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TRANSFORMATION TOWARDS SUSTAINABLE
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Implementation of a Freshwater Lens Assessment Protocol on Karst Islands

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Karst islands like those found in the Philippine Archipelago present extreme challenges for stakeholders to manage their water resources in a sustainable manner. Anthropogenic Climate Change, land development, point source pollution and increased population have all combined to alter the water balance on these fragile islands. Karst features, shallow depth to groundwater and the potential for dissolution, contribute greatly to these challenges. Combined, these factors pose an array of complex research questions. Field implementation of a Freshwater Lens Assessment Protocol (FLAP) was initiated on Bantayan Island in August 2017. Field mapping, well surveying, groundwater sampling and laboratory analysis have been completed for the first quarter of the yearlong study. Through the application of current groundwater characterization practices the research posits a novel approach for these hydrogeological environs. Through applying FLAP credible output for the characterization of the islands groundwater resources will be determined and integrated into an Adaptive Water Resource Management framework, empowering stakeholders to make informed decisions on sustainable abstraction strategies.

Introduction

The water resource beneath karst islands is poorly understood, resulting in the unsustainable management of the natural resource. This source, known as a Fresh Water Lens (FWL) is a lenticular body of freshwater the floats atop seawater. The path forward to arrest the scenario is through application of refined scientific assessment protocols and utilizing appropriate concepts of Adaptive Water Resource Management. During 2017, the researcher mobilized to Bantayan Island, Cebu Province, Philippines (Figure 1), and set up a field station, which included a laboratory and began a 12-month study. The research aim is to assess the impact of Saltwater Intrusion (SWI) on this karst island through the application of a Freshwater Lens Assessment Protocol (FLAP). The output of FLAP will be integrated into participatory Adaptive Water Resource Management framework for stakeholder engagement.

SWI can be characterized as the most widespread and important process impacting water quality on the planet (Bear, 1999). Jones (1999, p 51) stated 'This problem is intensified due to population growth, and the fact that about 70% of the world population occupies coastal plains.' (Jones, et.al., 1999. Geochemical Investigations. In: Bear et.al., Seawater Intrusion in Coastal Aquifers-Concepts, Methods and Practices. Kluwer Academic Publishers (p. 51-71). SWI has been a highly-studied condition in coastal aquifers starting with the work of Ghyben in 1889 and Herzberg in 1901 (Verruijt, 1968) and their well adopted Ghyben-Herzberg Formula (GHF) for estimating the depth of the interface between saltwater and freshwater. There have been many studies where the GHF has been applied and offered sound correlation with hydro-geochemical data. As well, there have been similar works that counter the assumptions made with the formula, in particular how it can be applied to semi-confined and anisotropic aquifers (Bear and Dagan, 1964a). Hence, understanding the hydrogeology of these environments is challenging. This paper will present the initial findings from implementation of FLAP, including field mapping, geomorphological field observations, domestic well survey, differential GPS (dGPS) field reconnaissance, and digital elevation model preparation.

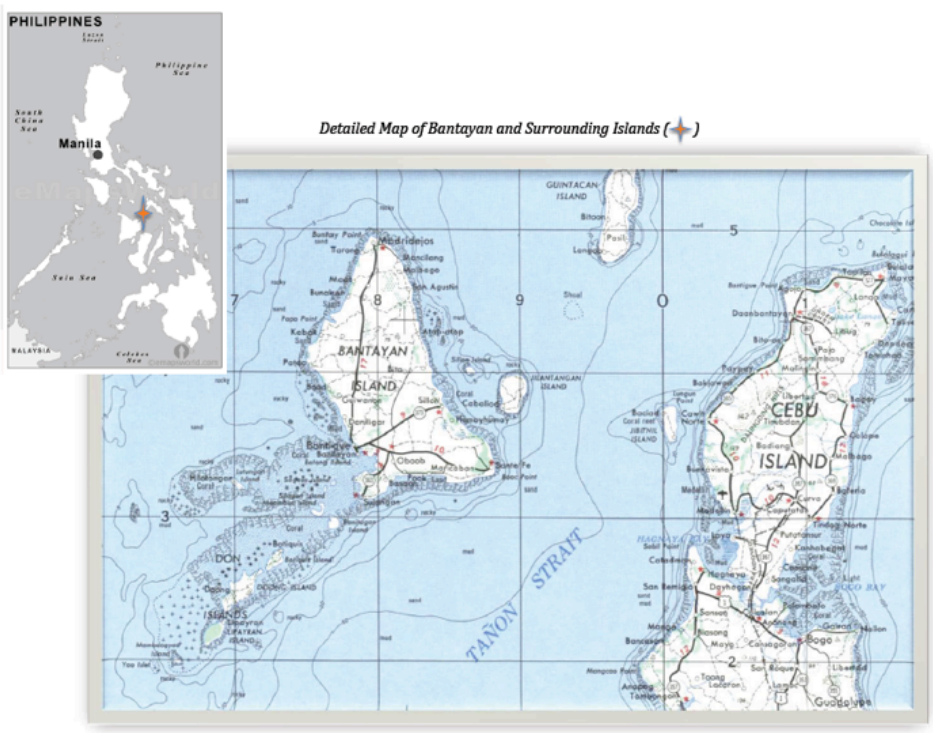

Figure 1. Detailed Map of Bantayan and Surrounding Islands

Source: GOOGLE MAP

Aim of the study

The main goal of the study is to assess the impact of SWI on karst islands water resources through the application of a Freshwater Lens Assessment Protocol integrated into a participatory Adaptive Water Resource Management framework for stakeholder engagement. Furthermore, this study wants to test the efficacy of FLAP and its ability to produce viable output for improved management of the FWL.

Description of the study area

The Philippine Archipelago, located in Southeast Asia, is composed of approximately 7000 islands that are home to a population of nearly 110 million people. Within the Archipelago, lies the Visaya Basin and the Cebu Province, which is central to the Archipelago. Roughly 5 km off the northwest Coast of Cebu, sits Bantayan Island and its seven islets. Bantayan Island is one of the larger islands, which belong to Cebu Province. It has a land area of about 110 square metres (main island) and a maximum elevation of 75 m. The population, as reported by the National Statistics Office for 2010, is 136,844 distributed between Bantayan (74,762), Madridejos (34,860) and Santa Fe (27,222) (NCSO, 2010).

Water resources on Bantayan can be characterized as de-centralized from the municipalities and serve roughly 20% of the population. The primary water supply for many islanders comes from shallow hand dug wells that penetrate the freshwater lens by approximately 1 metre (Photo 1). There exists a strong commercial presence on the island that utilizes an unknown quantity of groundwater for a burgeoning poultry industry, and in Santé Fe there is a strong tourism presence that utilizes groundwater for their operations, primarily from shallow wells that extract saltwater and make use of bottled water for their patrons. What was evident from the discussion between Municipal Engineers was that limited data sharing is practiced regarding current abstraction locations, rates and future expansion of their respective well fields from the FWL.

Photograph 1. Typical private well on Bantayan

Source: Author

Geologically, the island is composed of a karstic limestone deposited during the Pleistocene and Holocene epochs (Aurelio, Peña, & Taguibao, 2013). Eolianite deposits are present at the interior of the island and make up the highlands and principal recharge area of the FWL (Photo 2). These formations are welded atop a former igneous platform that was flooded by Pleistocene melt-water from the last glaciation. Bantayan, like many islands in this region of the world is home to fishermen and subsistence farmers who have resided upon these fragile outposts for generations. Islands such as those found in the Philippine Archipelago rely upon a very dynamic and fragile FWL that resides in an anisotropic aquifer for their primary water supply. As society becomes more water dependent, coupled with population increase, there is growing demand on the water supply. Increased development results in a net change in land cover, which impacts the recharge component of precipitation to the aquifer, thereby resulting in greater stress on the aquifer. Understanding the impacts of point and non-point source pollution from industry and the environment goes unchecked, and as demand on the water supply increases the only response is to increase abstraction. These effects compound and create a deleterious environment for the fragile aquifer and the citizens of these Islands.

Photograph 2. Eolianite Formation, Bantayan Island

Source: Author

Field Testing of FLAP: Methods of characterization and observations

Freshwater Lens Assessment Protocol

As a holistic method, the initial intention was to implement FLAP in a systematic approach, starting with the stakeholder surveys. Working with local Municipal Planning District Coordinators (MPDC) it was evident that developing a representative well field for groundwater monitoring and sampling was a more appropriate direction. In addition, the core elements of the protocol were incorporated into current field activities and included: local hydrogeological data acquisition and analysis, remote sensing data review, geomorphological field characterization, regional meteorological data acquisition, and local tidal monitoring. Detailed in the subsequent sections are progress made since implementation.

Groundwater monitoring and sampling

A domestic well survey was conducted across the island identifying strategically located private and community hand dug wells. These wells traverse the island in a north south orientation and several east-west transects through the highlands of the island, and the location of the freshwater lens. During this preliminary field reconnaissance, well owners were asked if they would be willing to participate in this research by allowing their well to be sampled and participate in a household survey questionnaire. Meetings with MPDC officials for the three municipalities and their respective water managers allowed for the incorporation of their wells into the database for possible inclusion into the study. After visiting approximately 75 well sites and utilizing a Garmin Montana 640 GPS unit to map their coordinates, the field data was imported to Google Earth and a preliminary base map was completed (Figure 2). This process brought forward a key finding in that the elevation control from a standard GPS unit was unsatisfactory for this research. In addition, local benchmarks were evaluated; however, most were damaged or unable to be located. To remedy this, an agreement with a local university was reached and a dGPS survey was made of the island, and a select number of private and community wells were surveyed for groundwater elevation purposes to facilitate the characterization of the FWL.

Figure 2. Preliminary Well Survey Map

Source: Google Earth

Figure 3. GNSS Map of Bantayan Island including the study well field

Source: Geographic Coordinate System University of San Carlos

The dGPS survey was completed and a final well field map and digital elevation model were created for Bantayan Island. Figure 3 presents the Global Navigation Satellite System (GNSS) map prepared from the dGPS survey. Based upon this final mapping, the well field was reduced to an n=52 wells for sampling.

The first round of groundwater sampling was initiated in late October 2017, and all 52 wells were sampled. Temperature, pH, total dissolved solids, electrical conductivity and salt were measured in the field using a Palintest Multi-Parameter Pocket Meter. Liquid levels were measured using a Heron instruments water tape and conductivity probe capable of distinguishing the water level surface. A Palintest Photometer 7100 was used in the lab to determine select anions (chloride, sulphate & bicarbonate) and cation (potassium) and trace elements (boron and bromide) from the collected groundwater sampling. The Palintest Photometer is a direct read photometer with an operating technique applied based upon the principles of optical absorbance and scattering visible light. The optical absorbance techniques are based on the use of Palintest (spectro) reagents, creating visible colours with specific analytes upon reaction. The list of analytes was selected for the determination of SWI. The results of this work are in process and will be reported in future work.

Geomorphological characterization

One of the key research questions posed was for the determination of the morphology of the FWL and what geomorphological features on Bantayan Island exist and how would they influence the lens dynamics. Field reconnaissance work was initiated in early August 2017 to begin this determination. Sinkholes, caves, karst outcroppings at grade, freshwater lens discharge points to the ocean were all relatively widespread across the Island. Surface water was found on both the east and west sides of the central highland area of Bantayan Island. The ponded areas are more widespread on the western side (i.e., leeward side) of the island than that of east. These ponded areas are likely a reef flat plate, as described by (Bailey, et. al. 2009) a semipermeable slab of reef rock that's acts as a confining layer to the aquifer below. As this research advances and the dry season begins, these features will continue to be monitored and their respective influences on the FWL dynamics will be evaluated.

Conclusion

The present study shows that FLAP is nimble and adaptable to the challenges found in this research setting. In addition, the preliminary observations offer the researcher confidence in field methods applied to date that have yielded credible out put for the determination of the configuration and morphology of the freshwater lens beneath Bantayan Island. The importance in establishing collegial collaboration agreements is evident in some of the preliminary successes in this research. The dGPS survey and associated mapping output has been incredibly important. These data files are being imported into ArcGIS for future mapping requirements for data interpretation and reduction. Challenges in accessing abstraction data from commercial applications remain a concern for the determination of a groundwater budget and hydrogeologic model development. However, pursuit of these data through stakeholder engagement will begin in earnest later this year and continue throughout the course of the year.

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