Assessing Subsurface Hydrology in Ntisaw, Cameroon

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December 1, 2011

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Project Background

In a rural village in the northwest province of Cameroon, approximately 1000 people in a village known as Ntisaw currently drink from a contaminated surface water source. Understanding the importance of safe drinking water for protecting human health, the village raised enough money to hire a local engineer in 1994 to construct a system to supply clean water and lessen the burden placed on women and children from having to haul water long distances. The hired engineer built a spring box to supply water via a gravity-fed water distribution system, but then ran off with the villages' money.

Fourteen years later, the community was still trying to gain access to clean drinking water. The project eventually came to the attention of the Engineers Without Borders national office, and in the fall of 2008, the Engineers Without Borders chapter at the University of Illinois at Urbana-Champaign (EWB-UIUC) was granted permission to complete the system. Site assessment trips were completed in the summer and winter of 2009. By the fall of 2010, designs were completed, supplies ordered, and the village was prepared to construct their system. Three students (myself included) and our mentor, traveled to the village to begin construction on the system during the winter of 2010/11. Over 6.5 km of pipeline was laid, 4 stone water storage tanks were built, and 14 public tap stands were placed strategically throughout the village.

By the summer of 2011, the system had been completed and water was flowing. There are two issues however. The first is that the catchment area surrounding the spring box is being contaminated by cattle that are permitted to graze in the area; which means the water supplied to the village may not be any safer to drink than the surface water they used previously. The second issue is that the spring box was not built correctly and has been known to run dry in the height of the dry season in severe drought years. Extending the current spring box is not an option as there would no longer be sufficient head to supply the water via gravity alone. Building a second spring box would be expensive and may potentially not fix the problem as there are diffuse (not point) springs in the area.

Therefore the proposed solution to the first problem is build a fence as well as dig a berm surrounding the fence to direct run-off downstream of the spring box. The solution for the second issue is to install a French drain (normally used in Illinois to drain fields and prevent crops from flooding) to provide water when the spring box is not sufficient. To determine water flow patterns and decide on the feasibility of such a plan, our team installed 31 monitoring wells throughout the catchment area while in-country this past January. This GIS project will look at both of those issues and examine the proposed solutions.

Data Sources

As this is a small community in rural Cameroon, accessing data with the needed resolution posed a significant challenge. Shuttle Radar Topography Mission 90 m data was downloaded, and Google™ Earth images were georeferenced. Water table information was provided via the 31 monitoring wells. Rain data was supposed to be provided by a member of the village; however, data from the last 4 months (which is crucial as it is the monsoon season) is still missing - the roads are too bad to travel to another town with internet access, and rolling black-outs have made using the internet impossible anyways. GPS data had been collected for parts of the community while in-country, and an abney level provided more accurate elevation data for the catchment. We also collected soil data in-country, however this data has not been used yet since modeling of bacteria flow patterns through soil is still a work in progress.

Methods

Geoferencing

The first step in this project was to save the Google™ Earth image of the village and upload it to ArcGIS. Four known points scattered throughout the area were used to georeference the image. Next I had to input very haphazardly recorded data from time-pressed trips into excel sheets. That information was then uploaded in files containing latitude and longitude information for the following: pipeline, storage tanks, public tap stands and spring box, and overlay these data (which was collected in-country with a GPS) onto the georeferenced map, as shown in figure 1. Since this figure only provides a visual reference to the village, both the image and uploaded data were left in the geographic coordinates World Geodetic System of 1984.

Although georeferencing was not the ideal methodology for gaining a basemap, the loss of elevation data was justified by the higher resolution it could provide compared to other sources (HydroSHEDs, SRTM); especially considering the fact that the catchment is less than 0.4 km^2. While figure 1 helps the reader visual the village, the main focus of this project is in the catchment area alone. Therefore the next step was to delineate the actual drainage area as well as add the data on the monitoring wells and fence, as shown in figure 2. Construction on a fence has already started in the village to protect the watershed from cattle. In reality though, the catchment is a significantly larger area (it is the green demarcated area), but extending the fence further was not an option as this is prime grazing land and we do not want to be responsible for creating cultural tensions in the area between the Fulani (who raise cattle) and the Wimbum (farmers). These data were also collected with a GPS while in-country. The points collected for the drainage area and fence were plotted as a polygon for more simple data analysis. Throughout the remainder of this paper, I will refer to “catchment area” as the area within the fence, and “drainage area” as the land within the green polygon. We also installed 31 monitoring wells using a hand auger in order to measure the water table height to determine annual fluctuations. Figure 3 shows a schematic of one. This data has been occasionally collected by the village, as well as by our travel teams.

Drainage calculations

While in-country, we defined our drainage area based solely on visual assessment of the landscape. There is a clearly defined horseshoe character to the land, as shown in figure 4. By walking along its rim and collecting GPS data, we could determine the potential drainage area (0.38 km^2). The data we collected was compared to SRTM downloaded data.

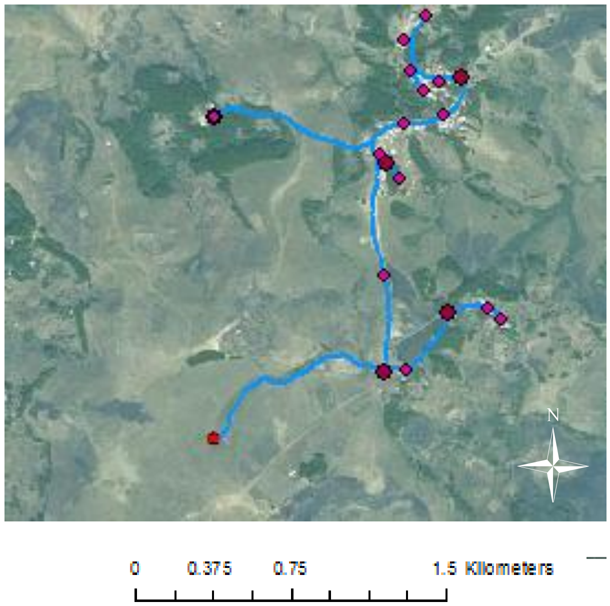


Figure 1. Georeferenced Google™ Earth image of Ntisaw Village, Cameroon created via ArcGIS. The blue line represents the pipeline, the large pink boxes are the storage tanks, the small pink boxes the public tap stands, and the red large box is the spring box.

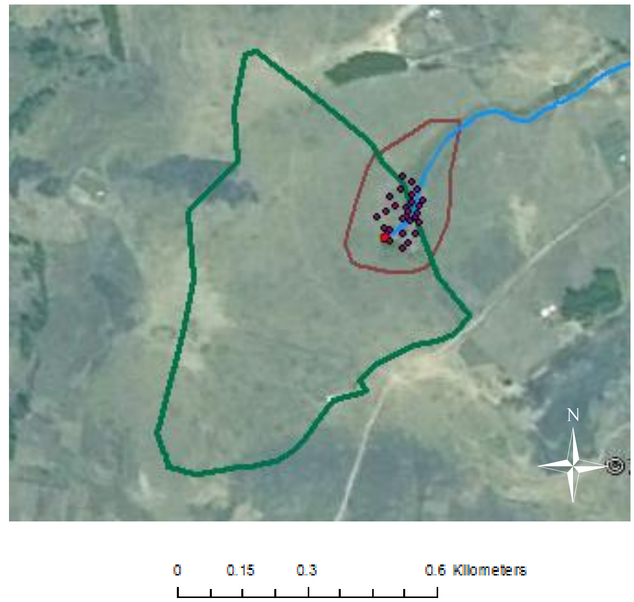


Figure 2. The brown line in this image represents the fence that has been installed to prevent cattle from grazing in the area. The green line represents the total drainage area. The purple dots are monitoring wells installed to measure the water table level. The red dot is the spring box.

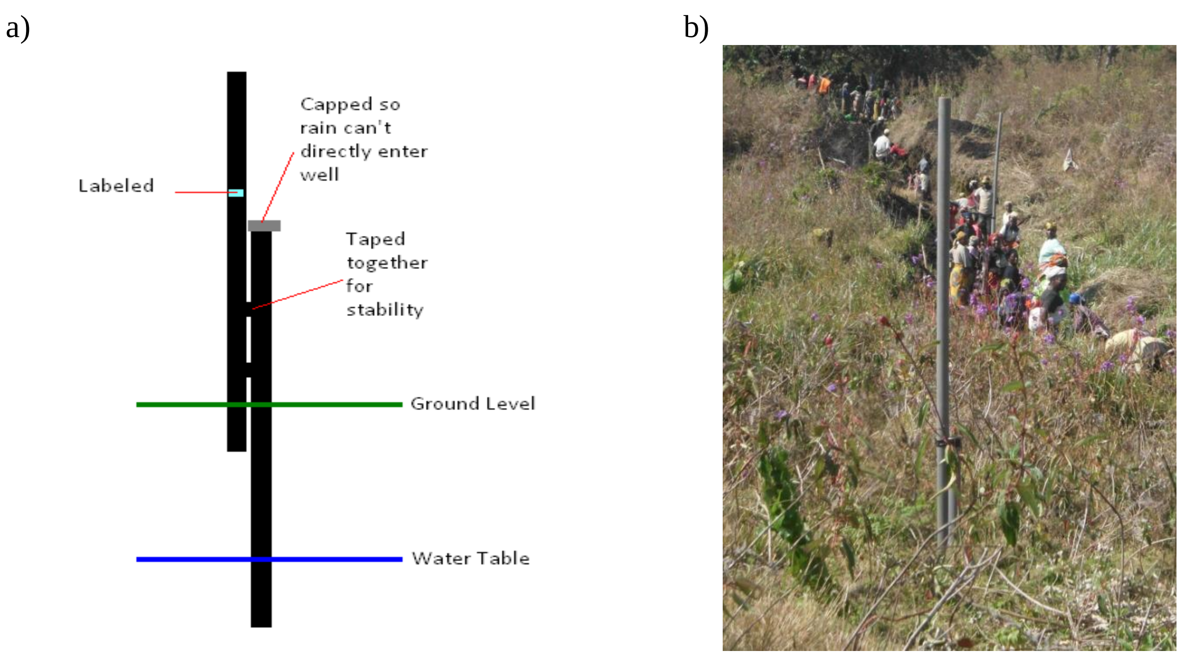


Figure 3. (a) Monitoring well diagram and (b) picture of ones installed. There are 31 wells located throughout the catchment. Of these, 27 require someone to measure the water table height personally with a float and tape measure. The remaining 4 are measured with a makeshift hobo logger/pressure transducer system that we devised for this application. Those 4 wells collect the water table height every 12 hours, and the only maintenance required is uploading the saved data every 2-3 months. This diagram was drawn by Manu Kumar, another EWB team member.

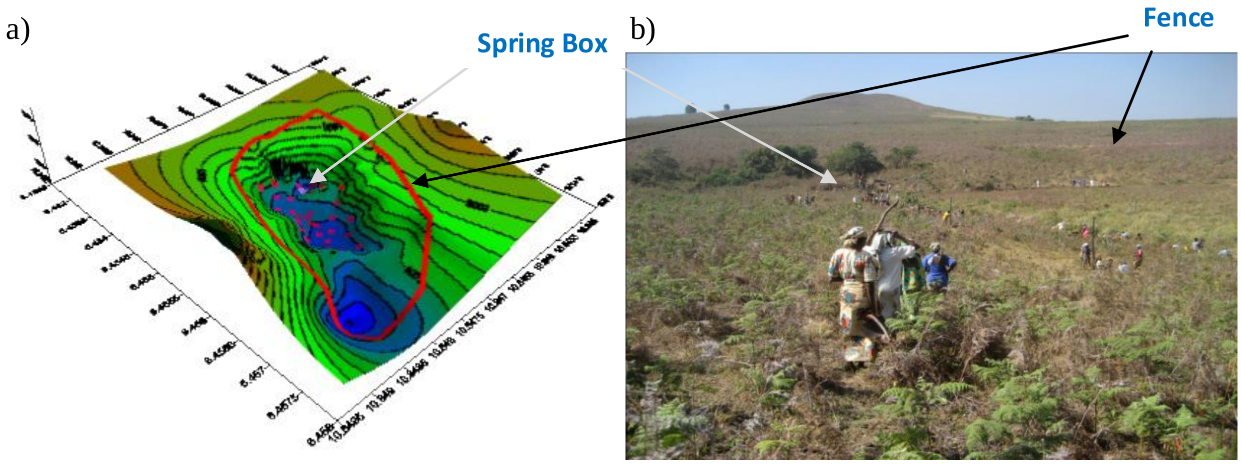


Figure 4. The catchment area and drainage basin are shown. (a) Elevation data points collected with an abney level were uploaded to Surfer Program. (b) A picture of the same area facing the same direction is also provided.

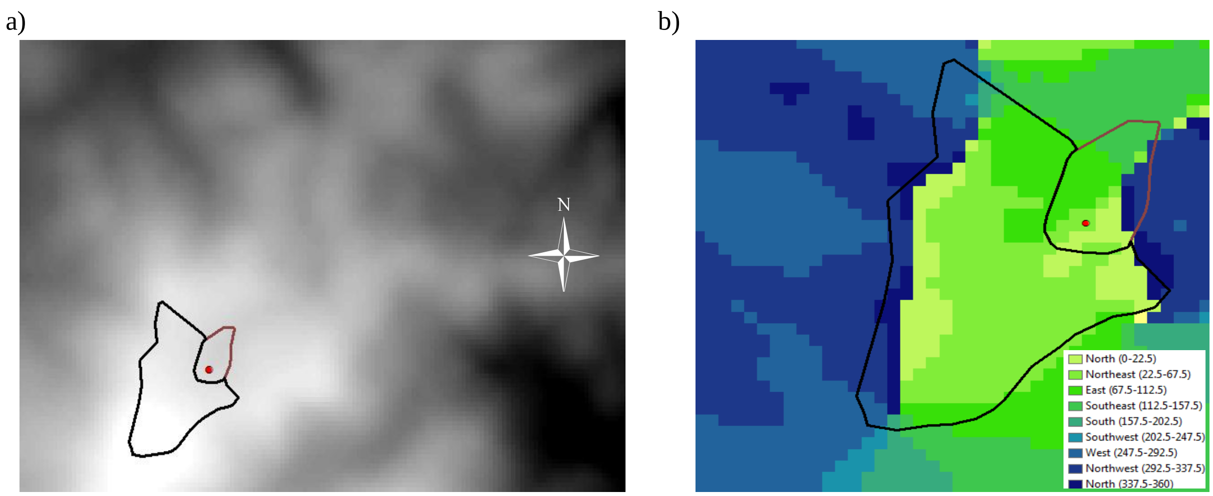


Figure 5. (a) Basemap of the entire village, clipped from the larger DEM that contained the entire NW province of Cameroon; and (b) aspect function after running it in ArcGIS for the catchment area.

In order to make this comparison, SRTM data (90 m) was added to ArcGIS. Using the "clip" function, the DEM size was matched with that of the georeferenced image for faster data analysis. The clipped DEM was then projected to the LGD2006_UTM_Zone_32N coordinate system, which was use throughout this entire project. Using the "fill" function, followed by the "aspect" function, a visual representation of the downward slope from cell to cell within the area was obtained. As shown in figure 5, our assumptions are relatively well-matched to those determined via ArcGIS with the downloaded DEM. Then using the area calculation function, the polygon drainage area was determined to be $0.38km^2$.

As mentioned previously, Ntisaw faces a distinct monsoon season. With this comes torrential rain fall, potentially causing the spring box to receive contaminated surface water, as the ground is not able to act as a natural filter during high intensity storms. Since we are trying to protect the spring box from receiving surface water or contaminated water, one of the goals of this GIS project was to model a berm on the outside of the fence to see how flow lines change with its installation. The berm will direct run-off water away from the catchment. Calculations were completed with the Rational Method to determine surface runoff using rain data that the village has been collecting. Comparing those results along with the ability of the village to create a large berm, it was determined that the height of the berm would be approximately 1.5 ft high. This would give the water more time to percolate through the soil and prevent heavy runoff from entering the drinking water supply.

To model the berm on ArcGIS, I first used the Editor tool to draw a polyline immediately adjacent to the fence line. Then using the feature to raster function, I turned the line into a raster with the same cell size and extent as the DEM. The raster calculator allowed me to assign elevation data to the raster (which I made the same size as the original DEM, plus one extra meter to model the berm). Finally, I created a mosaic dataset to overlay the berm raster with the original DEM. After I had all the correct elevation values assigned to each cell, I once again used the aspect function to determine downslope direction. As shown in figure 6, the downward slope is nearly identical to the original one (figure 5b), with one important difference – the slopes immediately before the berm change, demonstrating that water is directed away from the catchment.

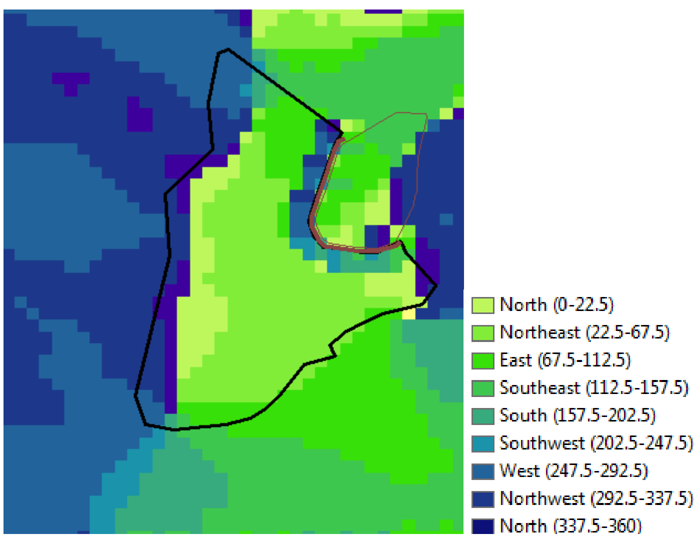


Figure 6. The catchment and drainage areas are shown, with a berm (dark brown line) modeled along the outskirts of the fence.

Water table height calculations

The next goal of the project was to determine if when the spring box ran dry, the French drain that was installed could provide supplement it. This is believed to be possible (even though the spring box and drain are in close physical proximity to each other) because another spring source is contributing to water that the French drain receives. In order to determine the feasibility of this, we collected elevation data of the catchment using an abney level while in-country. Since all points that were measured were referenced to one point in the catchment and assigned an arbitrary value, it is not correlated to the actual elevation in the DEM. However, since it is only the elevation of the water table subtracted from the ground level that is important, it does not matter that the height of the water table is in reference to an arbitrarily chosen elevation value or the actual one. For these calculations, the elevation data points that we collected were uploaded and then interpolated using natural neighbor. This is shown in figure 7, where the interpolated ground level elevation has the wells and spring box locations overlaid.

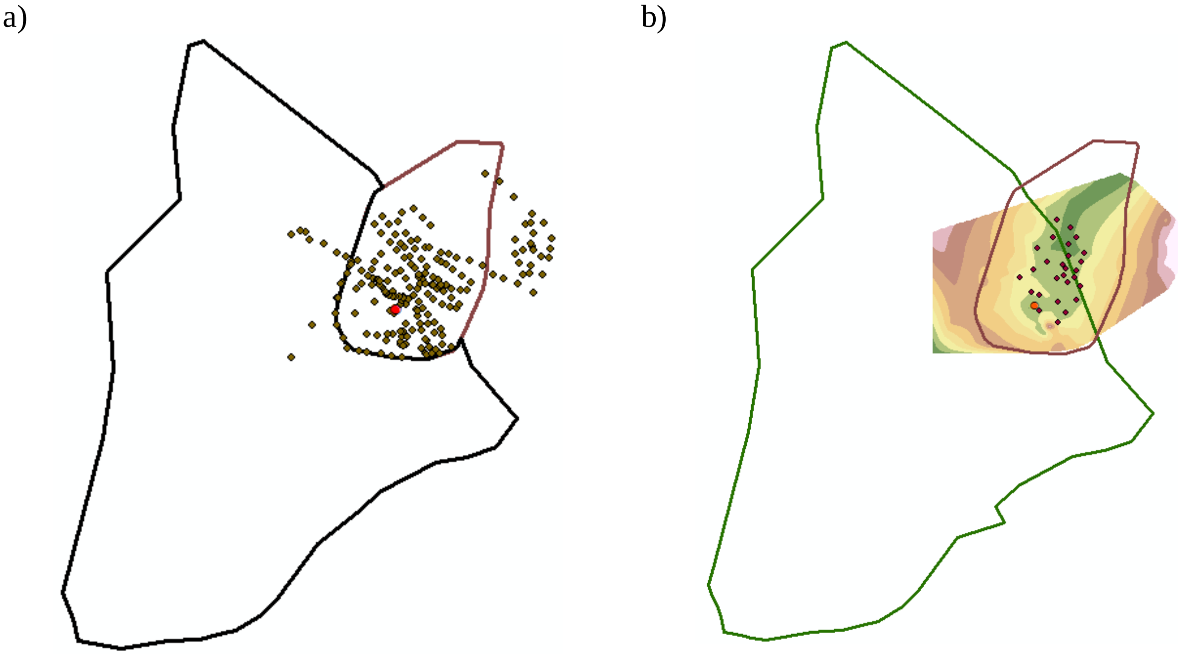


Figure 7. Elevation points collected in-country with an abney are displayed in (a) and interpolated using natural neighbor in (b).

With this information, the water table height at each of the wells could then be compared to the ground elevation, providing information on how the water table changes throughout the catchment area over the course of a year. Village members measured the water table height at each of the 27 wells (reminder: the 4 additional wells are automatically monitored) three times a week from January 2011 through March 2011. There is currently no other data, except one time-point at the end of May when the travel team was able to take measurements. This data is summarized in the time series video saved here[1].

As the video shows, there are small fluctuations in the water table from January through March. This is assuming that the collected data, which was averaged over a week, is reasonably accurate. However, the data point in May is relatively distinct from the others. This may be due to different measuring techniques undertaken by the village versus the EWB team, or it may be that the water table does change that drastically from the beginning of the dry season (Jan) to the beginning of the wet season (May). Without additional information, conclusions are hard to draw.

To build the time series, a mosaic dataset was created and rasters were added to it. For this case, the rasters were interpolated water table heights based on the data from the village and the travel team. Those rasters were labeled with dates, such that a time field could be added to

[1] Video saved at: https://webspace.utexas.edu/xythoswfs/webui/_xy-45077201_docstore1-t_ln6grC7y

the dataset and information directly uploaded to it. After enabling time on the layer, the function “calculate cell size ranges” was used to permit the layer to be zoomed in and out, and finally, the time slider window was used to play the video and export it.

The video can be summarized with the two images shown in figure 8. As the dry season progresses, there is a decrease in the water table height throughout the entire catchment. In January, the difference in water table height from the spring box to the drain is approximately 0.7 meters, and in May it is 1.2 meters. However, there is a more significant decrease at the spring box then at the French drain, implying that the water table height at the drain decreases more slowly, possibly due to the additional spring sources that are believed to feed into it. Based on this, it appears that the drain is still a possible option to consider, although clearly more accurate and extensive data is needed.

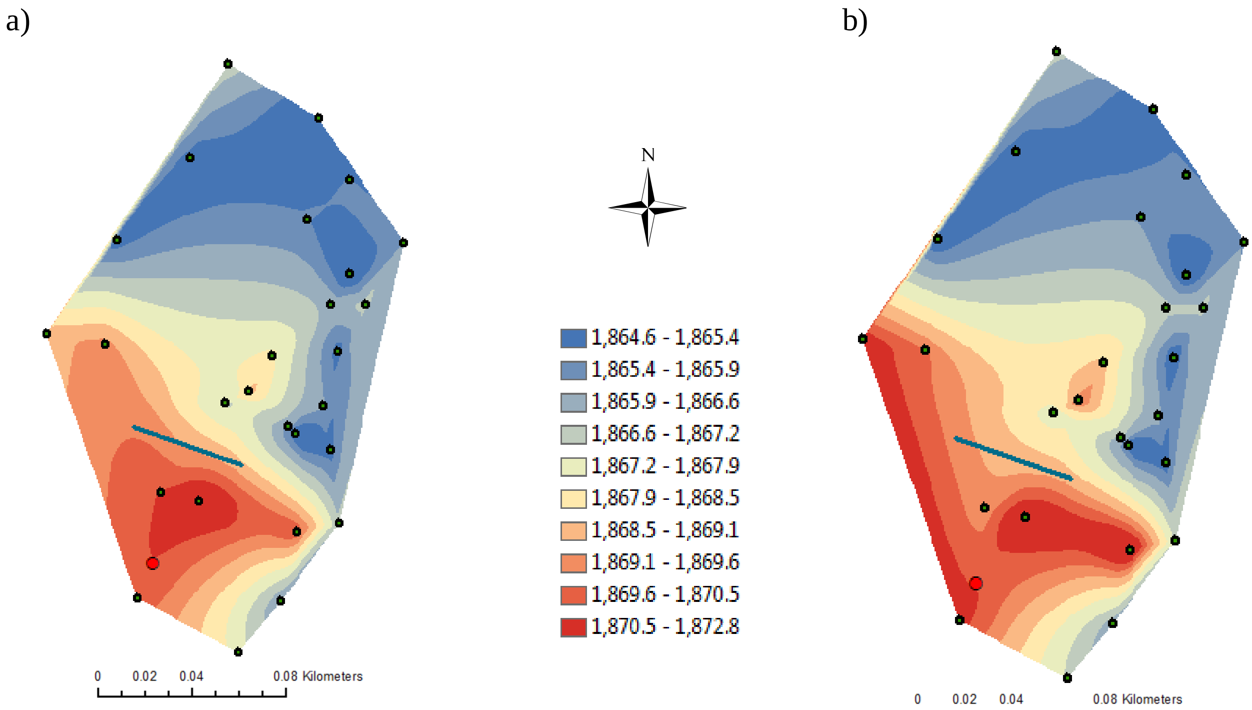


Figure 8. The water table height is shown for (a) January 2011 when collected by a village member; and (b) May 2011 when collected by the EWB UIUC team. The red dot represents the spring box, the black ones the wells, and the blue line the French drain.

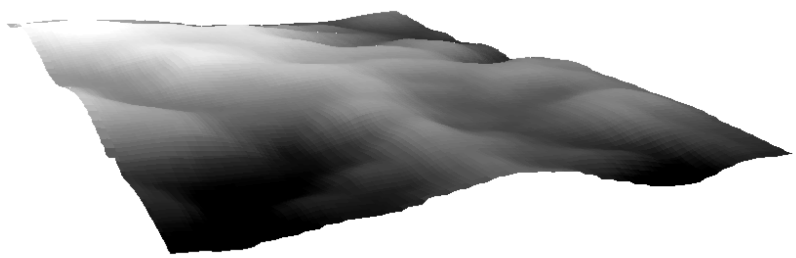
Results

Protecting the catchment is our number one priority. If this is not successfully accomplished, we will be providing contaminated drinking water, and the village will continue to face health issues. One way that we plan on reaching this goal is to construct a berm such that runoff is directed away from the spring box and French drain, preventing surface water from flowing into the catchment and allowing the soil to act as a natural filter. As demonstrated in this project, a berm will change flow patterns of water into the catchment area from the drainage area.

Our second goal is to provide water all year round (even in severe drought months). In order to do this, a secondary water system is necessary as the spring box has been known to run dry. One potential option is a French drain. Initial modeling of the fluctuations of the water table have now been started, however, significantly more data is necessary in order to make assumptions about the ultimate potential of the French drain.

Future Work

Future steps include interpolating the water table beyond the locations of the wells. In addition, bacterial contamination flow patterns from the drainage area into the catchment area will be modeled to determine the efficiency of the fence and how protected or unprotected the water source is. Additional data will be gathered on the water table heights at the drain and spring box for a more critical look at supplementing the spring box with the French drain in the height of the dry season. Along with this, rain data from the village will be correlated with the fluctuations in the water table. And finally, I would like to learn to properly use ArcScene in order to visualize in 3D the village and catchment to determine gravitational flow issues associated with a French drain and the possible installation of a water filter; currently it just looks like this and I do not know how to properly extract data from it!



Acknowledgements

I would like to give a special thanks to Fernando Salas for his infinite patience in helping me. Without him, even the basics such as uploading an excel sheet and properly displaying and projecting it would have been more painful than it already was! I also would like to thank the rest of my EWB team (especially our mentor Dr. Richard Cooke and the other technical lead, Andrew Rehn), since ultimately this is a group project with results that impact an entire community.

Resources

http://srtm.csi.cgiar.org/