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Research Article

Assessment of Groundwater Vulnerability to Contamination in Imo River Basin Southeastern Nigeria Using DRASTIC and GOD Models

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Abstract

The aim of this study is to use DRASTIC and GOD model in determining groundwater vulnerability to contamination in Imo River Basin southeastern Nigeria. According to DRASTIC model, 12% has a low class of groundwater vulnerability to contamination, whereas a total of 32% of the study area has moderate vulnerability and 56% has high vulnerability. The value for GOD model was 46.2% of low vulnerability and 53.8% of high vulnerability respectively. The final results indicate that the aquifer system in the interested area is not protected from contamination. To mitigate the contamination risks, a protective measure must be adopted.

Keywords: DRASTIC, GOD, Vulnerability, Imo River Basin

INTRODUCTION

Vulnerability is the degree to which human or environmental systems are likely to experience harm due to perturbation or stress and can be identified for a specified system, hazard, or group of hazards (Popescu et al., 2008). In hydrogeology, vulnerability assessments typically describe the susceptibility of the water table, a particular aquifer, or water well to contaminants that can reduce the groundwater quality (e.g., nitrates, industrial chemicals, and hydrocarbons). The contaminants may originate from a natural source (e.g., rock containing arsenic) or be introduced by human activity (e.g., agriculture: fertilizers; industry: chemical storage and spills) (Liggett and Talwar 2009). Vulnerability assessments are also powerful educational tools for raising public awareness of groundwater protection issues, which is an ongoing need (Nowlan, 2005). The intensive utilization of aquifers has changed the groundwater chemical quality.

According to Foster et al. (2002), contamination of groundwater occurs when the load of contaminants on the ground or leachates generated by urban, industrial, agricultural, or mining activities is not adequately controlled, and certain components exceed the natural attenuation capacity of subsoil and cover layers. The study of these changes requires the design of monitoring networks. One of the most successful tools for further investigation, protection, and monitoring system has been the use of vulnerability maps

Intrinsic vulnerability can be defined as the ease with which a contaminant introduced into the ground surface can reach and diffuse in groundwater (Vrba and Zoporozec, 1994). Specific vulnerability is used to define the vulnerability of groundwater to particular contaminants (Gogu and Dassargues, 2000). At present, groundwater-specific vulnerability is regarded as more meaningful than intrinsic vulnerability, because some affecting factors of intrinsic vulnerability, such as groundwater depth, net recharge, soil media, have been changed due to increasing effect of human activities.

Geology of the Imo River Basin

The Imo River Basin lies between Latitudes 4° 38'N and 6° 01'N and between Longitudes 6° 53'E and 7° 32'E and covers an area of about 9100 km^2 as shown in the topographic and location maps of the study area below Figures . There are two main sub- basins within the basin: The Oramirukwa—Otamiri sub- basin and the Aba River sub-basin (Uma, 1989).

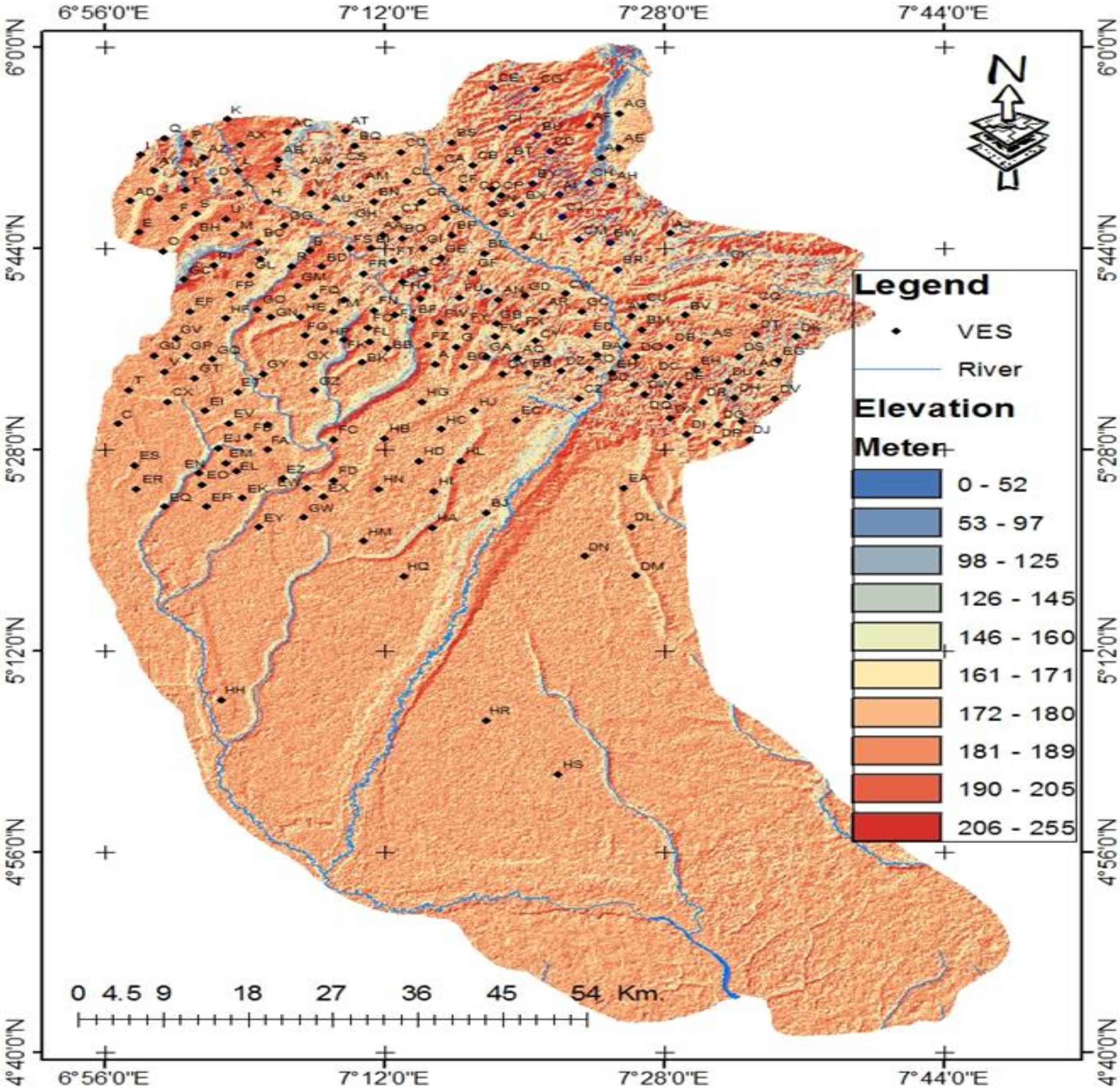

Figure 1. Digital Elevation map of the study area showing VES sounding points

The Imo River Basin is based on bedrock of a sequence of sedimentary rocks of about 5480 m thick and with ages ranging from Upper Cretaceous to Recent (Uma, 1986). The deposition of these sedimentary rocks is related to the opening of the South Atlantic Ocean and the formation of the rift-like Benue Trough of Nigeria in the Mesozoic (Schlumberger, 1985).

Generally, there are two different classes of formations underlying the Imo River Basin. About 80% of the basin consists in Coastal Plain Sand, which is composed of non-indurated sediments represented by the Benin and Ogwashi-Asaba Formations, and alluvial deposits at the estuary at the Southern end of the Imo River Basin. The remaining 20% is underlain by a series of sedimentary rock units that get younger southwestward, a direction that is parallel to the regional dip of the formations as shown in both table 1 and figure 2 below.

MATERIALS AND METHODS

In order to assess the aquifer vulnerability to pollution in Imo River Basin, two models were used: GOD and DRASTIC. The information about the layers for each model was provided via geographic information system (GIS). ArcGIS 10 software was used to create an interactive geodatabase, compile the geospatial data, compute the GOD and DRASTIC indexes, and to generate the final vulnerability maps.

DRASTIC method

DRASTIC has been applied to a number of groundwater basins. The name stands for depth to groundwater, recharge rate, aquifer media, soil media, topography, impact of vadose zone media, and hydraulic conductivity of the aquifer (Aller et al., 1987). Each parameter is subdivided into ranges with different ratings assigned in a scale of 1–10. A higher DRASTIC index shows greater groundwater pollution vulnerability (Aller et al., 1987). Weight multipliers are then used for each factor to balance and enhance its importance.

The final vertical vulnerability using the DRASTIC index is computed as the weighted sum overlay of the seven layers. DRASTIC vulnerability score at each point of the map is obtained via computing the score from the seven parameters valid at that location of the map. A GIS system makes this task extremely simple. DRASTIC index does not account directly for contaminating activities or groundwater contamination already present in the area of interest. It also does not account for the travel time within the aquifer. The DRASTIC index is finally computed by implying linear combinations of the products of rating and weights for each factor as follows (Aller et al., 1987):

$$\text{DRASTIC Index: } Di= D_R{*}D_W + R_R{*}R_W + A_R{*}A_W + S_R{*}S_W + T_R{*}T_W + I_R{*}I_W + C_R{*}C_W \qquad (1)$$

Where, R = Rating W = Weight
Where,
D_j = DRASTIC Index for a mapping unit , W_j = Weight factor for parameter j and R_j = Rating for parameter j

The subscripts R and W represent the rating and weighting respectively. The following parameters such as Depth to water level (D), soil media (S), aquifer media (A), and Impact to vadose zone (I) were estimated in this study using information extracted from the acquired pumping test data, well logs and VES data from the study area. On the other hand, the hydraulic conductivity of the various layers above the aquifer, used in calculating the DRASTIC Index, was estimated from pump test..The recharge of the aquifer is defined as the capacity of water to flow from the surficial unsaturated zones to the saturated zones of the aquifers. It depends mainly on the following factors which include net recharge (R), topography (T), impact of the vadose zone (I) and hydraulic conductivity. Net recharge (R) represents the amount of water that penetrates the ground surface and percolates down to the water table per unit area and as a rule of thumb is taken as 12% of the average annual rainfall per year (USEPA, 1985; Engel et al., 1996; Navulur and Engel, 1996). In the study area, since the average annual rainfall is 2200mm year, 12% of it was calculated and converted to inches and used to rate the aquifer based on the method adopted by Engel et al. (1996). The topography (T) which refers to the slope or steepness of the land surface generally dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone or not. Since the area was found to be relatively flat with the slope ranging from 0 to 3%, therefore, flat areas were assigned higher rates because the run off tends to be less. The influence of the vadose zone on intrinsic aquifer vulnerability depends on its porosity, on permeability and on the attenuation characteristics of the media.

Table 1. DRASTIC index ranges for qualitative risk categories (Aller, 1987, modified Piscopo, 2001)

	DRASTIC Qualitative Category			
	LOW	MODERATE	HIGH	VERY HIGH
DRASTIC INDEX (DI)	1 – 100	101 – 140	141 – 200	>200

In this study, each parameters of the DRASTIC model has been expressed as a thematic layer using ArcGIS 10 software in raster format. The Geostatistical Analyst extension with Kriging interpolation algorithm in ArcGIS was used to interpolate the points and create the raster map. Kriging has shown great success for interpolation in groundwater studies (Kumar, 2007; Gundogdu and Guney, 2007). Some information such as geological cross sections and drilled well logs data, soil texture, soil permeability, and rainfall were obtained from Yazd regional water authority. All produced layers were used to assess intrinsic groundwater vulnerability to pollution.

Table 2: Drastic rating and weighting values for the various hydrogeological settings in the study

VES	Latitude	Longitude		D		R		A		S		T		I		C		DI	Vulnerability
No.	(^{0}N)	(^{0}E)	Aq Depth	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		
AJ 01	N5 59.001	E7 27.314	89.3	1	5	7	4	5	3	10	2	2	1	5	5	2	3	101	Moderate
AJ 02	N5 54.960	E7 26.255	115	1	5	7	4	5	3	10	2	2	1	5	5	2	3	101	Moderate
AJ 03	N5 56.612	E7 18.470	142	1	5	7	4	5	3	10	2	2	1	5	5	2	3	101	Moderate
AJ 04	N5 51.484	E7 24.085	174	1	5	7	4	5	3	10	2	2	1	5	5	2	3	101	Moderate
AJ 05	N5 55.854	E7 25.554	89.2	1	5	7	4	5	3	10	2	2	1	5	5	2	3	101	Moderate
AM 40	N5 46.824	E7 04.089	184	1	5	8	4	8	3	8	2	10	1	8	5	4	3	139	Moderate
AM 41	N5 46.253	E7 03.054	83.5	1	5	8	4	8	3	8	2	10	1	8	5	4	3	139	Moderate
AM 42	N5 49.993	E7 01.385	187	1	5	8	4	8	3	8	2	10	1	8	5	4	3	139	Moderate
AM 43	N5 59.4	E6 59.293	153	1	5	8	4	8	3	8	2	10	1	8	5	4	3	139	Moderate
AM 44	N5 39.564	E6 59.051	175	1	5	8	4	8	3	8	2	10	1	8	5	4	3	139	Moderate
BN 195	N5 28.114	E7 20.087	137	1	5	9	4	9	3	8	2	9	1	9	5	8	3	162	High
BN 196	N5 28.995	E7 21.00	35.2	4	5	9	4	9	3	8	2	9	1	9	5	8	3	177	High
BN 197	N5 30.089	E7 20.988	51.2	1	5	9	4	9	3	8	2	9	1	9	5	8	3	162	High
BN 198	N5 44.784	E7 11.187	60.7	1	5	9	4	9	3	8	2	9	1	9	5	8	3	162	High
BN 199	N5 44.736	E7 10.911	80.3	1	5	9	4	9	3	8	2	9	1	9	5	8	3	162	High
IS 501	N5 41.153	E7 14.568	91	1	5	8	4	1	3	4	2	10	1	3	5	1	3	76	Low
IS 502	N5 42.156	E7 14.478	44.5	3	5	8	4	1	3	4	2	10	1	3	5	1	3	86	Low
IS 503	N5 44.111	E7 13.172	91.2	1	5	8	4	1	3	4	2	10	1	3	5	1	3	76	Low
IS 504	N5 42.445	E7 13.045	42.7	2	5	8	4	1	3	4	2	10	1	3	5	1	3	81	Low
IS 505	N5 43.934	E7 11.313	80.6	1	5	8	4	1	3	4	2	10	1	3	5	1	3	76	Low
NS 517	N5 43.084	E7 32.425	93.4	1	5	8	4	5	3	5	2	1	1	2	5	2	3	79	Low
NS 518	N5 46.207	E7 28.332	77.1	1	5	8	4	5	3	5	2	1	1	2	5	4	3	85	Low
NS 519	N5 54.925	E7 26.010	118	1	5	8	4	5	3	5	2	1	1	2	5	4	3	85	Low
NS 520	N5 28.721	E7 28.165	164	1	5	8	4	5	3	5	2	1	1	2	5	4	3	85	Low
NS 521	N5 45.693	E7 28.011	291	1	5	8	4	5	3	5	2	1	1	2	5	4	3	85	Low
OG 544	N5 41.441	E7 13.051	143	1	5	9	4	3	3	4	2	4	1	2	5	2	3	78	Low
OG 545	N5 42.929	E7 09.6093	44.8	2	5	9	4	3	3	4	2	4	1	4	5	2	3	93	Low
OG 546	N5 42.584	E7 11.256	60.1	1	5	9	4	3	3	4	2	4	1	4	5	2	3	88	Low
OG 547	N5 41.056	E7 14.577	74.3	1	5	9	4	3	3	4	2	4	1	4	5	2	3	88	Low
OG 548	N5 43.752	E7 10.649	152	1	5	9	4	3	3	4	2	4	1	4	5	2	3	88	Low

GOD Method

GOD is a vulnerability assessment method developed in Great Britain. Like DRASTIC, GOD is an overlay and index method designed to map groundwater vulnerability over large regions based on three parameters:(i) G, groundwater confinement, (ii) O is the overlying strata, and (iii) D, depth to groundwater. The lowest level for aquifer pollution vulnerability is attributed to values 0.1 (negligible), while the highest level is ascribed to values [0.7 (extreme). Scores are assigned to each of the three categories and then multiplied to yield a final score. The GOD index can be divided into five categories: negligible (0–0.1), low (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), and very high (0.7–1) (Foster et al. 2002). The higher number shows the greater relative pollution potential risk to another one. The groundwater confinement, overlying strata, type of soil, and depth to groundwater maps were created as described for DRASTIC model, but these maps were rated from 0 to 1 based on Table 3.

Table 3: GOD parameter rating method (After Foster, 1987)

0-0.1	0.2 -0.3	0.4-0-5	0.6-0.7	0.8- 1.0
Negligible	Low	Moderate	High	Extreme

Table 4: Vulnerability index assessment usig GOD

VES	Latitude	Longitude	Parameter			Rating			Total	Vulnerability
No.	(^{0}N)	(^{0}E)	G	O	D	G	O	D	Score	
AJ 01	N5 59.001	E7 27.314	SCF	SST	89.3	0.3	0.7	0.5	0.105	Low
AJ 02	N5 54.960	E7 26.255	SCF	SST	115	0.4	0.7	0.4	0.112	Low
AJ 03	N5 56.612	E7 18.470	SCF	SST	142	0.4	0.7	0.4	0.112	Low
AJ 04	N5 51.484	E7 24.085	SCF	SST	174	0.4	0.7	0.4	0.112	Low
AJ 05	N5 55.854	E7 25.554	SCF	SST	89.2	0.3	0.7	0.5	0.105	Low
AM 40	N5 46.824	E7 04.089	SCF	SD	184	0.4	0.7	0.4	0.112	Low
AM 41	N5 46.253	E7 03.054	SCF	SD	83.5	0.4	0.7	0.5	0.14	Low
AM 42	N5 49.993	E7 01.385	SCF	SD	187	0.4	0.7	0.4	0.112	Low
AM 43	N5 59.4	E6 59.293	SCF	SD	153	0.4	0.7	0.4	0.112	Low
AM 44	N5 39.564	E6 59.051	SCF	SD	175	0.4	0.7	0.4	0.112	Low
BN 195	N5 28.114	E7 20.087	UCF	SD/SST	137	0.6	0.7	0.4	0.168	Low
BN 196	N5 28.995	E7 21.00	UCF	SD/SST	35.2	0.9	0.8	0.7	0.504	High
BN 197	N5 30.089	E7 20.988	UCF	SD/SST	51.2	0.9	0.8	0.7	0.504	High
BN 198	N5 44.784	E7 11.187	UCF	SD/SST	60.7	0.9	0.8	0.7	0.504	High
BN 199	N5 44.736	E7 10.911	UCF	SD/SST	80.3	0.9	0.8	0.7	0.504	High
IS 501	N5 41.153	E7 14.568	CF	SH	91	0.9	0.8	0.7	0.504	High
IS 502	N5 42.156	E7 14.478	CF	SH	44.5	0.5	0.5	0.6	0.15	Low
IS 503	N5 44.111	E7 13.172	CF	SH	91.2	0.5	0.5	0.5	0.125	Low
IS 504	N5 42.445	E7 13.045	CF	SH	42.7	0.5	0.5	0.6	0.15	Low
IS 505	N5 43.934	E7 11.313	CF	SH	80.6	0.5	0.5	0.5	0.125	Low
NS 517	N5 43.084	E7 32.425	CF	SST/SH	93.4	0.5	0.5	0.5	0.125	Low
NS 518	N5 46.207	E7 28.332	CF	SST/SH	77.1	0.5	0.5	0.5	0.125	Low
NS 519	N5 54.925	E7 26.010	CF	SST/SH	118	0.5	0.5	0.4	0.1	Low
NS 520	N5 28.721	E7 28.165	CF	SST/SH	164	0.5	0.5	0.4	0.1	Low
NS 521	N5 45.693	E7 28.011	CF	SST/SH	291	0.5	0.5	0.4	0.1	Low
OG 544	N5 41.441	E7 13.051	CF	CL/SD	143	0.5	0.5	0.4	0.1	Low
OG 545	N5 42.929	E7 09.6093	CF	CL/SD	44.8	0.5	0.5	0.6	0.15	Low
OG 546	N5 42.584	E7 11.256	CF	CL/SD	60.1	0.5	0.5	0.5	0.125	Low
OG 547	N5 41.056	E7 14.577	CF	CL/SD	74.3	0.5	0.5	0.5	0.125	Low
OG 548	N5 43.752	E7 10.649	CF	CL/SD	152	0.5	0.5	0.4	0.1	Low

DISCUSSION

The result of the aquifer vulnerability assessment using DRASTIC and GOD model revealed that the area is generally highly vulnerable to groundwater contamination with the depth to water table and vadose zone having the highest impact on the intrinsic vulnerability of the aquifer systems in the area. Intrinsic aquifer vulnerability study using the DRASTIC technique revealed that the DRASTIC Index ranged between high, low and moderate vulnerability. The DRASTIC Index estimated within the study area ranged from a minimum value of 76 to a maximum value of 156 with a mean value of 116. A large portion of the study area estimated at 53.6% was classified as high vulnerability areas while about 34.5% of the study area was identified as moderate aquifer vulnerability areas and 11.9% was classified as low aquifer vulnerability using the DRASTIC Index. These results estimated from DRASTIC Index are in agreement with similar results from other parts of the Imo River Basin (Ugada et al., 2013; Eke et al. 2015). Eke et al. (2015) estimated a DRASTIC Index of 85–99 (low vulnerability), 102–140 (moderate vulnerability) and DI values > 140 (high vulnerability).Similarly, the aquifer vulnerability estimated using GOD revealed a range of 0.125 to 0.504 with a mean of 0.315. In addition, results using DRASTIC Index and GOD worldwide have been previously established by several authors (Babiker et al., 2005; Atiqur, 2008; Lathamani et al., 2015; Jang et al., 2017; Mondal et al., 2017; Oni and Akinlatu, 2017; Falowo et al., 2017; Aweto and Ohwoghere-Asuma, 2018; Oroji, 2018).

Most parts of the study area (80%) are within this class of extreme high vulnerability. This indicates that it will take surficial effluents or any other liquid waste in the study area some months to get into the groundwater; this is really worrisome in view of the huge and active sources of pollution like e-wastes, auto-mobile and motor scrap workshops, unprotected shallow municipal dumpsites and the general poor waste management in the study area (Ejiogu et al., 2017).

The high aquifer vulnerability of the study area especially within the Benin Formation (which is prone to leachate infiltration into the groundwater) has been previously established by Akankpo and Igbokwe (2011).

CONCLUSION

The purpose of this research was to assess the vulnerability potential of the Imo River Basin aquifer using the DRASTIC and GOD indexes. We also tested the performance of DRASTIC and GOD models for the evaluation of groundwater contamination. Results of this study in line with the geology of Imo River Basin revealed that DRASTIC and GOD models are suitable for evaluation of groundwater contamination in the study area. The vulnerability analysis for DRASTIC model reveals a mean index of 101 and 139 which indicate moderate vulnerability in Ajali and Ameki Formations ,162 in Benin Formation which indicate high vulnerability,76,85 and 77 in Imo Formation ,Nsukka Formation and Ogwasi/Asaba Formation respectively which indicate a correspondence low vulnerability. Analysis from GOD also reveals a mean index of 0.105,0.112 in Ajali and Ameki Formations which indicate low vulnerability,0.504 in Benin Formation which indicate high vulnerability,0.15,0125 and 0.1in Imo Shale, Nsukka and Ogwasi/Asaba Formations which low vulnerability respectively. The information layers for models were provided via geographic information system and techniques were used to provide and produce the vulnerability maps of the study area considering weight coefficients of each layer.

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