GIS based vulnerability assessment of shallow groundwater pollution in the southwest region of Bangladesh using GOD method

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Abstract
Groundwater is vulnerable to contamination due to anthropological and human activities. vulnerability map can be used as a decision-making tool to protect this resource from contamination. The main objective of this study is to determine the groundwater vulnerability for any form of contaminant from the surface. GOD is an overlay and index method designed to map groundwater vulnerability over large regions based on three parameters (groundwater confinement or aquifer type, overlying strata or overall lithology of the unsaturated zone, and depth to groundwater). The level of vulnerability is classified into five categories: very low, Low, Average, High and Very High. The vulnerability classes in this method indicate the most prominent vulnerable areas in the shallow groundwater. In shallow water tables―where permeability is high, showed more vulnerability than the deep-water level. The vulnerability map exhibits that the most of regions of the study area are in a medium level of vulnerability. A quarter of study area showed low vulnerability and 7.9% of study area are in high vulnerability.

Keywords: *GOD Index; Groundwater; GIS; Vulnerability; Contamination.*

1. Introduction

Groundwater is contemplated as the only and substantial freshwater resource particularly in areas with limited freshwater sources such as coastal region (Rahman et al., 2021; Rakib et al., 2020). Bangladesh has a large population density and consists of a coastal region. Almost 99% population of Bangladesh is primarily depend on groundwater as a reservoir of consumption water (Zahid et al., 2008). The availability of freshwater resources in the coastal region of Bangladesh is anticipated to decline by the 2050s and worsening groundwater quality is a key concern (Islam, Shen, et al., 2017). Therefore, it is vital to measure the vulnerability so that the respective authority can take the necessary step to protect the groundwater resources.
Groundwater vulnerability can be defined as a process of calculating the possibility of getting pollutants that may happen in a distinct event (Voudouris, 2009). Groundwater vulnerability assessment is essential to ensure fruitful and sustainable management of groundwater as well as have a great impact on identifying the vulnerable areas (Knouz et al., 2018).
Groundwater vulnerability can be assessed by different methods i.e., SINTACS (Civita, 1994), DRASTIC (Aller, 1985), SI (Ribeiro, 2000), GOD (Foster, 1987). One of the major advantages of these methods is that large areas can be assessed by considering controlling the movement of the contaminants (Thapinta and Hudak, 2003). Among the stated methods GOD is a rating system method. The modality of interpreting and quantification of the GOD parameters involving rating values is well detailed. A vast literature is available on the groundwater vulnerability indices developed at the regional scale with GOD method (Kerzabi et al., 2021; Lisboa et al., 2020; Boufekane & Saighi, 2018; Shrestha, Kafle & Pandey, 2017; Ghazavi & Ebrahimi, 2015; Kazakis & Voudouris, 2011). Present study focuses on measure groundwater

vulnerability by using the GOD method. Furthermore, the study analysis the sensitivity of the parameters involving in the vulnerability assessment.

2. Methodology

2.1. Study Area

The study area covers the southwest side which is considered as the coastal areas of Bangladesh namely Khulna, Satkhira and Bagerhut (Figure 1). The study area is covered approximately 10468.80 sq km which is 7.09% of the total land of Bangladesh; the study area located of latitude $88^0 55'0''$ E to $89^0 57'0''$ E and longitude of $21^0 39'0''$ N to $23^0 1'0''$ N approximately.

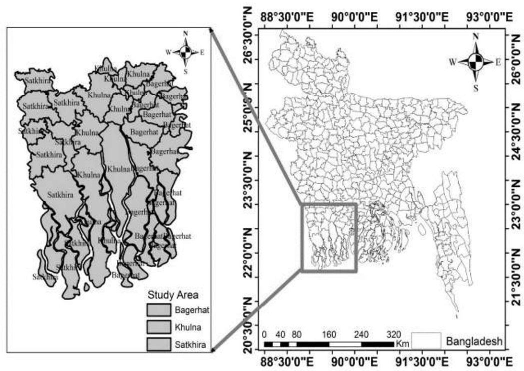

Figure 1. Study area.

2.2. Groundwater Vulnerability

The GOD method (Foster, 1987) is developed based on three hydrological and hydrogeological parameters; Groundwater occurrence (G), overall lithology of the aquifer (O) and depth of groundwater level (D). The individual parameter has separated into several categories with a suitable rating according to their weight (Table 1)(Foster, 1987).

Table 1: Ratting of parameters (Foster, 1987).

Parameters	Type	Ratting
Groundwater Occurrence (G)	No aquifer	0
	Aquifer confined and artesian	0.1
	Confined and non-artesian aquifer	0.2
	Semi-Confined Aquifer	0.3
	Aquifer with fairly permeable cover	0.4-0.6
	Unconfined aquifer	0.7-1
Overall lithology of aquifer (O)	Residual soil	0.4
	Alluvial silt, clay, marl, fine limestone	0.5
	Wind, silt, tuff, igneous rock, and fractured metamorphic	0.6
	Sand and gravel, sandstone, tuff	0.7
	Gravel (colluviums)	0.8
	Limestone	0.9
	Fractured or karst limestone	1
Depth of Water Table (D)	0-2	1
	2-5	0.9
	5-10	0.8
	10-20	0.7
	20-50	0.6
	50-100	0.5
	>100	0.4

Depending on some hypotheses such as (a) pollutants on the ground surface, (b) infiltration of contaminants on groundwater through the water table, and (c) permeability of contaminants the same as water, this method determines the vertical groundwater vulnerability. The value GOD index between 0 (minimum value) to 1 (maximum value) that is classified into five categories. The GOD Index is calculated by the multiplication of these three parameters (equation 1) (Gogu and Dassargues, 2000).

GOD Index = $X_G \times X_O \times X_D$ (1)

Here, X_G indicates the rating of the parameter Groundwater Occurrence; X_O indicates the rating of the lithology of the aquifer and, X_D indicates the rating of the depth of water table.

2.3. Data sampling and Analysis

For creating the parameters and vulnerability map, data i.e., aquifer type, unsaturated lithology zone, depth of water table collected from 513 borehole, and 22 piezometers of the study area (Fig. 2). The necessary data was collected from several institution from Bangladesh that is given below the table 2:

Table 2: Data collection sources.

Parameter	Source
Groundwater Occurrence (G)	Bangladesh Soil Research Institute
Overall lithology of aquifer (O)	Department of Public Health Engineering
Depth of Water Table (D	Bangladesh Water Development Board

2.4. Sensitivity Analysis

Sensitivity analysis is applied for the validation and estimation of the appropriateness of analytic results. In this study, a sensitivity analysis was done to assess the impact of three parameters for generating a vulnerability map. In this study we have used map removal sensitivity analysis developed by Napolitano and Fabbri, (1996) to validate the analytical results of this study. The map removal sensitivity can be measured by this following equation:

$S = (|V/N - V'/n|/V) \times 100$ (2)

Where, S is the measured sensitivity displayed in terms of variation index; V is the unperturbed GOD vulnerability index; V´ is the perturbed GOD vulnerability index; N is the number of data layer applied to compute V; and n is the number of data layer used to compute V´.

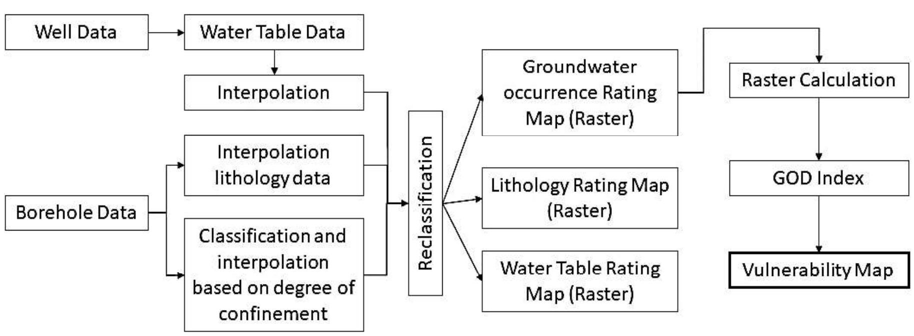

Figure 2. Process of generating vulnerability map by using GOD Method.

3. Result and Discussion

The type of aquifer in the study area was confined and unconfined (Figure 3a). Some zones in the study area are composed of fine sand, sandstones, and sand and most of the area is made of silty soil and clay (Figure 3b). Figure (3c) represents the depth of the water table in the study area.

Table 3 shows the classification of GOD vulnerability. Figure 5 shows that medium vulnerability areas 71.43% of the total study area, low vulnerability area 20.65% as well as highly vulnerable area 7.9%, and only 0.02% aquifer is having minor vulnerability. The high vulnerability was developed in those areas where shallow depth of aquifer as well as high permeability aquifer is presented. Vulnerability map (Figure 4) displays the city area of the Shatkira district described high vulnerability (0.5 to 0.7).

Furthermore, in Khulna and Bagerhat region where vulnerability high, the unconfined aquifer is the geological formation that indicates high vulnerability to the contaminant. Medium vulnerability (0.3 to 0.5) exhibits in most areas in this study, as sand and sandstone are the common geologic formation of the coastal regions. On the other hand, the water table has a great impact on pollution as the region has a very low water table. The rest of the area is relatively low vulnerable where clay or silty clay is the natural geological formation. As clay is comparatively impermeable, pollutants infiltrate more diminutive than another aquifer through it (Goldscheider, 2005). Also, the vulnerability map shows a small area in the Khulna district has a negligible vulnerability.

Table 3. Vulnerability Classification (Foster, 1987)

Vulnerability Class	GOD Index
0	No vulnerability
0-0.1	Negligible
0.1-0.3	Low vulnerability
0.3-0.5	Medium vulnerability
0.5-0.7	High vulnerability
0.7-1	Very high vulnerability

3.4. Sensitivity Analysis

Statistical summary of three parameters used to generate the GOD vulnerability map shown in Table 4. The lowest mean value was in groundwater occurrence (which is 0.28) and the highest contribution was by the depth of the water table (Mean = 0.93) while overall lithology was the second-ranked contribution (0.52). The coefficient of variations (CV) indicates that a high contribution to the variation of vulnerability is made by groundwater occurrence (78.57 %), while the lowest contribution is made by overall lithology (12.50 %). The results of the map removal sensitivity analysis are calculated by removing one data layer at a time (Table 4).

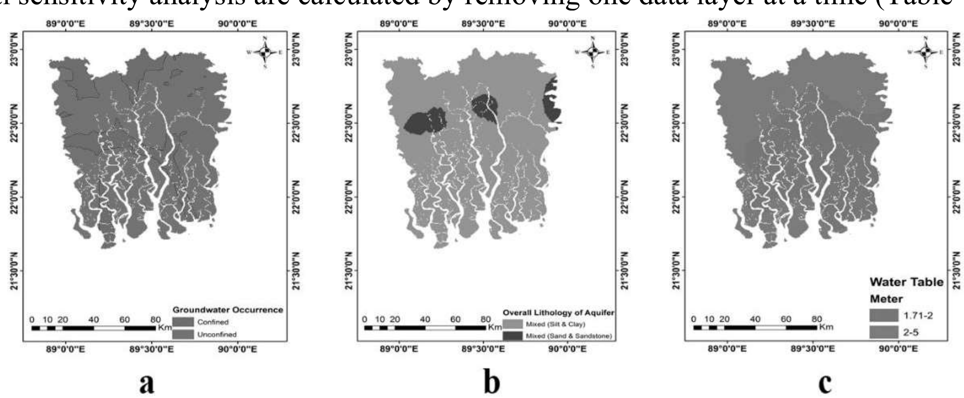

Figure 3. (a) Groundwater occurrence, (b) overall lithology, (c) Depth of water table

Table 5 showed the highest variation of the vulnerability index is observed when the groundwater occurrence parameter is removed from the computation which shows a high relative mean value of variation index (34.18%). Other two parameters-lithology (mean value of variation index is 0.87%) and depth of water table (mean value of variation index is (0.50%) showed very low sensitivity.

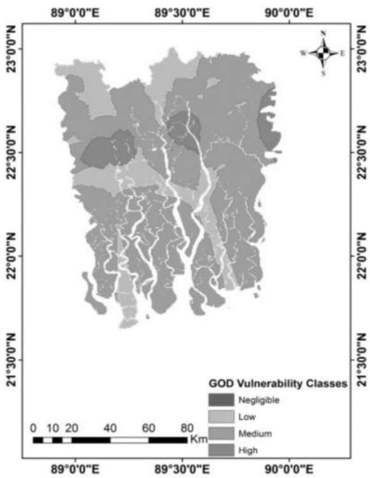

Figure 4. Vulnerability Map.

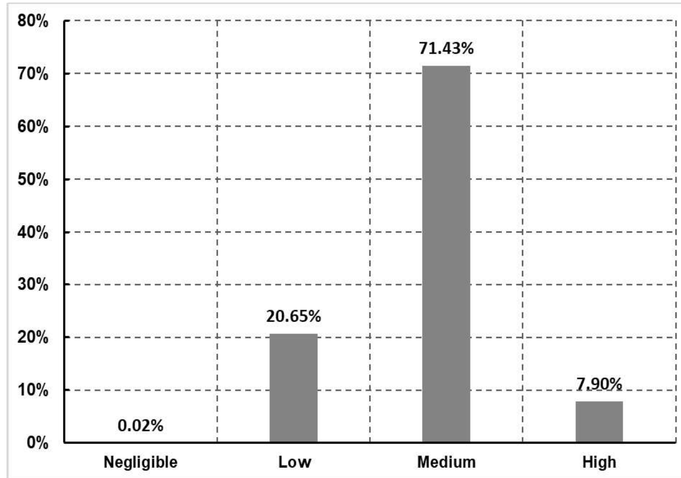

Figure 5. Measured vulnerability (%)

Table 4. A statistical summary of the GOD parameter maps.

Parameter	G	O	D
Mean	0.28	0.52	0.93
Maximum	0.9	0.7	1
Minimum	0.2	0.5	0.9
Standard Deviation	0.22	0.065	0.34
Coefficient of Variation (%)	78.57	12.50	36.55

Table 5: Statistics of one map removal sensitivity analysis

Parameter removed	Variation index (%)	
	Mean	**SD**
G	34.18	4.76
O	0.87	0.11
D	0.50	0.47

4. Conclusion

The Vulnerability map using the GOD method shows that 7.9% of high vulnerability situated in the almost center of three districts where the main source of pollution is wastewater from different sources also pesticides used in agricultural land. In the study area, most of the regions used as agricultural land are commonly used pesticides for the growth of the crops, which impacts groundwater pollution exceedingly. As a result, most of the area in this study shows medium vulnerability (71.43%). Some regions of the study area are covered by the confined aquifer, where the atmospheric pressure of groundwater is particularly high. This high atmospheric pressure on the aquifer degrades the contamination of groundwater. This is the reason for showing only 22.65% of Low vulnerability area in the vulnerability map. The southwest and southeast side of the study area mostly covered by mangrove forests and comparatively fewer human activities happen in there. In the vulnerability map majority of this area displays medium and low vulnerability. The geological formation and the water table is responsible for contaminant this area. Additionally, it is found in the sensitivity analysis that groundwater occurrence plays the most sensitive role in GOD method and the depth of water table is less sensitive than the other two parameters.

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