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Evaluation of Groundwater Vulnerability in the Densu River Basin of Ghana

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The paper evaluated the potential of groundwater pollution in the Densu River Basin of Ghana. Groundwater is an important resource in this basin currently supporting domestic, agricultural and industrial activities. The significance of water resources and the potential for groundwater quality to deteriorate due various anthropogenic activities within the Densu River Basin has necessitated this study using a combination of GIS and DRATIC methods. The study reveal that about 47% of the basin is exposed to high-risk, 43% exposed to medium-risk and 10% exposed to low-risk. It is recommended that the fast growing urban settlements in this high-risk prone areas need more careful urban planning of settlements, siting of irrigation schemes and sanitation facilities. The results in this research are replicable in other basins in Ghana and the sub-region.

Keywords: DRASTIC, Densu basin, GIS, groundwater pollution, groundwater vulnerability, Ghana

Introduction

Water plays an important role in every society. Not only is it vital for life, it also sustains the environment, contributes to the development of economic, health, social, recreational and cultural activities. As surface water quantity and quality continue to diminish over the years as a result of rapid population growth, urbanization and pollution in developing countries such as Ghana, the most available source of potable water supply is groundwater. About two billion people around the world are dependent on groundwater resource which is itself a vulnerable resource (Kemper, 2004).

These are evidenced in most parts of Africa and Asia where groundwater is being used by majority of the population living in rural, peri-urban and urban settlements for irrigation and domestic purposes. Notwithstanding this basic phenomenal use, the relevance and the demand for groundwater resource continue to increase due to new challenges such as climate change effects (Villholth, 2009, Audretsch & Thurik, 2000) and contamination and pollution of the resource through industrialisation, irrigation and urban rapid growth (Biswas, 1991). Therefore, the quality of groundwater resource is crucial to providing the needed demands for domestic, irrigation and industrial purposes. The contamination and pollution of groundwater is well noted and documented in several works in Ghana and globally (Cleary et al., 1981, Tripp & Jaffe, 1979, Schwarzenbach et al., 2010, Moussa et al., 2012, Bhattacharya et al., 2012, Kortatsi et al., 2008).

This emphasizes the growing vulnerability and susceptibility of groundwater to potential pollution challenges. Pollution of groundwater maybe defined as the contamination from industrial, domestic and agricultural water sources (Fried, 1975). In general terms, the artificial introduction of foreign matter to degrade the natural quality of groundwater is pollution. Whereas, it is ten times easier to physically evaluate the status of surface water quality, groundwater quality assessment is very difficult and in many cases, complex instruments and expert's knowledge are required to give a fair idea about the status of groundwater. Vulnerability of groundwater is heavily controlled by the geological setting of the area in question.

According to Vrba and Zaporozec (1994), aquifer vulnerability represents the various intrinsic properties of the complex system as a function of the sensitiveness of human and natural activities. Groundwater vulnerability is therefore a function of the interrelationships between geological setting and human activities, and the spatial-temporal understanding of this vulnerable potential promises a great leap towards decision making in water resources management.

Hence, groundwater vulnerability mapping becomes a crucial tool for quantifying the sensitivity of groundwater resources (Rahman, 2008) to its environment and presents a visual tool for decision making, planning and law enforcement. The advent of Geographic Information Systems (GIS) and its subsequent ability to derive catchment properties for

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river basins provides an important tool to estimating groundwater vulnerability.

Several methods are available for mapping groundwater vulnerability (Van Stempvoort et al., 1993, Dixon, 2005, Goldscheider, 2005). Goldsheider used the PI method (protective cover (P) and infiltration conditions (I) to assess the groundwater vulnerability of karsts aquifers in Germany. The PI method used in this research was found to be applicable for groundwater assessment for vulnerability.

In 1987, Aller et al (1987) developed the DRASTIC method and improved by Dixon (2005). Dixon used a fuzzy based model to improve the results of the DRASTIC index. The Aquifer Vulnerability Index (AVI) method was used by Van Stempvoort et al. (1993) for mapping the vulnerability of groundwater. They presented this method to be much easier than the DRASTIC, especially that only two key parameters are required by the AVI method (i.e. thickness of each sedimentary unit above the uppermost aquifer and estimated hydraulic conductivity of each of layer). Notwithstanding, the DRASTIC technique seems to be the most acceptable and user friendly method based on GIS approach (Al-Adamat et al., 2003, Aller et al., 1987, Merchant, 1994, Rundquist et al., 1991, Panagopoulos et al., 2006, YANG et al., 2012).

The term DRASTIC comes from integration of several factors. These include - Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and hydraulic Conductivity of the aquifer. The GIS technique allows for the spatial analysis of the DRASTIC approach using various satellite and cartographic maps, and pumping tests analysis. The general principles is that, each of these parameters in DRASTIC is weighted and rated and integrate together to give the informative vulnerability map of the groundwater status in a particular study area. Though commercial softwares for using DRASTIC approach are available, ILWIS Open provides a free and open source framework to implement this study.

The Densu River Basin is one of the significant river basins in Ghana serving as the source to the main potable water supply reservoir in the Accra-Ghana's national capital through the Weija dam and groundwater sources to both rural, urban, industrial and commercial agricultural activities in Eastern and Greater Accra regions of Ghana. These, the massive anthropogenic activities have the potential affect the quality of groundwater within the basin. The study assesses the groundwater vulnerability in the Densu River Basin of Ghana. This river basin is located in one of the fast developing regions of Ghana and unfortunately limited studies are available to provide information of the dangers of groundwater vulnerability. This information is particularly important to water resource managers, town and country planners, environmental and sanitation companies and the communities in this basin, to plan properly siting of environmental and sanitation facilities, carry out mining and agricultural activities to avoid heavy pollution of groundwater resources in the basin.

The Study Area

The Densu River Basin is one of the important basins of Ghana and borders with the Odaw and Volta Basins to the East and the Birim Basin in the Southwest and Ayensu and Okrudu in the West (Figure 1) showing the location of the wells. It is located within latitudes 50 30′ N to 60 20′ N and longitudes 00 10′ W to 00 35′ W. It has an estimated drainage area of 2,564 km^2 and elevation varying between 100m -800 m above sea level. The Densuriver flows southeast of Ghana before it enters southwards into the Weija Lake.

The Densu basin includes parts of six (6) districts in the Eastern Region (Akwapim North and South Districts, East and West Akim Districts, Suhum-Kraboa-Coaltar District and the New Juaben District), the Ga District in the Greater Accra Region and Awutu-Efutu-Senya District in the Central Region.

The basin's climate is characterized by temperatures of 32^{o}C in March/April and 23^{o}C in August. The average annual temperature is 27^{o}C. Generally, it also experiences variations in the duration, intensity, and distribution of rainfall. The rainfall falls under two distinct climatic zones -the dry equatorial climate of the south-eastern coastal plains and the wet semi-equatorial climate further north from the coast. These climatic zones are characterized by two rainfall regimes with different intensities. The major rainy season extends from April/May to July and peaks in June. The second rainfall period is a much lower and occurs during September/November. The annual rainfall ranges from 1700 mm in the wet interior to 800 mm in the dry equatorial zone near the coast (Dickson & Benneh, 1988).

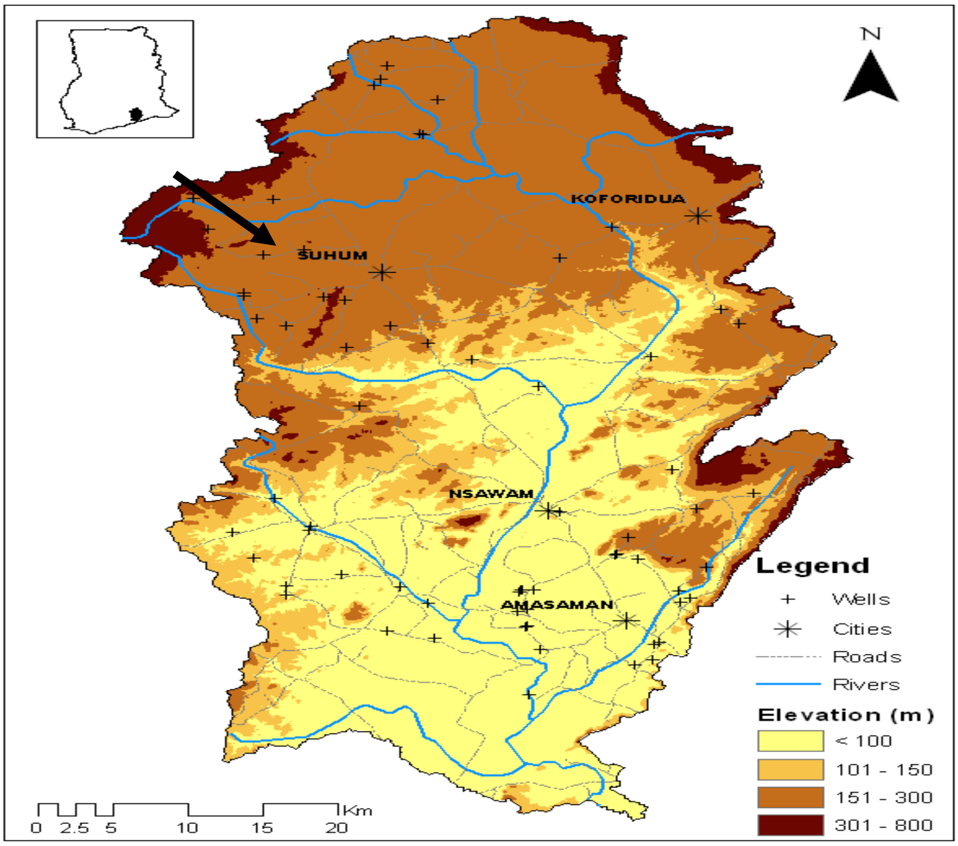

Figure 1. Map showing Densu river basin with thewell locations. Source: Anornu et al (2012).

Materials and Methods

The scientific logic and guideline of DRASTIC is well elaborated by Aller et al. (1987). However, Figure 2 illustrates figuratively the various parameters needed to be derived, weighted and rated for usein the DRASTIC formula. Table 1 shows the various data sources that were used. All relevant information raw data indicated were processed into acceptable GIS formats for ILWIS Open. The other built-in functions of ILWIS helped in the inal derivation of the vulnerability map for the Densu river basin.

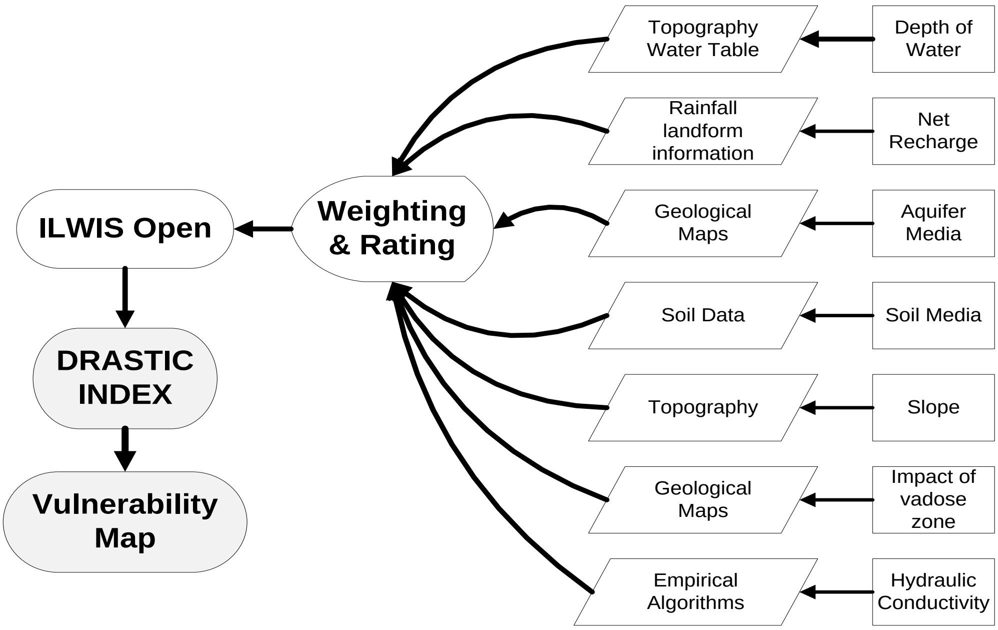

Figure 2. Methodological flowchart for using DRASTIC method in ILWIS open.

The concept of groundwater vulnerability is assumed that the physical environment provide some protection of the groundwater against natural impacts as regards to contaminants entering the subsurface environment. In order to achieve this, the main goal of a vulnerability map is to identify the various factors and their possible degree of impact on vulnerability (Panagopoulos et al., 2006, Rahman, 2008). As indicated in Figure 2, the various hydrogeological factors (D-depth to water, R-net recharge, A-aquifer media, S-soil media, T-topography, I-impact of the vadose zone and C-hydraulic conductivity of the aquifer) are weighted and rated using numerical values presented by (Aller et al., 1987, Rahman, 2008).Each of the factors of D, R, S, T, and C are evaluated on a relative scale and assigned one value per range. This system allows determining a numerical value for any hydrogeologic setting by using an additive model. The equation for determining the DRASTIC Index is:

$$\text{DRASTIC Index} = D_R D_w + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W, \quad (1)$$

$$\text{Where } R - \text{rating}, \quad W - \text{weight}$$

$$k = \frac{4W^2 R}{[H^2 - (H-d)^2])}, \quad (2)$$

Where,

K, is the hydraulic conductivity (LT^{-1}),
R, is recharge rate, (LT^{-1})
d, is the valley depth, (L)
H, is the aquifer thickness, (L)

W, is the length of effective groundwater drainage (L).

$W = \frac{1}{2D}$, (See Luo et al., 2010)

D is drainage density

Table 1. Parameters, data source and DRASTIC assigned weights.

No.	Parameter	Data source	DRASTIC weights
1	Depth of water	Pumping test data	5
2	Net recharge	TAMSAT rainfall data & annual ET estimation	4
3	Aquifer media	Geological map, Ghana	3
4	Soil media	Soil map, Ghana	2
5	Slope	SRTM 90m DEM	1
6	Impact of vadose zone	Well logs, geological map, Ghana	5
7	Hydraulic conductivity	Algorithm developed by (Luo and Pederson, 2012, Luo et al., 2011), see equation (2)	3

Results

The D in equation 2 was derived from previous watershed parameters(Anornu *et al*., 2012). The value of ***D*** was assumed to be equal to the total drainage length (737,301.90 m) divided by the total catchment area (2,626,023,623.77 m^2). As a result, W, was estimated to be $0.00028m^{-1}$. The recharge rate [R] was determined from rainfall estimates of Tropical Applications of Meteorology using Satellite data (TAMSAT). The accumulated annual rainfall for the year 2010 was used.

The relevance and reliability of using TAMSAT rainfall products has extensively been elaborated by Kabo-bah et al. (2012) and evapotranspiration estimates (Barry et al., 2005). Since it was difficult to stream flow measurements in the basin to support the recharge estimation in the basin, an indirect approximate approach was used. It was assumed that, the difference between the rainfall and the actual evapotranspiration was contributing to the runoff. This runoff was considered comparable to the stream discharge measurements. The aquifer thickness (H) was estimated from interpolated maps derived from pumping test analysis. However, the computed hydraulic conductivity for the study area was checked for consistency with other literature estimates. It was revealed that literature estimates of 0.01 ~ 0.05m/day (Lutz et al., 2007). However, the estimates from equation (2) vary between 0.002 ~0.02m/day. As it is well known, the accurate estimation of hydraulic conductivity is difficult but the general consistency of this estimate was found to be acceptable.

***Depth to water* (*D*)**

Depth to water (D) represents the depth from the ground to the water table. This was estimated from pumping tests. The estimates, D, are shown in Figure 3 (varies from 5.24 m to 5.41m). The variations of D were reclassified according to the DRASTIC rating scale. Since, the difference in variation was small throughout the study area and these values represented only a single rate DRASTIC value. Therefore, the map produced shows only that the highest rate of 10 (Figure 4).

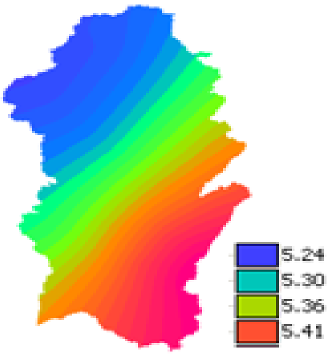

Figure 3: Depth to water estimate.

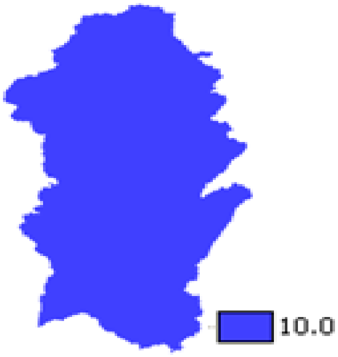

Figure 4. Rating for depth to water.

Aquifer media **(*A*)**

Aquifer media refers to the consolidated or unconsolidated medium which serves as an aquifer. This was obtained from the geological map. From the geological map, ratings for the aquifer media were ranked as shown in Figure 5.

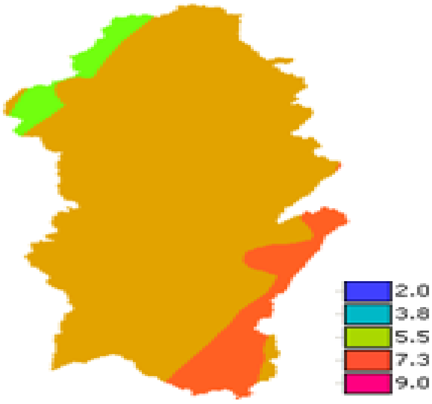

Figure 5: Rating of aquifer media.

Soil media **(*S*)**

Soil media is the uppermost portion of the vadose zone characterized by significant biological activity. Reference to the soil map of Ghana was made. This soil map was ranked as shown in Figure 6.

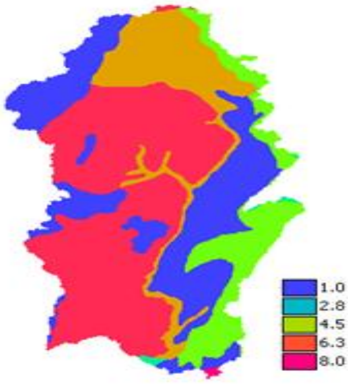

Figure 6: Rating of soil media.

Topography **(*T*)**

Topography refers to the slope of the terrain or the catchment. This scope variability of the land surface helps to regulate the likelihood that a pollutant will run off or remain on the surface in one area long enough to infiltrate. This was estimated using the SRTM 90m DEM. From the slope map (Figure 7), this was rated (Figure 8).

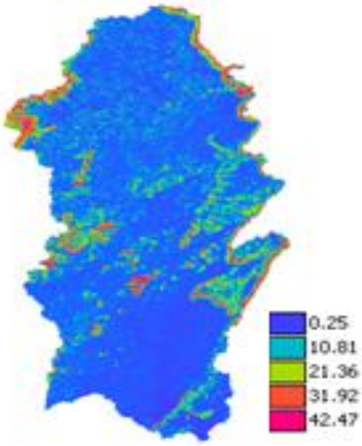

Figure 7: Slope map.

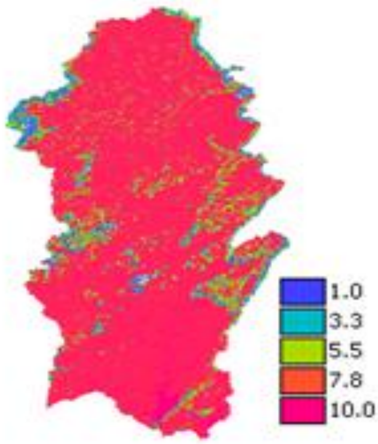

Figure 8. Rating for the slope map.

Impact of Vadose media (*I*)

The geological map together with the pumping tests was compared to derive the map provided in Figure 9.

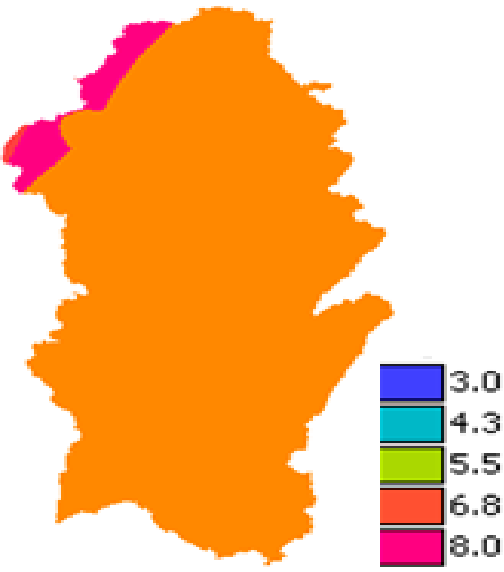

Figure 9. Rating of impact of vadose media.

Hydraulic conductivity of the aquifer (*C*)

This refers to the ability of the aquifer materials to transmit water and this controls the rate at which ground water will flow under a given hydraulic gradient. The computed hydraulic conductivity (Figure 10) was then rated.

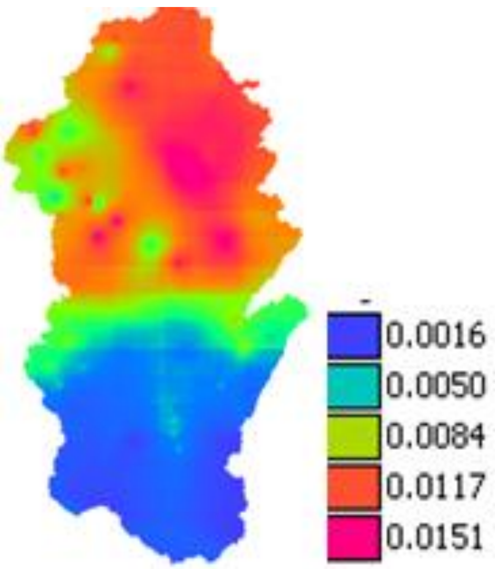

Figure 10. Hydraulic conductivity map.

Discussion

The DRASTIC method allows for easy interpretation of data by non-technical experts and in particular can be used for education purposes. The main purpose of this work was not to evaluate the sensitiveness of each of the parameters to computing the overall index, therefore the optimal use of the parameters most relevant as presented by (Rahman, 2008) was not done in this research. All seven parameters were used since it was easy deriving them from all relevant data sources. In this way, a reliable approximate estimate of the index was achieved.

The DRASTIC index developed (Figure 11) gives an indication of the prevailing vulnerability conditions in this Densu basin. The index values vary between 114 and 133. The map was regrouped into three parts. Based on the works of Aller et al. (1987) and Rahman (2008), the areas were reclassified according to “low risk”, “medium-risk” and “high risk”.

Therefore, areas with values between 114 and 120 were considered to be of low-risk, areas between 120 and 129 were considered to be of medium-risk and areas of more than 130 were considered to be of high risk. The high-risk, medium-risk and low-risk areas represent about 47% (NNW, NSW, NNE), 43% (NNE, NNW and NSW) and 10% (middle belt NN-S) respectively. Hence, about half of the basin geologically is inherent to groundwater vulnerability. Suhum, the district capital of Suhum-Kraboa-Coaltar District and a fast growing urban settlement falls within the high-risk zone.

Other fast growing urban settlements such as Nsawam and Koforidua are about 250m from the high-risk zone. The vulnerability zoning presented provides first-hand information about ensuring that human-induced factors such as surface water pollution, siting of sanitation facilities and irrigation activities are properly monitored, controlled and managed such that, it does not catalysed the groundwater vulnerability through pollution. Though, the DRASTIC method does not intend to indicate the degree of groundwater pollution, it provides the potential of groundwater being polluted(See Srinivasamoorthy et al., 2011, Sener et al., 2009, Jamrah et al., 2008).

Hence, the DRASTIC method has provided baseline information for water resource managers and all stakeholders in groundwater use and management in the Densu river basin, a non-technical overview of the vulnerability of groundwater in the basin.

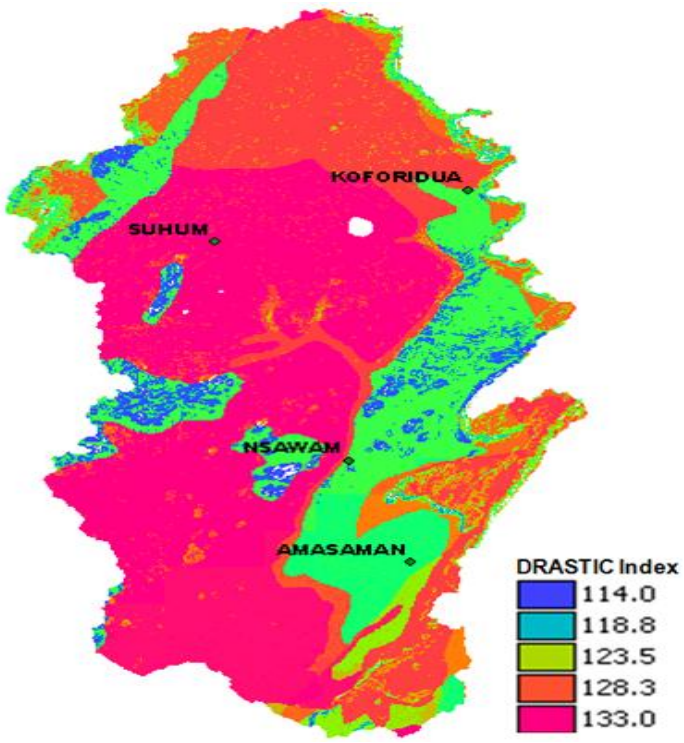

Figure 11. Groundwater vulnerability of the Densu river basin.

Conclusion

Groundwater resource is important for potable water supply in Ghana. This also holds true for the Densu River Basin. However, the rapid growth of population, poor urban planning and settlements, and pollution of surface water resources pose pollution risk for the basin's groundwater resources. In order to assess to the degree to which such groundwater resources could be exposed, the DRASTIC method was applied in the basin to evaluate the vulnerability of groundwater. This method typically uses the watershed topographic and geological characteristics to determine the natural susceptible vulnerability of the groundwater resource. The results showed that, about the low to high risk zones represent about 10% to 43% of the basin area. The index does not indicate the degree of pollution but however assesses the potentiality in groundwater getting polluted. Therefore, the results imply that, roughly 40% of the basin is susceptible to groundwater pollution. With this in mind, it is imperative that, decision makers, planners and lawmakers ensure that the total planning and utilization of the water resources in the basin are harnessed in such a way to minimize the pollution of the groundwater resource base. This research is applicable for studying larger basins such as the Volta River Basin of West Africa and many other small and larger basins in Africa. The use of this method in such larger basins can be useful information for the multiple stakeholders operating in these basins to plan, control and manage groundwater resources effectively and collaboratively. This would help in minimizing the dangers of polluting groundwater resources and saving populations depending on this resource against public health related diseases.

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References

AL-Adamat, R. A. N., Foster, I. D. L. & Baban, S. M. J. (2003). Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, Remote sensing and DRASTIC. *Applied Geography,* 23**,** 303-324.

Aller, L., Lehr, J. H., Petty, R. & Bennett, T. (1987). Drastic–a standardized system to evaluate groundwater pollution potential using hydrogeologic setting. *Journal of the Geological Society of India,* 29**,** 23-37.

Anornu, G., Kabo-Bah, A. & Kortatsi, B. (2012). Comparability studies of high and low resolution digital elevation models for watershed delineation in the tropics: Case of Densu River Basin of Ghana. *International Journal of Cooperative Studies,* 1(1) **,** 9-14.

Audretsch, D. B. & Thurik, A. R. (2000). Capitalism and democracy in the 21st Century: from the managed to the entrepreneurial economy. *Journal of Evolutionary Economics,* 10**,** 17-34.

Barry, B., Obuobie, E., Andreini, M., Andah, W. & Pluquet, M. (2005). The Volta river basin, Comparative study of river basin development and management. *Comprehensive assessment of water management in agriculture.* .

Bhattacharya, P., Sracek, O., EldvalL, B., Asklund, R., Barmen, G., ooo, Balfors, B. B.(2012). Hydrogeochemical study on the contamination of water resources in a part of Tarkwa mining area, Western Ghana. *Journal of African Earth Sciences*.

Biswas, A. K. (1991). Water for sustainable development in the 21st century. *International Journal of Water Resources Development*, 7**,** 219-224.

Cleary, R. W., Miller, D. & Pinder, G. F. (1981) *Groundwater pollution and hydrology*, Princeton Associates.

Dickson K. and Benneh G. (1988). A new geography of Ghana. Longman, London, U. K.

Dixon, B. (2005) Groundwater vulnerability mapping: A GIS and fuzzy rule based integrated tool. *Applied Geography*, 25**,** 327-347.

Fried, J. J. (1975) *Groundwater pollution: Theory, methodology, modelling, and practical rules*, Elsevier.

Goldscheider, N. (2005) Karst groundwater vulnerability mapping: application of a new method in the Swabian Alb, Germany. *Hydrogeology Journal*, 13**,** 555-564.

Jamrah, A., AL-Futaisi, A., Rajmohan, N. & AL-Yaroubi, S. (2008) Assessment of groundwater vulnerability in the coastal region of Oman using DRASTIC index method in GIS environment. *Environmental monitoring and assessment,* 147**,** 125-138.

Kabo-Bah A. T., Yuebo X., Andoh R. & Odai S. N. (2012) A Comparison of TAMSAT satellite rain derived products with meteorologically measured rainfall in the Volta Basin (West Africa). *7th International Conference on Water Sensitive Urban Design.* 21-23 February 2012 Melbourne, Australia. .

Kemper, K. E. (2004). Groundwater from development to management. *Hydrogeology Journal,* 12**,** 3-5.

Kortatsi, B. K., Tay, C. K., Anornu, G., Hayford, E. & Dartey, G. A. (2008). Hydrogeochemical evaluation of groundwater in the lower Offin basin, Ghana. *Environmental geology,* 53**,** 1651-1662.

Luo, W., Grudzinski, B. P & Pederson, D. T. (2011). Estimating hydraulic conductivity for the Martian subsurface based on drainage patterns - A case study in the Mare Tyrrhenum Quadrangle. *Geomorphology,* 125**,** 414-420.

Luo, W., Grudzinski, B. P. & Pederson, D. T. (2010). Estimating hydraulic conductivity from drainage patterns - A case study in the Oregon Cascades. *Geology,* 38**,** 335-338.

Luo, W. & Pederson, D. T. (2012). Hydraulic conductivity of the High Plains Aquifer re-evaluated using surface drainage patterns. *Geophysical Research Letters*, 39**,** L02402.

Lutz, A., Thomas, J. M., Pohll, G. & MckaY, W. A. (2007) . Groundwater resource sustainability in the Nabogo Basin of Ghana. *Journal of African Earth Sciences,* 49**,** 61-70.

Merchant, J. W. (1994). GIS-based groundwater pollution hazard assessment: a critical review of the DRASTIC model. *Photogrammetric engineering and remote sensing,* 60**,** 1117-1128.

Moussa, A. B., Zouari, K., Valles, V. & Jlassi, F. (2012). Hydrogeochemical Analysis of Groundwater Pollution in an Irrigated Land in Cap Bon Peninsula, North-Eastern Tunisia. *Arid Land Research and Management,* 26**,** 1-14.

Panagopoulos, G., Antonakos, A. & Lambrakis, N. (2006). Optimization of the DRASTIC method for groundwater vulnerability assessment via the use of simple statistical methods and GIS. *Hydrogeology Journal,* 14**,** 894-911.

Rahman, A. (2008). A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India. *Applied Geography,* 28**,** 32-53.

Rundquist, D. C., Peters, A. J., DI, L., Rodekohr, D. A., Ehrman, R. L. & Murray, G. (1991) Statewide groundwater • vulnerability assessment in nebraska using the drastic/GIS model. *Geocarto International,* 6**,** 51-58.

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U. & Wehrli, B. (2010). Global water pollution and human health. *Annual Review of Environment and Resources,* 35**,**109-136.

Sener, E., Sener, S. & Davraz, A. (2009). Assessment of aquifer vulnerability based on GIS and DRASTIC methods: a case study of the Senirkent-Uluborlu Basin (Isparta, Turkey). *Hydrogeology Journal,* 17**,** 2023-2035.

Srinivasamoorthy, K., Vijayaraghavan, K., Vasanthavigar, M., Sarma, V., Rajivgandhi, R., Chidambaram, S., ooo, P. & Manivannan, R. (2011). Assessment of groundwater vulnerability in Mettur region, Tamilnadu, India using drastic and GIS techniques. *Arabian Journal of Geosciences***,** 1-14.

Tripp, J. T. B. & JaffE, A. B. (1979). Preventing groundwater pollution: towards a coordinated strategy to protect critical recharge zones. *Harv. Envtl. L. Rev.,* 3**,** 1.

Van Stempvoort, D., Ewert, L. & Wassenaar, L. (1993) Aquifer vulnerability index: a GIS-compatible method for groundwater vulnerability mapping. *Canadian Water Resources Journal,* 18**,** 25-37.

Villholth, K. G. (2009). The neglected role of groundwater in climate change adaptation and disaster risk reduction. IOP Publishing.

Vrba, J., Zaporozec, A., (1994). Guidebook on mapping groundwater vulnerability. International Association of Hydrogeologists International Contributions to Hydrogeology, vol. 16. Heise, Hannover.

Yang, G., Jiang, Y. & Li, Y. (2012). Review on urban groundwater vulnerability assessment by using DRASTIC Model. *Ground water***,** 01.