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Monitoring geomorphic and hydrologic change at mine sites using satellite imagery: The Geita Gold Mine in Tanzania

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ABSTRACT

Large surface mining operations typically involve not only multiple pits but also the creation of new "mountains" of tailings. These operations dramatically change the local watershed topography and expose downslope agricultural fields and forest to tailings runoff. Given that most mine tailings expose large quantities of surface area to oxidation and transport by water, any heavy metals associated with the deposit are mobilized to move along with the runoff. In Tanzania, the Geita Gold Mine (GGM) area is such a site and the Government of Tanzania has yet to develop a water monitoring network to protect villages adjacent to the mines. As a result, mining company data are the only data available to monitor water supply and quality. Typically in mining and oil sand extraction, geospatial data are used to report and monitor land reclamation at the mining site, and while these efforts are useful, they do not consider hydrologic changes and risks. In this paper we evaluate the use of Digital Elevation Model (DEM) data from the Space shuttle Radar Topography Mission (SRTM) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) in an effort to identify the changes in local topography and surface hydrology around the GGM and assess the implications these changes have for the potential increased mobility of tailings and their effects upon farmers, village water supplies, and community forests using a hydrologic flow model. Results reveal that over 13 million m^3 of material has been removed from the main mining pits at GGM while over 81 million m^3 of material has been deposited elsewhere in tailings piles and waste dumps. These topographical changes have had a profound influence on the local surface hydrology, with some stream channels shifting up to 3 km from their original paths. Overall, approximately 37 km^2 of cultivated land is within the watersheds associated with potentially polluted streams and that future mining operations could impact up to 63 km^2 of cultivated land.

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Introduction

Environmental regulation of the extractive industries (EI) is observed to be difficult to enforce in both rich and poor countries (Gray & Shimshack, 2011; World Bank, 2010). Much mining and oil or gas development takes place in remote places that are not easily accessed by ground transportation. It is costly for governments to do field visits and to operate on-site monitoring instrumentation (Nobi, Dilipan, Thangaradjou, Sivakumar, & Kannon, 2010). Yet open pit mining operations generate significant environmental changes because of the huge amounts of material moved and processed, and the presence of heavy metals in most waste rock and ore bodies. Erosion, competition over water resources, and quantity and quality issues, as well as, pollution of air, water, and soil are almost always the result of such operations (Razo, Carrizales, Castro, Diaz-Barriga, & Monroy, 2004).

In the Geita District of Tanzania where Anglogold Ashanti operates the Geita Gold Mine (GGM), most of the inhabitants are farmers. Several complaints have arisen from people in the mine-adjacent communities of Katoma, Nyamalembo, and Nyakabale who were concerned about the deaths of animals, human illness, and soil contamination (Makene, Emel, & Murphy, 2012). In July 2007, 17 cows died after drinking from a mine tailings pond. In Nyamalembo, people complained of frequent flooding of their farm land and their houses during the rainy season to the point that they can no longer produce enough food for their family or even raise animals. We observed that many households in the area had no chickens, an abnormal situation given that it is common to see chickens wandering around homes in these rural communities. We were also told during a 2007 interview with an elder in the area that a child had been drowned by the flooding due to the mining project. An interviewee from Nyakabale Village (to the west of the

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mine site) told of his wife's illness from drinking the water in the area. Other Nyakabale residents complained that water resources needed for cattle were taken by the mining company and not replaced as promised (Emel, Makene, & Wangari, 2012). Research at the University of Dar es Salaam found amounts of heavy metals, particularly chromium and lead, in the soils and plants downstream of the waste rock piles to be many times greater than World Health Organization standards (Bitala, 2007). Unfortunately, people in the area are entirely dependent upon rivers and natural springs for water supply (see Fig. 1).

Monitoring water and air impacts is the responsibility of both the state and the mining company. But many state environmental agencies do not have the resources or the capacity to undertake the duties. Even in the US, environmental monitoring often means reviewing company reports. Horowitz (2010) provides an example in New Caledonia of how mining company self-disclosure of environmental monitoring results and models of probable pollution events may have little local salience if people do not trust how the data were produced and disclosed to the community. Makene et al.'s (2012) work on water pollution and water supply issues near the Geita Gold Mine in Tanzania (our study site) illustrates that two "worlds" of discourse exist in a mining region: one populated by instruments and data stemming from mining consultants, and the other a world of local knowledge and narratives about poisons and health effects given voice by villagers. Given the distrust existing between many host community members and mining companies (and the state in many cases) there is need for inexpensive, independent monitoring capability that might be undertaken by university or non-governmental organization staff (Office of the Compliance Advisor/Ombudsman, 2008).

Remotely sensed data provide a means of providing cost-effective analyses of environmental change at mining sites (Paull, Banks, Ballard, & Gillieson, 2006; Rigina, 2002). A number of studies have illustrated the utility of remotely sensed data for examining mining related land use change (including reclamation progress) (Demirel, Duzgun & Emil, 2011), classification of tailings deposition areas (Trisasongko, Lees, & Paull, 2006), and identification of hydrogeomorphological change (Akiwumi & Butler, 2008). In a European Union-funded comprehensive assessment of the use of remote sensing for mineral resource development, Tote, Reusen, Delalieux, Goossens, and Kolodyazhnyy (2010, p. 12) claim that the "relatively small number of studies related to the environmental impacts of mining and remote sensing indicates under-utilization in this sector".

The purpose of this study was to explore the use of using freely available remotely sensed and GIS data for identifying hydrologic regime changes within a mining affected watershed. Our goal was to determine how the drainage patterns might change with the alterations in elevation caused by mining pits and by piling overburden and tailings. Additionally we created a "potential pollution" map by illustrating where tailings and runoff might flow in the Geita Gold Mine complex in northern Tanzania.

Study area

The Geita Gold Mine, situated at the headwaters of the Mtakuja River that drains into Lake Victoria, is owned by Anglogold Ashanti, a South African mining company (Fig. 2). The project, named for the biggest town in Geita Region, is a multiple open pit mining operation with potential for underground development. Mined ore is processed using a crusher, a grinding circuit, a gravity circuit, a 5.2 Mt per annum carbon-in-leach plant, and a 14-tonne stripping plant. In 2012, approximately 531,000 ounces of gold were produced. To obtain this amount, five million metric tons of ore was processed, the bulk of which became "tailings" which are piled in hills and in ponds. The amount of overburden, or rock removed to get to the ore bodies, is not included in this category but is estimated to be at least the same amount as the ore and possibly several times more (possibly over 50 Mt (see Anglogold, 2011)). The overburden is placed on the landscape near the mining pits to be "reclaimed" through grading and re-vegetation.

Large scale mining began in 1999 although the area has been a site of sporadic small-scale mining since Germany colonized Tanzania in the late 19th century. Underground mining from 1930s through the 1960s produced nearly 1 million ounces of gold. Artisanal mining is also common in the area, producing its own mélange of water and soil degradation (Mwakaje, 2012). Since 2000, Anglogold Ashanti has processed over 60 million tons of ore (our estimate). Process waste is pumped as slurry to a tailings storage facility. Water from the tailings facility is decanted and recycled back to the processing plant (Anglogold Ashanti, 2006). The process water originates from Lake Victoria and is pumped through a pipeline to the mine site.

In addition to mining, the major economic activities in the area are farming, livestock keeping and fishing. Water is very important for all of these endeavors, and in the Geita area, it is relatively scarce. Average annual rainfall is 950 mm, with Miombo woodlands, acacia species, scrubs and grasses predominant. Crops include cotton, paddy and maize. The wet season is bimodal with rains occurring from October through December and February through April. June through August is very dry with no rainfall in July during many years.

Data and methods

Remotely sensed data

Two Digital Elevation Models (DEMs) were used to measure topographic and hydrologic change in the study area over a period from February 1, 2000 to October 1, 2006. The February 2000 DEM (90 m) was derived from the Shuttle Radar Topography Mission (SRTM) (Jarvis, Reuter, Nelson, & Guevara, 2008) while the October 2006 DEM (30 m) was derived from four images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

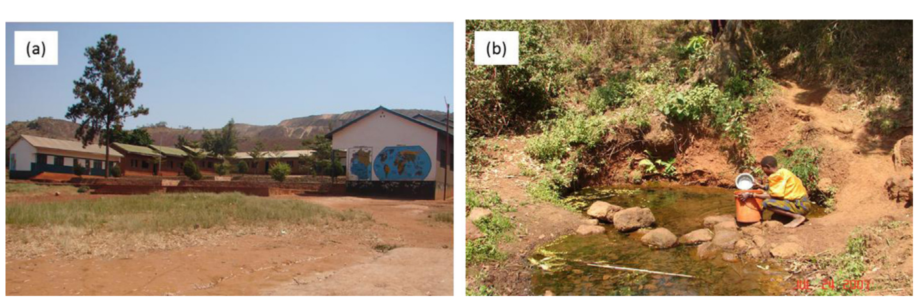

Fig. 1. Mine tailings from Geita mine, in background, overshadowing the primary school in Nyamalembo village (a), and a local woman draws water from a spring 1 km downstream from the Geita mine complex (b).

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