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Water resource assessment of Karst Islands and the development of a freshwater lens assessment protocol

R. DiFilippo (USA), I. Smout & L. Bosher

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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. A field reconnaissance and semi-structured interviews were completed on Bantayan Island in 2016. Drawing upon current groundwater characterization practices the research posits a novel approach for these hydrogeologic environs. With the application of the Freshwater Lens Assessment Protocol (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. 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 2016, the researcher travelled to Bantayan Island, Cebu Province, Philippines (Figure 1), and conducted a preliminary assessment that included a field reconnaissance and a series of semi-structured stakeholder interviews. The purpose of the assessment was to gain a contextual understanding of water resource availability, evaluate the island geomorphology and listen to the sentiment of the islanders regarding changes to natural climate and how they incorporate such change into their daily lives. The outcome of this work has crystalized the magnitude of the need; and the lack of technical capacity to arrest the problem of Salt Water Intrusion (SWI).

SWI can be characterized as the most widespread and important process impacting water quality on the planet (Bear, 1999). This point can be amplified by data from a recent study by Small and Cohen 2001, the proportion of people living within various distances from a coastline are estimated as follows: 100 km, 38%; 150 km, 44%, 200 km, 50% and 400 km 67%. 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 salt water 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 address the dimensions of the groundwater resource problem on karst islands; the methodological approach advanced thus leading towards the selection of a case study location.

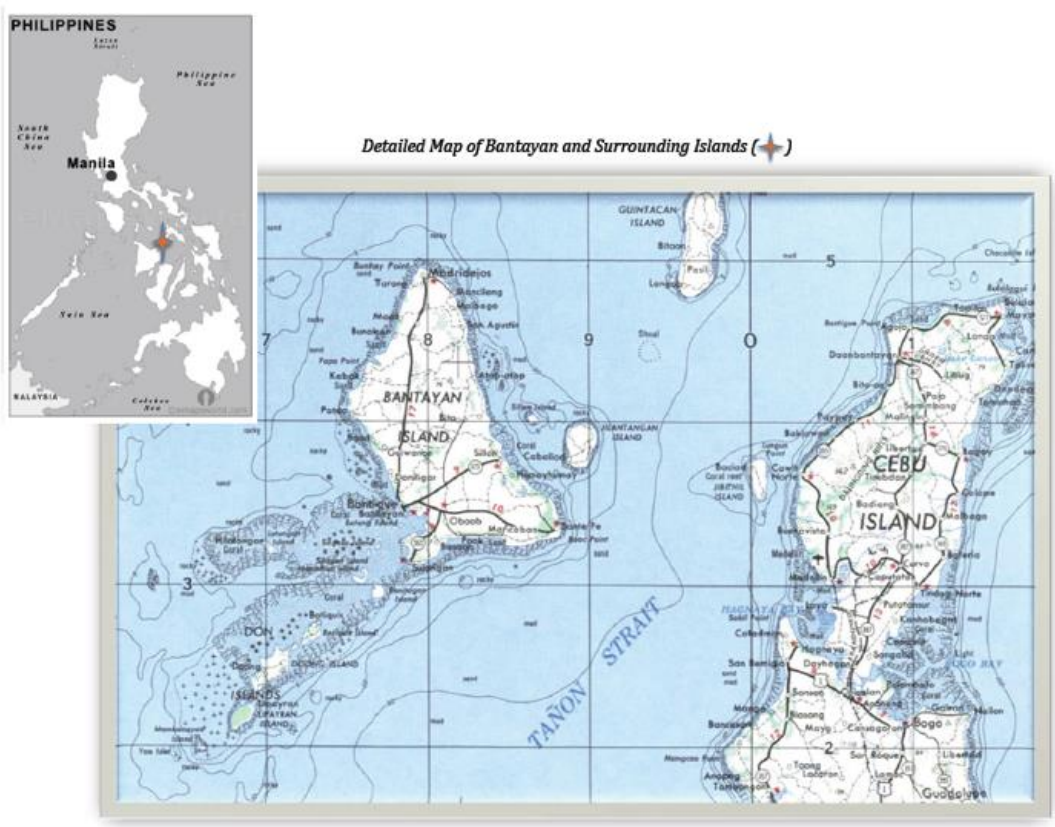

Figure 1. Detailed map of Bantayan and surrounding islands

Source: Google Map

Context

The environmental factors at work are complex and typically outside of the stakeholders' view. One such factor is the adverse results of SWI in productive aquifers involving reduction in the available freshwater storage volume and the simultaneous contamination of production wells, given that less than 1 % of seawater (250 mg/L chloride concentration) renders freshwater unsuitable for drinking and has toxic effects on plants (Ataie-Ashtiani et al. 2013). Furthermore, as noted by (Holding & Allen 2015) islands exposed to intense episodic rainfall, lack of soil cover, well-developed karstic features, and shallow depths to the vadose zone cumulatively result in significant impact of organic matter to the Fresh Water Lens (FWL). Such an environment accelerates the potential for dissolution greater than that predicted solely by simulations of inorganic mixing between basal FWLs and underlying saline groundwater. In recognition to these cogent points, the research under consideration is time sensitive, as is the response by stakeholders.

Demand for water is heightened by the lack of consistent precipitation and effective recharge, coupled with increased demand from industrial, commercial and domestic users. Stakeholders look for answers to solve their water demand challenge, yet from my discussions there is no resolution. SWI and the resulting contamination of the FWL is a common occurrence in the region, and the initial reaction to its discovery is to drill more wells into the aquifer or further inland from the coast. To overcome this response, the researcher puts forth a new paradigm in a holistic characterization strategy and stakeholder engagement practice through:

- Application of the Freshwater Lens Assessment Protocol (FLAP), and
- Assimilation of Adaptive Water Resource Management principles.

Filling the GAP in research - freshwater lens assessment protocol

Developing the current research beyond the current hydrogeologic regime to the field conditions described above demands a clear and concise methodology with appropriate rigor applied in data acquisition practices and interpretation skills to determine the characteristics of the FWL and the associated water resources. It is for this reason that this research posits such a methodology for application, with an emphasis on developing countries where the technical resource capacity is limited. The FLAP affords a holistic approach to assessment, data management and projected simulation of the aquifer (Figure 2).

Figure 2. Freshwater lens assessment protocol

Source: Author

Freshwater lens assessment protocol

As a holistic method, the FLAP shall be implemented in a systematic approach, starting with the Stakeholder Surveys. Working with local municipalities and provincial and national governments, a series of semi-structured interviews will be performed to determine the sentiment of stakeholders on the issues surrounding water resource management. While the surveys are underway, the core elements of the protocol will be proceeding and include: local hydrogeologic data acquisition and analysis, remote sensing data review, regional meteorological data acquisition, local tidal monitoring, groundwater monitoring and sampling. A culmination to the fieldwork will be stakeholder workshops discussing the output from the FLAP and integrating the findings into an Adaptive Water Resource Management framework, with an emphasis on the sustainable management of the FWL.

Case study: Bantayan Island, Cebu Province, Philippines

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 sets Bantayan Island and its seven islets. Bantayan Island, composed of three municipalities (Bantayan, Madridjesos, and Sante Fe), has an area of approximately 140 square km with a maximum elevation of 75

meters above sea level, located central on the island. The population is approximately 115,000 people mostly living on the main island and along the coastline.

Water resources on the Islands can be characterized as limited, with the Islets relying upon rainwater harvesting for their primary water source; salt producing wells and the importation of bottled water from nearby Bantayan. Water resources on Bantayan can be characterized as de-centralized from the municipalities and serve roughly 20% of the population. There exists a strong commercial presence on the island, which utilizes an unknown quantity of groundwater for a burgeoning poultry industry, and in Santé Fe there is a strong tourism presence, which utilizes groundwater for their operations, primarily from shallow wells that extract salt water 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.

Geologically, the island is composed of a karstic limestone, laid down during the Pleistocene and Holocene epochs (Aurelio et al. 2013). These formations are welded atop a former igneous platform; which 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, which 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.

Discussion and recommendations

The challenges are diverse and woven into stakeholder's expectations; however, they can be synthesized as follows: the demands for economic growth influence the need for increasing the abstraction of groundwater; therefore, knowledge about the sustainability of the source is essential. Commercial growth in the industrial sector, tourism and associated population demands place greater stresses on the FWL. This pressure results in government leaders searching for solutions to their water problems, and in most instances they suggest a treatment approach. However, most of these regions lack adequate power reserves and finances for treatment technologies, such as desalinization.

Systematic methodologies for the assessment and characterization of environmental resources are the benchmark in the research community for determining the dynamics and condition of the environment and its interaction with other media. FLAP is a systematic methodology for characterization of the lens morphology, and the influence of both natural and anthropogenic influences. This research will establish a tool for the methodical collection of hydrogeologic data for this complex environment to enable stakeholders a set of criteria for improved management of the groundwater resource.

The intended outcome will include a technical component and a social instrument for assimilation into future water resource decision-making strategies. Part one will be a two-dimensional simulation of the FWL, the saline plume and an island specific Water Budget. From these data sustainable targets for abstraction scenarios will be established. Sustainability will be considered under the guidelines presented by the Brundtland Report; as summarized: In 1987, the United Nations defined sustainable development as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland 1987)." It will be under this definition that the management concepts introduced pursuant to the methodology advanced will be formulated.

Part two will be the application of a groundwater-indexing tool, (GALDIT) (Chachadi 2005) (Figure 3).

The data generated from part one will serve as input to GALDIT. The use of GALDIT as a screening tool for data that is being collected and examined for the first time has gained limited exposure in the research community; however, the tool offers promise as an additional decision support instrument. GALDIT would be applied for identification of saline impact, scaling island wide vulnerability in groundwater and as a precursor for the design of future characterization initiatives. GALDIT output will be integrated into a GIS environment.

GALDIT

- **G**roundwater Occurrance-Unconfined, Confined or Leaky Confined
- **A**quifer Hydraulic Conductivity
- **L**=Height of Groundwater Level above Sea Level
- **D**istance from the shore
- **I**mpact from existing status of seawater intrusion
- **T**hickness of the Aquifer that is being mapped

Figure 3. GALDIT Index

Source: Chacchadi, A.G. et al., 2005

There is potential for application of Adaptive Water Resource Management (AWRM) principles, as a decision framework to enable the stakeholder's guidelines to improve management of this resource. This would improve stakeholders' current ex-ante risk reduction mentality with risk management thinking in order to achieve actionable results for the stakeholders. With the United Nations adoption of Resolution 70/1 'Transforming our world: the 2030 Agenda for Sustainable Development with 17 SDGs and relative targets to be achieved by 2030 (UN 2015), significant challenges are omnipresent for Government. These challenges associated with Goal 6 include issues of water scarcity, access to safe drinking water, sanitation, water quality, flood risks and trans-boundary water. This daunting task can be achieved with local knowledge and practice in water resource management joining with Government in application of holistic characterization techniques and AWRM principles. (Gleick 1998) offers motivation for this research in stating, "By acknowledging a human right to water and expressing the willingness to meet this right for those currently deprived of it, the water community would have a useful tool for addressing one of the most fundamental failures of 20th century development."

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Contact details

About the author: Bob DiFilippo is a Research Student at Loughborough University with particular interests in groundwater research in vulnerable environs, with a specific interest in the effects of Climate Change on coastal communities in developing countries.

Robert M. DiFilippo
Loughborough University, UK.
(+44) 7585 153 707
Email: R.M.Difilippo@lboro.ac.uk

Ian Smout
Principal Programme Manager
WEDC, Loughborough University, UK.
Tel: 01509 222885
Email: i.k.smout@lboro.ac.uk
www: http://wedc.lboro.ac.uk/

Dr Lee Bosher
Senior Lecturer
WEDC, Loughborough University, UK.
Tel: 01509 222885
Email: l.bosher@lboro.ac.uk
www: http://wedc.lboro.ac.uk/