A COMMUNITY-BASED WATER HARVESTING SYSTEM

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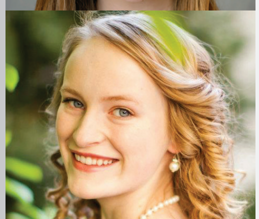

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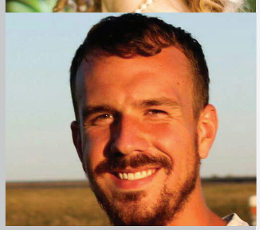

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Mentors

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Abstract

The World Health Organization (WHO) states it is a human right to have access to sufficient, safe water within one kilometer of the home (WHO, 2015b). However, 1.6 billion people experience economic water shortage and struggle to secure water for personal and domestic use (UN-Water & FAO, 2007). In the village of Endallah, Tanzania, seasonal rainfalls, high rates of evaporation, and inadequate water harvesting infrastructure leave many of the approximately 900 households facing economic water shortage. Around 90% of villagers depend on rainfed subsistence farming; however, annual crop yields are not consistent due to sporadic rainfall. The purpose of this research was to quantify water use, access, and needs in the village of Endallah to inform the design of a sustainable, community-based water harvesting system. In January 2015, a Purdue University Global Development Team traveled to Endallah to survey 25 households on their water collection and use. The results from the 12-question survey were coded, analyzed, and interpreted. The survey showed a significant need to improve water access in Endallah. Based on the survey results, most people in Endallah spend over three hours a day collecting water for domestic use. Water needs in Endallah have not been previously quantified, so the results will be crucial to the development of an accessible, community-based water harvesting system. Ultimately, by decreasing economic water shortage, the people of Endallah will have greater access to water for domestic consumption and can move toward using water to improve livestock health and agricultural productivity.

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Keywords

water harvesting, Tanzania, water scarcity, food security, community development, participatory design, water use, sand dams, interdisciplinary design, community survey

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A COMMUNITY-BASED WATER HARVESTING SYSTEM:

Understanding Water Use in Endallah, Tanzania

Marisa Henry, Grace Baldwin, and Garrett Quathamer, Engineering

INTRODUCTION

Securing access to water has always been central to societal development; water is essential to life and supports poverty alleviation, economic growth, and agricultural stability and productivity (Grey & Sadoff, 2006). The United Nations recognizes access to sufficient, safe, accessible water for personal and domestic use as a human right. However, nearly 40% of the global population continues to face water scarcity and struggles to secure adequate water to meet daily needs (Figure 1). Physical water scarcity impacts 1.2 billion people globally, while economic water scarcity (a lack of necessary infrastructure for water collection) affects an additional 1.6 billion people (UN-Water & FAO, 2007).

Compared to surrounding countries, Tanzania has relatively large quantities of water, but many areas face economic water scarcity (Morisset & Wane, 2012). The bimodal rainfall pattern, in which only 8% of rainfall

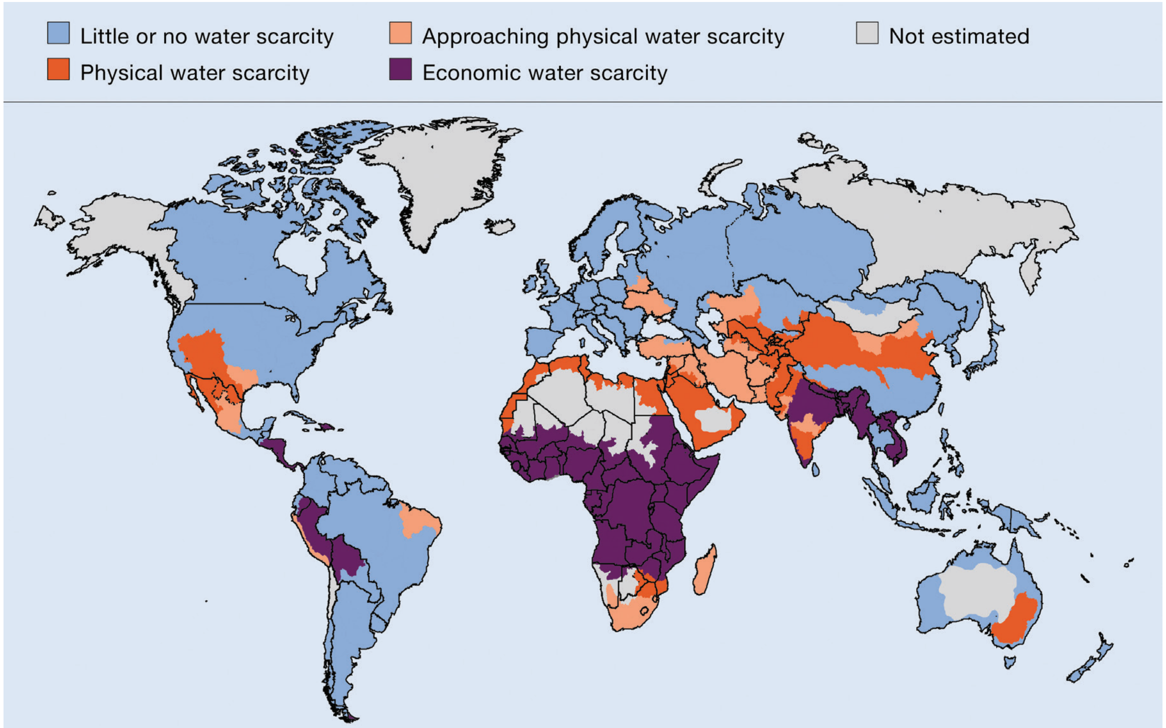

Figure 1. Global physical and economic water scarcity (Comprehensive Assessment of Water Management in Agriculture, 2007).

occurs between June and October, often leads to droughts and limited water access in communities (NCEP, 2010). In rural areas of Tanzania where rainfed subsistence agriculture is practiced, adequate food supplies are dependent upon access to natural resources, specifically water (World Bank Group, 2010). Consequently, inconsistent rainfall patterns can threaten food security. The World Health Organization (WHO) defines food security as "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (WHO, 2015a). In Tanzania, over one million people are food insecure (International Federation of Red Cross and Red Crescent Societies, 2011).

The approach to water regulation and management in Tanzania is decentralized, which leaves most decisions regarding water usage up to local authorities. This structure promotes an Integrated Water Resources Management (IWRM) system that encourages participatory planning and management of water resources to balance water use across sectors. In rural Tanzania, IWRM can increase water access for personal and domestic use while planning for the potential expansion of harvested water to agricultural use.

Students from Purdue University have been working to address economic water scarcity in Tanzania through partnerships with Catholic Relief Services (CRS) and the Nelson Mandela African Institute of Science and Technology (NM-AIST). Previously established connections between NM-AIST and the nearby village of Endallah provided an opportunity for productive collaboration to improve water access in the community. Building off a Purdue University agricultural and biological engineering senior design project from 2012, a Global Development Team (GDT) was established in 2014 by the Global Engineering Program to address the interdisciplinary challenge of water access in Endallah. The GDT's specific objectives are to: 1) develop a sustainable, community-based water harvesting system and 2) engage the community and stakeholders in participatory design.

To ensure the long-term success of the community-based water harvesting system, it is necessary to design for the Iraqw culture in Endallah. Utilizing an IWRM approach requires a clear understanding of communities and their perceptions of the water resources with which they interact. Previous research done by Purdue students and faculty in Endallah focused primarily on collecting quantitative data regarding soil types, climate, watershed data, and geographic analysis. However, this data set lacked the villagers' perceptions and thoughts on a new water harvesting system. To address this gap, a community survey was designed to generate understanding of the Endallah community and its water resources. This contextual information will lead to a clearer, more accurate understanding of a culturally appropriate water harvesting system. The specific objectives of the survey are to gain a better understanding of current: 1) water uses, 2) water access, and 3) water needs in Endallah.

STUDY AREA

As in surrounding areas, the community of Endallah experiences high rates of evaporation and bimodal rainfalls. Average annual rainfall of approximately 940 mm is distributed primarily between two wet seasons, the longest from February to May and the shorter from November to December (Figure 2). Seasonal streams are present during heavy rain events (Sheehan, 2014). During the long dry season from June to October, streambeds in Endallah are dry and less than 5% of the average annual rainfall, 38 mm, occurs (NCEP, 2010). Seasonally distributed rainfall paired with inadequate water infrastructure limits the community's ability to collect and retain water from the wet season, contributing to economic water scarcity (Figure 1).

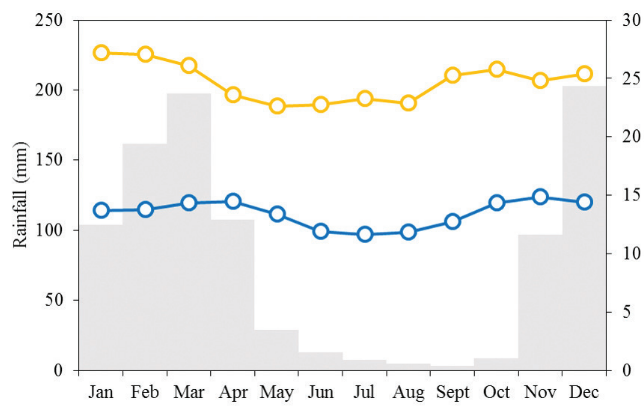

Figure 2. Average monthly maximum (yellow) and minimum (blue) temperatures and rainfall (gray) from 2006–2009 at the NCEP Station 33356, 22.5 kilometers northwest of the Endallah village center (NCEP, 2010).

Endallah is a centralized village of approximately 5,800 people of Iraqw origin. Most members of the community are agropastoralists, raising a variety of livestock and participating in subsistence farming (Thornton, 1981). In Iraqw culture, there is little hierarchical structure, a strong sense of neighborly support, and rarely major internal conflicts. It is common to make communal decisions and implementing changes requires consensus (Thornton, 1981). Having more reliable water sources would decrease water scarcity concerns and potentially allow the community to increase crop yield and diversity, as well as enable the expansion of livestock production. These changes would thereby increase food security (International Federation of Red Cross and Red Crescent Societies, 2011).

METHODOLOGY

A survey was designed and implemented in collaboration with the Institutional Review Board (IRB) at Purdue and partners at NM-AIST to develop an understanding of Endallah's current water resources and needs. This information will allow the GDT to move forward working with the community to develop a sustainable water harvesting system.

Survey Design

To establish a baseline of current water resources and use in Endallah, survey questions encouraged easily measureable responses and fostered dialogue to supplement quantitative information with qualitative, open-ended responses. Survey questions were divided into three subsections aligned with the three main research objectives. Water use questions focused on household demographics, quantities of water collected, and prioritization of water use. Water access questions investigated local water sources visited and the amount of time involved in water collection. Water needs questions concentrated on the villagers' personal ideal circumstances for fetching water (Table 1).

Survey Implementation

During a three-day period in January 2015, 25 households upstream of the village center were surveyed with the assistance of a fellow NM-AIST collaborator and several Endallah community leaders as translators (Figure 3). Translations were made between English and the local dialects: Swahili and Cushitic. Responses were recorded in English both electronically on a tablet and by hand; they were later converted into formats conducive for analysis. Additionally, participating households were marked using GPS coordinates with an accuracy of ±4.5 meters.

Survey Analysis

To preserve original survey responses, adjustments were documented and analyses were performed using Microsoft Excel 2013. The qualitative structure of the survey questions required coding survey answers to compare responses across the 25 households. Coding and analysis of responses were based on the question format (Table 1). Unrelated and no comment responses were omitted from the descriptive statistics portion of the analysis. Responses not suited for quantitative analysis

Question Format	Coding and Analysis Procedure	Questions
Yes/No	Converted response to binary. (yes; no) Descriptive statistics were calculated for valid responses.	Do you have adequate access to water? (2) Do you irrigate crops? (1) Do you own animals? (1)
Numerical	Converted to numerical value (0, 1, 5, etc.). Descriptive statistics were calculated for valid responses.	How many people are in your household? (1) How many animals do you own? (1) How far do you walk to collect water? (2) How often do you go to collect water? (2) How much water do you collect for domestic use and for livestock use? (1)
Categories	Created categories based on emergent response themes and coded for presences or absences. Descriptive statistics were calculated for valid responses.	What types of animals do you own? (1) Where do you go to collect water? (2) How do you prioritize water? (1)
Open-ended	Summaries of common themes were created for responses, quotations selected to highlight these points.	How far would you be willing to walk to get water? (3) Has your access to water changed in the past years? (2)

Table 1. Coding and analysis procedures for survey responses based on question format. Numbers following example questions indicate topic of assessment of current: 1) water uses, 2) water access, 3) water needs in Endallah, Tanzania.

Figure 3. Members of the GDT Marisa Henry and Garrett Quathamer working with translators to survey an Endallah household (photo courtesy of Marisa Henry).

still provided insight in a qualitative manner. Due to the open-ended format of the survey, some responses were adjusted by unit conversion and averaging to facilitate comparisons across households. For example, reported round-trip walking distances were converted to times using an average rural walking speed of 4 kilometers per hour (Bryceson, Bradbury, & Bradbury, 2008). The standard water use metric, daily water use per capita (L $person^{-1}$ day^{-1}), was calculated using Equation 1:

$$\textit{Daily per Capita Water Use} = \frac{(\textit{Liters Collected per Trip} \times \textit{Trips Per Day})}{(\textit{People per Household})}$$

RESULTS AND DISCUSSION

Time constraints, accessibility challenges, and lack of a map of households in Endallah limited the sample size and prevented the possibility of a randomized survey. The survey focused on three different clusters of households upstream from the village center. The Endallah community leaders suggested these areas because of the lack of water infrastructure further upstream where a water harvesting system could have a significant impact. Despite the survey's small sample size, representative of only 3% of the community, the results still give insight to current water uses, access, and needs in these clusters.

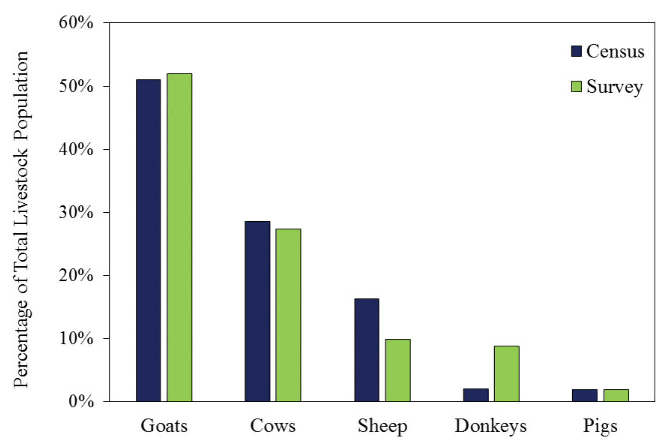

Figure 4. Percentage of goats, cows, sheep, donkeys, and pigs of the total livestock populations; 9,068 animals in the Endallah census (Endallah Village, 2012) and 512 animals reported in this survey.

Community Water Use

On average, the 25 surveyed households were comprised of 6.4 ± 2.4 individuals. Based on the 2012 Endallah census taken by the village, there were 906 households corresponding to approximately 5,800 people in Endallah (Endallah Village, 2012). Ninety-two percent of these households owned livestock, not including chickens or dogs. The average total number of livestock owned per household was 20.5 ± 17.8 animals. This data is proportionally consistent with the census taken by the village in 2012 (Figure 4). One difference to note is the total number of livestock represented in the 25 households is approximately double what would be expected from the census totals. This discrepancy could be the result of different understandings of livestock ownership. Some people report livestock they help care for instead of livestock they physically own, leading to an overestimation of the totals.

Calculated daily per capita water use includes all water collected and varies greatly between households. The average household water use was 20.7 ± 14.0 liters (Table 2). Differences in the number of livestock each household owned and what proportion of livestock was brought directly to a water source could contribute to this variation. Unlike domestic water, which must be transported to the household, some livestock may be taken directly to water sources (Figure 5). Sixty percent of the respondents stated they take all of their livestock directly to a water source. An additional 20% stated they brought their larger livestock (cows, donkeys, sheep, and adult goats) to the water source and watered the remaining animals with collected water. Additionally, different domestic water use practices, including bathing and washing clothes, could cause noticeable variations. All but one of the respondents ranked domestic use as their primary water priority (Table 2). When asked about agricultural water use, all households responded that they did not irrigate crops and only two households mentioned irrigating small fruit trees as needed.

Household	People per Household	Water Use *(L person^{-1} day^{-1})*	Water Use Priority *Domestic (D), Livestock (L)*
1	6	25.0	D > L
2	6	9.52	D > L
3	4	37.5	-
4	12	12.5	D > L
5	5	30.0	D
6	7	17.9	D
7	2	50.0	D
8	6	14.3	D > L
9	6	33.3	D > L
10	10	20.0	D > L
11	9	11.1	D
12	3	66.7	D
13	7	21.4	D
14	3	25.0	D
15	7	12.2	D
16	5	11.4	D
17	10	10.0	D
18	4	14.3	D
19	9	11.1	D
20	7	7.14	D
21	5	20.0	D > L
22	6	8.33	D
23	7	14.3	L > D
24	9	22.2	D
25	4	12.5	D

Table 2. Household water use response summary.

Community Water Access

When asked if they had "adequate access" to water, 77% of the respondents (n = 22) said no. Those who gave explanations often noted they did not need larger quantities of water, just more accessible water.

To estimate water accessibility in Endallah, households were asked which local water source(s) they visited and how far they had to walk to collect water. A nearby spring and a seasonal streambed near Lake Manyara were both visited by 40% of the surveyed households, while hand-dug wells and the village center hand pump were respectively visited by 20% and 16% of the households. (Table 3; Figure 6). Some respondents elaborated on which sources they used during the dry season and which they used during the rainy season if they varied. Additionally, three households stated they did not go to geographically closer water sources, like the village center hand pump, because of long queues or unreliability during the dry season.

Water collection travel time was used for comparisons over distance traveled for two reasons: 1) over 70% of households reported times and 2) times are assumed to be a more accurate representation of water access since walking speeds can vary greatly based on the person, water carried, and route taken. The average reported round-trip

Figure 5. Villager gathering water from hand-dug well for cattle (photo courtesy of Marisa Henry).

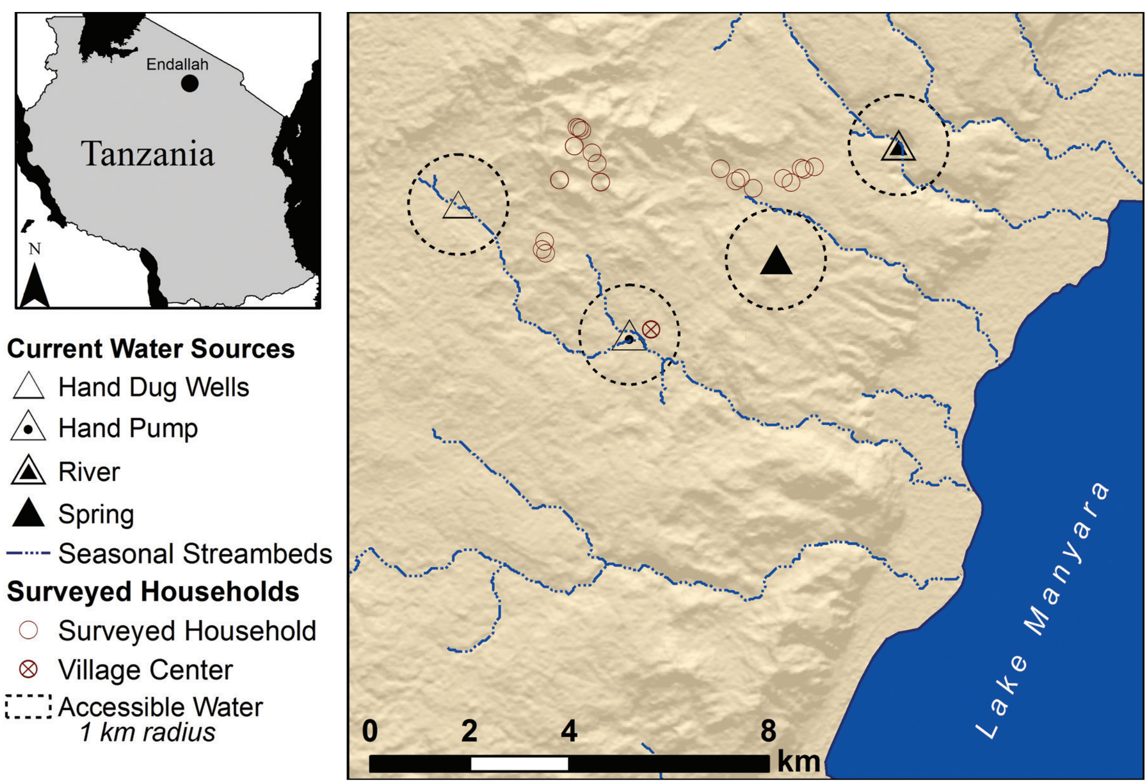

Figure 6. Map of surveyed households, current water sources, and area hillshade produced from a regional 1-arc second digital elevation map (METI & NASA, 2011).

walking time to collect water is 3.5 hours (Table 3). Using a walking speed of 4 kilometers per hour to convert reported distances to time is consistent with the WHO standards of accessible water (water within 1 kilometer of the home or collection time of less than half an hour round-trip) (Bryceson, Bradbury, & Bradbury, 2008; WHO, 2015b).

The average number of household trips to collect water per week is 8.5 ± 4.5 trips (Table 3). The total amount of water collected per household per trip was 104 ± 41.3 liters, typically in 25-liter buckets. It can be seen that sometimes villagers who live closer to a water source may travel more times per week, but will collect less water each trip. They ultimately spend approximately the same amount of time as other households that may fetch more water fewer times a week, while traveling longer distances (Table 3). Survey respondents spend large amounts of time and energy to procure water.

Community Water Needs

Every household expressed interest in having a more accessible source of water. Some stated they would be happy with any water source closer than what is currently used (8%), while others hoped for water "as close as possible" (56%). One household stated, "bring it as close as possible because this is a central location and will help a lot of people."

Household	Round Trip Travel Time to Water Source *(hrs)*	Volume of Water Collected *(L)*	Water Collection Trips per Week	Visited Water Source(s) *(1, 2, 3, 4)*
1	3.3	75	14.0	2, 3
2	3.3	100	4.0	3
3	4.0	150	7.0	3
4	3.0	150	7.0	3
5	2.5	125	7.0	3
6	2.0	100	7.0	3
7	2.0	150	7.0	3
8	2.0	200	4.0	3
9	4.0	100	7.0	3
10	4.0	100	14.0	3
11	4.0	100	7.0	4
12	4.0	150	14.0	4
13	4.0	75	7.0	4
14	6.0	150	7.0	4
15	5.0	100	4.0	4
16	4.0	50	4.0	4
17	4.0	100	14.0	4
18	6.0	100	4.0	4
19	4.0	50	7.0	4
20	4.0	50	7.0	4
21	4.0	50	14.0	1
22	3.0	100	3.5	1
23	2.0	33	21.0	1, 2
24	2.0	100	14.0	1, 2
25	1.3	50	7.0	1, 2

Table 3. Household water access response summary. Visited water sources represent 1) hand-dug wells, 2) the village center hand pump, 3) the riverbed near Lake Manyara, and 4) a spring.

Figure 7. Villager collecting water from a local spring (photo courtesy of Marisa Henry).

Fifty-two percent reported a decrease in crop yields in recent years and another 44% reported variation in crop yields between years. Only one household reported increased crop yields. A respondent explained that he produced only 120 kilograms of maize per acre last year. This is two-thirds less than the average yield in the Arusha region, which is approximately 400 kilograms per acre (Rowhani, Lobell, Linderman, & Ramankutty, 2011). Another household described, "[yield] depends on rain-fall. Last year they did not have enough rain and yields were low." While these variations in crop yield cannot be linked directly to insufficient water access, the importance of providing growing crops with adequate water is well known (World Bank Group, 2010).

CONCLUSIONS

The community of Endallah faces serious economic water shortage. Many households spend over three hours a day collecting water for personal and domestic use. Per capita water use varies greatly between households, but on average people use 20 liters of water per person per day. According to the WHO, people require between 50 and 100 liters of water per day to ensure basic needs are met (WHO, 2015b). In general, collected water is not used to irrigate crops, and local rainfed subsistence agriculture is being threatened by inconsistent rains, which may lead to food security concerns in the near future.

Combining results from this survey with quantitative data including rainfall patterns, watershed data, and geographic analysis of the area will allow for the successful design of a sustainable, community-based water harvesting system in Endallah. An IWRM approach to the design will improve water access for personal and domestic use and help plan for the potential expansion of water use in agriculture.

Suggestions for Future Survey Modifications

Engineers often fail to engage in participatory design practices, but understanding water use and priority in water-scarce regions is vital to the design and location of water harvesting infrastructure. To maximize survey util-ity, research teams should: 1) consult with local partners to address culturally relevant water concerns, 2) ensure accessible units for all questions, and 3) ask for specific examples to understand individual experiences. In characterizing water access, future surveys should explicitly ask respondents for walking times to water. Additionally, having respondents mark their route to water sources on a map would generate more accurate distance measurements.

Depending on the survey's purpose, either a random sample can be used or a specific group of people can be targeted. In the case of the Endallah survey, identifying households randomly was not feasible due to time and resource constraints.

Future Work

The survey results are currently being used by Purdue's GDT to help inform the design of several water infrastructure improvements in Endallah. The results have helped quantify water uses, identify potential locations for improvement, and clarify the community needs. To move toward a sustainable solution, designs for a sand dam to increase water storage and solar pumps to improve efficiency of current sources are being developed. Sand dams are a type of dam built on seasonal streams in which sand accumulates upstream of the dam wall to create an artificial aquifer. When compared to a traditional open-surface dam, this method of water storage can reduce evaporation, protect water from pathogens and pollutants, and act as a type of filtration system (Rainwater Harvesting Implementation Network, 2009). This dam would target households upstream of the seasonal stream that are farther from current water sources.

Working with the community to establish a water management system also will ensure the sustainability of the resources. Potential impacts of increased water access, including food security implications, are being researched by the GDT. Currently, none of the survey respondents irrigate their field crops, even though over 50% reported a recent decrease in crop yields. While the goal of designing a community-based water harvesting system is to increase water access primarily to better satisfy domestic water needs, once domestic needs are adequately met, irrigation techniques can be considered to increase food security. A sand dam and pump system will help improve access to water and move Endallah closer to food and water security.

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