Groundwater Risk Assessment for Shallow Aquifers within the Atankwidi Basin of (Ghana)

Maxwell Anim-Gyampo, Geoffrey K. Anornu, Sampson K. Agodzo, and Emmanuel K. Appiah-Adjei

Abstract

This study reveals the potential risk to the quality of shallow groundwater aquifers from the application of agro-chemicals in upscaling crop production to ensure food security within the Atankwidi basin of Ghana, using the combination of DRASTIC and Arc GIS methods. The DRASTIC indices ranged from 41 to 117, representing the lowest to highest vulnerable areas. 34.4, 93.3 and 63.9 km^2 representing 20, 48.8 and 33.2% of the area had low, moderate and high vulnerabilities with indices ranging between 41–71, 71–88 and 88–117, respectively. The moderate and high vulnerable areas, which constituted approximately 80% of the area, were underlain by clay-loam and sandy-loam soils, respectively, where major farming takes place. The most vulnerable areas were in the highest elevated areas (recharge), with the shallowest depth to water-table and the highest permeability values. Sensitivity analysis using a map removal approach revealed influential parameters in the order of Hydraulic conductivity (C) > Soil type (S) > Depth to water table (D) > Net Recharge (R) > Influence of vadose zone (I) > Topography (T) > Aquifer material (A). The validation of the model using heavy metals measured in shallow aquifers showed the highest values within the most vulnerable areas and the lowest values in the least vulnerable ones.

Keywords

Atankwidi • DRASTIC index • Ghana • Groundwater risk assessment • Shallow aquifers

1 Introduction

Groundwater, especially in arid and semi-arid regions, remains the most and sometimes the only reliable source of water to meet the domestic, agricultural and industrial demands of inhabitants [1] due to its quality and quantity, compared with surficial waters. However, anthropogenic activities [2] could result in a deterioration in the quality of groundwater [3] due to the leaching of heavy metals (e.g. Pb, Cd, As, Hg, Ni etc.) through the soil into the saturated zone underground.

To improve food security and lower poverty levels, the Atankwidi basin in Ghana had been earmarked for the upscaling of irrigational farming by the government of Ghana [4], with an anticipated utilization of groundwater [5] and large quantities of agrochemicals, since previous hydrological studies revealed surface water as very unreliable.

Thus, a potential risk to groundwater contamination, and consequently, potential health implications to human health and aspects of the ecosystem are envisaged. This study evaluates the intrinsic vulnerability of shallow aquifers within the Atankwidi basin of Ghana to assess their potential resilience to contamination from leachates from agricultural fields by mapping out the most vulnerable area(s).

2 Materials and Methods

The area (Fig. 1) is located between Lon 0°, 50′–1°, 10′ W and Lat: 10°, 45–11°, 00′ N, with an area of 286 km^2. It is endowed with large tracks of fertile soils that can support

M. Anim-Gyampo (✉)
Earth Science Department, University for Development Studies, Box 24 Navrongo, Ghana
e-mail: gyampom@gmail.com

M. Anim-Gyampo · G. K. Anornu
Civil Engineering Department, College of Engineering, KNUST, PMB, Kumasi, Ghana

S. K. Agodzo
Department of Agricultural Engineering, College of Engineering, KNUST, PMB, Kumasi, Ghana

E. K. Appiah-Adjei
Geological Engineering, College of Engineering, KNUST, PMB, Kumasi, Ghana

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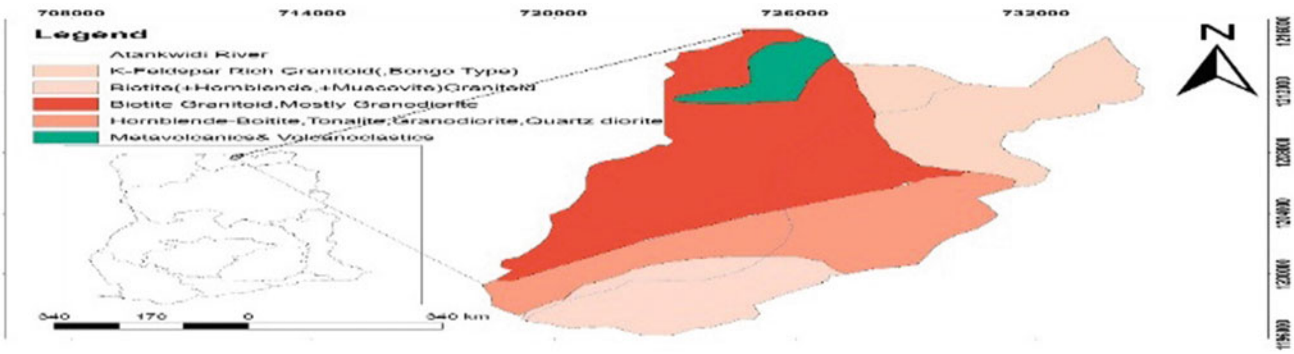

Fig. 1 The study area

large scale irrigational farming of which approximately 80% are uncultivated [4].

2.1 Determination of Intrinsic Vulnerability Shallow Aquifers

The Groundwater risk was assessed using a combination DRASTIC index (DI) and GIS tools. According to [6], DRASTIC is an acronym which incorporates seven parameters of the hydrogeological and physical characteristics of an area, namely depth to water table (D), net recharge (R), aquifer media (A), soil type (S), topography (T), influence of vadose zone (I) and hydraulic conductivity (C). DI = $\sum$ (weight * Rating of each of parameter in DRASTIC). Weights (between 1 and 5) reflecting the relative influence on the rate of infiltrating groundwater were assigned to each parameter with the most influential assigned 5 and vice versa [6]. Thus, in this study, the assigned weights are D-5; R-3; A-2; S-4; T-1; I-4 and C-3. The product (i.e. W*R) of the assigned weights and ratings based on variations in hydrogeological and geographical conditions were utilized by the Geostatistical Analyst and Spatial Analyst Tools in the GIS to create classified raster layer (index layer) for each parameter. Overlay analysis (summation of all index layers) using Spatial Analyst Tools under "Overlay" in Arc-GIS was carried out to produce a single composite layer (Risk map or DRASTIC model). The Scores (DRASTIC Indices) obtained from the DRASTIC model were reclassified into three categories as low; moderate and high vulnerable zones.

3 Results and Discussion

3.1 Groundwater Vulnerability Map

The final vulnerability map using the seven hydro-geological data layers showed in Fig. 2a–g is as depicted in Fig. 3.

The vulnerability map (Fig. 3) revealed that: out of 191.27 km^2, about 34.48 km^2 (20%) had low risk with a DI

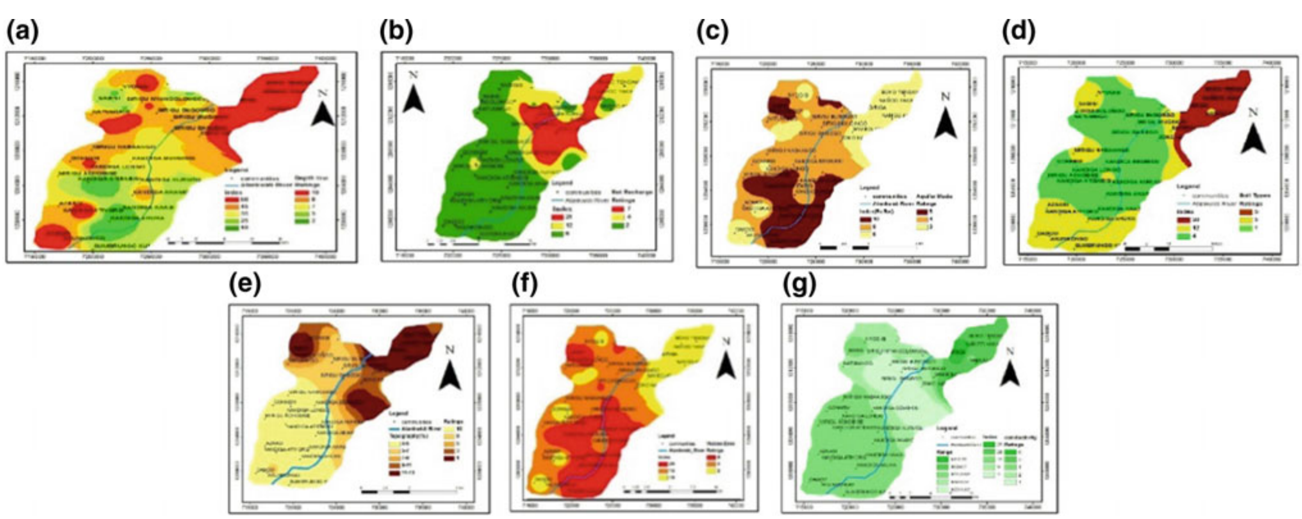

Fig. 2 **a** Depth to aquifer media (D). **b** Net recharge (R). **c** Aquifer media (A). **d** Soil media (S). **e** Topography (T); **f** Impact of the vadose zone (I). **g** Hydraulic conductivity (C)

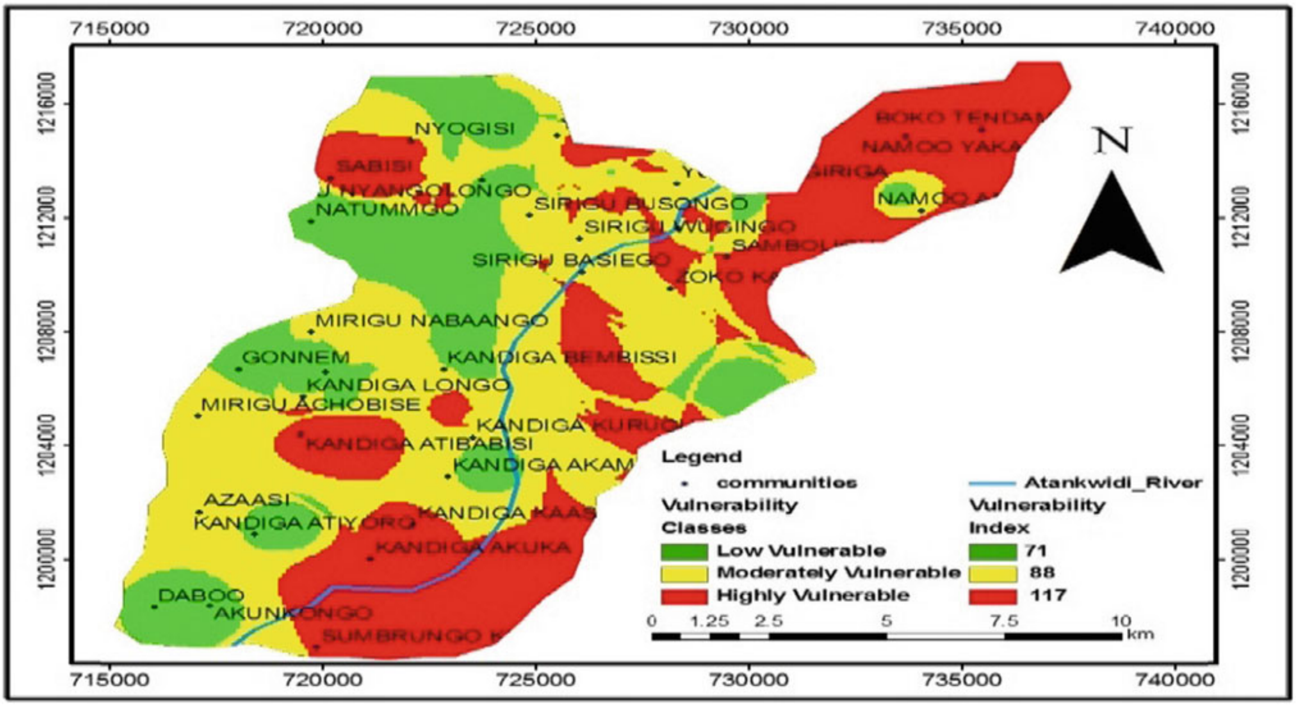

Fig. 3 Groundwater vulnerability zones of Atankwidi catchment

range of 40–71, about 93.31 km^2 (48.8%) were under a moderately vulnerable zone with a DI between 71 and 88, while about 63.48 km^2 (33.2%) were under the highly vulnerable zone with a DI ranging from 88 to 117. The moderate to highly vulnerable areas constitute about 80% of the entire Atankwidi catchment, signifying that a greater part of the area could be at risk in terms of aquifer pollution potential. Moderate and highly vulnerable zones are incidentally located in areas known for intensive modern irrigation farming involving the use of agro-chemicals (e.g. fertilizers, weedicides, pesticides etc.). Areas under the high vulnerability zones have a low depth to water-table and coarse sandy-loam soils.

3.2 Sensitivity Analyses

The map removal analysis [7] indicated the order of influence of the parameters based on mean variation index as C > S > D > R > I > T > A.

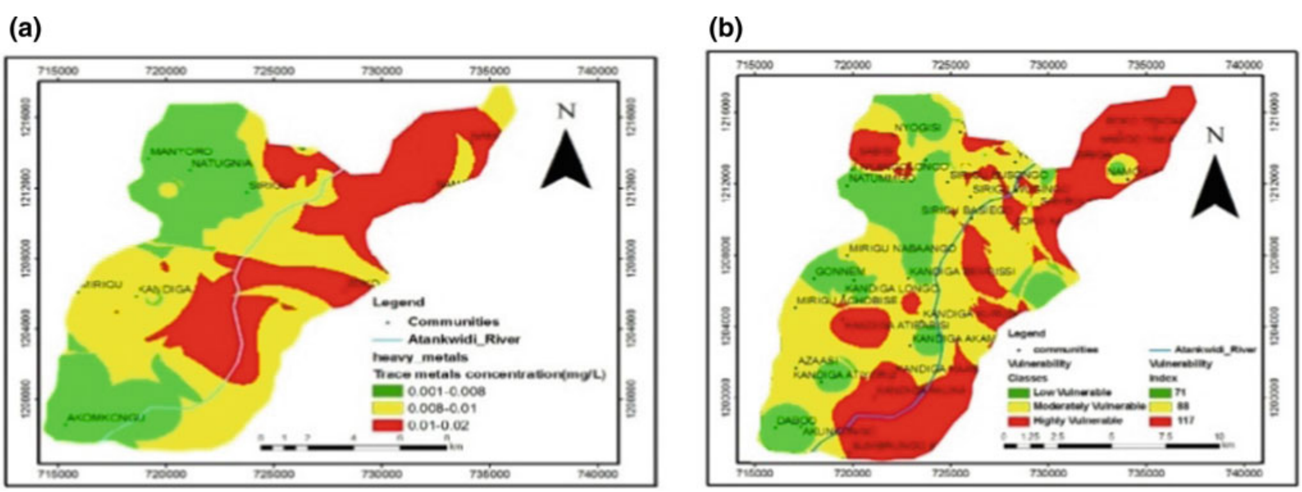

Fig. 4 **a** Composite thematic map of heavy metals, **b** vulnerability model of basin

3.3 Validation of DRASTIC Model

Analysis of measured concentrations of some heavy metals (Zn, Cu, Cr, As, Pb, Cd and Ni) of health significance [8] in 30 groundwater samples (Fig. 4a) revealed that the moderate to high risk zones contained elevated concentrations of heavy metals compared to low vulnerability zones.

4 Conclusions

About 33.2, 48.8 and 20% of the area had high, moderate and low risk potentials to contamination, respectively, with about 80% of the area having moderate to high risks. Moderate to high risk areas coincided with elevated areas (recharge) and intense farming areas (sandy-loam soils). Low risk areas were localized in low-lying, clay-rich areas. Validation using heavy metals from groundwater samples indicates that moderate to high risk areas had elevated concentrations of heavy metals and vice versa.

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