Journal of Environmental Science and Management 16(2): 19-27 (December 2013)
ISSN 0119-1144

GIS-Based Assessment of Groundwater Vulnerability to Contamination in Boracay Island Using DRASTIC Model

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ABSTRACT

The study was conducted to assess the vulnerability of groundwater resource to contamination in Boracay Island, Aklan, Philippines, using the DRASTIC model in combination with Quantum Geographic Information System (QGIS). Specifically, the study determined the vulnerability of groundwater resource to pollution contamination by computing its vulnerability index. From this, a groundwater vulnerability map was developed and policy intervention recommendations were formulated targeted to ensure the sustainability of ecotourism industry on the island. Results confirmed the high vulnerability of Boracay Island's groundwater resources to contamination and that unregulated pressures due to tourism development could lead to the further degradation of its groundwater and coastal resources. In terms of spatial extent, the groundwater resources of Boracay Island that were found to be vulnerable to contamination are as follows: approximately 410.28 ha (40.87 %) are moderately vulnerable; 562.37 ha (56.01 %) are highly vulnerable; and 30.95 ha (3.08 %) are considered as very highly vulnerable. The study likewise exhibited the combined use of the DRASTIC model and Quantum GIS as an effective method for groundwater contamination vulnerability assessment. It also demonstrated the effectiveness of the model in developing vulnerability maps and the combined use of the model and QGIS in identifying vulnerable areas to contamination that can aid in policy making, planning and management interventions to attain sustainable ecotourism industry in an island ecosystem. The immediate legislation of local ordinance to construct sewerage system on identified critical areas is recommended to mitigate the deterioration of aquatic resources in Boracay Island in the future.

Key words: *Groundwater Vulnerability Assessment, Boracay Island, DRASTIC Model, GIS*

INTRODUCTION

The environmental and health consequences of coastal tourism are often unexpected but are observed to be severe whenever they occur. The Boracay Island, in the Municipality of Malay, Province of Aklan, Philippines, is dubbed as one of the most beautiful beaches in the world because of its famous powdery white sand beaches and crystalline waters. Many people consider the island a paradise, hence swelling of population and influx of tourists are observed in the island every year. As a result, tourism developments cropped up which led to the observed exhaustion of groundwater supplies and chronic shortages of potable water which led to the shipment of bottled water into the island (*Smith 1992*). In addition, seepage from poorly maintained septic tanks (used in place of a tertiary sewage treatment system) were thought to have contaminated the groundwater, which evidently caused health risks and annual algal blooms from January to April in the coastal areas. According to *Goreau* (*2007*), majority of the sewage produced on the island is by the local residents, and most of it simply flows into the ground. Problems similar to that in Boracay have been reported in the islands of the Caribbean of the Dominican Republic (*Jorge 1997*) and in Barbados, Antigua, St Lucia and Grenada (*Cambers 1992*). Therefore, a study to assess the vulnerability of groundwater resource of Boracay Island is important. This is to develop a groundwater vulnerability index in the area and a groundwater vulnerability map for the Boracay Island's groundwater resources. Results can aid in policy making and planning in order to balance tourism developments and groundwater resource integrity for human well-being, as well as in the implementation of mitigation measures to attain sustainable management of groundwater resources and coastal tourism industry in the Philippine's leading tourist destination, the Boracay Island.

METHODOLOGY

The conceptual framework as shown in **Figure 1** is generally concentrated on groundwater vulnerability assessment of coastal aquifers in Boracay Island, Malay, Aklan, Philippines by determining the vulnerability index and developing a vulnerability map using the model adopted from *Aller et al.* (*1987*) and Quantum Geographic Information System (QGIS) which is a free and open source GIS used to process the data in order to generate the vulnerability map. This study was conducted from June 2012 to October 2012.

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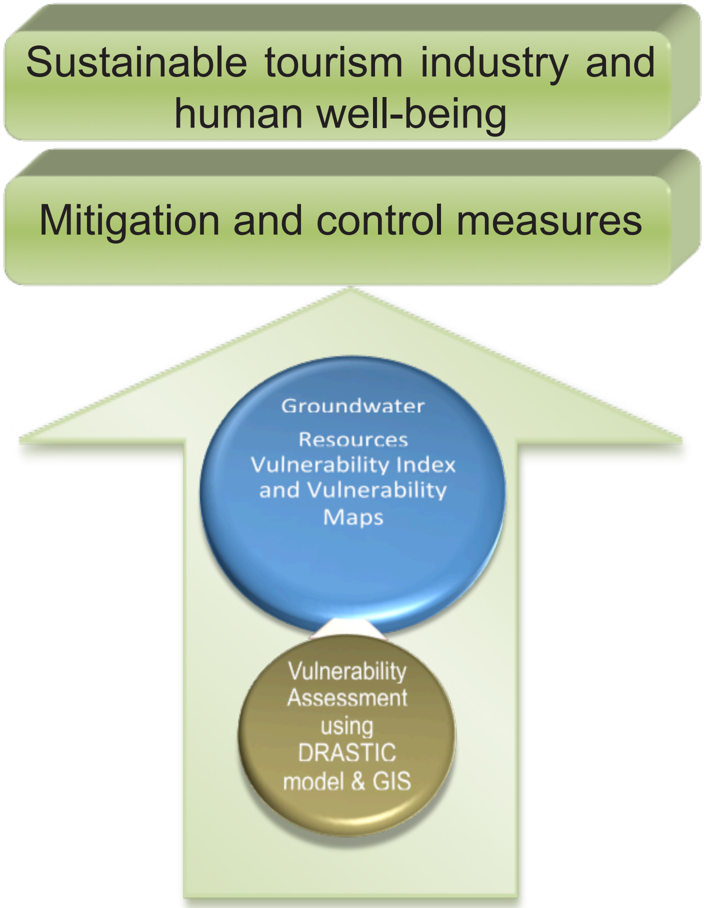

Figure 1. Conceptual framework of the study.

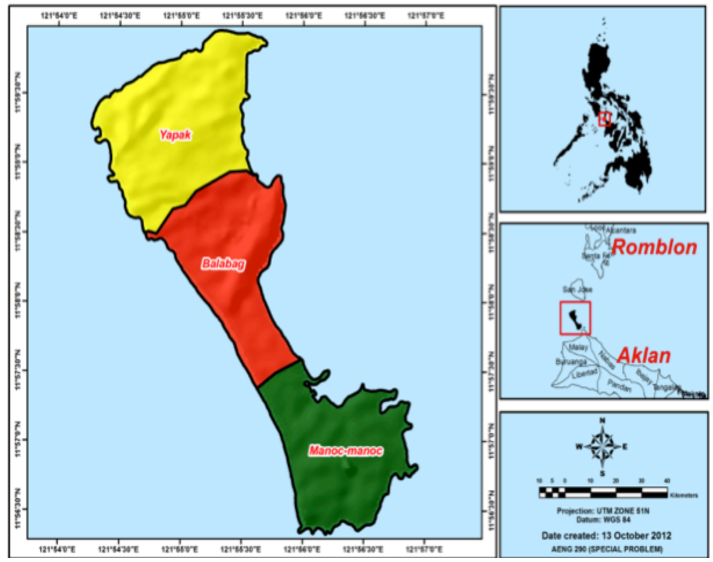

Figure 2. Location map of Boracay Island.

Location and Physical Features of the Study Area

The island of Boracay (11°57'–12°00' latitude and 121°56' - 121°57' longitude) of the northwestern tip of Panay in the Western Visayas and under the administrative jurisdiction of the Municipality of Malay, Province of Aklan. The land mass measures 6.8 km long by 3.3 km at its widest distance, with highest elevations ranging from 50 to 105 m above mean sea level. Boracay Island has a total land area of 1,006.64 ha and is comprised of three barangays (Manocmanoc, Balabag, and Yapak) (**Figure 2**).

DRASTIC Modeling

In 1987, an United States Environmental Protection Agency (USEPA)-funded research to develop a method for evaluating pollution potential anywhere in the United States successfully produced the DRASTIC model (*Aller et al. 1987*). The DRASTIC was used to evaluate the relative vulnerability of areas to groundwater contamination by focusing on hydrogeologic factors that influence pollution potential. The hydrogeologic factors include Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and hydraulic Conductivity that make up the acronym DRASTIC. The rating schemes and weights assigned to the seven hydrogeological factors that comprise the basis of the DRASTIC method were adopted from *Aller et al.* (*1987*). DRASTIC model has been used in detailed studies to delineate areas where aquifer vulnerability is higher and land use suggests a potential source of pollution (*Gogu and Dassargues 2000*). It is an economical tool to identify the zones of concern and as a tool to overcome problems of haphazard, uncontrolled development of land and of undesirable activities having an impact on groundwater quality (*Thirumalaivasan et al. 2003*).

In this study, each DRASTIC factor was assigned a DRASTIC weight ranging from 1 to 5 and was further assigned a rating, typically from 1 to 10, based on a range of information within the parameter. Higher ratings and weights indicated higher risk of vulnerability

The values of the ratings and weights for each parameter are plugged into an equation to determine the pollution potential known as the DRASTIC Index. The equation for the DRASTIC Index is as follows (*Aller et al. 1987*):

Drastic Index (DI) =

$$DR*DW + RR*RW + AR*AW + SR*SW + TR*TW + IR*IW + CR*CW$$

Where:
DR = numerical rating of depth to water
DW = numerical weight of depth to water
RR = numerical rating of net recharge
RW = numerical weight of net recharge
AR = numerical rating of aquifer media
AW = numerical weight of aquifer media
SR = numerical rating of soil media
SW = numerical weight of soil media
TR = numerical rating of topography

TW = numerical weight of topography
IR = numerical rating of impact of vadose zone media
IW = numerical weight of impact of vadose zone media
CR = numerical rating of hydraulic conductivity
CW = numerical weight of hydraulic conductivity

The numerical weights and ratings, which were established using the Delphi technique (*Aller et al. 1987*), are well defined and have been used worldwide (*Al-Adamatet al. 2003; Anwar et al. 2003; Babiker et al. 2005; Chandrashekhar et al. 1999; Margane 2003; Napolitano 1995; Rundquist et al. 1991; Shahid 2000*). The Delphi technique utilizes the practical and research experiences of professionals in the area of interest to assess levels of risk. Typically, the experts are asked to rate the risk level of certain activities under a set of initial conditions. The activities and conditions presented are general in nature and not site specific. A scale of risk is established prior to start of the project (a scale of 1–5 with 5 being the highest possible risk). The highest weight (5) has been assigned to two parameters, the depth to water and impact of the vadose zones because the shallower the water table, the higher the chance of pollutants to reach to groundwater.

The resulting DRASTIC index represents a relative measure of groundwater vulnerability to contamination. The higher the DRASTIC index, the greater the vulnerability of the aquifer to contamination. A site with low DRASTIC index is not free from groundwater contamination, but it is less susceptible to contamination when compared with the sites that have high DRASTIC indices. The DRASTIC index results can be converted into qualitative risk categories using **Table 1**.

Preliminary Data Acquisition

The study utilized the available hydrological and geophysical data from reports of government institutions such as Environmental Management Bureau (EMB) and Mines and Geosciences Bureau (MGB) both of Department

Table 1. DRASTIC index ranges for qualitative risk categories.

DRASTIC qualitative category	Low	Moderate	High	Very high
DRASTIC index	1- 100	101-140	141-200	>200

Preparation of DRASTIC Input Data

The DRASTIC method relied on seven parameters in the development of the vulnerability map. Since the method involves the evaluation and characterization of highly variable input data, Quantum Geographic Information System (QGIS) was heavily employed in data development and processing.

of Environmental and Natural Resources (DENR) and the Local Government Unit (LGU) of Malay, Aklan. **Table 2** summarizes data used for creation of hydro-geological parameters for DRASTIC model and their sources.

Data Preparation

Maps obtained from different sources were digitized. All map layers were projected using the Universal Transverse Mercator (UTM) Projection Zone 51N, WGS84/UTM to avoid errors or any inconsistencies in the overlay analysis of both vectors and rasters and to permit calculation.

Groundwater Vulnerability Mapping

The seven sets of data layers were digitized and were converted to raster data sets. These were then processed using Quantum GIS. Once the DRASTIC Index has been computed, it is possible to identify areas that are more likely to be susceptible to groundwater contamination relative to others. The higher the DRASTIC Index, the greater the groundwater pollution potential (**Figure 3)**.

Depth to Water Factor

The groundwater resources of Boracay Island are of shallow freshwater lenses that occur in unconfined condition. The depth to the water table as measured from existing wells in all three barangays of the island varies from 0.58 to 4.096 m based on the report of MGB Regional Office VI as based on its Geo-Environmental Assessment conducted in July 2000. This may make it highly susceptible to contamination from surface pollution sources. The thematic map developed used the rating of 10 to this parameter for it falls between the ranges of 0-5 m (**Figure 4)**.

Net Recharge Factor

Based on the Boracay Environmental Master Plan (Boracay EMP) of DENR in 2008, the highest monthly rainfall value that occurs regularly in October is 299.7 mm while the average total annual rainfall is recorded at 1,985 mm throughout the island. The indicative recharge to the island's aquifer is considerably low and was estimated as 10% of rainfall, which is a typical net recharge rate as a fraction of annual rainfall in most aquifers in the Philippines based on the report of the National Water Resources Board, though it depends on land cover and rock types. Hence, the net recharge is only 198.5 mm, therefore was given a rate of 1 (**Figure 5**).

Aquifer Media Factor

The semi-detailed geologic mapping conducted by the MGB, Iloilo City in July 2000 showed the

Table 2. Data used for the creation of hydrogeological parameters for DRASTIC model.

Parameter	Data Type	Source/s	Format	Output Layer
1	Coastal Survey (Water Table)	DENR-MGB (2007)	Table	Depth to Water (D)
2	Average Annual Rainfall	Climatologic Data, Boracay EMP, DENR Reg. VI (2008)	Table	Net Recharge (R)
3	Geologic and Structural Map	DENR-MGB Reg VI	Vector Map	Aquifer Media (A)
4	Soil Map and Land Use Map	Malay LGU, CLUP, Malay	Vector Map	Topography (T)
5	Topographic Map	Malay LGU, CLUP, Malay, DEM (SRTM http://srtm.csi.cgiar.org)	Vector Map	Topography (T)
6	Geological Profile	DENR-MGB Reg VI (2000)	Vector Map	Impact of Vadose Zone (I)
7	Hydraulic Conductivity	DENR-MGB, Reg VI (2000), Lindsley et.al, Hydrology for Engineers	Table	Hydraulic Conductivity (C)

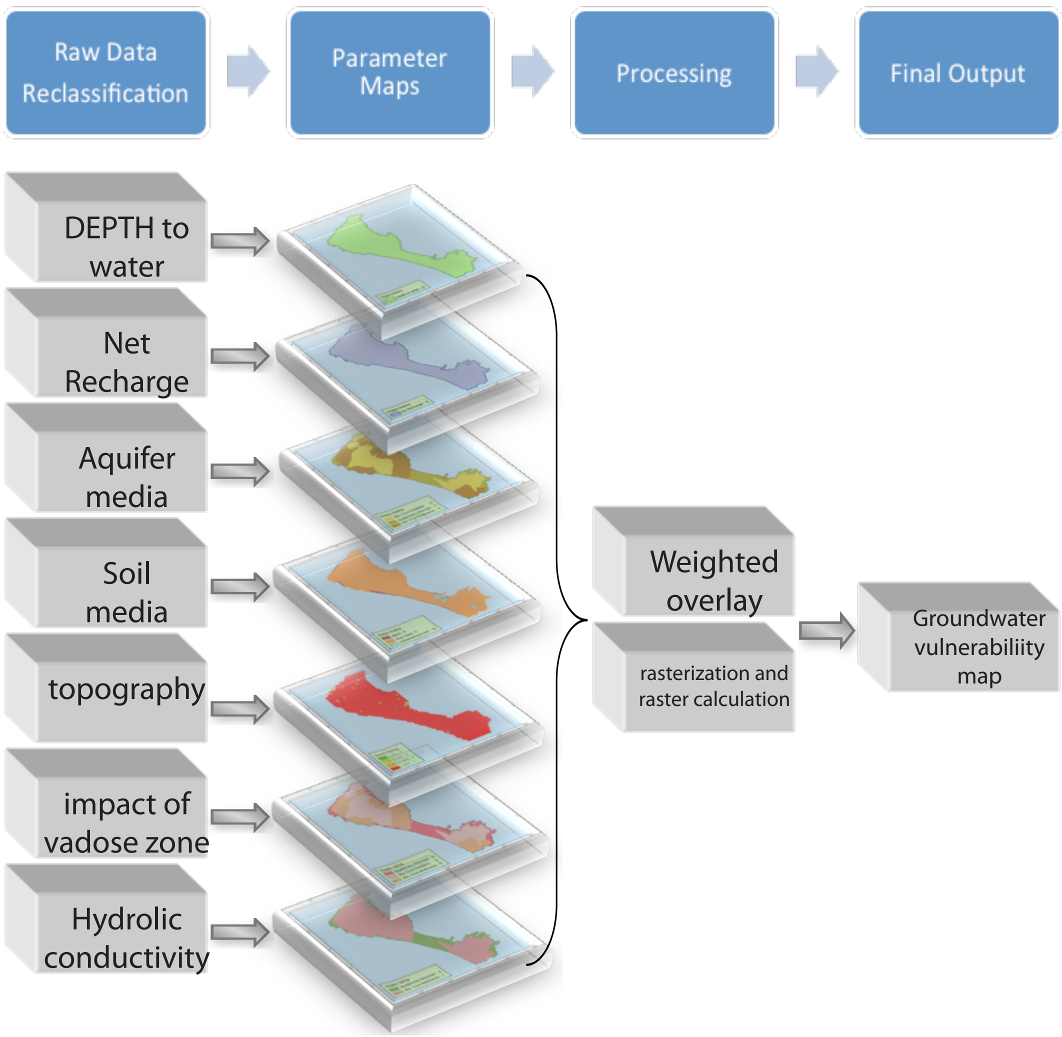

Figure 3. GIS mapping flow chart for groundwater vulnerability assessment.

following geologic formations in the island: the Sta. Cruz Sediments, characterized by the reefal coralline limestone, dominates the coastal fringes and outcrops at the northern coastal periphery, the central NE trending ridge, and the NNE trending haystack feature at the SW block. The sedimentary formation was dated Early Pliocene to Early Pleistocene (Sheet 3355-I, Geological Map of Malay Quadrangle, Philippine Bureau of Mines and Geosciences). Its stratigraphy consists of coralline limestone, calcareous sandstone, siltstone, shale, and basal conglomerate.

The northern-central and SE block sections exposures of the reworked calcirudite may be the calcareous sedimentary rocks underlying the coralline limestone in the stratigraphic section of Sta. Cruz Sediment. This is because the lithology of the said areas is portrayed by the same reworked, weathered, eroded and redeposited, crushed, crumbly, and friable limestone breccia that is still apparently

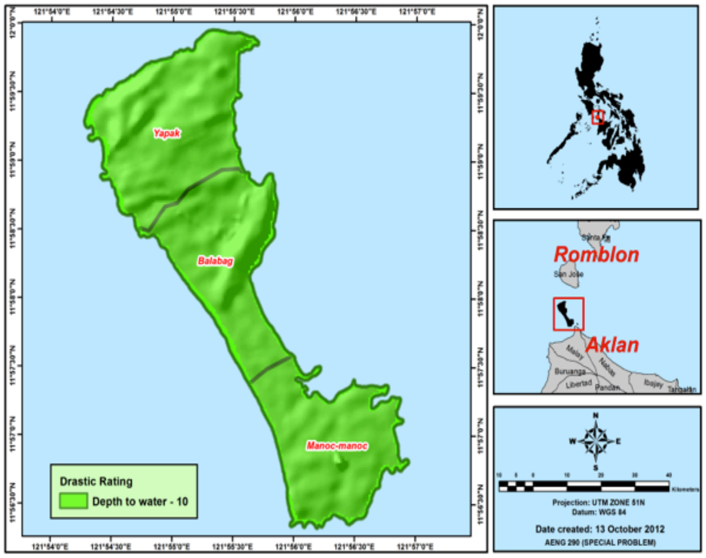

Figure 4. Depth to water thematic map or layer developed through GIS.

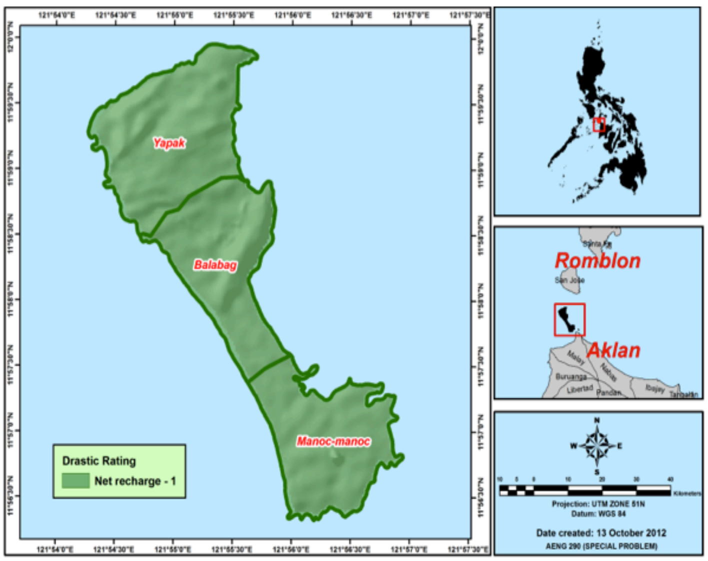

Figure 5. Net recharge thematic map or layer developed through GIS.

dissected by crisscrossing faults.

The Quaternary Alluvium composed of unconsolidated calcareous sands, silts, and clay with some shell and coral fragments dominate the central section of the island and is prominently observed on beaches and its coastal area (**Figure 6**).

Soil Media Factor

The soil characteristics of Boracay Island consist of the following types namely; 1) Alimodian Clay Loam, 2) San Miguel Clay Loam, 3) Hydrosol and 4) Sand (*DENR 2008*). The northern and southern portions of the island are hilly and are generally of Alimodian Clay Loam type. The central portion or what looks like the "waist" of Boracay Island on the map is predominantly flat consisting of San Miguel Clay Loam. Spread in some parts of the island is the Hydrosol type associated with the mangroves, nipa, wetlands, swamps, and fishpond areas. Sand is dominant along beach bounds (**Figure 7).**

Topography Factor

Based on Malay Local Government Unit (LGU) data, about two-thirds of the total land area of Boracay is between 8 % – 16 % slopes (**Figure 8**). Lowland and gently sloping areas are found near the shoreline. The Northern and Southern ends of the Island are hilly and wider than the central part (*CLUP 2008*).

In order to compute the slope, the Digital Elevation Model (DEM) of Boracay Island at a resolution of 90 m was used within the GIS environment. There is a readily available option in the Spatial Analyst of GIS where it is straightforward to compute the slope of the ground surface

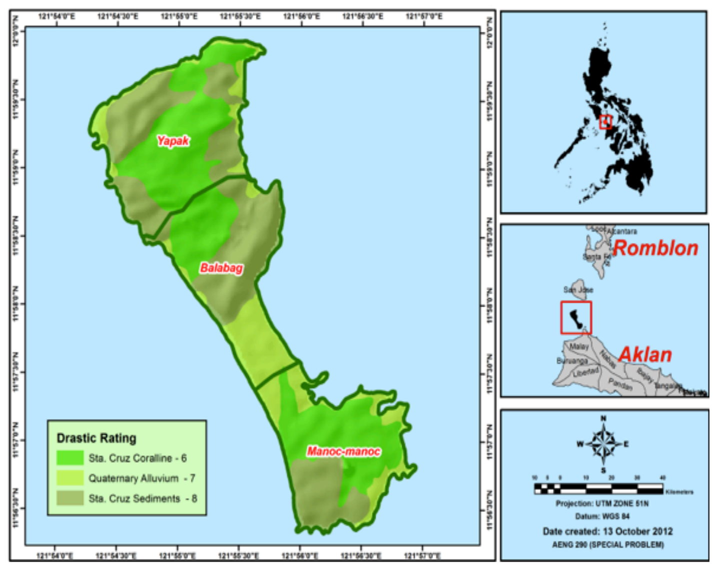

Figure 6. Aquifer Media thematic map or layer developed through GIS.

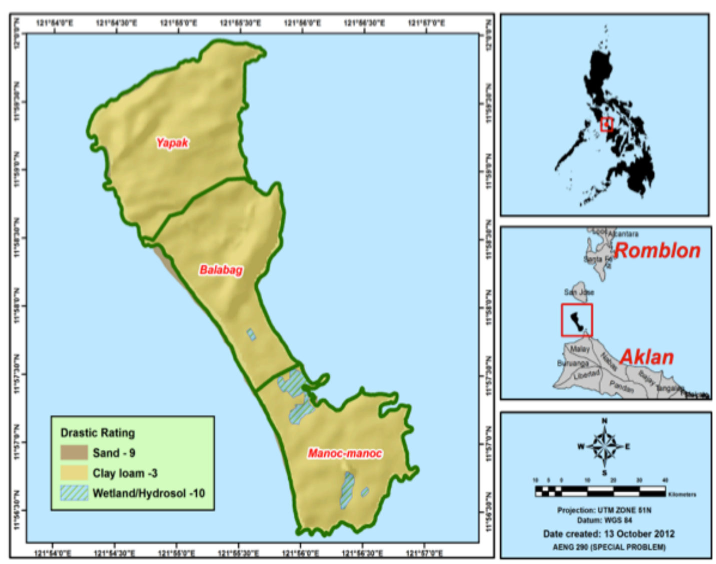

Figure 7. Soil Media thematic map or layer developed through GIS.

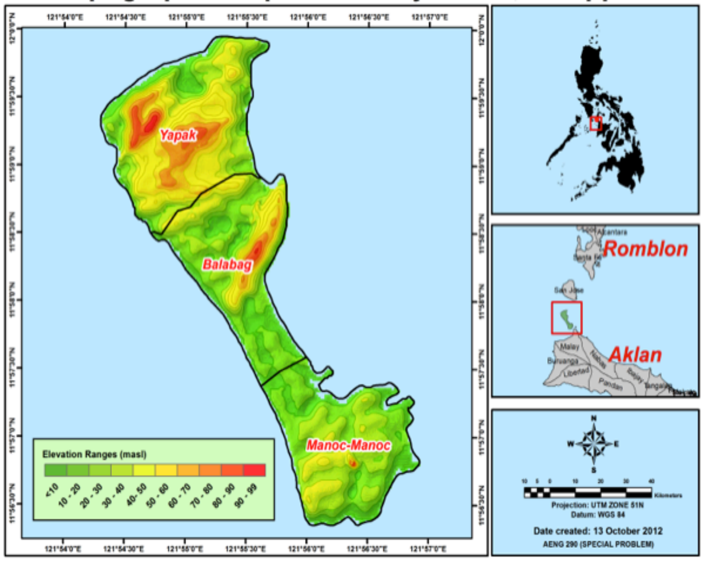

Figure 8. Topographic map of Boracay, Malay, Aklan, Philippines.

from the grid of the DEM. Through the use of Raster Extraction function of QGIS, the contour was determined based on the DEM raster at 30 m resolution. After computing the slope, the resulting grid was processed to derive the ratings. The rating was done based on reclassified range of elevation (**Figure 9**).

Impact of the Vadose Zone Media Factor

The texture of the vadose zone, which is the unsaturated zone above the water table, is among the factors that determine the time of travel of the contaminant through it. In surficial aquifers just like in Boracay Island, the ratings for the vadose zone are generally the same as the aquifer media. It was assumed that the unsaturated zone is a continuation and extension of the aquifer media and thus the same GIS shapefile used earlier in characterizing the impact of the aquifer was also used herein. Furthermore, in this study the vadose zone rating was equal to the aquifer media rating (**Figure 10**).

Hydraulic Conductivity Factor

Hydraulic conductivity values, which are the rate at which water flows horizontally through an aquifer, are usually derived from pumping tests, slug tests and other field or laboratory methods. They may also be obtained from groundwater flow models and in such a case the hydraulic conductivity represents averages over large areas. However, due to data limitations and absence of well log data and pump test data in the area, hydraulic conductivity parameter was computed using the following equation (*Linsley et al. 1988*):

$$K = k\,(w/\mu)$$

where:

K = coefficient of permeability or the hydraulic conductivity
k = intrinsic permeability of the medium
k_{qa} = 50 darcy or $4.9346165 \times 10^{-11}\ m^2$
k_{ss} = 0.05 darcy or $4.9346165 \times 10^{-13}\ m^2$
w = specific weight of the fluid ($9.81\ kN\ m^{-3}$)
μ = absolute viscosity($1.787 \times 10^{-3}\ N\ s\ m^{-2}$)

Based on the computations, the hydraulic conductivity of quaternary alluvium as composed of sand deposits was $23.32\ m\ d^{-1}$. While that of the Sta. Cruz sediments was $0.023\ m\ d^{-1}$, thus a DRASTIC rating of 4 and 1, respectively (**Figure 11**).

Groundwater vulnerability overlay

The weighted linear combination was applied to compute for the groundwater vulnerability index or

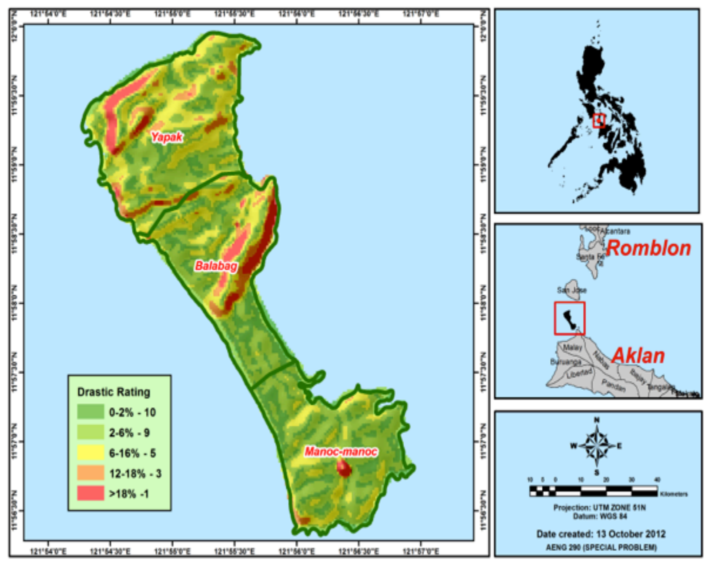

Figure 9. Topographic map or layer developed through GIS using the slope rating.

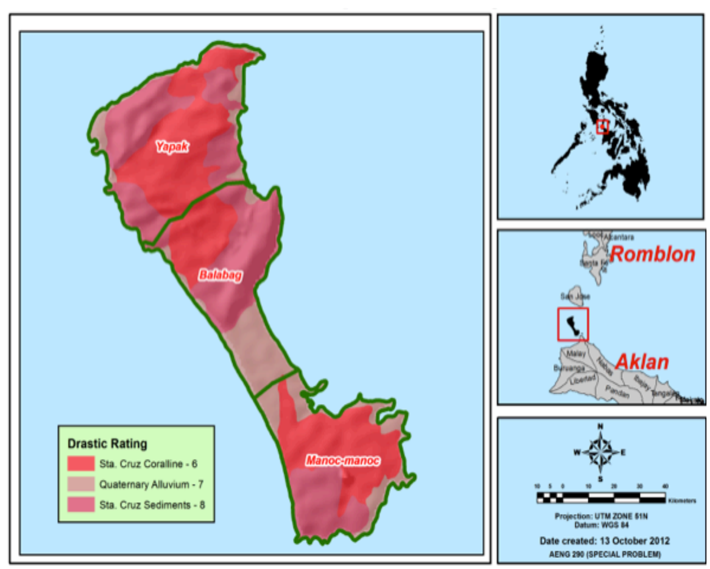

Figure 10. Impact of the vadose zone thematic map or layer developed through GIS.

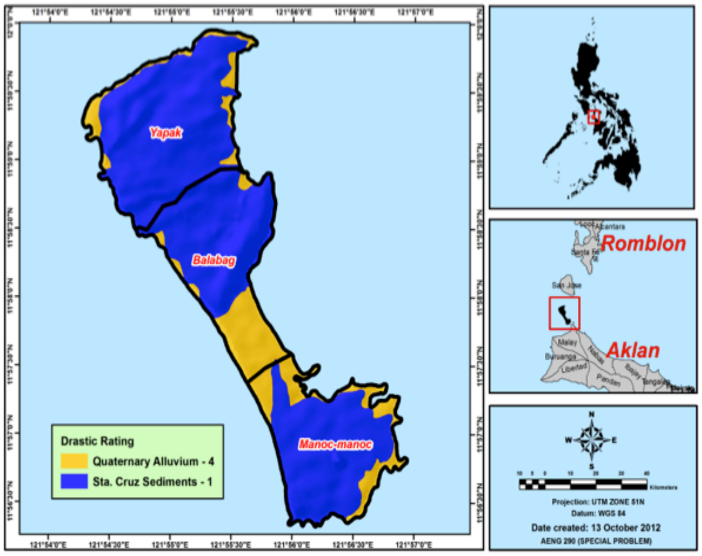

Figure 11. Hydraulic conductivity thematic map or layer developed through GIS.

DRASTIC index of Boracay Island. Then, this was used to derive a raster calculator expression in QGIS which generated the Vulnerability or DRASTIC Index (DI) Map.

Rate grids for the seven hydrogeological parameters of the DRASTIC model were then obtained. The rating values in the cells of each grid were multiplied by the weight of each parameter. Thus, seven grids representing the relevant multiplications were obtained. The final DRASTIC index grid was computed by summing up the seven grids using GIS to delineate the vulnerability.

RESULTS AND DISCUSSION

Groundwater Vulnerability

The groundwater vulnerability map showed that most of the areas were highly and moderately vulnerable to contamination. This pattern is mainly dictated by the shallow water level and variation in soil media, aquifer media, vadose zone and topography. GIS analysis also aided in the calculation of the affected area. In **Table 3**, a total of 562.37 ha (56.0 %) in all three barangays of Boracay Island were highly vulnerable and a total of 410.28 ha (40.9 %) were moderately vulnerable to contamination. About 30.95 ha (3.1 %) were considered very highly vulnerable areas. It further showed that Brgy. Manoc-Manoc has the widest area (23.70 ha) that is very highly vulnerable to contamination, while most of the areas that is highly vulnerable are located in Brgy. Balabag (223.10 ha) and near the coastlines or low lying areas of the two other barangays.

These vulnerable areas are also the built-up areas where tourism developments had cropped-up. Health risks due to groundwater contamination from sewage pollution is highly probable in these areas since still many of the business establishments as well as residential areas do not have proper sewerage system or are not connected to the sewerage facility of the island.

The locations of the inventoried wells were also plotted into the vulnerability map to spot which among the wells were vulnerable to contamination. The overlay showed that most of the existing wells used by the local people either for drinking, washing and other domestic chores were located in highly vulnerable areas (**Figure 12**). Mitigation and control should therefore focus on these zones to avoid health problems due to groundwater utilization. It is then practical to demarcate and systematically study these vulnerable zones to facilitate any mitigation and control scheme proposed or considered necessary so as to avoid degradation of the groundwater resources and coastal waters which are important resources in attaining sustainable tourism industry and human well-being.

Policy Integration Towards Sustainable Tourism and Human Well-Being

The groundwater vulnerability map or the DRASTIC

Table 3. Areas (ha) vulnerable to groundwater contamination in different barangays of Boracay Island.

	Low	Moderate	High	Very high
Balabag	0.08	79.26	223.10	1.07
Manoc-manoc	0.18	144.27	142.20	23.70
Yapak	0.11	186.75	197.07	6.18
Total (ha)	0.37	410.28	562.37	30.95
Percent (%)	0.04	40.87	56.01	3.08

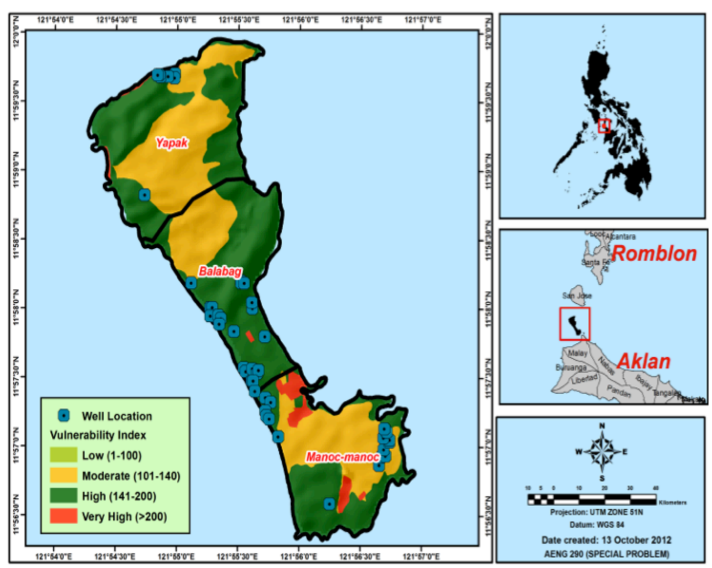

Figure 12. Groundwater vulnerability map showing the locations of the inventoried wells in Boracay Island.

index map has shown the vulnerability of the groundwater resources of Boracay Island. The establishment of sewerage treatment plant in the area to address groundwater contamination from domestic waste and other pollutants coming from commercial establishments and local residents is a good strategy in order to mitigate the contamination of groundwater resources. However, many if not majority of the commercial establishments and residents are not connected to the sewerage treatment plant for some other reasons aside from the possibility that the capacity of the treatment plant cannot cater to the needs of tourism industry in the island. Hence, a policy should be enforced to protect the groundwater resources of Boracay Island so as not to enhance the proliferation of contaminants such as sewage pollution in aquifers given the fact that these aquifers are vulnerable to contamination based on this study. Groundwater also leads to coastal waters, thus, protection of groundwater resources will also preserve the integrity of coastal waters. Mitigation and control strategies can be based on the vulnerability map index developed. The highly vulnerable areas must be given the utmost attention and should be protected as soon as possible through an ordinance requiring a sewerage system to all establishments including those in the residential areas to ensure the sustainability of the Boracay tourism industry and human well-being. This is also to avoid the repeat of the incident that happened in 1997 when the waters of Boracay Island were declared unsafe for recreational activities due to the presence of very high levels of coliform.

CONCLUSIONS AND RECOMMENDATIONS

The study has shown the effectiveness in the combined use of the DRASTIC model and GIS in assessing groundwater contamination vulnerability. The GIS technology has provided an efficient environment for analyses and high capabilities of handling spatial data in the study area. Furthermore, it provided a picture of the knowledge and information that the research wants its stakeholders to perceive.

Groundwater resources of Boracay Island were found to be vulnerable to contamination using DRASTIC MODEL which demonstrates an effective method to develop, improve and verify groundwater vulnerability maps. This study has also demonstrated the use of the model in a small setting, like Boracay Island. This method, with a little refinement, can be used throughout the country to create new groundwater vulnerability maps if none exists.

Special attention should be made to the areas having moderate to very high contamination vulnerability potential as shown in the vulnerability or DRASTIC Index map of Boracay Island. Decision makers can make use of this map in determining areas where groundwater monitoring and management is highly advisable because remediation of contaminated groundwater is prohibitively expensive and time-consuming. Prevention is particularly important in an effective groundwater management.

This study was limited to intrinsic vulnerability to groundwater contamination and no anthropogenic disturbance was considered. Future specific vulnerability assessments are recommended in order to delineate areas with high potential for specific contamination considering anthropogenic activities and land use pattern.

Developing a modified DRASTIC groundwater vulnerability map will be recommended if a specific contamination ensues. Sensitivity analysis of GIS-based DRASTIC model indices is further recommended so as to determine the significance of each DRASTIC parameter inclusion or exclusion as applied to a specific area.

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ACKNOWLEDGMENT

Great appreciation and thanks is extended to Dr. Decibel F. Eslava, and Mr. Teodorico Marquez Jr. of SESAM, UPLB, for his help in the GIS analysis. The staff and officers of the Mines and Geosciences Bureau (MGB) Region VI, Environmental Management Bureau (EMB) Region VI and the Local Government Unit of Malay, Aklan are likewise acknowledged for their unselfish support and for providing the authors with the basic and secondary data.