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Water Quality Pilot Study for Traditional Water Structure Revitalization Potential in the Deccan Plateau of India

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ABSTRACT: Traditional water structures such as stepwells and canal systems historically function as sustainable water sources. They are advantageous within India's cyclic climate of flooding and drought, especially in regions of the Deccan plateau. Structures in the Deccan particularly tend to leverage laterite, a porous, geological feature specific to the region. Laterite is especially useful for collecting and maintaining water from surrounding aquifers, permitting reliable storage of water even during the dry season. Unfortunately, many of these structures have been damaged, polluted, and misused. This pilot study investigates the water quality of traditional water structures in the western Deccan Plateau region of India and their potential for revitalization. Samples were drawn from traditional water structures and domestic taps located across Central Maharashtra and Northern Karnataka. Water quality parameters were converted into a single water quality index (WQI) to characterize their current state. Qualitative site information such as degree of conservation and visible pollution level are compared via WQI. Quality amongst some traditional water structures was discovered to be comparable to domestic drinking sources despite a lack of conservation and usage in the former. Some sites exhibited strong potential for revitalization as domestic and agricultural water sources. Finally, a detailed case study of a *Karez* system in Bidar outlines current characteristics, challenges, and future work in promoting sustainable development practices for revitalizing traditional water structures.

Keywords: water structures, Deccan Plateau, water quality, revitalization

AUTHOR'S NOTE: About a year ago, I found myself hobbling off a bus in Maharashtra, India. My fibula was fractured and I was backpacking India on crutches—trying to grasp as good of an understanding as I could on the water usage in rural India. It all started when Eric and I met our advisor, Dr. Walter Hakala, who suggested we travel with him to India. We saw it as an opportunity not only to explore Deccani architecture and their beautiful water systems, but to also explore water quality amongst many of these traditional water structures. We wanted to identify the state of these water structures and see if they had utility in revitalization. As it turns out, these aged, polluted, and unused water structures were not all that bad! In fact, not only are they (sometimes) comparable in drinking water quality to municipal sources—they also have high potential, if restored, to bring cultural and religious value. Revitalizing these old methods could prove useful as sustainable water sources in the future of India as water becomes a more constrained resource.

Introduction

The Deccan Plateau consists of several present-day states, principally including Telangana, Maharashtra, Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu. The region has produced numerous major dynasties in history, including the Pallavas, Satavahana, Vakataka, Chalukya, and Rashtrakuta dynasties, as well as the Kakatiya, Kamma Nayakas, Vijayanagara, and Maratha empires. Prominent Indo-Muslim architecture, including the water sites discussed in this paper, were built by the Muslim Bahmani sultanate, the post-Bahmani Deccan sultanates, and the Nizam of Hyderabad (Sohoni 2018; Michell and Philon 2018). The region has witnessed conquer and turmoil with the formation of Muslim states, power struggles between dynasties, and was briefly home to the Mughal capital in Aurangabad under Emperor Aurangzeb (Pillai, 2018). The region was a battleground for the eighteenth century French and British rivalry, with the British emerging victorious. They would establish two major presidencies within the plateau: Bombay and Madras. After independence in 1947, most of the native states were incorporated into the present-day Republic of India. In 1956 the States Reorganisation Act redistricted states along linguistic lines, leading to the current political states (Koshi 2016).

Water for many of these great dynasties was a symbol of power. It was cherished and is manifested in many architectural wonders (Bindia 2004). One example is

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at Daulatabad, a historic fort that contains an elaborate system of reservoirs, tanks, wells, and channels—some still utilized today (World Monuments Fund 2020). However, an estimated 70 percent of India's fresh water sources are now polluted (Banerji 2018; Asian Development Research Institute 2017). Such pollution includes agricultural agents, septic leakage, industrial waste, landfill leaching, and mining (Gupta, Rai, Pandey, and Sharma 2009; Agrawal, Pandey, and Sharma 2010). Water pollution leads to a myriad of diseases and is responsible for the death of over 14,000 individuals every day. As such, it is a major concern for both developing and industrialized nations (Agrawal, Pandey, and Sharma 2010).

Background

The region of our focus is the Deccan Plateau of India. Basaltic lavas characterize this region, with alternating layers of thickness occupying preexisting valleys. A key component of the soil in the regions of Bidar is laterite, formed as a derivative of basalt. Laterite is a porous rock that is typically rich in iron which causes its rusty-red color. The formation of laterite typically relies on cyclic wet and dry seasons. Rocks are leached of soluble salts within the rock from the constant rainfall and then the salts are deposited on the surface all via capillary action. These salts are then washed away the next rainy season, forming porous pockets where the salts once existed (Whitten and Brooks 1972). In some regions of the Deccan, this geological composition is especially beneficial for agriculture and water storage.

Common crops grown in the moisture retentive areas include cotton, sugarcane, millet, rice, oilseeds, wheat, as well as tea and coffee plantations in the southern areas (Heitzman and Worden 1995). Such crops are highly dependent on climate, which in the Deccan, can vary widely. Most annual rainfall falls in the northern and eastern regions, including Madhya Pradesh and Chhattisgarh. The southern region, especially central-western Maharashtra and northern Karnataka fall under a "rain shadow," and receives about 50 to 1,000 mm (2 to 39 inches) of rainfall a year. While this water might be sufficient in quantity, in many cases, it is not sufficient in quality.

For a water source to be usable, it necessitates both quantity and quality. Two major factors affecting water in India are (1) the overuse and misuse of bore wells and (2) pollutant contamination (Sharma 2017). Bore drilling is commonly utilized around the world, not only for water extraction but also for petroleum and natural gas extraction (Chen 2018). However, cases of overused bore wells drain aquifers by drawing more water than

Figure 1: Thematic map of geographical regions of India (Deccan Plateau 2019)

is annually replenished; one study suggests that India's average groundwater levels are being depleted by an average of 0.3 meters per year, and up to 4 meters per year in the worst scenarios (Economist 2016). These wells can reach down into "paleo-historic storages," depleting millennia old water sources (Sainath 2016).

Unfortunately, farmers often consider these wells their only option. Sinking new bore wells costs about 150,000 INR ($2,114 USD) on average, which is extremely burdensome on small farmers, who are only assured 6,000 INR annually (Sainath 2016). Many of these farmers are under significant financial debt which has been linked to an increase in suicide rates of up to 45 individuals per day (Singh 2019). Natural water structures that harness groundwater aquifers closer to the surface are historically sustainable and could prove a potential solution to combat aquifer depletion, economic hardship, and increase the quantity of water available to nearby communities (Khandekar, Kamadi, and Collyns 2015).

Even with the abundance of water in these natural water structures, this groundwater is potentially unsafe; the 2006 Department of Drinking Water Supply figures indicate unhealthily high abundance of chemicals across India: fluoride in 203 out of 593 reporting districts, iron in 206 districts, salinity in 137 districts, nitrate in 109 districts, and arsenic in 35 districts (Shankar 2011). Furthermore, the lack of proper wastewater treatment is widespread. Currently, 93 percent of sewage in India terminates in natural waterways without treatment (Chaturvedi 2017).

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Unfortunately, this remained true in our observations; sewage was prevalent at many of the sample sites.

For municipal waste disposal in India, especially in rural areas, residents tend to use open-incineration or disposal in waterways (Kumar S., Smith, Fowler, Velis, Kumar S. J., Arya, Kumar R. and Cheeseman 2017). Some suggest the adoption and widespread use of burning is related to the longstanding Hindu religious rite of cremation—such a practice in India even inspired the modern cremation movement in the West (Arnold 2016). Much of this practice is ultimately linked to limited awareness caused by lack of education and a lack of suitable infrastructure; many municipalities fail to provide waste dumping facilities (Ferronato and Torretta 2019). Incentives for infrastructure improvement include waste-to-energy facilities, which is proven to be a major opportunity; however, a key barrier is a shortage of qualified engineers and environmental professionals (Kumar et al. 2017).

Municipal pollution of waterways, coupled with the lack of usage and circulation of these water structures results in rapid eutrophication (Majumder, Gupta, Saha, Datta, and Mondal 2006). Again, environmental education is a potential method by which to combat these common practices of pollution and preserve the utility of these sites (Sarkar, Saha, Takada, A. Bhattacharya, Mishra, and B. Bhattacharya 2007). However, before enhancing rural education, it is suggested that fundamental improvements in sanitation are necessary; this highlights the circular nature of water quality rooted in the intertwined sustainable development issues of sanitation, poverty, lack of infrastructure, and lack of education (Malik 2015).

Traditional Water Structures

India's climate is characterized by annually cyclic floods and droughts. The northern and inland regions of the Deccan Plateau typically receive rainfall of about 700 mm annually due to geographic sheltering from the western Ghats (Baumann 2008). The central Deccan region, along with the western states of Gujarat and Rajasthan, typically receive the least annual rainfall in India, making these regions especially susceptible to drought. Consequently, many regions have adopted their own idiosyncratic ground water harvesting techniques from early water structures. They are distinguished by name, language, cultural references, and geological construction. Such structures include horizontal well-canal systems called *karez* or *qanat*, which work to recharge nearby well systems. Others include *baoli* (stepwells), *anicut* (dams), and *hauz* (water reservoirs) (Barah 1996; Davison-Jenkins 1997; Pal 2016). All are traditional methods of providing accessible groundwater to users.

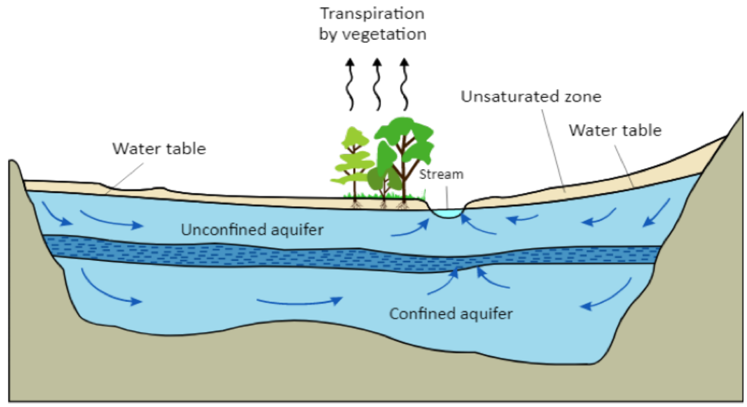

Figure 2: Hydrogeological setting of groundwater (Hillewaert 2007)

Figure 3: Examples of traditional water structure sample sites (a) Daulatabad Fort; (b) Bidar karez; (c) Bidar Fort; (d) Chaukhandi; (e) Shahpur Karez Mother Well; (f) Ashtoor.

Figure 3 displays examples of *baoli*, or stepwells, in (a), (c), (d), and (f). *Karez* system components of both the (e) head and the (b) mouth of this underground horizontal canal system are also pictured.

While there are many names for these structures, their general architectural forms and categories are common across great physical and cultural distances. For instance, a horizontal well system in Bidar paralleled canal systems common to Iran and Pakistan. Another example is while stepwells have high frequency in the Deccan, they are also found in different geometries across Europe and Africa. In the Deccan, however, these structures are distinguished by

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their basaltic rocks and laterite, which function especially well for retaining water.

Aside from function, there also exists a cultural impetus that historically has driven the construction of these structures. Some are opulent and decorated, representing the establishment of former rulers. Much of these decorations also serve the purpose of venerating religion. They are built as "temple tanks," and are claimed to prevent and cure diseases; examples include the Bhramanya Dev temple in Madhya Pradesh. Offerings to ancestors are also made at these water structures, such as at the Dakshinaarka temple (Kannikeswaran 1996).

Stories of miracles also encompass stepwells. A story that dates back to the thirteenth century recounts how devout followers of Nizamuddin Auliya, a Sufi saint, were tasked with stopping work on a *baoli*, and instead were forced into building a citadel for Ghiasuddin Tughlaq, the new sultan of Delhi. The laborers continued to work on the *baoli* for the saint at night, enraging Ghazi Malik; he banned the sale of oil lamps to stop their work. It is said that the saint blessed the well's water and told his followers to use that instead; miraculously, it burned (India's Magnificent Stepwells 2019).

Additionally, these traditional water structures even emerged as social spaces for women. While they were used for agriculture and drinking, they were also used for bathing and washing—historically feminine roles. The architecture of Hindu stepwells especially was encompassed by fertility goddesses—with few cases of male gods—perhaps also indicating the strong linkage to women. Women at these sites participated in gatherings to sing *bhajans* and narrate stories as religious activities. However, these often extended into sessions where women were able to talk about their problems and form a support group—this included Muslim women, who were excluded from mosques and bazaars in many societies (Dhwani, 2019).

Traditional water structures have recently been documented online via a crowdsourcing website called "Stepwells.org" (Earis 2016). However, many of these traditional water structures have undergone stress from pollution, neglect, and abandonment with the onset of modern water distribution systems such as piping. With the increased abundance of industrialized plastic and foil packaging—correspondent with India's rapid development—many of these sites are used as places to discard waste. Both their functional sustainability as a water source and cultural significance drives the question: Why have they become increasingly neglected and abandoned? Secondly, is there potential for them to re-emerge as sustainable structures—proving beneficial in increasing water sustainability and reinvigorating the culture surrounding these structures?

Methodology

To explore revitalization potential from a quantitative perspective, we examined water quality within traditional water structures and bodies in the western Deccan plateau—a region of India with an abundance of water structures. We sampled areas with known clusters of traditional water bodies across Maharashtra and Northern Karnataka. Our geographical sample size was relatively small due to time and resource constraints; hence, our study is limited in scope and should only be considered a pilot study specific to these regions.

Our research was primarily focused in and around the two cities of Aurangabad and Bidar because of the abundance of various traditional water structures. Aurangabad is situated in a dry region of central Maharashtra and is heavily influenced by local steppe climate. The city is known for several educational institutions, including Marathwada University, and is located near the Ajanta and Ellora caves—both are UNESCO World Heritage sites. Bidar is located on an escarpment in the northernmost region of Karnataka, near the border of Telangana. This city is characterized by rapid urbanization, an over 500-year-old fort, and hosts the second largest Indian Air Force training center in the country (Sohoni 2015). Aurangabad's rainy season is between the months of June to September; Bidar's rainy season is in a similar time frame: from June to October (Climate Graph 2018). Sites where water samples were taken and analyzed are included in Appendix A.

India's Deccan Plateau has a seasonal pattern that consists of winter, the dry season (November to February), summer (March to June), and the monsoon or rainy season (June to October). Our samples were taken in the month of January during the dry season. Some of the traditional water structure sites we visited had dry wells, and thus no samples were taken at these sites.

The study was limited by cost, portability, and customs restrictions in the water quality assays utilized in India. The kits employed included a 14-parameter water testing strip from two separate companies, two general electronic water quality test meters which measured an additional four parameters, and general bacteria concentration testing. The parameters measured are included in Appendix B. The parameters of greatest relevance to this study included lead, iron, nitrate, total dissolved solids (TDS/EC), chlorine, and pH. These parameters received

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greater weighting when a single metric of overall water quality was developed due to the significance of their health consequences as outlined in the WHO guidelines for healthy drinking-water quality (World Health Organization 2017).

A parameter called "visible pollution" was developed based on photographs and physical surveying of the area surrounding sample sites. This involved multiple individuals rating the site pollution level on a scale of 1 to 7 by method of general site observations. These ratings by multiple individuals were then averaged for each site and are considered as the visible pollution index.

We generated a single parameter for each specific site, *j*, that is composed of a linear combination of each specific chemical parameter, *i*, of total parameters, *n*. A weight was determined for each specific chemical parameter by giving reference to the toxicity of ingesting, or otherwise coming into contact with, the given substance. Normalization of some specific weight, w_i, then yields w_{rel_i}. The singular metric generated for each site is noted as the water quality index (WQI). This equation is similar to a prior water quality evaluation described by Rao and Krishna (2014).

$$W_{rel_i} = \frac{W_i}{\sum_i^n W_i} \tag{1}$$

$$WQI_j = \sum_i^n W_{rel_i} \times \frac{(j_i - i_0) + |j_1 - j_0|}{2} \tag{2}$$

We further note that j_i represents the value for a specific parameter *i* at site *j*. Additionally i_0 is the WHO standard for chemical parameter *i*. WQI_j therefore represents the linearly composed, weighted sum of chemical parameters which exceed the WHO standard, at some site *j*. A sensitivity analysis on the weighting was conducted and variation in parameter weighting could affect WQI results. These weightings are a possible source of error within assumptions for this study.

Table 1: Critical Parameter Weights

Chemical Parameter	Weight	WHO Standards	Relative Weights
Lead	10	15 ppb	0.1818
Iron	10	.3 ppm	0.1818
Nitrate	8	10 ppm	0.1454
Bacteria	8	n/a	0.1454
TDS; EC	8	500; 1000	0.1454
Chlorine	6	5 ppm	0.1090
pH	5	n/a	0.0909

Current Status and Results

Data compiled for each site was averaged and normalized against the WHO standard value regarding each parameter. While numerous parameters were tested, the parameters considered were narrowed down to lead, iron, nitrates, bacteria/coliform, TDS/EC, chlorine, and pH. The parameters not considered were either redundant or did not have a significant effect on water quality. Results for each site can be seen in Appendix A. This was a reduction from the entire dataset of chemical measurements taken because parameters most hazardous to health were prioritized in this study.

We are able to compare our quantitative WQI with a variety of qualitative parameters regarding each sample site. These qualitative parameters included architectural structure type, location, level of conservation, visible pollution, and water source type. Some findings of potential interest are shown in the following section.

To understand the general quality of the sites surveyed, we compared the water quality metric against WHO standards for safe drinking levels to see how many sites failed a given number of standards. Our results show all of the sites failed at least one standard and most failed most standards. Few failed more than five of the six major standards tested.

Our results regarding the water quality of traditional water structures across the Deccan in comparison to modern municipal sources such as tap water from bore wells is shown in a combined dot and boxplot in Figure 4 below. It appears that contemporary sources have higher water quality than traditional sources when analyzed with our WQI metric. This is theorized to be related to the lack of care and usage of traditional water sites. Some traditional sites shown have WQI levels comparable to contemporary sites, perhaps indicating potential for usage as sustainable agricultural or municipal water sources. There exists significant variance amongst the traditional water structures, likely due to the variation in factors such as pollution, location, usage, and conservation levels.

Exploring the level of conservation amongst all of the sites, we found little relationship between conservation efforts and corresponding water quality. Many preserved sites scored poorly when employing our WQI. Conservation amongst traditional sites, was split into three categories: preserved, partially preserved, and unpreserved. Preserved structures had some level of supervision or oversight, which occurred in a variety of forms including but not limited to religious institutions, tourism, and historic site security. Partially preserved sites were recognized by locals and partially maintained

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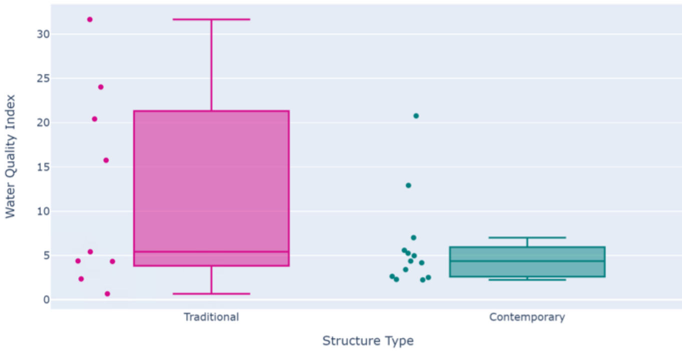

Figure 4: Water structure type versus WQI

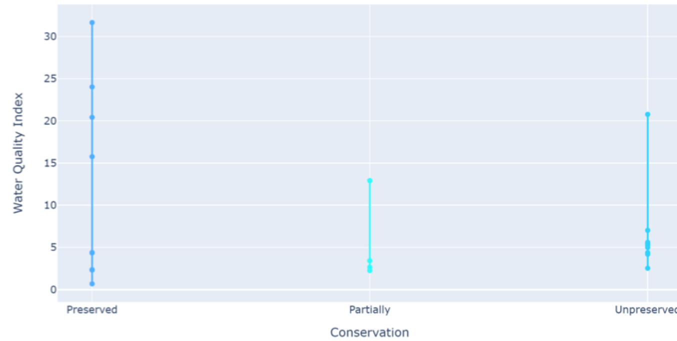

Figure 5: Structure Conservation versus WQI

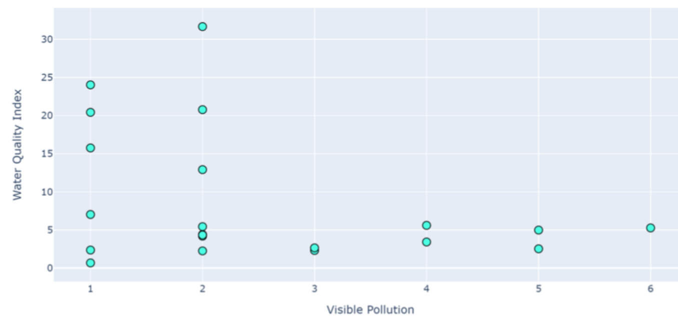

Figure 6: Visible pollution versus WQI

by the constituents. Unpreserved sites were completely abandoned and had no signs of revitalization or maintenance efforts; most were stagnant, polluted bodies of water. We found that the only preserved site possessed the lowest WQI (thus, the highest water quality). However, some unpreserved sites showed similarly low levels of WQI. The variation in the data and lack of sample size makes it difficult to conclude the effect of conservation on water quality, as seen in Figure 5.

We hypothesize that no strong correlation between conservation efforts and lower water quality index (more potable water) is due to a continuation of past contamination practices by some residents, and nonpoint source pollution (NPS). Maintained sites typically are not able to afford constant protection via gates or guards; thus, we observed some municipal waste at even highly conserved sites. Less easily discernible is the possibility of NPS such as excess fertilizer, urban runoff, sediment, salt from irrigation, and atmospheric deposition. Understanding NPS is especially essential for groundwater in agricultural regions such as the areas of rural India we sampled (Kourakos, Klein, Cortis, and Harter 2012). NPS as a confounding factor on water body revitalization is not unique; it has been observed in many water sources throughout India (Jha, Singh, Ojha, and Bhatia 2006). However, we also note lack of correlation could be due to small sample size, as well as potential flaws in our classification ontology.

Visible pollution is a metric taken based on the average of two individuals observing the site in the field and rating the pollution level on a scale of 10-70, with 70 being the highest level of pollution. It is apparent that the higher visible pollution levels do not show correlation to better or worse WQI levels as seen in Figure 6.

Interestingly, we notice even the most visibly "clean-looking" water sources can contain the most harmful substances in the forms of heavy metals, high levels of nitrates, and so on. Thus, even the most visibly appealing water sources could be extremely hazardous.

The most potable water occurred at the Kumatgi Hauz, one of the more isolated sites which corresponded to a visible pollution rating of 2 and a partially preserved level of conservation (Philon and Arni 2014). It was in a relatively flat area likely fed by the nearby artificial reservoir. It is hypothesized that its location—farther from major populations than other structures we visited—aided in the mitigation of pollution and bolstered the low WQI.

Additionally, the three religious sites (all stepwells) had generally low WQI, regardless of preservation; Amrut Tirth in Khuldabad and the wells at Chaukhandi, Bidar showed WQI of 2.52, 4.37, and 4.97 respectively. This puts them amongst some of the highest quality sites we visited. This potentially suggests that religious significance could play a part in preventing pollution and aid in maintenance of revitalized sites. Lastly, in general, there was no correlation between structure type and water quality; this is likely due to the minimal role of structure type in mitigating NPS pollution or municipal waste.

Based on our findings, traditional water structures show potential for agricultural and drinking water usage. In rare cases, they can be utilized as sources in their current state. But in most cases, further treatment and remediation must

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Figure 7: Sample from the Kumatgi Hauz

be undertaken. Advocating for the cultural and religious value of these structures could prevent degradation and be potential sustainable development strategies beyond simply desilting and removing municipal waste.

Future Work

Our water quality analysis was done with limited metrics. Future work could include the addition of measurements relating to possible arsenic contamination from bore wells both by extraction from crops and directly in water concentration from wells; this can also be studied in its transport to municipalities. Furthermore, metrics of dissolved oxygen concentration, chemical oxygen demand, and total organic carbons could assist in understanding the water quality and aquatic life within these water structures. Specific microbial assays might help determine the severity level of bacteria and other microbes in the water; particular metrics of exploration would include resistance of present microbes to non-chemical methods such as heating, filtration, and radiation, which are more likely to be feasible than chemical treatments in low-resource communities.

Longitudinal case studies could be explored where entire cycle analysis of water is conducted on a particular community, tracing from rainwater to aquifers, then through the water systems (both traditional and contemporary) and to municipal sources and irrigation sources. Water quality at various intervals could be explored over time and at various seasons of the year using continuously monitoring water quality field sensors.

A Case Study of the Naubad Karez System in Bidar

A *karez* (also known as *qanat*) is a "tunnel through which groundwater is conducted to the command area by gravity" (Khan and Nawaz 1995). It is an irrigation system that dates back to 1000 B.C.E. with origins in Persia and can be thought of as a horizontal well (see Figure 8 below). These tunnel systems are the same systems the Hamas and Taliban are utilizing for strategic maneuvers (Kelso 2001). Traditional construction begins with digging of the motherwell. In the case of Afghanistan, Pakistan, and Iran, these are often built on alluvial fans (Datta 2019). The sites we visited had no indication of alluvial fans and rather were built typically on hilltops or local plateaus. Such structures were classified as rain-fed *karez* systems rather than as the other three forms: alluvial or piedmont *karez*, infiltration gallery *karez*, and spring *karez*. From the motherwell, a tunnel is dug in the shortest possible distance to the command area, where water demand exists. Air vents are typically dug approximately 30 meters apart and utilized as both pressure relief and as a location to remove tunnel sediment during construction and subsequent maintenance. The *karez* tunnel emerges at the surface near the command area with water flowing at a gradient of 1-meter vertical depth per 1000 meters horizontal length in order to limit damage to the tunnel and maintain a sustainable flow rate (Khan and Nawaz 1995).

Bidar is unique in the sense that many neighborhood villages cover the natural *karez* system. Furthermore, unlike many traditional *karez* systems, it transports water from a lower altitude to a higher one; the mother well is lower than the mouth of the *karez*. Small depressions between vents allow for water storage, which, when it flows over, will progress forward and upward until it reaches the mouth (Goode 2018).

With the continued development and urbanization of India, unplanned organic growth often exploits natural and historic systems such as the *karez*. Until three years ago, the *karez* system did not contain free flowing water—many vents and pathways were blocked by garbage, damaged from erosion, and crowded with silt due to lack of usage. Local NGO Team Yuva and the Indian Heritage Cities Network Foundation (IHCNF) handled the revitalization effort, which entailed clearing the tunnels of silt and debris. The project was initiated and funded by the Karnataka urban infrastructure Development Finance Corporation (KUIDFC), a state governmental branch.

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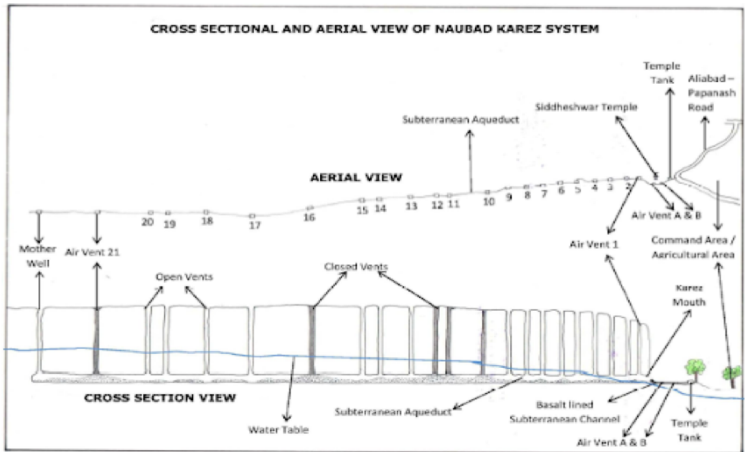

Figure 8: Naubad karez system (Kutty 2018)

Unfortunately, the *karez* system (like other traditional water bodies) faces the challenge of cleanliness. Municipal waste on roads and in open drains can, and often does, seep into and pollute the water. In the case of Bidar, many locals are even consciously and consistently utilizing the *karez* system as a sewage tunnel. This was supported by our analysis of the nitrate content (along with a variety of parameters) of the water at various points along the *karez*: high nitrate content indicates a high likelihood of human waste contamination, animal defecation, or fertilizer runoff. Water quality of the Naubad *karez* system was analyzed at three major points of access: (1) mother well; (2) opening/vent; (3); end/municipal.

There exists a noticeable increase in nitrate concentration as well as in dissolved solids as one continues from the mother well to the end of the *karez*—the municipal draw. In the case of Bidar, this could be due to the aforementioned use of the *karez* system as a means for sewage and waste disposal, as nitrate is a strong indicator of fecal waste. According to a representative from IHCNF, Mr. Govindan Kutty, despite the knowledge of waste and sewage dumping upstream, residents downstream continue to utilize the *karez* system for drinking water. In a similar case in rural Andhra Pradesh, Hamoudi et al. studied the response of residents when questioned about their water quality: 90 percent of the tested households had fecal bacteria contamination. Interestingly, instead of remediating their water source with a filter or other methods, most affected residents initially reacted by purchasing more commercially sourced water, but often reverted to contaminated sources within a month (Hamoudi et al. 2012). Likewise, residents continue to drink water from lower portions of the *karez* without regard for quality, even after IHCNF and local NGO groups gave warnings. Perhaps this is because the *karez* is their only source of water, they simply cannot afford commercially sourced water, or there is no funding for a public treatment system.

Table 2: Analysis of three points in the Naubad karez

Site No.	Location	Nitrate	TDS	WQI
16	Mother well	25	188	5.6429
14	Mouth	25	212	7.2857
15	Municipal draw	50	213	9.1429

Though education and revitalization of old water systems are prime tools for local NGO goals concerning historical conservation and sustainable water systems, often funding is undermined by bureaucratic processes and changing leadership. India has amended legislation such as the Foreign Contribution Regulatory Act, curbing contributions from international nonprofit organizations—though, this reformation is sometimes necessary to combat potential corruption within NGO funding structures themselves. In general, however, this legislation makes contributions from overseas NGOs and organizations more difficult (Kumar, S. 2019). Some argue that the original practice of employing ancient water systems was lost to bore wells and piping after the British colonization of India (Unnikrishnan, Nagendra, Broto 2018).

Historical preservation proposals take years to process; one of Mr. Govindan Kutty's pending proposals has been processing for five years. According to Govindan Kutty, such processing time is often accompanied by a change of leadership, which again delays processing even further. New leadership results in the need to reeducate and persuade new leaders that traditional water systems are important and, in some cases, profitable for both commercial and touristic purposes. Often this education and relationship redevelopment takes years.

Despite this, functional bureaucracy undoubtedly does exist. One example within Bidar is an air force base which has allowed for the preservation of nearby lands and thus, the *Karez* system in Bidar was able to be restored and the watershed was able to be recharged. In this case, a government body aided in the maintenance of these revitalization sites in an indirect way; searching for similar symbiotic relationships between government entities and water structures could aid in sustainable development.

Currently, the region around Bidar and regions within Maharashtra suffer from drought. Unfortunately, the current practices of some farmers can contribute to the water deficit. Cultivating non-native cash crops in the region—such as sugarcane and cotton—can be a highly unsustainable practice (Singh, A. 2016; Mohan 2015;

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Roy 2016). The farmers in some regions of Bidar receive free electricity and thus are able to operate pumps and irrigation systems ceaselessly, limited only by water availability. When wells run dry, though, the typical solution is to drill another bore well on their property—either in a different location, or simply deeper. This practice is unsustainable and farmers cannot afford it. Thus, one of their only options is to lobby government officials in the hope that they will subsidize more drilling (Gupta 2019).

One suggested solution to this is the usage of alternative, more native crop species such as guava, fig, and millet (Rajendran 2001). Some farmers in Bidar are starting to cultivate millet as a more sustainable crop for the semi-arid region with information from Govindan Kutty's NGO. The region is also exploring education options for affordable drip irrigation techniques, which are much more efficient in water usage, but costly and difficult to maintain (Narayanamoorthy, Devika, and Bhattarai 2016).

Revitalized traditional water systems such as the *karez* in Bidar provide new opportunities for sustainable water distribution. Built on a large geologic fracture which serves as a water source, the *karez* distributes water great distances to various municipalities. Since its revitalization, it has yet to dry up.

Challenges to the implementation of a system like the *karez* predominantly include urbanization and sanitation. The region has uncontrolled population growth and few zoning laws, which often leads to these traditional structures being demolished, neglected, and polluted (Dellapenna 2009). Additionally, sanitation and sewage treatment must be improved and separated from these systems; potential suggestions included increased composting and increased recycling, but none of these systems are in place yet. However, even with these resources, lack of accessibility still provides barriers. In Bidar, a sewage treatment plant exists, but constituents do not have piping to it. The city has high technological potential but lacks holistic infrastructure integration.

Suggestions which aim to mitigate the negative effects of urbanization on sustainable traditional water systems are generally centered around government legislation. The most successful systems often have zoning laws, or no build zones to help the recharge of the *karez* and prevent pollution (Wagle, Warghade, and Sathe, 2012). Unfortunately, even in locations with zoning laws, corruption and bribery can still result in illegal construction and exploitation (Rajendran, 2001). The creation of new zoning laws and the implementation of more anti-corruption legislation would certainly aid in the protection of the *Karez* and similar water systems. Additionally, educational programs concerning sanitary practices could potentially increase public demand for government intervention.

In summary, we observe a functional revitalization program must not only include initial restoration (desilting, cleaning, reconstruction), but also incorporate various initiatives, the first being educational. Understanding sanitary practices and the impact of water quality on public welfare is essential in order to draw public commitment (Dellapenna 2009). The work of NGOs and the IHCNF hold promise for this cornerstone of progress. From here, the financial incentive of the *karez* and other systems must be shifted into a more sustainable framework, with the support of residents (Aartsen 2018). This could come in many different forms, including (1) lowering and altering the distribution of water to less needy species of crops, (2) attracting tourists by marketing water systems' cultural value, and/or (3) removing financial incentives by use of sustainable zoning and anti-corruption legislation. Public support would help to drive these more technical changes, though they are initially derived directly from education.

While the *karez* system appears to be functioning successfully in Bidar, unfortunately, it is unlikely that an equal set of conditions will be found in many other cities across the Deccan. These traditional water structures typically run beneath currently established houses, and residents often are reluctant to cooperate with NGO and government inquiries about land near their homes (Kutty 2018).

Conclusions

Our water quality pilot study shows that many of the observed traditional water structures have varying degrees of pollution, usage, and maintenance. However, even visibly neglected and polluted water sources still have high potential for restoration, sometimes with a water quality index that is comparable to municipal drinking water. Revitalization includes both initial restoration and maintenance: without maintenance, structures can fall into their prior states of neglect. A particular case study of the Bidar *karez* system shows positive applications, but also exemplifies a specific set of sociopolitical conditions needed for this type of revitalization to be successfully maintained. Barriers to this goal include uncontrolled urbanization and lack of sanitation. We also observe that a lack of education surrounding the significance of water structures—both functionally and culturally, combined with the short-term financial incentive of unsustainable farming practices, also represents a burden to sustainable revitalization. Potential solutions—as suggested by local

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NGOs—include leveraging cultural heritage value or tourism as a secondary incentive for both initial restoration and maintenance. Additionally suggested was enhanced government involvement in land protection to prevent pollution. Future work includes longitudinal case studies that examine the hydrology and water quality surrounding these sites in an epidemiological fashion. Additionally, an investigation into new potential maintenance policies of these sites should be studied to explore not only barriers to initial restoration, but also barriers to sustainability.

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