MODELING SITE SUITABILITY FOR COMMUNITY WATER ACCESS POINTS IN THE MAYANGE SECTOR OF RWANDA

R. Maxwell Baber
MS GIS Program
University of Redlands
Redlands, California 92373 USA
max_baber@redlands.edu

Abstract

Faculty and students from the University of Redlands undergraduate Environmental Studies and graduate Geographic Information Systems programs – in partnership with the Centre for Geographic Information Systems at the National University of Rwanda (CGIS NUR) and the Millennium Villages Project (MVP) – used GIS and Global Positioning System (GPS) technologies to develop a database of existing community water access points in the Mayange sector of Rwanda and explore characteristics associated with better water quality and quantity. Members of the project team field-captured water access point locations and surveyed local residents at water access sites regarding household water usage habits, along with information about frequency of water collection and amount collected daily. Spatial dimensions of land use and land cover were likewise evaluated and incorporated, along with the water access point data, into a cartographic model to support improved access to better quality water supply. Data collection occurred in a subset of the Mayange sector, and model results were applied to a broader portion of the sector to evaluate potential for locating new water access points. A well-developed model supports more effective diagnoses of problems with existing public water sources and also identifies areas well-suited for new water access point locations. Field data collection and model development was managed by the University of Redlands project team with support from the National University of Rwanda GIS Centre and MVP staff. In addition to data collected and interviews conducted in the field by members of the project team, additional information was derived from surveys previously conducted by MVP regarding household water use and water sources in one section of Mayange. Further, the National University of Rwanda Centre for Geographic Information Systems in Butare likewise provided base data on environmental, demographic, and topographic conditions. These data were incorporated into a GIS database to prepare for model development. The premise behind the model is simple: information about known locations of high quality, reliable water can be used to predict other locations where a good water source is likely to be found. Moreover, that same information can be used to diagnose the limitations of existing water sources. To develop the model, environmental and socio-cultural information for existing higher quality sites were compiled and formatted within a GIS, and these characterizations were applied to other geographic locations. There were limitations in available data that, in some cases (such as population density), required the use of surrogate data (in

this case housing density) for input into the cartographic model. The degree to which various prospective water access locations (as identified by the model) are similar to existing better quality water resource sites determines suitability as a water access point. Model results were output as maps, where each area on the map is ranked according to water access point suitability, enabling locations of lower quality water access points to be easily compared with the better water access point locations. The model allows the project team to better diagnose problems at lower quality sites and to identify new areas that may prove to be suitable locations for water source improvement projects.

Introduction

The University of Redlands has an undergraduate degree program in environmental science, an applied research group known as the Redlands Institute (RI) and a one year intensive Master of Science in Geographic Information Systems (MS GIS) degree program in These three programs are designed to work in complementary and synergistic ways to enhance students' knowledge of environmental issues and to facilitate applied learning through exposure to 'real world' projects.

In December 2007, a project proposal (*Developing a GIS-Based Suitability Model for Rural Water Supply in Rwanda*) was submitted to and subsequently funded by the Southern California World Water Forum program, administered as an educational initiative by the Metropolitan Water District of Southern California. Our project endeavored to support one among twelve of the Millennium Villages Projects (MVP) located in Africa – the Mayange sector of Rwanda in this case – using GPS to map water access points in this region and model results towards guiding MVP staff in their decision making as they planned improvements in community access to water resources. The Millennium Village in Rwanda is located in Mayange sector in Bugesera district, Eastern Province (Figure 1). The area is almost completely deforested and receives ~800mm of intermittent annual rainfall. Crop failures due to lack of rainfall are increasingly common and drinking water supplies are scarce and often dirty and unreliable. Women and children bear the major burden of water collection, traveling long distances, almost always on foot. Pumps and faucets are often neglected or broken and conservation measures are essentially non existent. Access to water tables deeper than about 50 meters is not possible in most areas due to lack of power for motorized pumps.

Rwanda is a relatively small yet densely populated nation located more than 1,000 kilometers distant from East Africa's Indian Ocean coast. It is situated on a hilly plateau composed largely of volcanic soils, many parts of the country above 1,700 meters, another 1,000 meters higher in the mountainous north and west, and somewhat lower towards Tanzania to the east. The Nile-Congo divide runs through the mountains of western Rwanda.

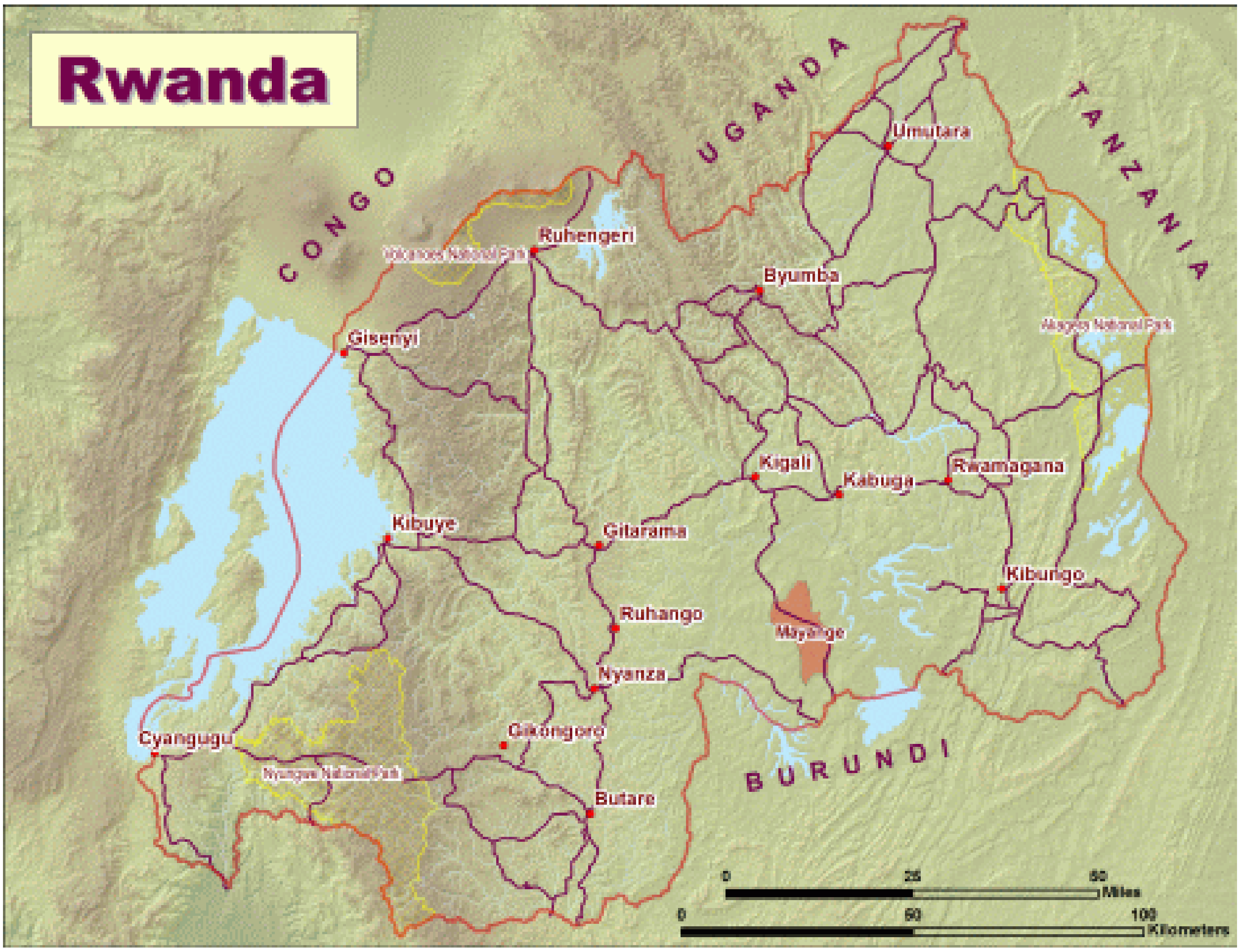

Figure 1. Mayange sector highlighted in light red, approximately 30 kilometers south of Rwanda capital Kigali

In Mayange there are challenges for all aspects of water use: access and availability, quality, ownership and upkeep of water access points, environmental degradation and water source contamination. Millennium Promise development goals include a fifty percent reduction by 2015 in populations that lack sustainable access to safe drinking water. Sub-Saharan Africa is the greatest challenge, experiencing a 23 percent increase in population without access to safe drinking water from 1990-2004. Nearly half of the developing world suffers effects from water-borne disease. MVP staff in Mayange support a variety of initiatives designed to improve agriculture, health, education, and economic development. Current Mayange sources of water include the following (Figure 2):

- piped water system
- boreholes
- shallow protected and unprotected wells
- rainwater from puddles

- rainwater harvesting from rooftops
- collection of rainwater and surface runoff in water ponds

Figure 2. Open pit well, shallow well, water tap from national water system, and borehole well (clockwise from upper left)

The objective of our project was to assist MVP to use GIS and global positioning system (GPS) technologies to identify ways to improve community water access points in Mayange. The term 'water access point' refers to that variety water sources found and mapped throughout the community. MVP's challenge is to identify suitable locations for new water access points, whether provided in the form of newly drilled borehole wells or as water taps connected to newly built extensions to the national water system.

In addition to field data collection with GPS, we also utilized a variety of spatial data layers provided by the Millennium Villages Project and also the Centre for Geographic Information Systems & Remote Sensing at the National University of Rwanda (CGIS NUR). These data were incorporated in a GIS database and supported model development. Analysis performed by the University of Redlands team, our CGIS NUR counterparts, students and MVP staff. Maps, tables and other documentation summarizing the outcomes of the analysis have been shared with MVP staff and included in the final project report. Field data gathered by University of Redlands undergraduates and MVP staff in Mayange were used in spatial analysis assignments within the University of Redlands graduate GIS program, exploring different geographic characteristics associated with the variety of water access points.

Mayange sector data for this project includes the following:

- SRTM terrain raster
- QuickBird image, subset of Mayange sector
- Roads/trails data extracted from QuickBird image
- House locations extracted from QuickBird image
- Lake features extracted from QuickBird image
- Mayange sector boundary
- Boundaries for administrative subdivisions (cells)
- Water access points from GPS field collection

The 90 meter SRTM raster was resampled to smooth appearance for use at Mayange data scale. The QuickBird image was obtained by MVP after they began local efforts in 2006 but before they were fully aware of the Mayange sector's full spatial extent. GIS staff at the Earth Institute located at Columbia University in New York City (one of three lead project partners, along with the United Nations Development Programme and the Millennium Promise, a not-for-profit educational foundation) extracted roads, houses, and lake locations to GIS feature layers. Administrative boundaries were provided by CGIS NUR staff, and water access points were collected in the field by University of Redlands undergraduates partnered with MVP staff.

Project Development

Teams of University of Redlands faculty and undergraduate students visited the Mayange sector during May 2008 and again in May 2009. Preparation for fieldwork was introduced during planning sessions at CGIS NUR facilities in Butare prior to visiting the Mayange field site. GIS data for the Mayange area was assembled into a project database, and students were given opportunity to acquaint with the use of GPS receivers. Redlands students participating in this project did not have prior experience, and thus needed time to practice and develop basic field data collection competence.
Project planning continued with MVP staff on arrival at their offices in Nyamata, just northwest of the Mayange sector. Given logistical difficulties associated with driving multiple field data collection teams into the study area along with local guides and translators, the planning task took on a bit of an ad hoc nature, reviewing what had been accomplished at the end of each day, and figuring out what was possible each morning

given the impact our team was having on the day-to-day MVP operational routine that was somewhat disrupted by our visit.

The Mayange sector is sub-divided into five administrative cells, including Gakamba, Kibirizi, Kagenge, Mbyo and Kibenga (Figure 3). A military installation is located in the southern portion of Mbyo, is out of bounds for civilians and therefore not within the MVP area of interest. A stream network does not exist, but a lake fed by groundwater is located along the southwestern border. Population in Mayange totals about 25,000. Population is generally clustered on ridges and agriculture dominates the valleys.

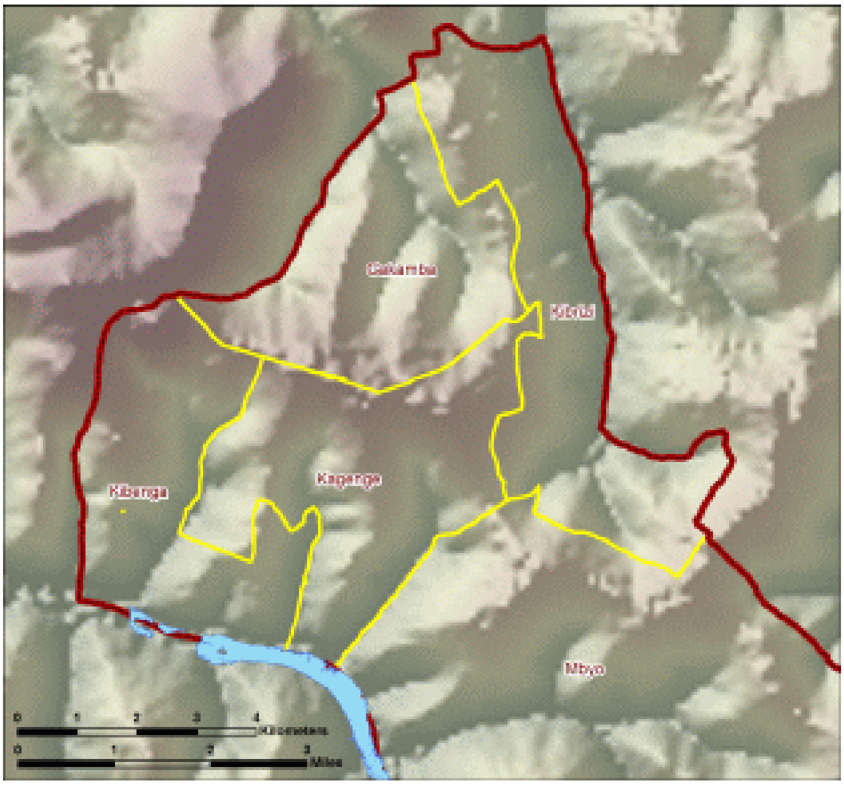

Figure 3. The five administrative sub-units (cells) of Mayange

The QuickBird aerial image acquired by MVP for the Mayange sector (Figure 4) is revealed by overlay with sector boundary data to be a subset of the study area. Lack of certainty regarding Mayange boundaries was explored using local guides, validating that the northern perimeter extended much further than the spatial limits

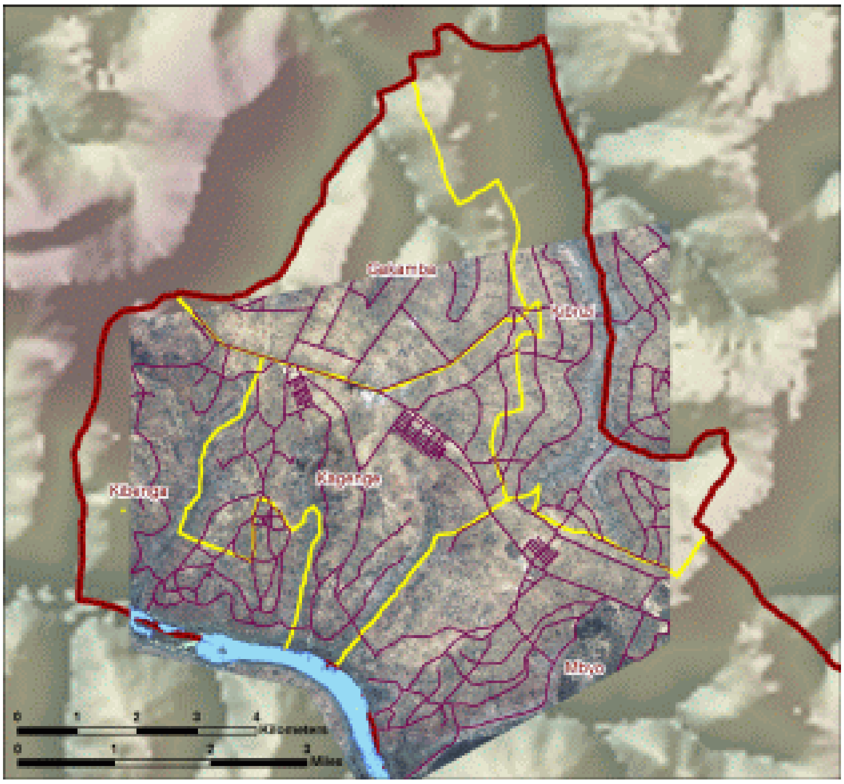

Figure 4. Study area coverage provided by QuickBird image

of the QuickBird image. This restricted effective data modeling to the area covered by this image, which was used to derive the best available local feature data.

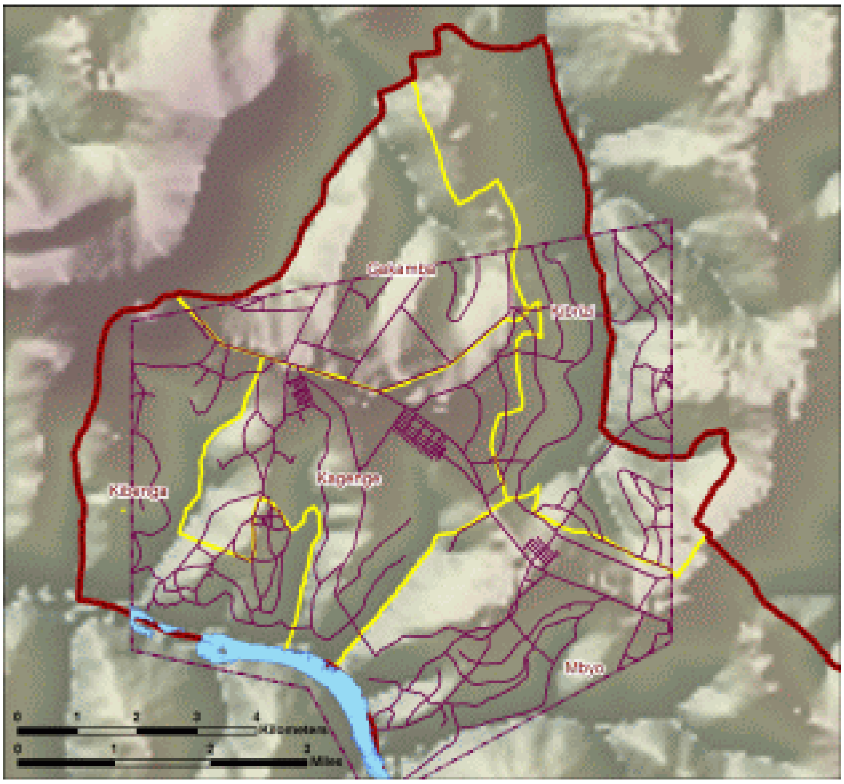

Figure 5. Road network extracted from QuickBird image

A road feature layer extracted by Earth Institute staff from the QuickBird image gives a highly accurate reference for this local transportation network (Figure 5). Except for the main highway that bisects Mayange from northwest to southeast, these are dirt roads, often little more than trails. Very few motorized vehicles traverse these routes away from the main highway, other than those from non-governmental organizations (NGO) that support local development.

A feature layer showing the location of households in the Mayange core (Figure 6) presents an analog for population density. Earth Institute staff was able to extract these features from the QuickBird image because of the relatively uniform use of corrugated metal roofs on the vast majority of houses (more than 95 percent, from visual estimation). Highest density is apparent in three resettlement areas established

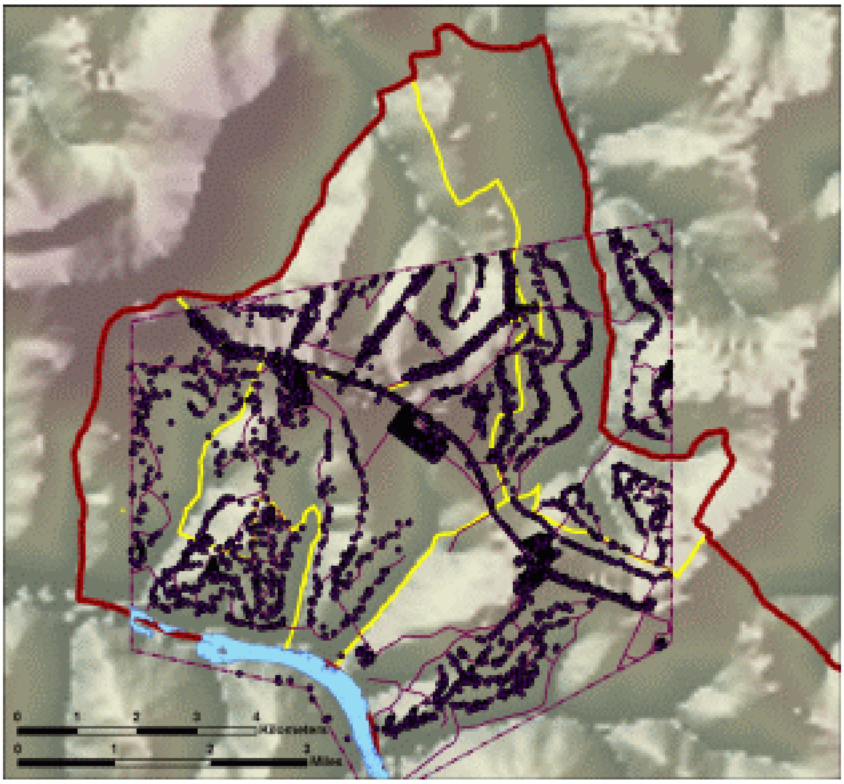

Figure 6. Households in the Mayange sector

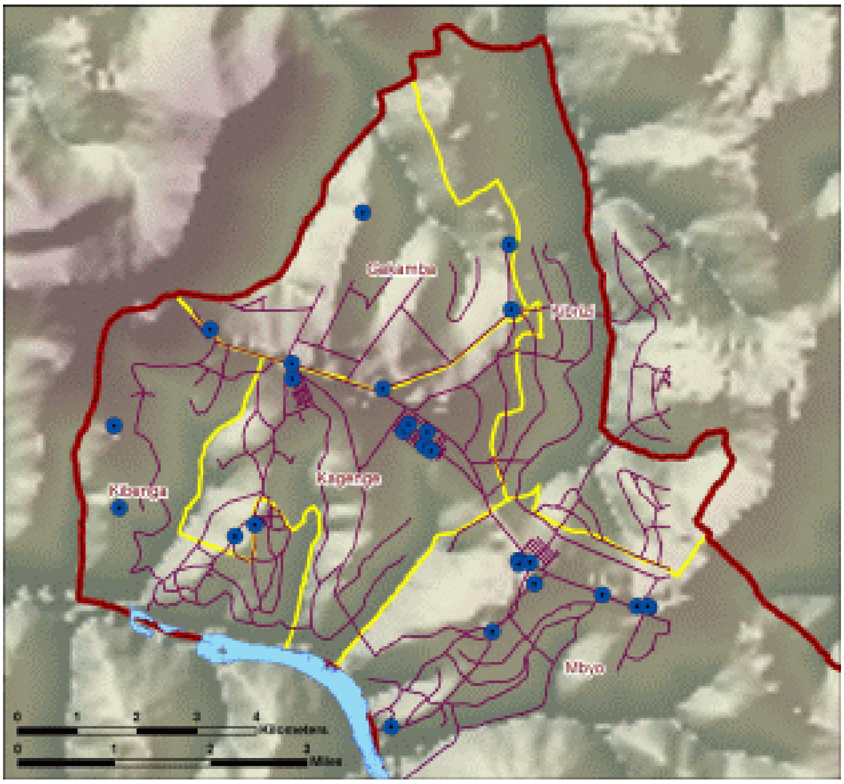

Figure 7. Water tap (connected with national system) locations in Mayange

subsequent to the civil war and 1994 genocide.

Existing water taps – those water access points directly connected to the national water system – are sparsely distributed through Mayange insufficiently serving the needs of 25,000 in population (Figure 7). MVP's goal is to ensure that no household is further than one kilometer away from a water tap. Households gather water from water access points via 20 liter "jerry can" and carry home across considerable distances, often several times each day.

A Euclidean distance raster was derived from the existing water tap locations, for input into a simple model designed to identify suitability for new proposed water tap locations (Figure 8). Raster output extent was masked to boundary of the QuickBird image, source of the household analog for population distribution. This distance raster was then reclassified for model input, with higher values providing

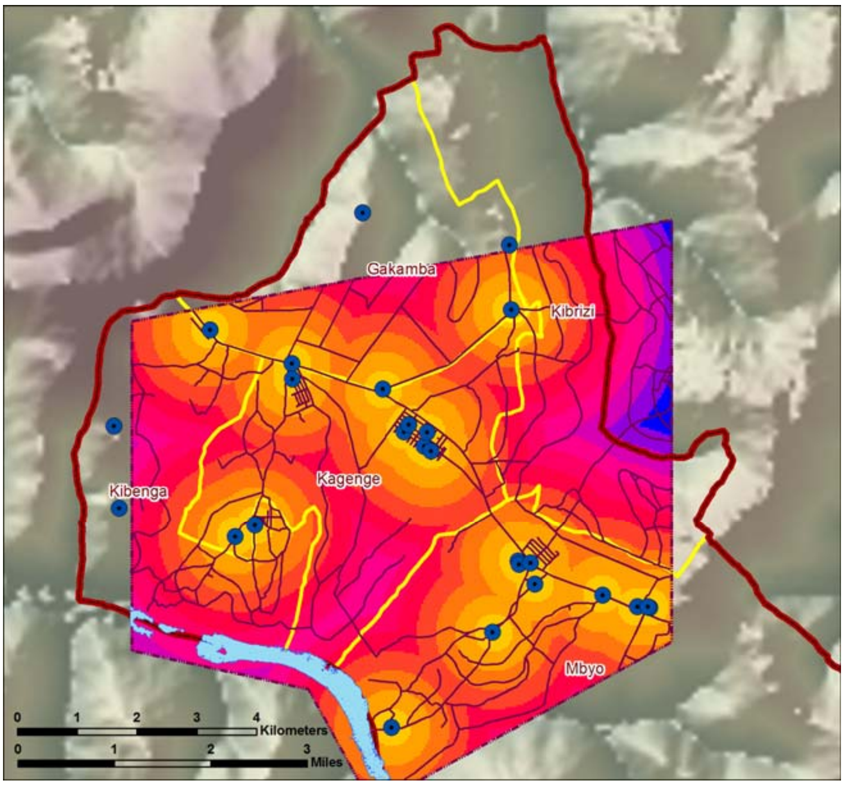

Figure 8. Euclidean distance raster derived from water tap locations

a criterion indicating higher need for new water taps.

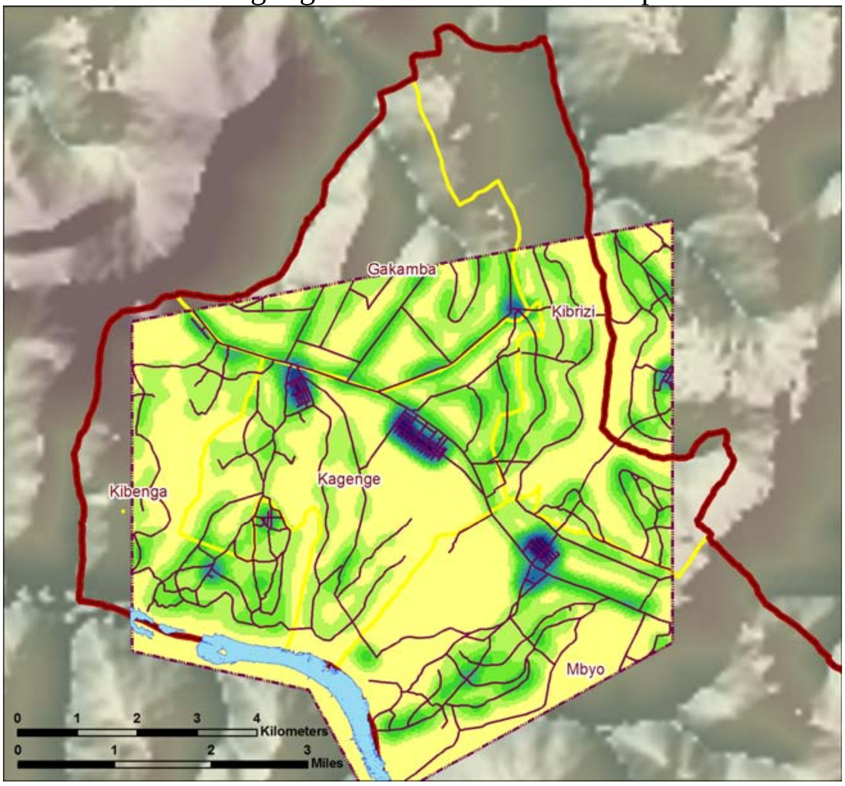

Figure 9. Density of households in Mayange core

Density of households was derived from the location of household features, as a second input into the simple suitability model for new proposed water tap locations (Figure 9). Highest density values are found in those post-civil war resettlement locations, which are general but not uniformly better served by access to existing water taps. This density raster was likewise reclassified for model input, with higher values providing a second model criterion.

Overlay of the reclassified household density and distance from existing water tap locations reveals greatest needs for new proposed water tap locations in those areas with higher density populations underserved by existing national water supply (Figure 10). These areas of greater need include much of the southern portion of Kibirizi, and that portion of Kagenge proximate to the nearby lake. One surprise is the lack of a water tap in one

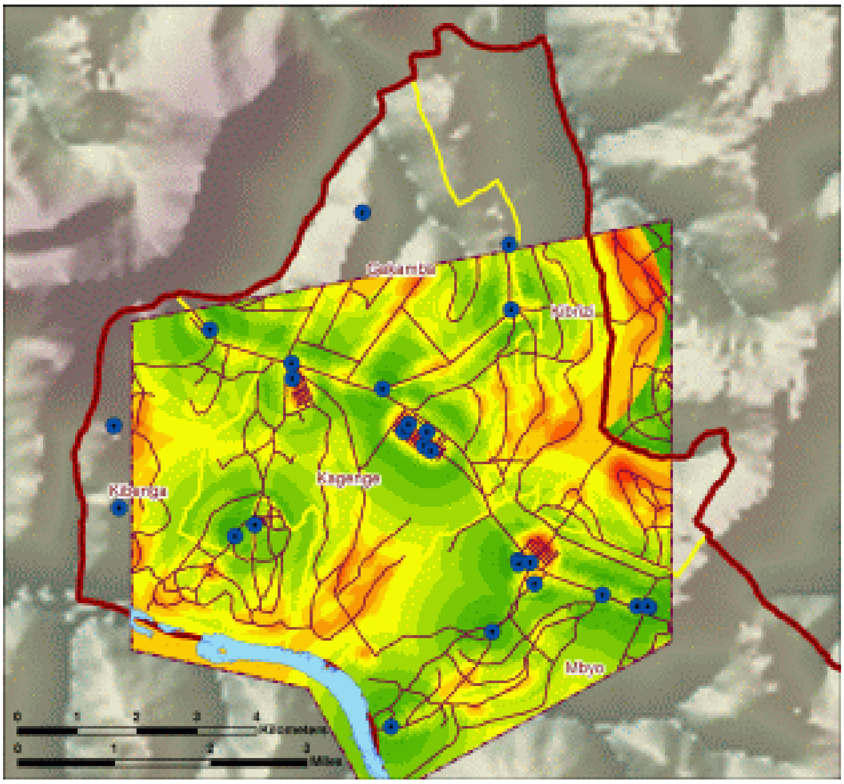

Figure 10. Overlay result, red shades indicating greater water tap need, existing water taps represented by dark blue point symbols

of the densely populated resettlement areas in Mbyo.

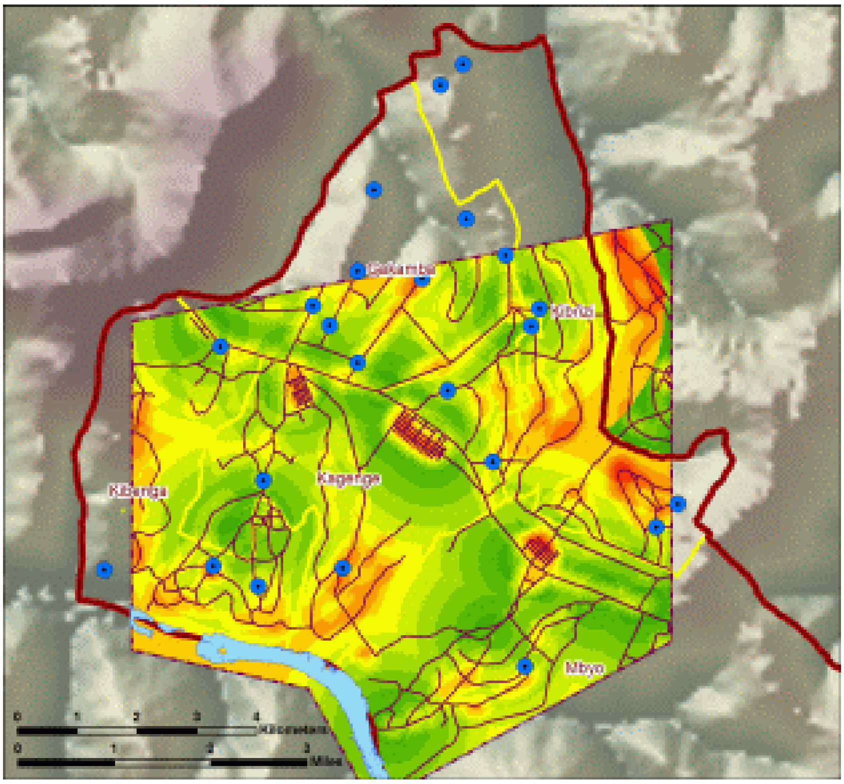

Figure 11. Proposed water tap locations symbolized in light blue atop model results, revealing inconsistent correspondence between need and proposed new sites

Finally, the set of proposed water tap locations field mapped as indicated by MVP staff reveals inconsistency in effective correspondence between those locations proposed by MVP staff and areas of greatest need for improved accessibility to national water system, as indicated by this simple suitability model (Figure 11). These results suggest clear benefits from using GIS in resource assessment and evaluation for improving access to water resources.

Conclusions

Many challenges exist for those organizations working to improve living conditions in the developing world. GIS provides a useful means to improve the efficiencies and effectiveness of community planning and development in Rwanda. Improvements in data availability in this region and increased use of geographic technologies can enhance abilities to manage natural resources and support quality of life in rural areas.

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