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A PRELIMINARY INVESTIGATION OF WATER AND SOIL QUALITY IN FOUR FOREST RESERVES NEAR KAMPALA, UGANDA

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There are four forest reserves that are located on the outskirts of Kampala, Uganda that area conservation groups have deemed extremely important to protect through restoration practices and the enhancement of environmental research and education. These reserves, which have suffered greatly from human encroachment, are part of the once expansive lowland forests adjacent to Lake Victoria, the second largest freshwater lake in the world. Although the biodiversity of living species is being studied in this region, the geologic component is lacking. This paper discusses baseline geologic data (e.g. soil and hydrology assessments, water chemistry) collected from Kitubulu, Zika, Mabira, and Mpanga Forests. The preliminary data collected may indicate early stages of environmental degradation. Elevated Fe and low pH in some surface waters may indicate influence of mine tailings, whereas depleted dissolved oxygen may indicate increased turbidity from siltation. The preliminary data set has defined measurable and practical geologic parameters that should be monitored continuously in order to track the overall health of the Lake Victoria catchment basin. To date, there has been no systematic monitoring of watershed health in this area because of lack of laboratory analysis capacity in Uganda. Employing the help and support of local conservation groups, and college students from Makerere University, are essential to the success of a long term soil and water quality monitoring program.

INTRODUCTION

People living in equatorial third world countries often rely heavily on the use of forest materials to sustain themselves. Primarily, wood is harvested at significant amounts for cooking and building materials. Forest degradation in developing countries continues to impact natural landscapes and may result in larger consequences such as an altered global climate (Chapman and Chapman, 2002).. This is particularly true in Uganda where sensitive ecosystems can be devastated by unmonitored timber collection. A team of experts from Ugandan government ministries recently reported that nearly 10% of Uganda's gross domestic product will be spent adapting to negative consequences of forest degradation on food and energy production (Tenywa, 2007). The lack of landuse planning and the doubling of the Ugandan population in the last 20 years have resulted in sprawling poor communities that encroach on forested areas outside of the capital city, Kampala. Threats to forests, particularly in the Lake Victoria basin, are likely to intensify given the projected population of 50 million in the next 20 years (Baranga, 2004; Mugisha, 2002; Naughton-Treves and Chapman, 2002).

Lake Victoria basin is known as Africa's single most source of inland fisheries production (Balirwa et al., 2003) and generates $250,000 to $500,000 in fish exports alone (Ntiba et al., 2001). Waves of dramatic environmental challenges and degradation to the lake have happened over the past ninety years. Research has indicated that human disturbance over time has elevated the inputs of nitrogen (circa 1920's) and phosphate (circa 1950's) due to ill farming practices, fertilizer application, and later, the introduction of flower farms (Gophen et al., 1995). The introduction of nonnative Nile Perch (*Lates niloticus*) in the early 1960's resulted in a mass extinction (about 65%) of endemic Lake Victoria fishes (Wittea et al., 2007; Gophen et al., 1995). More recently, over fishing, law enforcement, and harmonization among riparian countries (Tanzania, Uganda, Kenya) continue to devastate the basins water (Ntiba et al., 2001).

Although biological diversity has been explored in the Lake Victoria basin, and more specifically the Kampala forests, the geologic and hydrologic data gathered by research scientists remains sparse. In general, the geology of Uganda is largely explored for the purpose of rock ore and mineral extraction only (Schuler and Trauth, 2008; Uganda Geological Survey, 1942). This is due to the great economic impact mining has for the country and the Congo (Essick, 2001). The primary mineral resources mined within a 100 km radius of Kampala include columbite-tantalite, bismuth, iron ore, and sand (Okedi, 2007). According to the Ugandan Mine Division, in 2007 the country made $88 million on permitted mineral exports (Okedi, 2007). Recognized as a profitable venture, for the past 10 years the Ugandan government has been working to establish Mining Acts and Regulations. However, the Acts put into place (Mineral Policy Act, 2001; The Mining Act, 2003; Mining Regulations, 2004) are devoid of environmental regulation.

More specifically, the four Kampala-area forest reserves suffer from uncontrolled forest product exploitation and illegal activity involving the removal of iron ore and sand. In this base-line study we were interested in identifying impacts of deforestation and mining on water resources, describing forests and forest characteristics important to water circulation, sediment movement, and lake/stream habitat. This project was initiated based on the growing interest in the field of forestry to understand the benefits of forest hydrology to successful restoration practices (Chang, 2006; Hewlett, 2002). Geologic and hydrologic parameters, such as the measurement of soil erosion, are traditionally an on going monitored variable in areas where forests have been rehabilitated (Wenhua, 2004; Schoenholtz et al., 2000; Aide and Cavelier, 1994).

STUDY AREA

There are four forest reserves on the outskirts of Kampala that are being protected and restored through local leadership (Figure 1). There are two evergreen lowland rainforests (Kitubulu forest, 80 hectares; Zika 10 hectares) that lie on the northeast side of Entebbe Bay, south of Kampala, Uganda's capital. These small forest reserves are important remnants of the lowland forests adjacent to Lake Victoria that act as filtration for water pollution and silt that threatens to enter the basin. Moreover, the proximity of Kitubulu and Zika to the 1.6 million people residing in the capital city (Ugandan Bureau of Statistics, 2011) puts pressures on its natural resources and land for homesteading. Kitubulu may best be known for the commemorative tree planting that joined the National Forest Authority with the Queen of England and delegates during the Commonwealth meeting in Uganda in 2007. Despite the positive attention Kitubulu received for being a protected forest reserve several acres (> 2) of lake shore land have been sold and the rest continue to be at risk (Ssebuyira, 2011). The Mpanga forest reserve (453 hectares) protects an extensive patch of compact remnant tropical, moist evergreen, and swamp forest. Located west of Kampala, this forest reserve combines about 40 small adjoining reserves to form a corridor of forested land totaling some 251 km^2. The dominant tree species found only in Mpanga forest reserves are *Celtis mildbraedii* and *Bosquilela phobero.* These two species are intensely sought after by traditional drum makers in nearby Mpambire village. Upon dedication in 1953, researchers visiting Mpanga forest reserve created a system of footpaths to promote accessibility to field sites. Unfortunately, these footpaths make for easy conduits for movement of illegally felling trees. A conservation group called Mpigi Ecotourism has initiated tree nursery projects in villages outside of Mpanga forest reserve boundaries to promote conservation. The Mabira Forest reserve is the largest of the four forest reserves at 30,000 hectares. It is located east of Kampala and is a semi-deciduous forest with hills and valleys containing papyrus swamps. Although a forest reserve since 1932, plans indicate a project to clear-cut of one-third of the land for sugar cane plantation (Businge, 2007).

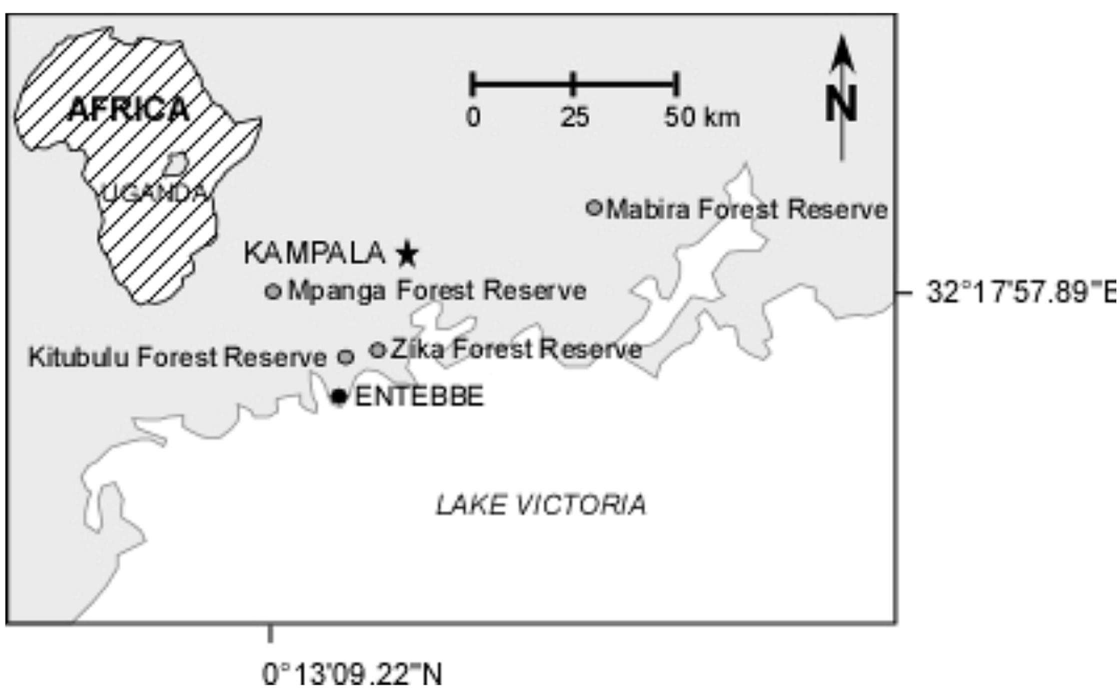

Figure 1. Site map of the four forest reserves located near Uganda's city capital, Kampala.

The four reserves form an important biogeographical region and are within the catchment area for Lake Victoria. The water resources of these reserves are under pressure from deforestation, homesteading, and misuse. Forms of encroachment include dumping trash and toxic waste, as well as running illegal businesses such as washing bays, where Ugandans bring their vehicles to be cleaned by villagers using the forest's stream. Illegal sand mining for the production of bricks has caused visible siltation in some river systems. Communities struggling to meet pressing needs for food, income generation, healthcare, and education densely populate the villages adjacent to these reserves. The need to provide for families continues to take precedence over protecting forest reserves (Olanya, 2007). Moreover, it is likely that the popularity of these forests for recreation will continue to grow given the close proximity of these forests to Kampala and Entebbe.

METHODOLOGY

The field data collection was carried out in the dry month of June. A reconnaissance survey was first conducted to locate the possible water bodies within the forest reserves. Open water bodies (streams and lakes) were considered optimal for water sampling. Sites that were accessible and safe to sample were selected. The locations of sampling sites were marked using Global Positioning System (GPS) though in some instances due to either bad weather or dense canopy cover it was not possible to take GPS readings. As many samples as possible were collected at each forest reserve. Time, ultimately, was the limiting factor in the collection of more data.

Water samples were collected at each sample site using 0.5 liter plastic bottles. The bottles were completely submerged and capped under water. All parameters were measured in the field immediately upon collection. The water quality parameters measure at each forest reserve includes temperature (°C), hydrogen ion concentration (pH), dissolved oxygen, total ammonia, phosphates, total hardness ($CaCO_3$), total chlorine, and total iron. All measurements reported in Table 1 are listed in units of parts per million. Temperature and dissolved oxygen was measured in the field using a portable YSI Model 550A. The hydrogen ion concentration (pH) was measured using a portable HM digital 200 pH meter. These instruments were calibrated at the start of each session according to instrument guidelines. For the ease of sample collection, and the difficulty of transporting wet chemicals internationally, we opted not to use field chemical test kits for the collection of this preliminary water chemistry data. For these reasons, the other parameters (total ammonia, phosphates, total hardness, total chlorine, and total iron) were measured using Hach brand chemical test strips. The accuracy of the test strips are +/- 1 ppm.

At each forest reserve a preliminary geologic and hydrologic site assessment was conducted. The site assessment included a series of descriptions of physical settings: 1. A description of local and regional topography that included the geology, elevation, stream piracy, vegetation, and climate. 2. A description of past, current, and future land use planning in and adjacent to the forest reserve. 3. A preliminary soil survey to describe the soil color and texture using Munsell chart color categorization, and USDA soil textural classification. 4. A description of the area hydrology that included the evaluation of natural streams through the measurements of flow rate, discharge, and bedload capacity. In addition, an investigation of the proximity of natural streams to exposed mining tailings, livestock (or similar), waste water, sewage, solid waste disposal was carried out.

RESULTS

The authors measured a low dissolved oxygen level (2 ppm) and a basic pH of 8.4 at both sites in Kitubulu forest reserve (Table 1). The water temperature was much warmer than at the other forests we visited; ranging from 23.2 to 27.7 °C. A range in hardness was identified at the two locations (50-240 ppm).

The authors were able to identify and sample five locations at Mabira forest reserve. Water temperature ranged from 19.3-19.8 °C. At location M3 a pH of 4.0 was recorded; the other locations ranged from 6.8-7.8. The dissolved oxygen measured at location M3 was <10 ppm. This dissolved oxygen was found to be similar at the other locations (ranging from 8.9-10). The iron was found to be 0.3 ppm at all of the Mabira forest sample sites, except M3, where it rose to 7.2 ppm.

The water temperature at two sample locations in Zika forest reserve was recorded at 20.7 and 20.8 °C. The pH at both locations was slightly acidic at 6.2. The dissolved oxygen at Z1 was 7.0 ppm and 7.8 ppm at Z2. The total hardness was measured at 25 ppm (Z1) and 50 ppm (Z2). Total iron content in both water samples was measured at 0.3 ppm.

At Mpanga forest reserves the water temperature was reported at 20°C (P1) and 22.7 °C (P2) at two locations. At P1 the pH was measured at 6.2, P2 at 7.2. The dissolved oxygen was measured at 6.3 and 7.2 ppm, for Z1 and Z2, respectively. Some total iron is reported at P1 (0.3 ppm), but none at P2. At all sample sites in all four forest reserves the total ammonia reported was 0.25 ppm.

The second part of the field investigation included analysis for both soil color classification and grain size texture (Table 2). All soil samples monitored for grain size was found to be coarse sand except for the sample collected at K1 (fine sand) and Z2 (medium sand). The color of the soil varied between forest reserves and between locations within each forest reserve. At Kitubulu forest reserve the color was found to be reddish-brown at K1, light grey at K2. At Zika forest reserve, very dark yellowish-brow was determined to be the color at Z1 and black for Z2. Four soil samples were analyzed at Mabira forest reserve. Three of these (M1, M2, M4) are established to be black in color; M3 was classified as olive-brown. The soil at Mpanga forest reserve varied between the two locations; P1 was very dark grey, P2 was reddish-brown.

DISCUSSION AND CONCLUSIONS

The first goal of this preliminary study was to determine the potential for establishing long term water and soil monitoring stations at the four forest reserves near the capital city of Kampala that are endangered by human encroachment and misuse. Through this research project the authors were able to select sampling locations that are both safe and accessible.

The second goal was to collect a baseline data set of water and soil analysis at each of the forest reserves. Although preliminary, the results of the water chemistry may provide some evidence of landscape degradation already occurring. A very acidic pH of 4.0 was reported at site M3 at Mabira forest reserve. This site also had an unusually high total iron content of 7.2 ppm (USEPA recommends 0.3 ppm in drinking water) and a hardness of 0 ppm (classified as soft water). Although suspect, the chemical conditions could reflect an environment impeded by mining or leaching. For example, in areas known to have acid mine drainage the buffering ability of water is depleted by neutralizing carbonate and bicarbonate ions to form carbonic acid (H_2CO^3).

$$H^+ + CO_3^{2-} \longleftrightarrow HCO^{3-} \quad (1a)$$

$$H^+ + HCO_3- \longleftrightarrow H_2CO^3 \quad (1b)$$

Once exposed to acid mine drainage, the affected carbonate buffering system is not able to control changes in pH as well. The buffering system is completely destroyed below a pH of 4.2,

Table 1. Water chemistry collected from four forest reserves near Kampala, Uganda.

Site Name and Sample Number	Temperature (°C)	pH	Dissolved Oxygen	Phosphate	Total Hardness	Total Chlorine	Total Iron	Total Ammonia
Kitubulu-K1	27.7	8.4	<2	15	50	0	0	0.25
Kitubulu-K2	23.2	8.4	<2	0	240	0	0	0.25
Mabira- M1	19.3	7.8	8.9	5	240	0	0.15	0.25
Mabira-M2	19.5	7.8	10	5	50	0	0.3	0.25
Mabira- M3	19.6	4	<10	5	0	0	7.2	0.3
Mabira-M4	19.7	7.2	9	5	50	0	0.3	0.25
Mabira-M5	19.8	6.8	8	5	50	0	0.3	0.25
Zika-Z1	20.8	6.2	7	5	25	0	0.3	0.25
Zika-Z2	20.7	6.2	7.8	5	50	0	0.3	0.25
Mpanga-P1	20	7.2	7.2	5	50	0	0.3	0.25
Mpanga-P2	22.7	6.2	6.3	5	50	0	0	0.25
Please note that all chemical measurements are reported in units of parts per million								

Table 2. Soil description and Munsell chart colors reported for each of the sample sites within the four forest reserves near Kampala, Uganda.

Site Name and Sample Number		Grain Size Classification
Kitubulu-K1	reddish brown	fine sand
Kitubulu-K2	light gray	coarse sand
Mabira- M1	black	coarse sand
Mabira-M2	black	coarse sand
Mabira- M3	olive brown	coarse sand
Mabira-M4	black	coarse sand
Mabira-M5	black	coarse sand
Zika-Z1	very dark yellowish brown	coarse sand
Zika-Z2	black	medium sand
Mpanga-P1	very dark gray	coarse sand
Mpanga-P2	reddish brown	coarse sand

where all carbonate and bicarbonate ions are converted to carbonic acid. The carbonic acid readily breaks down into water and carbon dioxide (Farmer and Richardson, 1981).

$$H_2CO_3 \longrightarrow H_2O + CO_2 \qquad (1c)$$

At Site 3, we measured an acidic pH and reported no hardness. Moreover, 0.5 km upstream at site M1, the total hardness was reported at 240 ppm (classified as very hard water); this is the highest reading reported at Mabira forest reserves. Water hardness has been known to be a useful indicator of upstream mining activity because often it is found to be considerably higher in watersheds with active or abandoned mines. Ferrous iron (Fe^{2+}) from acid generating reactions and calcium (Ca^{2+}) from acid-neutralizing reactions may contribute to higher than average levels of water hardness (Farmer and Richardson, 1981). It needs to be mentioned, that at none of the sites did the authors find the typical orange waters evident of drainage.

The very low dissolved oxygen readings (< 2ppm) reported at both sites in Kitubulu forest reserve are also of concern. Dissolve oxygen levels below 2 ppm can result in the demise of both vertebrates and invertebrates living in the water system (Ice and Sugden, 2003; Nebeker, 1972). The low levels in dissolved oxygen may be directly influenced by the elevated water temperature reported (23.2 and 27.7 °C). Our second hypothesis to explain the low dissolved oxygen involves siltation blocking light that prevents photosynthesis to produce oxygen. The authors believe that these temperature and dissolved oxygen values have little to do with the collection site as Kitubulu is a dense evergreen canopy rainforest and the stream was shaded. Moreover, the sample day was cloudy. Sedimentation from an upstream carwash bay and an adjacent illegal sand pit may be adding siltation (turbidity) to this stream causing it to inadvertently warm. The large value (15 ppm) reported for phosphate at K1 is likely a runoff signature from the detergent being used at the car wash bays or sewage from nearby homestead communities. The recommended level of total phosphorus in stream ecosystems to avoid algal blooms is 0.01 to 0.1 ppm (USEPA, 1988). Raw sewage typically has phosphate levels around 10 ppm (Laws, 2000). The jump in total hardness at site K2 is curious and comes without explanation.

The other preliminary data collected from Zika and Mpanga does not currently pose alarming threat. The slightly acidic pH of Zika forest reserve (6.2) is questionable and needs to be further monitored. The water quality of Zika forest reserve is particularly important as the streams cross cutting empty into Lake Victoria.

The drainage class of a soil can be determined from the colors and color patterns in the soil's lower horizons (subsoil) (Pendleton and Nickerson, 1951). The bright, high chroma yellowish or reddish-brown color of soils found at Kitubulu (K1), Zika (Z2) and Mpanga (P2) is largely due to the presence of hydrated iron (III) oxides. Soils with yellow colors tend to occupy wetter landscape positions which results in the hydration of the iron (III) oxides. This is a suspected result for all three forest reserves mentioned as Kitubulu and Zika are classified as evergreen rainforests, and Mpanga as a papyrus swamp. Grey colors of soils found in Kitubulu (K2) and Mpanga (P1) are caused by several substances, mainly quartz, kaolinite, and other clay minerals, calcium and magnesium carbonates (limestone), and reduced iron compounds. These colors occur in permanently saturated soil horizons; these soils often have a bluish appearance. The soil descriptions fit the geologic setting of which these samples were collected in Kitubulu and Mpanga. The black appearance at the majority of the forest reserves reflects the accumulation of organic matter and humus at the surface. These black soils can indicate high annual precipitation and indicate soils with a high moisture content. The majority of samples collected in Mabira were black. This was suspected because Mabira is a moist tropical evergreen swamp forest. It can be observed that varying soil type is found at each forest. This would be considered typical due to the vast acreage that delineates forest boundaries.

FUTURE RESEARCH

Through this research project the authors now have a better understanding of the geologic and hydrologic setting of each of these four forest reserves. The second phase of this project will be to spearhead forest hydrology conservation that is evidence based and builds capacity. Through the application of the Water Quality Index (WQI), and assessment of physical characteristics of water bodies in Kampala area forests, the authors will establish a scientific basis for gauging the impact of development and human encroachment. Through our further delineation of soil type, we plan to communicate to locals some better landuse management strategies for crop planting, rotation, and harvesting. We also plan to follow up on our suspicions of mining, siltation, and carwash bay contamination.

At minimum, this data needs to be collected for a full year to reflect the changes in seasonal rainfall and temperature. Recognizing the need for balancing conservation of natural resources and stewardship grounded in sustainable use the authors will assess community perceptions of watershed health and implement conservation efforts. The authors will provide opportunities for Ugandan college students to collaborate with university scientists and community partners in forest hydrology data collection. Thus, the project's design has both physical and human science components.

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