Dominican Republic Research, Service, and Teaching: Drinking Water and Indoor Air

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Abstract

Teaching, research, and service in the Dominican Republic and on-campus led by the Engineering for Development program at Mercer University are presented. The research and service focus is improved health and livelihoods among rural populations, through improving environmental health conditions (e.g. access to water, less-polluting cooking practices, etc.). Research, service, and training are performed in the field in the El Cercado area of San Juan province, Dominican Republic. The experiences are shared back at Mercer University, where additional research is performed and examples from the field are used to stimulate and complement the teaching of fundamental engineering concepts, as well as principles of sustainable development.

The water activities focus on improving access to safe drinking water to local communities through: construction, expansion, and rehabilitation of gravity flow systems; pilot action research for improving spring protection through low-cost drilling of horizontal wells using portable drills; and building the capacity of stakeholders at the local level. Through household surveys, the potential for household rainwater harvesting is assessed, as is the potential for reducing indoor air pollution caused by the burning of biomass (e.g. wood) in enclosed or semi-enclosed kitchens. These field research and service activities are used as examples in the teaching of various technical concepts in undergraduate engineering classes at Mercer University, e.g. using gravity flow water systems to help teach students about flow through pipes, rainfall data to size water storage tanks, and indoor air pollution data to calculate typical inhalation dosing for a child vs. adult.

Keywords

Groundwater, Sustainability, Engineering for Development, Energy Poverty

Introduction

Mercer University's Engineering for Development program (E4D – e4d.mercer.edu) provides students with the appropriate skills to work as engineering professionals in the humanitarian and development sectors, both internationally and domestically. E4D offers classes, an undergraduate minor, and a graduate concentration in Engineering for Development, to students in all engineering specialties[1]. Through the university's Mercer On Mission (MOM – mom.mercer.edu) international service program, E4D is working with rural communities in El Cercado, Dominican Republic. MOM consists of numerous Mercer faculty-led programs to various countries, with a focus on conducting sustainable service and research activities to improve quality of life among target populations. MOM students enroll in six summer credit hours and take on-campus courses lasting 1-2 weeks prior to trip departure. The students then typically spend three weeks in-country, working with the faculty leaders alongside the host community. MOM is funded by donations and a portion of the university budget, and pays for student expenses including the roundtrip transportation to the host community and room and board while abroad.

Building upon prior water supply research and service by collaborators[2,3], since 2017 Mercer has been working with community groups and the local organizing entity, San Pedro Apóstol Catholic Church, to improve environmental health conditions in El Cercado. Mercer's research and service in El Cercado currently focuses on improvements to spring and groundwater protection, gravity flow system infrastructure, and cooking practices.

El Cercado is a small, rural town located in the San Juan de la Maguana province of the Dominican Republic, about 14 miles east of the border with Haiti. The town name in English means "the enclosed"; the town center lies in a valley and is surrounded by mountains. These mountains provide valuable groundwater resources for the communities' drinking and other water needs in the form of springs. Typically, communities build (with or without outside assistance) spring-fed gravity flow water supply systems, which deliver water to yard or community taps via networks of conduction and distribution pipes. For the rest of the communities, water is collected (typically by women and children) from springs or rivers and carried back to the households. Water delivered through these systems is often bacteriologically contaminated, especially in the absence of in-line chlorinators or point-of-use disinfection. For this reason, many residents in the town of El Cercado purchase purified water in 3- or 5-gallon sized containers for drinking and kitchen needs; however, many others do not.

Residents of El Cercado and the surrounding rural communities are generally of low socioeconomic status. Although the electric grid has now reached all communities in the area, the electricity is unreliable and outages lasting several days are not uncommon. Residents commonly rely on cooking with wood using three-stone fires in kitchens (often separate from the main house structure). The price of propane gas tanks and refills, as well as the cost of stoves, often prevents residents from purchasing this kitchen appliance.

Dominican Republic Field Research & Service

Since early-2017, research and assessments have been conducted by Mercer University in El Cercado, Dominican Republic, to understand the current conditions of community spring-fed piped water supply systems (primarily gravity flow systems) and groundwater resources (springs). Additionally, Mercer has worked with local communities on expansion of community piped water systems, helping with labor and providing partial funding to construct three stone masonry water storage tanks and install piping to communities. WASH (water, indoor air, sanitation, and hygiene) surveys conducted at households in communities over eight days have been utilized to identify issues with the water supply systems regarding water quality, quantity, point-of-use disinfection, and infrastructure. Interviews with the local water systems technician also shed light on these issues from a more technical point of view and provide an overview of the different communities' systems and components. Baseline assessments of groundwater protection infrastructure and resources, and interviews with a local agricultural project leader who is familiar with the resources and mountains in the study area, give a comprehensive understanding of the location of infrastructure and resources, potential water quality problems, and current conditions.

Community Water Supplies and Groundwater

Through the WASH household surveys, it was learned that some heads of household were under the impression that their tap water was contaminated and that purified bottled water was a better option. This opinion was usually supported by the fact that households reported experiencing more cases of sickness from drinking tap water. For some households, the water supply quantity was not sufficient or regular and they often had to walk to a neighbor's house or collect water from a surface water source for household needs. Furthermore, it was apparent from the surveys that only a small percentage of households reported using point-of-use water treatment (e.g. filtration or chlorination) - approximately 16%. Through interviews with the local water system technician, it was learned that not all community piped water systems have chlorinators. Some conduction pipes, especially those which pass through streams or rivers, have become rusted, leading to holes that allow potentially contaminated surface water into the piped systems. The community systems commonly have illegal connections, usually used for irrigating fields. Some of these connections have been tampered with, leading to constant leaks that can leave downstream households with little water at pressure. Conditions of spring protection structures ('spring boxes') in the study area were observed, and it was concluded that the majority of them are in disrepair and are structurally compromised by inadequate construction or natural deterioration (e.g. root damage) which could cause contamination of the spring water. Many springs were observed to be surrounded by farming and animal grazing, so the runoff from these lands into the spring catchment is another likely source of pollution. Overall, there is potential for improvement in the community piped water supply systems and protection of springs and groundwater.

Household Rainwater Harvesting

Some of the community-level water distribution systems in the El Cercado area are insufficient. There are only a few homes (less than 3% of those surveyed) that receive in-home access to water (i.e. tap water into the home faucets). During the rainy season in El Cercado flooding occurs in some areas. Sometimes, this causes the main water distribution system to experience pipe and connection failures (e.g. due to road and pipe washouts). During the May-June 2017 study period, the water conduction line that conveyed spring water to the town of El Cercado and several other outlying communities was washed out (along with a road) high up on the mountain; this meant the serviced communities and households were without tap water until reparations could be made. This affected much of the town, and the residence where Mercer students and faculty were staying had to access alternative sources for water for showering. Events like this are not uncommon (i.e., pipes running alongside or in river beds are washed out with heavy rains) and cause households to spend increased time on collection of water for drinking and household uses from unimproved sources (such as collecting river water with buckets; about 18% of the households surveyed reported collecting river water as a secondary source).

A possible solution to this issue is rainwater harvesting (as a primary or secondary water source), channeling rain that falls onto rooftops into storage tanks. The household WASH surveys included observation of the household structures in order to explore potential for rainwater harvesting systems. Information on roofing material and area allow for assessment of the potential for rainwater harvesting as a primary or secondary water source, given rainfall data, and for the calculation of required water storage tank size.

Indoor Air Pollution

Indoor air pollution (IAP) contributes to over 4.3 million deaths per year. This is partly due to an estimated 3 billion people worldwide heating homes and cooking using solid fuels in open fires[4]. Teaching and improving cooking methods can significantly improve health in developing communities. Research is currently being conducted by Mercer students on the state of energy usage in El Cercado and potential ways of improving basic cooking practices. WASH surveys indicate that though many residents have access to electricity, there is significant room for improvement with respect to cooking practices contributing to IAP.

Women and children in developing countries are typically affected by IAP to a much greater extent than men. This is due largely to women generally being responsible for cooking and care of children, and thus spending a disproportionate amount of time inside their home, often near the fire or stove[5]. Children are likely to be spending time in the home near their mother, and young children may even be carried on their mother's back while cooking is being done. The potential negative health effects of IAP are greater in children than adults.

Participants in household WASH surveys in the El Cercado area were asked to identify their primary energy sources, with the results showing that the majority of residents cooked using solid fuels. Out of 146 total households surveyed concerning their primary cooking fuels, 112 (77%) claimed wood and 40 (27%) claimed gas as a primary cooking fuel, whereas only 1 household (1%) claimed electricity and 1 (1%) claimed charcoal as a primary cooking fuel. (Note: some respondents listed more than one primary cooking fuel). These trends clearly indicate that wood is the most prevalent primary cooking fuel, with gas as the second most prevalent. When asked about secondary cooking fuels, 38 households (26%) claimed wood, 78 households (53%) claimed gas, 6 (4%) households claimed charcoal, and 2 (1%) households claimed electricity. Household cooking setups were then audited based upon several factors, including the type (three-stone fire, gas cook stove, kitchen, or biomass fire) and location (indoor or outdoor). Out of 107 households, 87 (81%) cooked over a three-stone fire.

Bringing Field Research Back to the Classroom

Data and information collected through research and service in the Dominican Republic are incorporated into Mercer University engineering courses as part of lectures, case studies, and assignments. In the Engineering for Development course (taught at the senior and master's level; Fall 2017), gravity flow water system data from systems in El Cercado are being used to help teach the fundamentals of liquid flow through pipes. This water system design example is explained in some detail in this paper. Additionally, students have analyzed WASH survey data from the May-June 2017 trip to investigate the potential for household rainwater harvesting systems, and to better understand cooking practices and the associated risks from IAP. Follow-up surveys are being conducted during 2018 trips to the study area, including a week-long trip in early-January 2018 that focused on additional assessments of mountain springs and household access to electricity. Example household rainwater harvesting tank sizing and indoor air pollution inhalation dosing exercises are briefly described.

Water System Design & Groundwater Hydrology Teaching Module

Students apply fundamental principles of flow through pipes and engineering judgement in a class lesson and activity on spring-fed gravity flow systems. They use data collected on elevation, location, and water quality at an area spring box, and elevation and location of a water storage tank which was constructed by community members and Mercer students during the Summer 2017 Mercer On Mission trip. These are incorporated into a lesson presented to students on spring-fed gravity flow community piped water systems. Students also complete a multi-step project where they design the pipe conduction network connecting the tank and the spring box (Figure 1), using engineering judgement and provided information to determine pipe material, diameter, lengths, slope, etc. In subsequent steps of the project, students analyze how their design is impacted by typical problems encountered in development projects, such as erosion of road material during heavy rains which exposes water supply piping. The students then re-design or improve their conduction network to overcome these problems. Through this lesson and project, students apply their engineering knowledge to a real-world scenario and learn about problems encountered in development projects that they may not learn in other courses. See abbreviated project assignment summary in the Appendix.

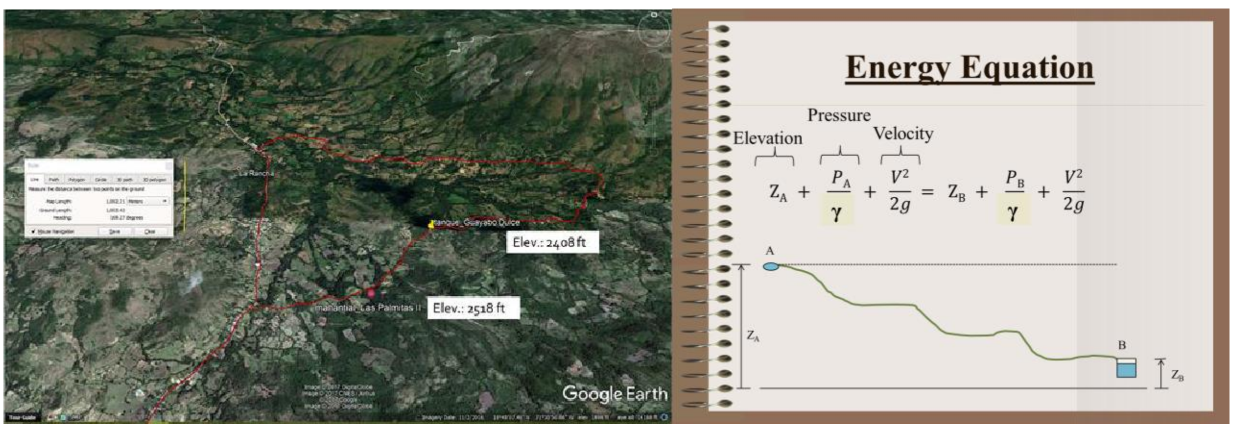

Figure 1: Aerial view map provided to students showing the spring source (pink dot) and water storage tank (yellow marker) with respect to community roads (red lines) [left]; teaching slide showing energy equation and sample pipeline profile [right].

Additionally, data collected on geology and groundwater flow through hydrogeological research activities will be incorporated as case studies in courses such as Groundwater Hydrology, where students will use the information for estimating in-situ aquifer transmissivity, flow paths, and storativity. This adds to Mercer's current use of manual drilling as an appropriate way to teach students about groundwater hydrology topics such as water wells, drilling, and groundwater flow[6].

Household Rainwater Harvesting & Indoor Air Quality Teaching Exercises

Given information on average annual rainfall for El Cercado, broken down by month (Figure 2a), average roof square footage, and roofing material, students in the Engineering for Development class are assigned the task of determining the potential for household rainwater harvesting as either a primary or secondary water supply source, and to size a water storage tank.

Additionally, data and photos (e.g., Figure 2b) collected in El Cercado are used in lessons to familiarize students with typical cooking practices in developing communities and to educate them on the effects of IAP and potential methods of addressing it. Students perform a calculation exercise of a common inhalation dose for both a young child and an adult, given a typical indoor particulate matter (PM2.5) concentration from cooking with wood, and considering various factors (fraction of pollution absorbed by body, breathing rate, exposure time, and body weight).

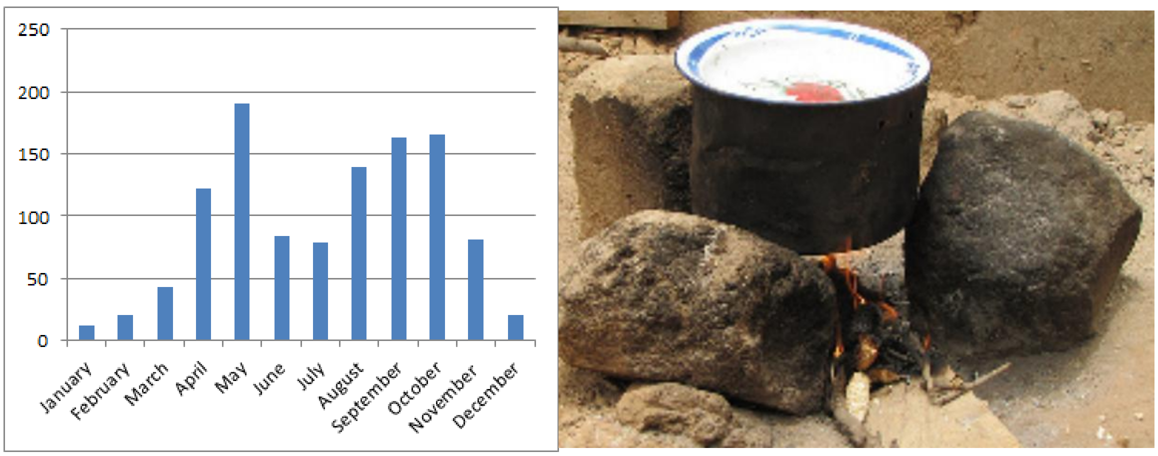

Figure 2: a. Average monthly rainfall data for El Cercado, in mm[7] [left]; b. type of cooking set-up (3-stone stove, burning wood) commonly used by residents of El Cercado [right].

Continuing Work

As Mercer's research and service work in the Dominican Republic continues to advance, further opportunities will develop for student learning in the field and back on campus. With time, it is planned for the real-world engineering examples currently taught in engineering for development and groundwater courses to be incorporated into more classes within Mercer University's School of Engineering, as appropriate.

A group of three Mercer University School of Engineering faculty members and approximately a dozen Mercer students will participate in the Summer 2018 Mercer On Mission program (May-June 2018). These students come from a range of engineering specialties (environmental, mechanical, electrical, computer, and biomedical) as well as from other disciplines (business and global health). Service-focused research for 2018 is building upon Mercer's 2017 work, and focusing on three key topics: (1) groundwater research that includes pilot action research for improving spring protection through low-cost drilling of horizontal wells using portable drills; (2) alleviation of energy poverty in rural areas through renewable energy microgrids, and (3) testing of a Mercer-developed, low-cost indoor air quality monitor. In addition to research, the 2018 Mercer team will work alongside a community in El Cercado to construct/improve water supply infrastructure.

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Dr. Michael MacCarthy is an Assistant Professor of Environmental & Civil Engineering at Mercer University, where he directs the Engineering for Development program (e4d.mercer.edu). He has twenty years’ of experience in water resources engineering, international development, and project management, including nearly a decade living and working in less-developed countries. Mike’s research interests include global WASH (Water, indoor Air, Sanitation, & Hygiene), low-cost technologies, self-supply, and social marketing. He teaches undergraduate and graduate courses in engineering for development and water resources engineering.

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Mónica Resto is pursuing a Master’s degree in Environmental Engineering at Mercer University with a graduate concentration in Engineering for Development. She received her Bachelor of Science degree in Civil Engineering from the University of South Florida. Her research interests are in groundwater flow, geology, and appropriate technologies. Monica's graduate research involves utilizing low-cost, portable technologies to study mountainous geology and hydrogeology and improve access to water for communities in isolated developing areas. Her primary field research site is the El Cercado area in the Dominican Republic. She is an Adjunct Professor for Mercer On Mission's program in the Dominican Republic.

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Dr. Ryan Schweitzer is an environmental engineer with over ten years' experience in the environmental health sector working primarily on water and sanitation projects. He has extensive quantitative and qualitative research experience directing formative research projects as well as developing monitoring, evaluation, and learning frameworks for assessing the impact and sustainability of WASH interventions and programmes. He has worked on capacity building initiatives with government and water ministries in Ethiopia, Rwanda, Sudan, and Liberia. He has worked in over a dozen countries in South and Central America, Africa, Middle East, and Asia. In his current role as a Water and Sanitation Sector Specialist with UNHCR (United Nations High Commission for Refugees) Ryan provides technical support to Bangladesh and 6 countries in Southern Africa. He also is the institutional lead on menstrual hygiene management and on UNHCR's sanitation waste to value and borehole solar pumping initiatives.

Appendix - Engineering for Development Gravity Flow Water System Assignment

In a module of the course titled Engineering for Development, students learn about the design of gravity flow water systems and the feasibility studies that precede, through in-class lectures. Feasibility studies include both social and technical aspects. Students learn tools for assessing community needs, building community capacity, and initiating water committees to manage, maintain, and improve community water systems. They also receive information on topography, water quality, source supply, and community demand analysis, which are all components of the technical feasibility study. Students learn about how conduction and distribution networks are designed, and how hydraulic grade lines and the topographical study figure into the design and placement of gravity flow water system components such as break-pressure tanks and sedimentation tanks.

To better understand the feasibility study and design processes, they are given an assignment which incorporates both of these course topics. The assignment information is based on data and background information collected during the research and service trip to El Cercado in summer of 2017, and general assumptions for rural areas, as discussed in the course module.

Students assume that the social feasibility study has been conducted, and that a water committee has been formed in the community. They then calculate the spring source supply volume and the community demand. They reflect on whether the source will provide all of the water needs for the community through the design life, and if not, how they would advise the water committee.

The students utilize information on a spring box in the community La Rancha in El Cercado, a water storage tank that was constructed during the summer 2017 trip, and beneficiary community information to design the conduction network which will convey the spring water to the water storage tank. They are given an aerial map (Figure 1) which contains a measured distance, and utilize source supply information, engineering judgement, and their knowledge from fluid mechanics and/or engineering hydraulics courses.

Furthermore, the students answer short-essay questions regarding impacts on their designed conduction networks of commonly encountered problems in development work. They first consider the placement of their piping, given the fact that typically earthen side roads in rural communities are in poor conditions and are carved by rain during the rainy season, causing the exposure of pipes which are trenched and buried under roadways. They also consider the fact that mountain roads can be washed out during heavy precipitation events, taking with them piping buried in the ground and discuss how they would change their conduction network design to prevent or reduce the possibility of this type of pipe system failure.