river water for other domestic needs, drank piped water, roof-collected rainwater, and borehole water, respectively. A clear profile of a typical household drinking river water in the upper and middle watershed emerged, characterized by a combination of poverty, low maternal education, river proximity, mud floor and thatch roof housing, and agricultural occupation. The profile and list of hot spot locations of diarrhea diseases from drinking river water provided the basis for identifying and developing a low cost home-based intervention to treat river water in high risk households to reduce the high diarrhea disease burden associated with river water consumption. The three step investigation laid the foundation for proceeding with a joint intervention program with the Ministry of Health to develop and implement the BioSand filter, a household-level point-of-use water treatment technology, for high risk households in the watershed (see Tiwari and Jenkins, 2008; Jenkins, et al. 2009; and Jenkins and Tiwari, 2010).

Practical Implications

The River Njoro watershed provided a useful unifying framework and physically coherent unit of analysis for investigating water-borne diseases in a country like Kenya where a large portion of the population continues to depend on open water sources for their domestic water supplies. The three step approach used to investigate local

Figure 3. Household drinking water source in each zone of the River Njoro watershed (2004 SUMAWA Project Socio-Economic Survey of Watershed Residents).



diarrhea and water-borne disease hot spots and risk factors provides a replicable and simple approach to design a local diarrhea disease control program that geographically targets and tailors efforts on the sub-populations with the highest disease burdens. The process described here could be relatively easily replicated throughout much of Kenya, as it depends on locally available information, skills, and knowledge of existing public health personnel who are generally widely present throughout Kenya's health system. A small amount of outside technical assistance is necessary to guide and assist local personnel and support them to identify and develop the most appropriate control interventions.

The watershed framework also entails outreach and collaboration with the new Water Resources Management Authority in Kenya. The methodology used in Njoro could be standardized and supported by regular outside technical visits or decentralized support meetings. The approach allows for the development of highly targeted and tailored interventions to address specific local diarrhea disease risk practices that are associated with the largest portion of local disease burden. However, the process may need to be repeated at intervals, as successful interventions change the local landscape of hot spots and high-risk practices.

Further Reading

Jenkins, M.W. 2008. "Gross Fecal Pollution of a Rural Watershed in Kenya: Research Identifying Cattle as a Major Source in the River Njoro Watershed." *Research Brief 08-01 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

Jenkins, M.W., and S.K. Tiwari. 2010. "Health and Non-Health Impacts of the BioSand Filter for Rural Kenya." *Research Brief 10-02 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

Jenkins, M.W., S.K. Tiwari, J. Darby, D. Nyakash, W. Saenyi, and K. Langenbach. 2009. "The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya." *Research Brief 09-06 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

Tiwari, S.K., and M.W. Jenkins. 2008. "Point-of-use Treatment Options for Improving Household Water Quality Among Rural Populations in the River Njoro Watershed, Kenya." *Research Brief 08-02 SUMAWA.* Global Livestock Collaborative Research Support Program (GL-CRSP), University of California, Davis – Davis, CA.

UNICEF/WHO. 2009. *Diarrhoea: Why children are dying and what can be done.* Report prepared by E. W. Johansson and T. Wardlaw for the United Nations Children's Fund (UNICEF)/World Health Organization (WHO), New York, NY.

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