Visualizing the Invisible - a Design Artifact for Managing Groundwater

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Short Paper

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Introduction

Due to human influence, global climate change has negatively impacted many natural resources. One culminating issue regarding climate change is water scarcity. Rising temperatures and overall changes to climates have resulted in diminished water supply in many areas of the world. This is an especially dire issue in India, where there is a heavy dependence on groundwater. India depends on groundwater for both human and agricultural consumption, yet this dwindling resource accounts for 40% of their country's water supply (Yeung, 2019).

Sustainability is key when thinking of solutions for managing the groundwater crisis in India. One such solution is a trans-disciplinary research project known as Managing Aquifer Recharge and Sustaining Groundwater through Village-Level Intervention (MARVI). MARVI is an international project that aims to educate rural Indian communities about their groundwater resources in an effort to impart knowledge on sustainable water management. This project is focused on a network of 250 groundwater wells that spans two watersheds and five villages located in the Aravalli district in Gujarat and the Udaipur district in Rajasthan, India. MARVI collaborates with village-level volunteers referred to as Bhujal Jankaars (BJ) ["groundwater informed"] who monitor every well for groundwater levels and water quality indicators (Maheshwari, 2017). To make this monitoring easier and more affordable for rural communities, prior optimization of the well network has decreased the number of wells necessary to monitor while also decreasing the monitoring from weekly to biweekly.

Aside from well optimization, an overarching goal for MARVI is to provide a way for rural communities to understand the groundwater information extracted from the wells. Preferably, in a way that is both visual and interactive. This way, the results would be more easily understood by rural communities, stakeholders, or anyone else viewing the data. By utilizing the three cycles of design science principles (Hevner et al., 2004), an interactive dashboard artifact was constructed to meet the major goal.

Background

Groundwater

The groundwater resources in India are growing ever smaller due to a lack of regulation and rising population. Groundwater is predominantly accessed through underwater pumps, making it simple to extract water from a well. Easy extraction also prompts heavy usage and consumption of groundwater, which necessitates drilling deeper into the ground in order to attempt to source more water. This is not a sustainable remedy since water levels are still steadily declining. Predicting groundwater fluctuations has grown in prevalence as global concerns rise over water shortages. While the field is still actively changing, "the most obvious input variables in groundwater level predictions studies are rainfall, evaporation, temperature and pumping patterns" (Yadav et al., 2019). A similar method was used to collect rainfall data on the Shetrunji river basin, a hard rock aquifer, in Gujarat, an adjacent state directly south of Rajasthan (Patel et al. 2016).

In addition to deeper wells, another issue from climate change that negatively impacts water availability in India is rainfall. Groundwater wells are replenished during the monsoon season in India as that is the only time of the year with consistent rainfall, otherwise there is no way for the water supply to be renewed. This season only lasts between June and September, and a single season is not enough to fully recharge all groundwater sources. Unfortunately, rainfall levels are becoming more unpredictable and have seen a general decline in the last few years. This means that India's groundwater supply is being used too heavily while also not being able to replenish as much water compared to preceding years.

Studies from the past two decades on groundwater trends in India have reflected this overall declining trend in groundwater as well. There was a noted decrease of approximately 109km^3 in water supply throughout the country between 2002 and 2008, likely due to heavy irrigation (Rodell et al., 2008). More recently, despite regular levels of rainfall, areas in northern India still encountered groundwater depletion due to extensive irrigation and the eastern region of the country faces the same issues (Rodell et al., 2018). This also further reflects the notion that human intervention and excessive water pumping is the predominant cause of the water crisis, not solely climate change.

Since groundwater is just about invisible, predicting and forecasting groundwater level variation is becoming more significant as the water crisis escalates. There are a few different approaches to take in predicting groundwater, whether it is a forecasting method or some sort of spatial interpolation. Some studies on predicting future groundwater levels have made note of significant variables or indicators of groundwater behavior. Many predictive models opted to use rainfall, temperature, humidity, and preceding groundwater levels with various levels of success (Tao et al., 2022). For the MARVI project, many similar indicators were also used. Specifically: rainfall, groundwater level, elevation, pH, electrical conductivity (EC), and total dissolved solids (TDS). All six indicators are present in the dashboard to help educate viewers about rainfall, water quality, and groundwater levels while also allowing for further analysis. An analysis using principal component analysis could be coupled with certain selection criteria to collect rainfall data via weather radar, satellite or other remote sensors allowing data collection without the reliance on expensive rainfall gauge equipment (Dai et al., 2017).

Methodology

Design Science

The dashboard design artifact was constructed while complying with pre-existing conventions of design science research (Hevner, 2007). Compliance with these conventions predominantly refers to the three cycles of design. As seen in Figure 1, the framework for creating the dashboard closely follows these cycles.

The environment of this research framework consists of the people involved in the project, the related organization, and the technology used to gather the data. In MARVI's context, the people involved are either rural Indian communities or project stakeholders as they are the intended audience for the dashboard. The groundwater recording software mentioned is used by volunteers to monitor the groundwater wells, the project data is collected through this software. MARVI seeks to understand aquifer behavior in order to better sustain water supply, along with educating rural communities to ensure future sustainable behavior so they can sustain themselves. The aim and application of this design science research is to construct a dashboard that will aid the aforementioned business needs.

For the knowledge base, the foundations predominantly lie in design theory, groundwater theory, and analytics computational methodologies. The knowledge base from these areas is necessary when constructing a design science artifact meant to address groundwater. The methodologies involved pertain to data analysis, most of which was performed via computational and empirical techniques. Knowledge on the design science process and dashboard design are applied when constructing the groundwater dashboard, which prompts future additions to the knowledge base in terms of dashboard design. Bringing both the knowledge base and environment into the center of the framework leads to a third cycle of construction and evaluation. After the dashboard is created, then it must be evaluated.

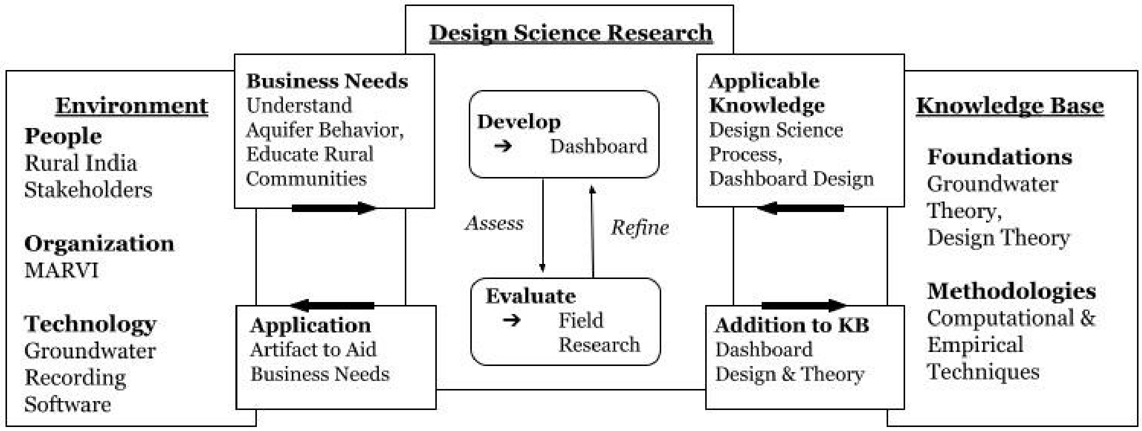

Figure 1. MARVI Design Research Framework

Evaluating a design artifact is key when assessing whether or not its purpose is actually being achieved. If the evaluation process returns negative feedback on the intended purpose, then the artifact can be improved. This is a repeated process and is necessary for design science research (Venable et al. 2016).

Data

The data used within the dashboard was recorded and collected by BJs. This data was collected from the 250 wells within the two watersheds, where they were monitored weekly. Table 1 contains a guide to the data used within the dashboard. Rainfall data was collected weekly when applicable among the five villages. BJs recorded the data via a smartphone app called MyWell, which allows for easy data entry by the BJs while also recording the geographic well location in longitude and latitude format. The MyWell app was constructed by the MARVI project previously in order to aid volunteers in recording data. This app allows for the collection of groundwater levels, rainfall amounts, and water quality indicators while also providing historical data to the end user (Maheshwari, 2017). Other data in the dashboard is identifying well data such as their unique ID, the depth of the well in meters, and the elevation in meters. This data is used to separate between individual wells while also providing more information in tandem with the groundwater level and water quality data.

Use Cases

There are three use cases for the dashboard determined by the stakeholders of the projects:

1. Based on water level depth and rainfall data collected over the last 8 years, what are the patterns on the groundwater changes in wells over time, across villages?
2. How are these patterns related to parameters such as rainfall?
3. How does the water level in the wells respond to rainfall amounts during the monsoon season?

To address these use cases, multiple filters were put in place. The dashboard includes filters for villages, years, months, and seasons. These filters allow for end users to control all the elements involved in the use cases and potentially glean additional insights. The inclusion of these filters allows the dashboard to be fully customizable by an end user, especially after all other components of the dashboard are connected with both the filters and each other.

Data Element	Type	Measurement Unit
Groundwater Level	Float	m
pH	Float	pH
TDS	Float	mg/l
EC	Float	mS/cm
Rainfall	Float	m
Elevation	Float	m
Well Depth	Float	m
Latitude	Geo	X
Longitude	Geo	Y

Table 1. Dashboard Data Description

Design Artifact

The dashboard was created via Tableau, and is currently hosted on a Github site. The MARVI dashboard, as seen in Figure 2, is an interactive object that allows end users to view the collected groundwater data and use filters to drill down into the data. The main component of the dashboard is the groundwater/water quality explorer, which has a map representing all of the 250 wells within the area. There is an option to choose whether the explorer will display groundwater or water quality data for ease of understanding. If set on water quality, the wells will be colored by their average pH and a tooltip will appear automatically when hovering over a specific well. The water quality tooltip displays the village the well is located within, unique well ID, average pH, average TDS, average EC, and the coordinates of the well. If the explorer is set to groundwater, the wells will instead be colored by their average groundwater level and the tooltip will show slightly different information. Rather than display water quality indicators, the groundwater tooltip will instead show the average groundwater level and the depth of the well. Other information, such as the village, well ID, and coordinates, is also included within the groundwater tooltip.

Aside from the explorer, there are also three other modules residing under the main component. From left to right, they represent the average rainfall by village, average groundwater by village, and the average pH by village. All three modules are capable of treating each other as a filter, meaning that selecting a village within one of the modules will isolate that village within the other two, as well as within the explorer. The modules also simultaneously change when the filters on the right are selected. The dashboard filters consist of village, year, month, and season.

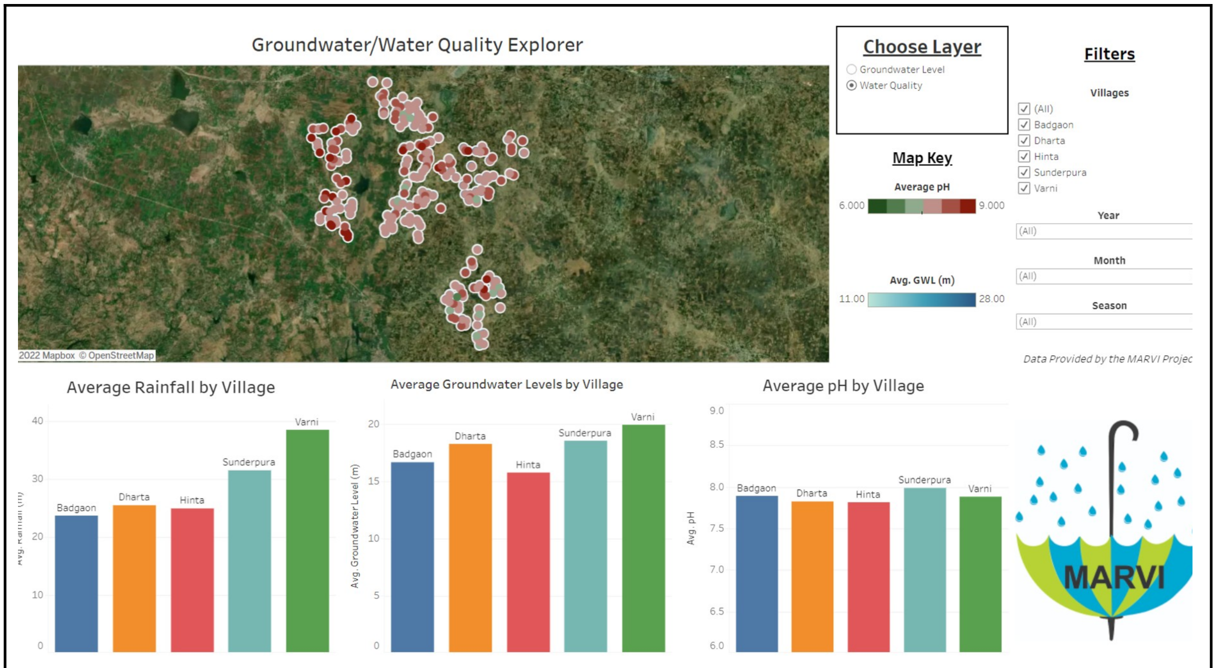

Figure 2. Image of MARVI Dashboard Artifact

Design Evaluation and Artifact Utility

For the MARVI dashboard, the evaluation process is defined by a Qualtrics survey. The survey was submitted to the Institutional Review Board (IRB) for approval and was determined to be exempt. The survey consists of statements on a Likert Scale that asks participants to agree with whether or not they understood the purpose of the dashboard, if they could operate and navigate the dashboard easily, and how appealing the colors were. Participants were also provided an opportunity to leave any open-ended suggestions for the dashboard. The most important information to glean from participants is whether or not the dashboard helps them better understand groundwater and water quality of the wells in that area. The dashboard has gone through two rounds of feedback.

One notable improvement to the dashboard from the feedback would be the water quality data. One participant suggested adding water quality data to the graph so the audience can understand more about groundwater than just the water level. One of the three water quality indicators in the dashboard, TDS, was suggested by a participant. Other improvements from the feedback was the inclusion of units of measurements when applicable, and color adjustment. The first round of feedback implied changing the colors within the dashboard, the improvements to the color resulted in more agreeable feedback from the second round. With the improvements to the dashboard, the intended purpose of educating the public about groundwater availability is achieved.

Limitations

One particular limitation is in the availability of rainfall data and how it behaves in comparison to the groundwater and water quality data. Since the nature of rainfall in India is not year-long, it doesn't cooperate quite as well as the other modules with regards to filters in the dashboard interface. While the rainfall module behaves like the other two modules (that show pH and groundwater level) with the season filter, it is not as easily altered with the year or month filter. However, this did not seem to be a major issue for the stakeholders as they are familiar with the nature of rainfall in India.

Other limitations within the data are in the water quality data. The original water quality data had more than three indicators, but all other indicators such as mineral, fluoride and turbidity had too many nulls to be properly utilized. This, in contrast to the issue with rainfall data, is a data entry issue. The recorded data over the years sees changes in which indicators are being recorded and how often, and there are some discrepancies in how the recorded dates are structured. pH, EC, and TDS were the only indicators that were consistently recorded over the entire period of time. Some other indicators, such as turbidity, may be useful if there were fewer missing values present. The lack of other indicators did not seem to be a major issue with the stakeholders who evaluated the artifact.

Conclusion

Following two cycles of evaluation and improvement, the MARVI design artifact addresses the associated use cases and educates end users about groundwater availability. The interactive aspect of the dashboard is helpful for those who may learn better by directly interacting with the data while also potentially feeling more personable. The identifying well data within the tooltips would help the audience recognize potential patterns between wells, perhaps in elevation or well depth. Since the dashboard is now optimized for both desktop and mobile views, it is much more accessible to the general public as well. The current state of the dashboard and its presented data may prompt better management of groundwater and further action in terms of groundwater policy.

The dashboard still necessitates further evaluation and improvement following survey results and feedback, which will be conducted in the near future. Some discussed changes to be made are an added language option for easier understanding for those who are not able to read English, along with an animation component. Once the dashboard is determined to be fully improved, it can then be connected to the MyWell app. This would allow rural Indian communities to interact with the dashboard themselves rather than just stakeholders or others within the MARVI project. Connecting the dashboard to MyWell is an end goal since this would allow the dashboard to fulfill its purpose of educating these communities about their groundwater resources. In addition to connecting the dashboard to MyWell, it will also be opened to newer data. The current data within the dashboard is static, once the design is finalized then it will be retrofitted to allow for new data and automatic updates. This, on top of connecting to the app, will provide more reliable and relevant information to its audience.

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