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# Groundwater vulnerability assessment using modified hydrological DRASTIC model in Meycauayan City, Bulacan, Philippines

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## Abstract

DRASTIC System coupled with a geologic software was used in this study to determine the location of potential areas in Meycauayan City were groundwater is susceptible to pollution. The state of groundwater pollution is a critical issue with increasing population and industrial development in Meycauayan City. The main objective of the study was to show areas of the highest potential for groundwater pollution based on hydro-geological conditions and human impacts. Eight major hydro-geological factors (Depth to the water table, net Recharge, Aquifer media, Soil media, Topography, Impact to Vadose zone and Hydraulic Conductivity) adding Land Cover as the last parameter incorporated into the modified DRASTIC model and geographical information system (GIS) to create a groundwater vulnerability map by overlaying the available hydro-geological data. The result showed that the groundwater resources of Meycauayan City were found to be high potential vulnerable to contamination having a vulnerability index of 180 using DRASTIC MODEL. For groundwater management, the generated maps could be used as a tool for decision making in by the Local Government Units (LGU) in their Comprehensive Land Use Plan (CLUP) where they can identify where the development will take place. This could be used to assist in the formulation of policies related to groundwater resource management and protection in Meycauayan City.

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**Introduction**

Groundwater is a very important natural resource and can be thought of as a second source of water supply for rural areas faced with limited accessible surface water or community water pipeline (Dixon, 2005). It is a significant valuable asset removed from the earth through an all-around bored into an aquifer that has been recharged or renewed by downpour and streams . Groundwater is the main source utilized consistently in industry, exchange, and agribusiness and in particular for drinking (Twarakavi & Kaluarachchi, 2006).

According to Vias *et al.* (2005), groundwater accounts for about 89 percent of fresh water on our planet, which is why it is one of the most important natural resources we are challenged to manage, given the well - documented worldwide water scarcity. The presence of hard rock aquifers in some countries can be problematic, as some of these aquifer systems have low storage and yields, leading to greater pollutant vulnerability through crack and fracture flows. Both natural and anthropogenic influences may contaminate groundwater. Residential, municipal, commercial, industrial, and agricultural activities can all have an impact on the quality of groundwater, resulting in poor drinking water quality, water loss, and high clean - up costs and high costs for alternative supplies of water and/or potential health issues.

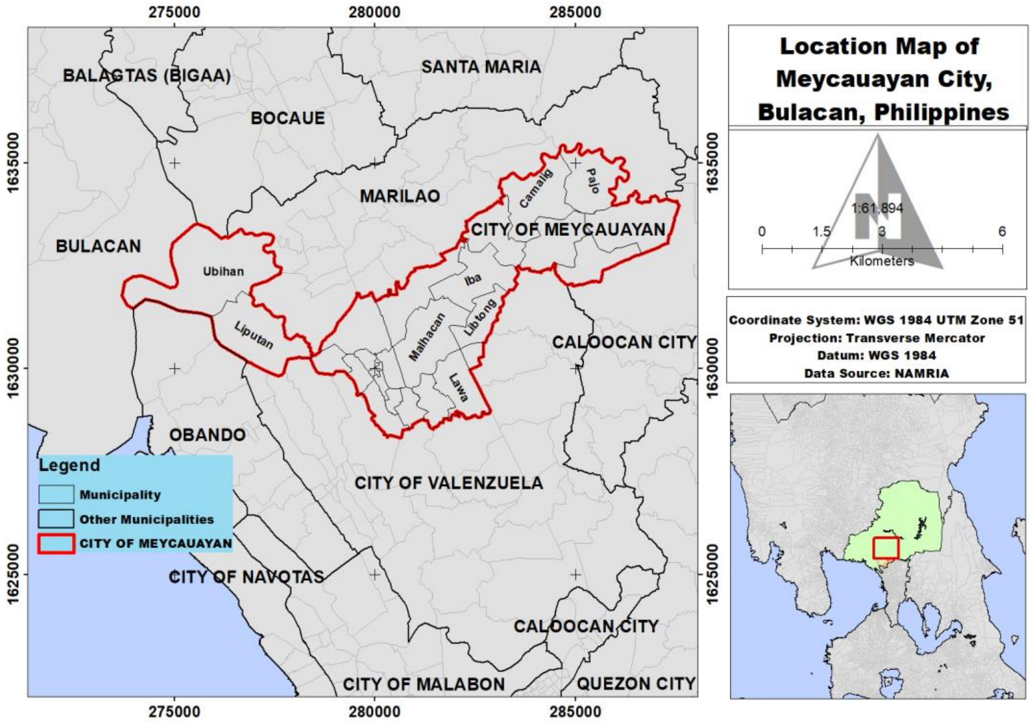


**Fig. 1.** Location Map of Meycauayan City, Bulacan.

The City of Meycauayan is bordered by the towns of Sta. Maria, San Jose del Monte, Marilao, and Obando in the province of Bulacan and City of Valenzuela. It encompasses an aggregate area of 3,210 hectares presently composed of twenty six (26) barangay's, representing 1.17 percent of the total land area of the province of Bulacan. (Draft Comprehensive Land Use Plan of Meycauayan City). The Marilao, Meycauayan and Obando River System (MMORS) in the Province of Bulacan, Philippines, is home to hundreds of thousands of people and numerous industries, such as leather tanning, gold smelting, and recycling of lead acid batteries. Most of these industries dump their untreated wastewater into the river, that eventually contaminate the area's groundwater (Mendoza *et al.*, 2012).

A a recent study conducted by National Water Resources Board (NWRB, 2018), Meycauayan City is one of the key urban centers in the Philippines experiencing water stress due to the increasing water demand . Furthemore, the city's groundwater supply is getting depleted, according to a 2009 study done by the Institute of Philippine of Ateneo de Manila University. Aside from indicating that the groundwater table has gone down, the study also found out that seawater had intruded into the city's aquifers. These findings were affirmed by another study made by the National Water Resources Board in collaboration with ADMU's Economics Department.

Currently, the groundwater sector of Meycauayan City is confronted with four (4) interrelated problems namely (1) Salt water intrusion, (2) unregulated extraction, (3) limited knowledge on water quality and (4) forcasted deficit. These problems are exacerbated by the absence of an institution that will oversee the proper monitoring and management of the water resources and the forecasted deficit in groundwater availability. These highly urbanized cities rely mostly on groundwater for water supply, resulting in uncontrolled withdrawal from groundwater aquifers in recent years. Rapid and uncontrolled urban development has reduced aquifer recharge and has eventually resulted in the decline of groundwater levels as well as saltwater intrusion. (NWRB, 2018). In hydrogeology, vulnerability assessment is typically utilized to assess the susceptibility of a water table, an aquifer, or water well to contaminants that can reduce groundwater quality. It is primarily caused by anthropogenic and agricultural activities, Nobre *et al.* (2005) and Rahman (2008). These potential sources of pollution are responsible for the deterioration of groundwater quality, consequently increasing vulnerability.

Vulnerability assessment was recognized for its ability to identify areas that are more likely to become contaminated due to anthropogenic activity on or near the surface of the earth than others. Once these areas have been identified, they can be targeted by careful land use planning, intensive monitoring and pollution prevention (Babiker *et al.*, 2004). The assessment of groundwater vulnerability to contamination has proven to be an effective tool for the delineation of protection zones in the affected area.

Therefore, the need to study the vulnerability of groundwater resource of Meycauayan City is important. This is to develop a groundwater vulnerability index in the area and a groundwater vulnerability map for the Meycauayan groundwater resources. Results can aid in policy making and planning in order to balance industrial 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.

## Materials and methods

*Research Design*

A multi-method research design was employed to meet the objectives of the study. The method includes a structured survey method, ocular inspection, and generation of maps using Geographical Information System.

*Generation of Maps for DRASTIC Model.*

The method that was used in mapping the groundwater vulnerability was the DRASTIC Method. It is an overlay and index approach in estimating groundwater vulnerability which involves acquiring and combining maps of the parameters that affect the conveyance of contaminations from the surface to groundwater, then assigning an index value to those parameters based on their relative contribution to groundwater pollution which results to a spatially oriented vulnerability index.

It works under the assumption that the contamination move along with the flow of water, contamination occurs in the ground level, and the contaminant enters the water table when rain falls on the surface and percolates into the saturated zone. It takes into account (7) seven hydrological parameters such as the Depth to Water Table (D), Net Recharge (R), Aquifer Media (A), Soil Media (S), Topography (T) Impact of vadose zone (I), hydraulic Conductivity (C) and Land cover (L)Each parameter is given weight and rating value ranging from 1-10 based on its significance or importance in affecting contamination of water that were determined by the US Environmental Protection Agency or the US EPA (Aller *et al.*, 1987).

*Data Collection*

Most of the data used in this study are readily available and are obtained from several government and non-government institutions. Well records found inside the Meycauayan City were obtained from the Philippine Groundwater Data Bank of Local Water Utilities Administration (LWUA).The 20 year Mean Annual Rainfall for the study area was requested from the Philippine Atmospheric, Geophysical, and Astronomical Services (PAG-ASA). These data coming from three different weather stations (PAG-ASA Science Garden, Clark Airport, Pampanga and DOST PAG-ASA Munoz) were used and interpolated to develop hydrological models and downscale projected climatic station around Meycauayan City. Existing thematic maps that were used in generating the groundwater vulnerability map of Meycauayan City were also directly acquired from several government institutions. The Digital Elevation Model (DEM) and land cover map for Meycauayan City was obtained from the National Mapping Resource Information Agency (NAMRIA), Soil Map of the Philippines acquired from the Department of Agriculture's Bureau of Soil and Water Management (DA-BSWM). These maps should be ensured that their spatial reference is set to World Geodetic System 1984 Universal Transverse Mercator Zone 51 N (WGS 1984 UTM ZONE 51N) in order to avoid conflicts of overlaying in ArcGIS. Maps that are not set to the aforementioned spatial reference where projected using ArcGIS Project functions.

## Results and discussion

*Findings in each DRASTIC Rating*

Following the methodological application, thematic map of each parameter and groundwater vulnerability map were developed to evaluate groundwater deterioration vulnerability. In this section, findings in each designated DRASTIC rating in relation to DRASTIC parameters for Meycauayan City are presented and discussed as follows:

*Depth to groundwater*

Generally as shown in Fig. 2, the depth to water in the study area is high (304.21m) as the maximum depth, and gradually decreseas within boundaries.

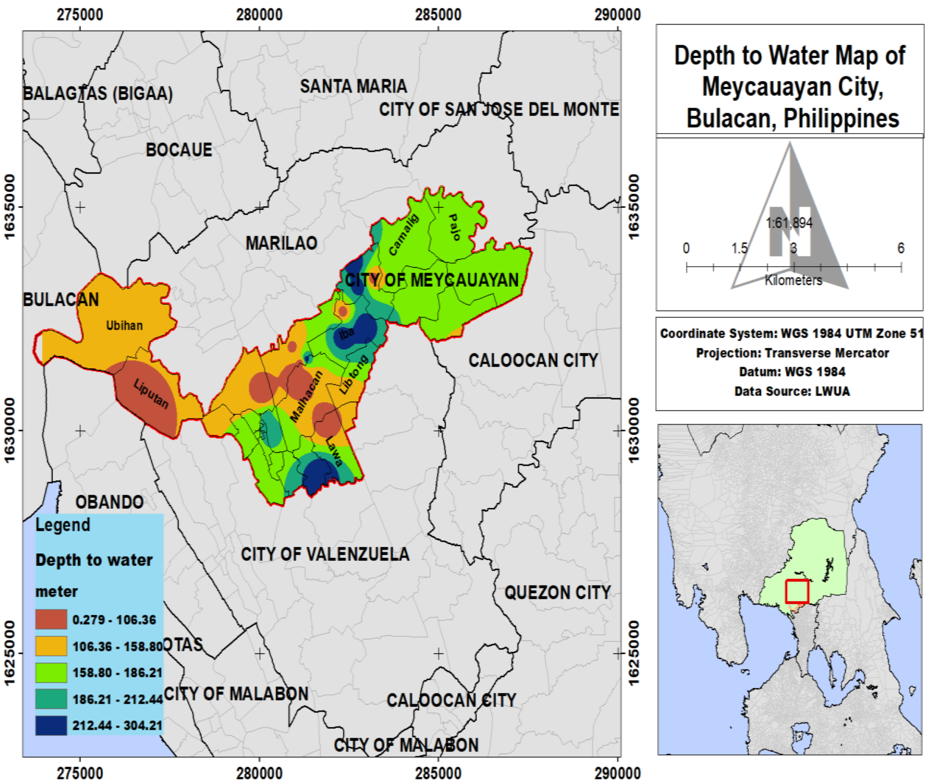


**Fig. 2.** Depth to Water Table DRASTIC layer in Meycauayan City.

It is noticeable that Barangay's Liputan, parts of Malhacan and Libtong were considered to be the most vulnerable in terms of depth to groundwater table. This means that the contaminants can easily penetrate to the water table in these areas. Depth to groundwater represents the depth of material from the ground surface to the water table through which a contaminant travels before reaching the aquifer.

The shallower the water depth, the more vulnerable the aquifer is to pollution and vice versa. The depth to water is also important because it provides the maximum opportunity for oxidation by atmospheric oxygen and related to the effect of the vadose zone. In general, there is a greater chance for attenuation to occur as the depth to water increases because deeper water levels imply longer travel times. The results of mean groundwater depth were derived from 21 existing deep wells data from Local Waterworks Utilities Association (LWUA).

*Net Recharge Factor*

Net recharge is the total quantity of water (in meters), which infiltrates from the ground surface to the aquifer on an annual basis. This recharge water is thus available to transport a contaminant vertically to the water table and horizontally within the aquifer. As shown in fig. 3, it can be seen that the some part of the city is almost highly vulnerable to net recharge with a value 2.51 meter located in the vicinities from Barangay Ubihan and Liputan which considered to be the lowland areas of the City. The lowest value for net recharge in Meycauayan City is 1.09 meter covering the most of the Barangays. According to Department of Science and Technology- Philippine Atmospheric Geophysical and Astronomical Services (DOST-PAG-ASA), climatic conditions in Meycauayan are generally favorable due to its proximity to Manila Bay. The weather pattern is described as relatively dry and cool from November to April and with light frequent rainfall during the wet season from May to October.

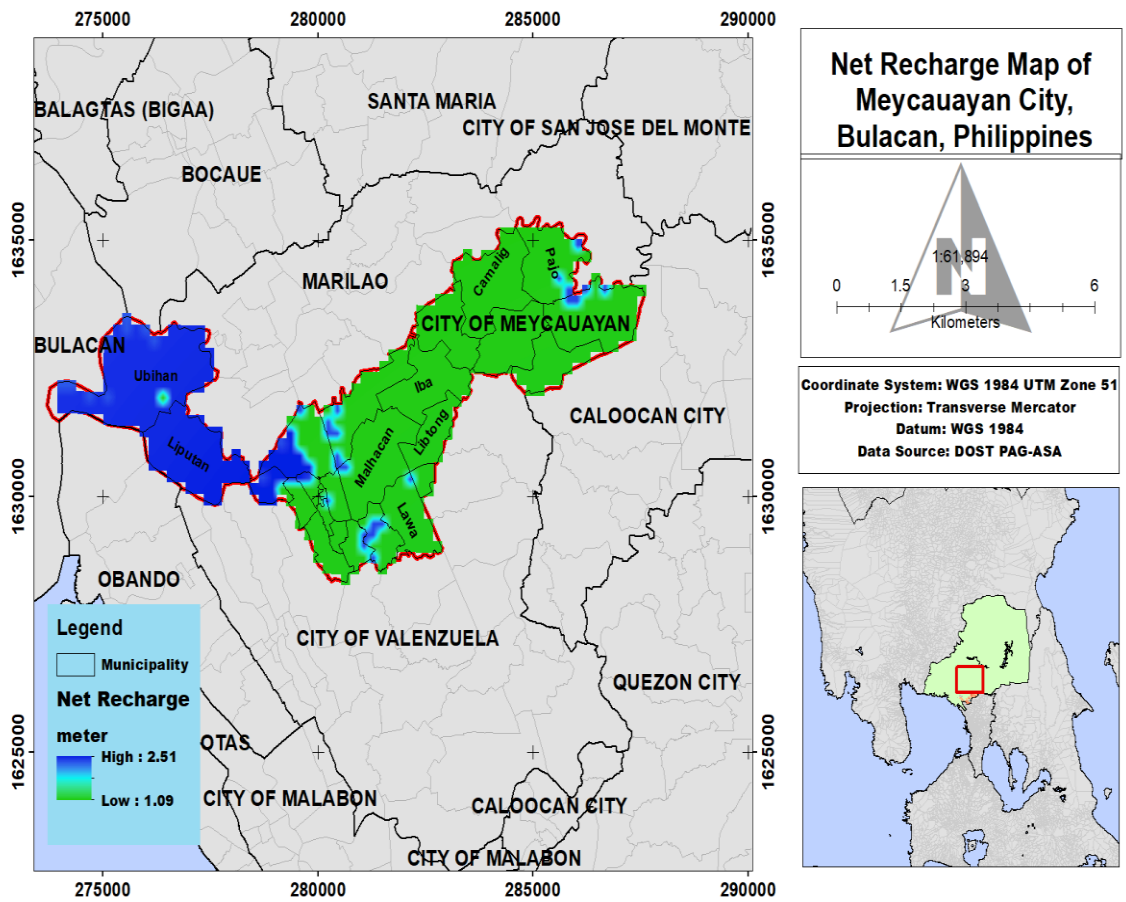


**Fig. 3.** Net Recharge DRASTIC Layer of Meycauayan City.

*Aquifer Media*

Aquifer media and constituents are the path through which water is transported to the aquifer. It is describe as consolidated and unconsolidated rock where water is contained. This will include the pore spaces and fractures of the media where water is held. The aquifer media therefore affect the flow within the aquifer. This flow path controls the rate of contaminant contact within the aquifer (Aller *et al.,* 1987). Aquifer media determine the flow rate, levels, and types of contamination, as well as aquifer groundwater reserves. These contaminants reach the groundwater through weak soil layers within the aquifer media. As shown in fig. 4, the aquifer layers within the aquifer region recorded a adobe sandstone constituent. This type of aquifer has high porosity due to its ability to release water very quickly and this also implies that the contaminants can easily infiltrate in the groundwater table. Different rating of the type of aquifer media was assigned for developing aquifer media map. Aquifer media for the complete area is covered with adobe, adobe sandstone, clay, clay with sandstone, sandstone, and tuff.

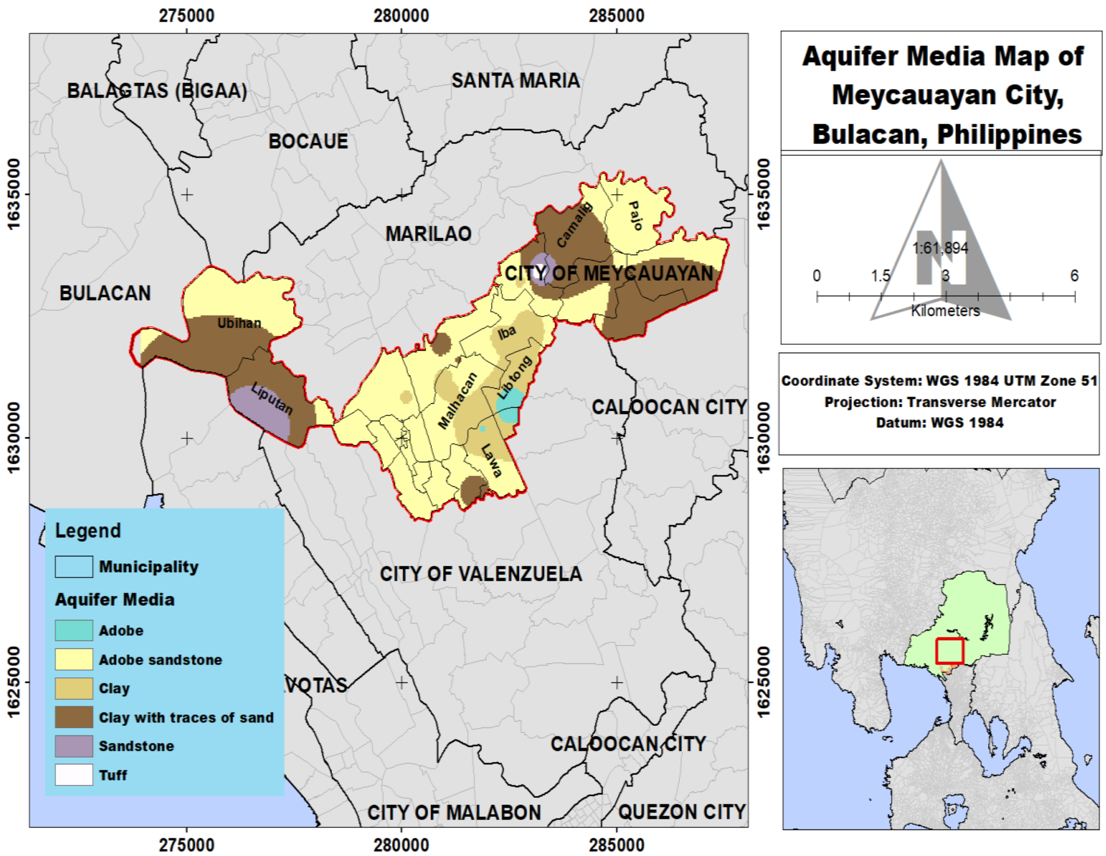


**Fig. 4.** Aquifer Media DRASTIC Layer of Meycauayan City.

*Soil Media*

Soil has a significant impact on the amount of recharge that can infiltrate into the ground, and hence on the ability of a contaminant to move vertically into the vadose zone. The presence of fine-textured materials such as silts and clays can decrease relative soil permeability and restrict contaminant migration. In Meycauayan City, the material in soil media is composed of fine sandy loam, silty clay loam, loam, and most areas are clay loam. Clay has less porosity value than sand and silt, reducing aquifer vulnerability. Sandy soils are therefore assigned a higher rating than clay soils. The soil has a significant impact on the amount of recharge that can be infiltrated into the ground and thus on the contaminant's ability to move vertically into the vadose area.

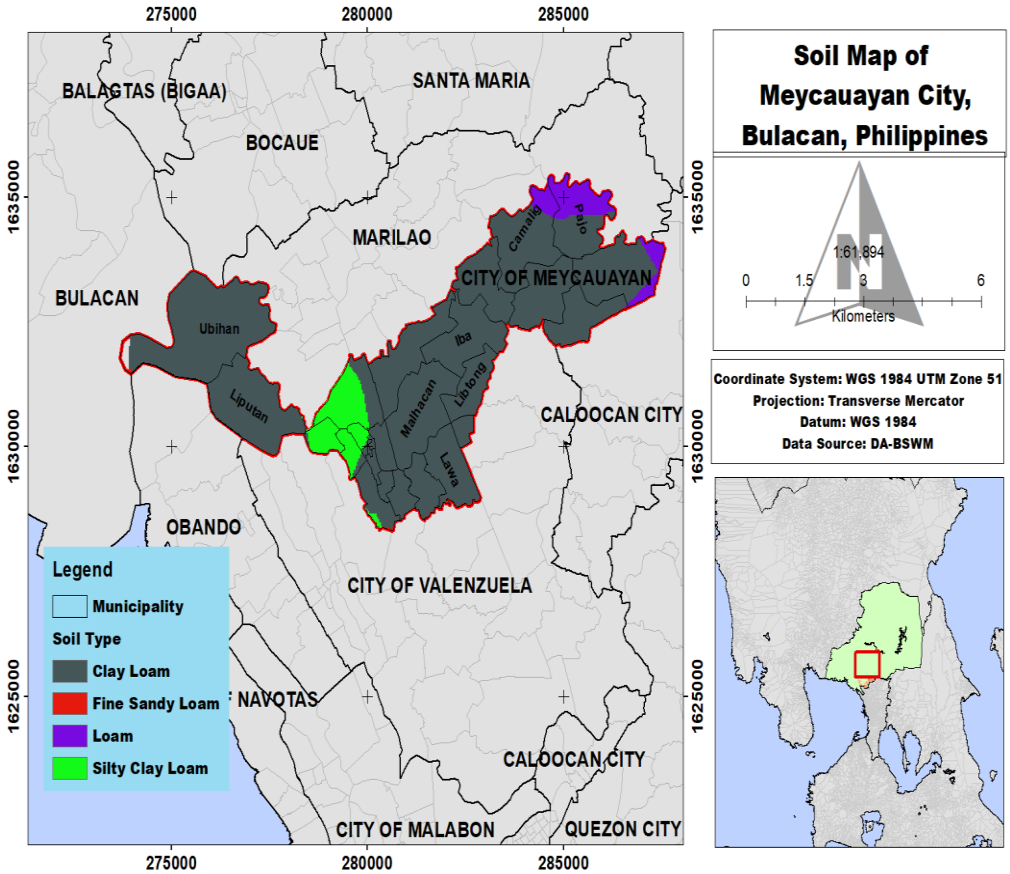


**Fig. 5.** Soil Media DRASTIC Layer of Meycauayan City.

*Topography*

The general topography of the land is relatively flat with almost moderately rolling hills. The slope of the land dips towards the west to northwesterly direction. The slope varying from index maximum rating 9 and minimum 5, respectively. The topography layer with slopes of 0-6% covers most of the area (Fig. 6). Topography is assigned a rating value of one, reflecting its low to moderate effect on groundwater vulnerability.

As shown in Fig. 6, the nearer part of the Northeast portion which includes Barangays Lawa, Ubihan, Cainigin, Bancal, Calvario, and Liputan with less than 2% to 6% while the outer parts covering Barangays Malhacan, Pantoc, Libtong, Iba has an elevation from 6% to 12 % slope. Barangay Bahay Pare and has a particular ranging up to 50 meters above sea level.

On the central part, the slope averages from 6% meters to 12% slope. This comprises Barangays Poblacion, Hulo, Bañga, Calvario and Saluysoy, whereas Barangay Malhacan has certain areas elevated up to 6-10% slope. On the other hand, Barangays Ubihan and Liputan have the lowest slope of less than 2% and most of the areas are covered by water. Areas with low-lying elevation are also highly vulnerable while elevated areas such as mountainous regions are the least vulnerable.

*Impacts of Vadose Zone*

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. The layer in the Vadose Zone has four types of material; a) Shale, with rating of 3, b.) Both igneous rock, sand and gravel, assigned rating of 8, and c.) Adobe with a rating of 1 DRASTIC model assigned a value of 5 to the Vadose Zone as indicated to its importance to percolation and thus aquifer contamination (vulnerability). Meycauayan City produces moderately vulnerable areas, and lastly adobe clay layers is the least.

DRASTIC index of 30 and 40 for the vadose zone impact indicates its high influence on aquifer vulnerability. As shown in fig. 7, it is observable that igneous rock, sand and gravel of the vadose zone generate the most vulnerable areas in the map, while shale category material in the central and east-south regions of Meycauayan City produces moderately vulnerable areas, and lastly adobe clay layers is the least vulnerable among the four.

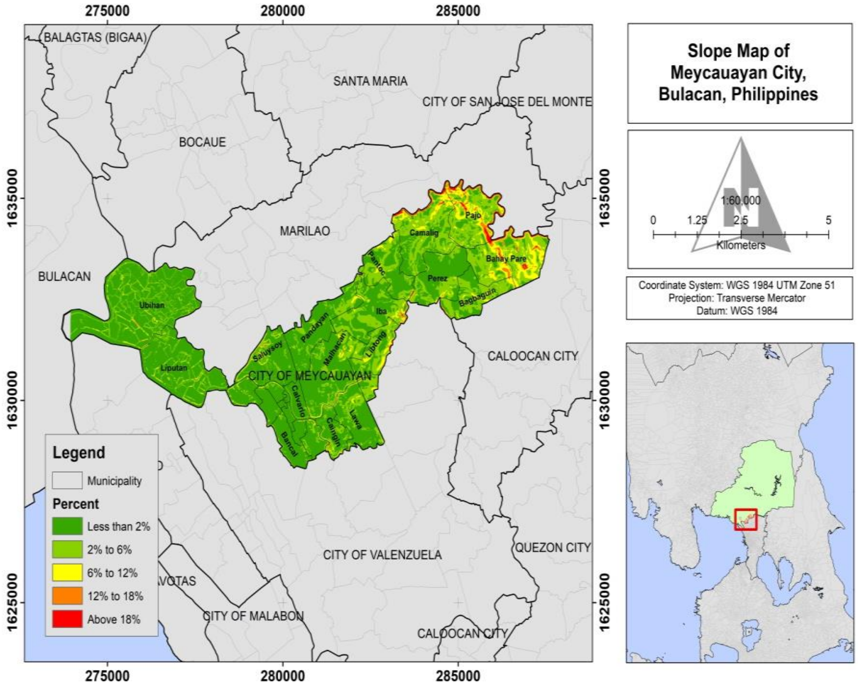


**Fig. 6.** Slope Media DRASTIC layer of Meycauayan City.

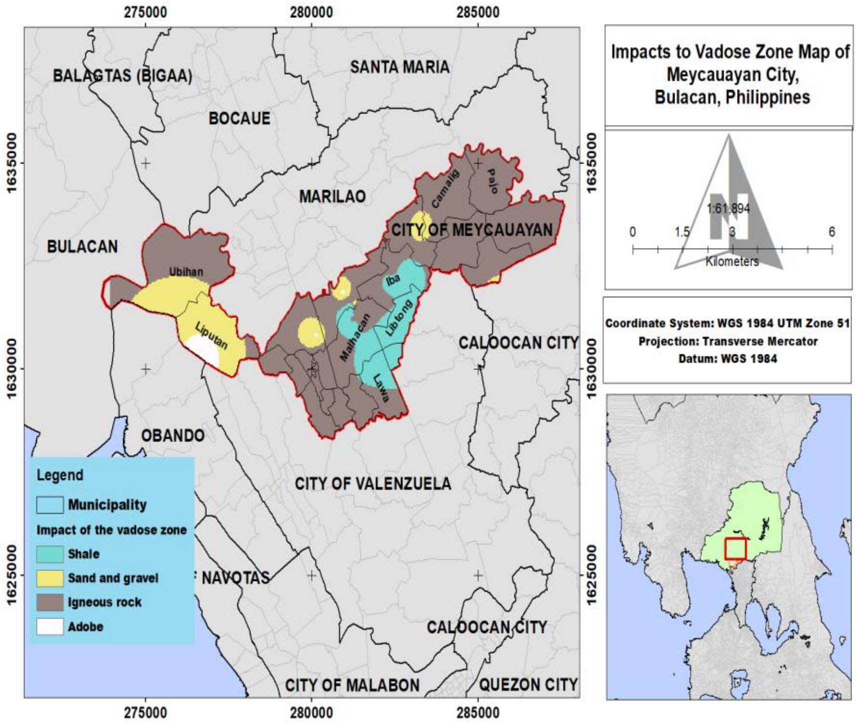


**Fig. 7.** Impact to Vadose Zone DRASTIC Layer in Meycauayan City.

*Hydraulic Conductivity*

The hydraulic conductivity correlates with aquifer capacity to transmit water. High values mean high contamination potential. The Meycauayan City aquifer area is divided into two categories relating to hydraulic conductivity values and assigned rating 1 as the lowest and 10 is the highest. Hydraulic Conductivity is affected by water level and layers material. Using DRASTIC Index, calculated values for hydraulic conductivity ranges from $9.7x10^{-4}$ to 0.32874cm/s in Meycauayan City (Fig. 10). As observed, hydraulic conductivity is highest and concentrated in central portion of the city attributed mainly to the aquifer and soil media that represents and allows more pollutants to penetrate and attract contaminants to groundwater.

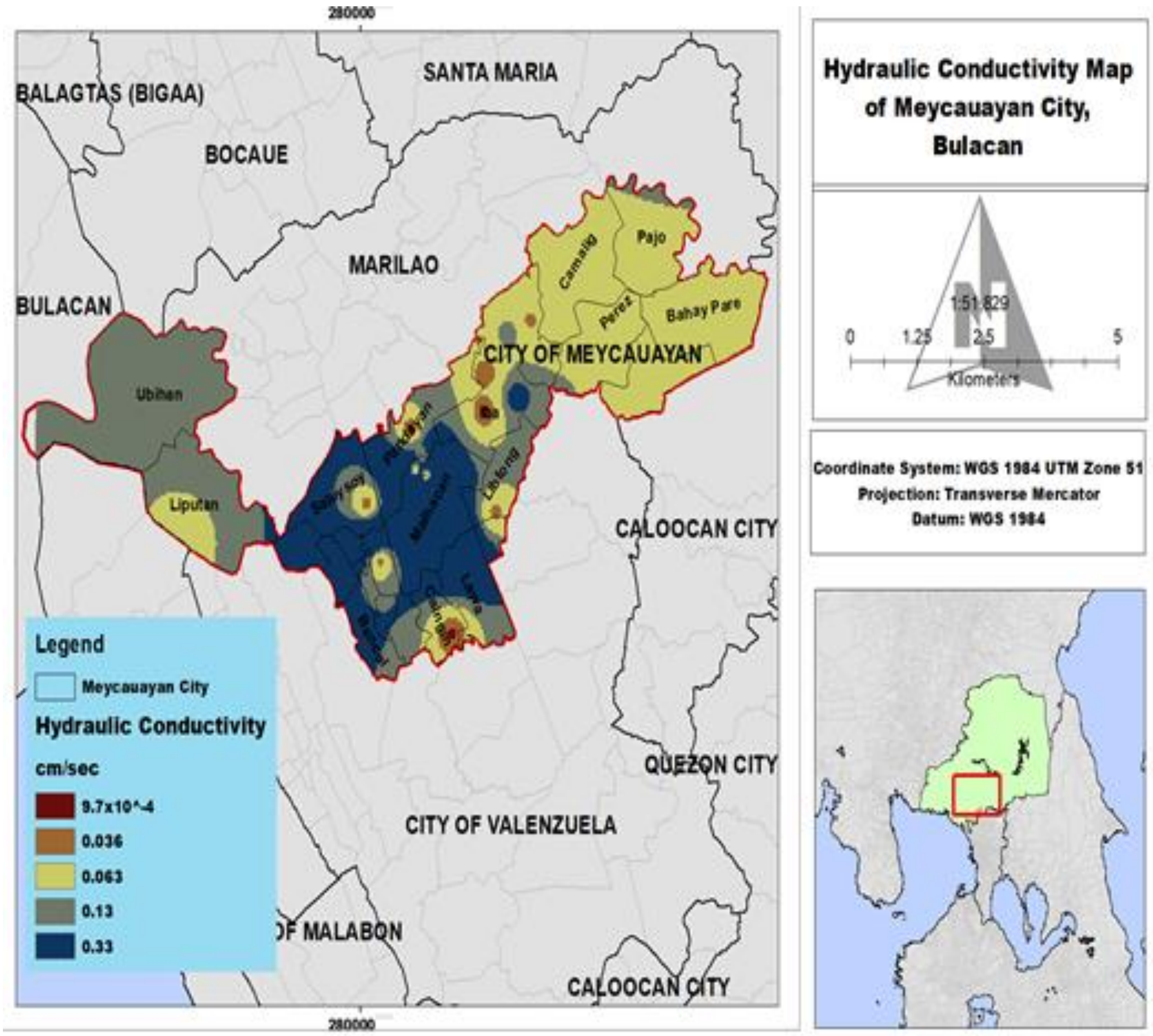


**Fig. 8.** Hydraulic Conductivity DRASTIC Layer in Meycauayan City.

*Land Cover*

Some part of the city is covered under the moderate vulnerable zone due to the agricultural activities. The areas around inland water, fisheponds, shurbs, and grassland are low vulnerability (Fig. 11). The urban areas showed high vulnerability to pollution. According to the Municipal Planning and Development office of Meycauayan City, the city experienced a fast and permanent land-use change over the last two decades,

where the location of industries generates a rapid population growth, therefore the agricultural sector increase its activity and land coverage in the surroundings of the urban centers.

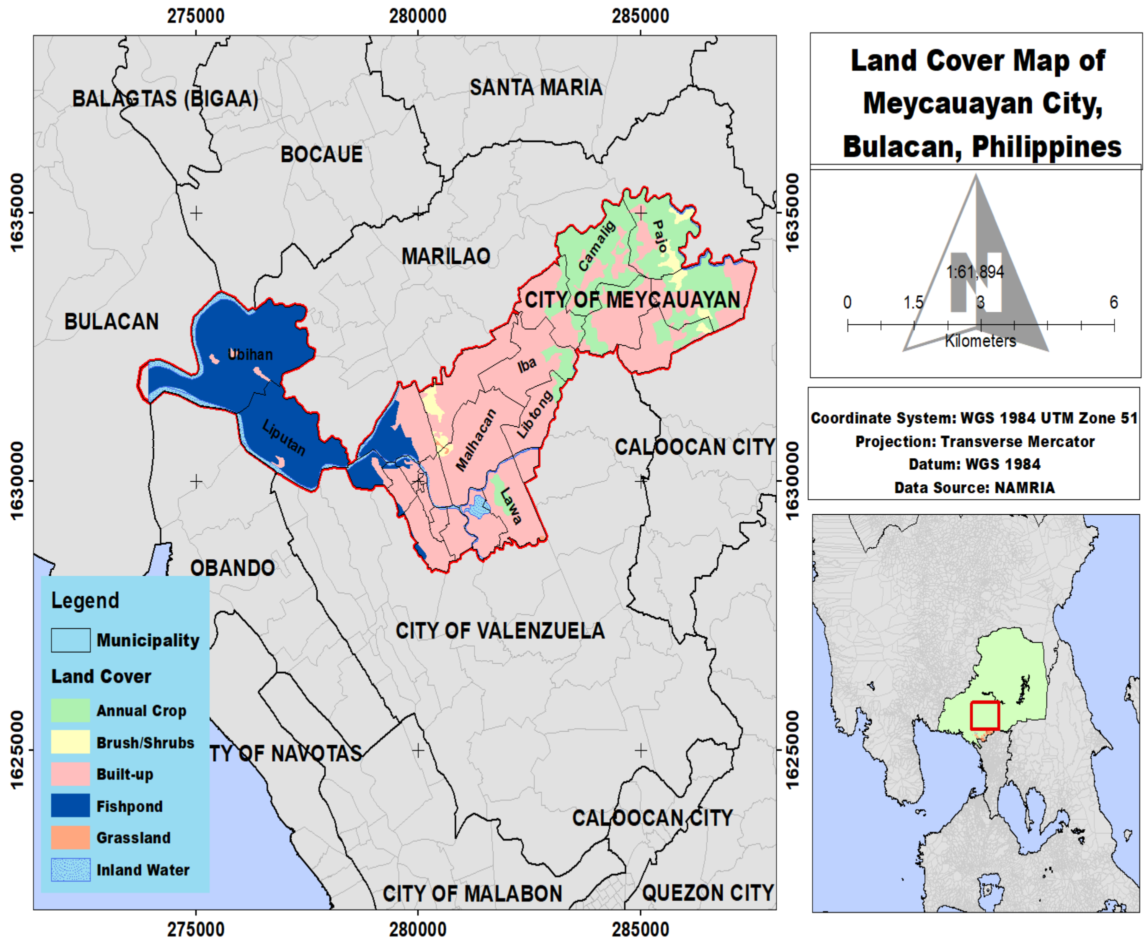


**Fig. 9.** DRASTIC Map for Land Cover in Meycauayan City.

*Groundwater Vulnerability Map of Meycauayan City*

The groundwater vulnerability map showed that most of the areas have low vulnerability to contamination. This pattern is mainly dictated by the shallow water level and variation in soil media, aquifer media, vadose zone and topography. This condition, it is due to the high aquifer permeability coming from the sedimentary nature of the vadose zone.

The aquifer combination was of quaternary alluvium and sandstones, medium recharge, shallow groundwater and medium hydraulic conductivity. It is also noticeable that some northeastern portion of the city is consistently more vulnerable than its southern counterpart.

The highly vulnerable portion of the city could be located in the Barangay of Calvario, Bancal, Caingin and and some part of Lawa. These vulnerable areas found to be the built-up areas since still many of the business establishment as well as residential areas do not have proper sewerage system or are not connected to the sewerage facility of the city.

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 as shown in Fig. 10. 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 to avoid degradation of the groundwater resources and coastal waters, which are important resources in attaining sustainable tourism industry and human well-being.

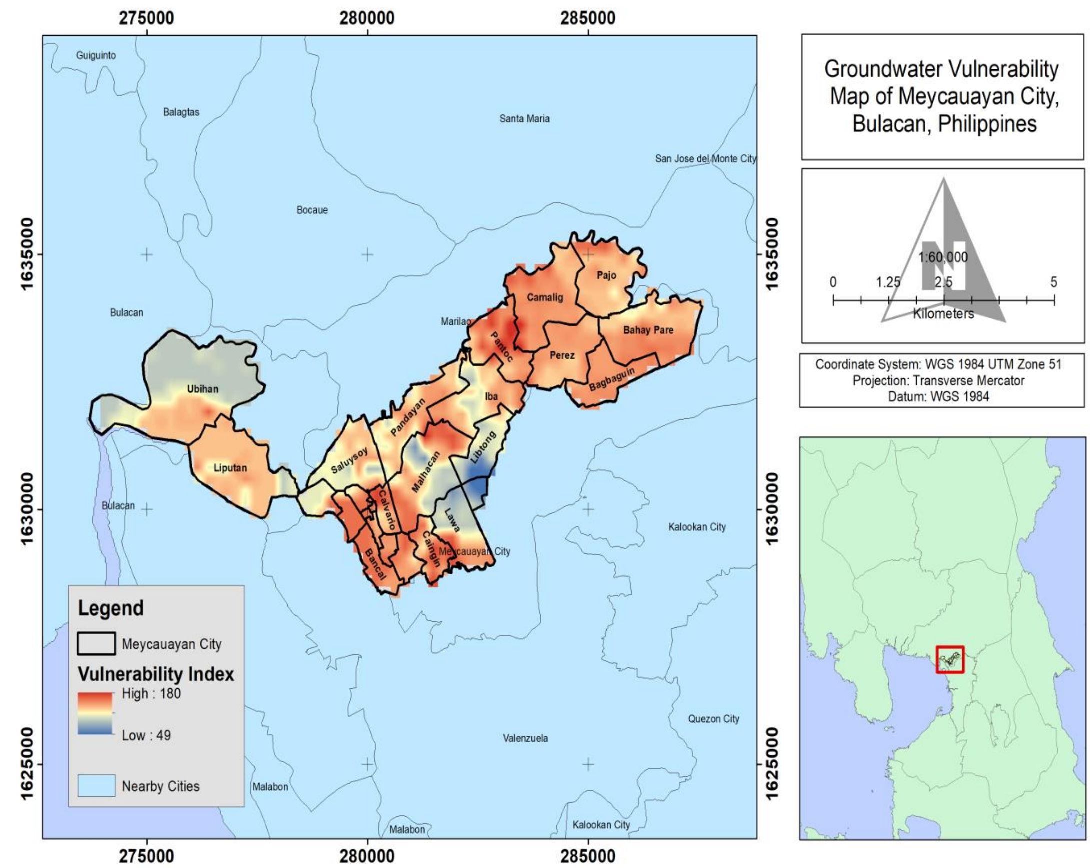


**Fig. 10.** Groundwater Vulnerability Map of Meycauayan City.

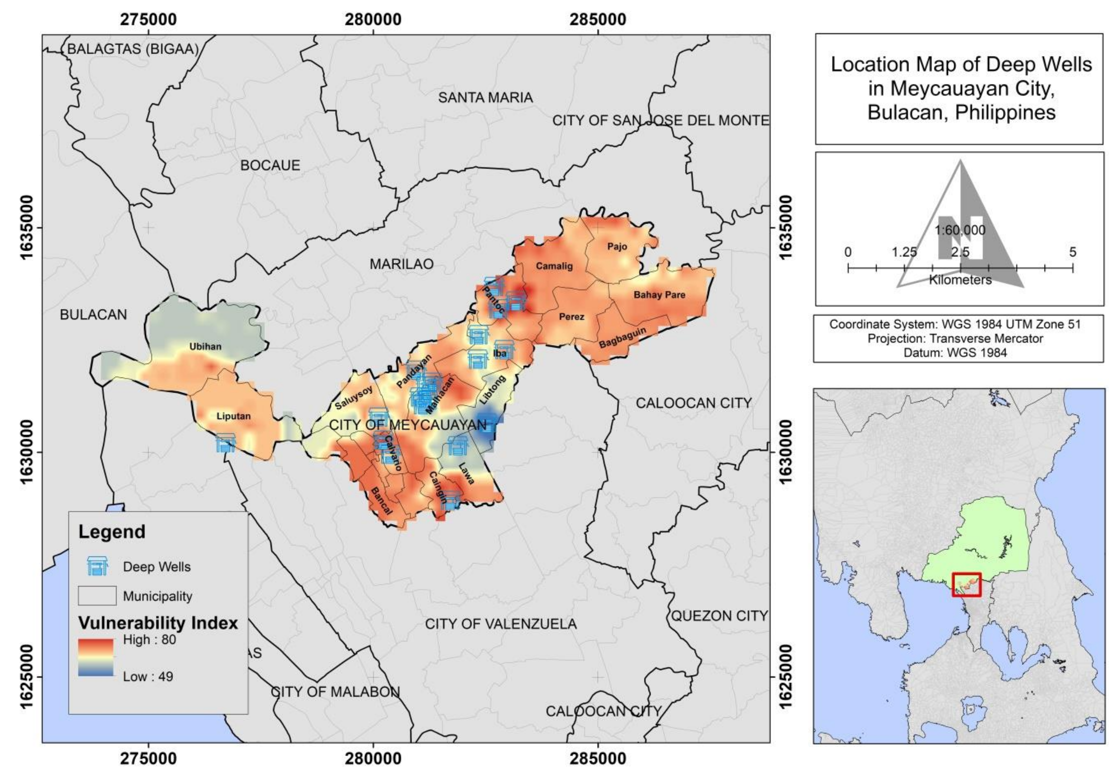


**Fig. 11.** Location of deep wells in Meycauayan City.

**Conclusions and recommendations**

The study has shown the effectiveness of 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. In general, the groundwater resources of Meycauayan City were found to have high potential vulnerability to contamination having vulnerability index of 180 using DRASTIC MODEL.

DRATIC model 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 in the Philippines. This method, with a little refinement, can be used throughout the country to create new groundwater vulnerability maps if none exists. The result could be used for planning and groundwater management. For planning purposes, the vulnerability map could be used by concerned agencies for zoning and aquifer protection. Highly vulnerable areas could be protected from pollution. Sites of production wells could be placed in less vulnerable areas. Landfills and dumpsite need to be protected by lining the aquifer and located in less vulnerable areas. The map result indicating high and less vulnerable areas could be used by the Local Government units (LGU) in their Comprehensive Land Use Plan (CLUP) where they can identify where potential/zoning development will take place. Special attention should be made to the areas having moderate to very high contamination vulnerability potential as shown in the vulnerability or DI map of Meycauayan City.

For groundwater management , the generated maps could be used as a tool for decision making. This is a scientific basis in the formulation of policies related to groundwater resource management and protection. In order to validate and improve the results, the use of other methods such as GOD and SINTACTS are recommended for comparison and validation on vulnerability index. The use of sensitivity analysis could determine if the parameters are sensitive. Additional data could be collected in the field to improve and validate the result.

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