Groundwater vulnerability to pollution assessment using two different models in Halabja Saidsadiq Basin, Iraq.

Twana O. Abdullah¹, Salahalddin S. Ali², Nadhir A. Al-Ansari³, Sven Knutsson⁴

¹ Department of Geology, University of Sulaimani, Kurdistan Region, NE. Iraq and Department of Civil, Environmental and Natural Resources and Engineering, Division of Mining and Geotechnical Engineering, Lulea University of Technology, Sweden. Twana.abdullah@ltu.se
² President of University of Sulaimani, Kurdistan Region, NE. Iraq. salahalddin.ali@univsul.edu.iq
³ & ⁴ Department of Civil, Environmental and Natural Resources and Engineering, Division of Mining and Geotechnical Engineering, Lulea University of Technology, Sweden, Nadhir.alansari@ltu.se, Sven.Knutsson@ltu.se

INTRODUCTION

Halabja and Saidsadiq Basin (HSB) considered to be one of the most important basins in Kurdistan Region, NE of Iraq, in terms of groundwater aquifers. The concentration of economic, agricultural and social activities within the basin makes it of prime significance to the region. Exhaustive agricultural activities are extensive and located close to groundwater wells, which pose...
imminent threats to these resources. Moreover, the authoritative structure of Halabja has been changed from a district to governorate in March 2014; this will improve the start of more economic improvement and progression. In perspective of these progressions, there is an expansion of the quantities of human making a beeline for live in this basin and its surrounding areas. This is forcing a developing interest in water which has set significant weights on water resources. Therefore, groundwater contamination is of particular concern as groundwater resources are the principal source of water for drinking, agriculture, irrigation and industrial activities.

Groundwater vulnerability is evaluating the ability of pollutant to transport from the earth surface to reach a productive aquifer. The vulnerability studies can supply precious information about stakeholder working on preventing further deterioration of the environment (Mendoza & Barmen, 2006). To simplify the identification of the groundwater condition and to resist the pollutants in the reservoirs, several methods were recommended such as DRASTIC, VLDA, COP, GOD, SINTACS, etc. These different methods are offered under the form of numerical excerpt systems based on the negotiation of the different factors affecting the hydrogeological system (Attoui and Bousnoubra, 2012).

Different vulnerability models were applied previously for the studied area; while it is very important to confirm the computed vulnerability model is reflecting the real vulnerability system for the area. So the main objective of the current study is to compare the achieved vulnerability map from two different models namely VLDA and COP, in order to select more sensible model to be applied for the area.

STUDY AREA

The study basin is located in the northeastern part of Iraq, geographically it is located between the latitude 35° 00 00" and 35° 36’ 00” N and the longitude 45° 36’ 00" and 46° 12’ 00” E (Figure 1). The entire study area is about 1278 square kilometers and its population of early 2015 of about 190,727. This basin divided into two sub-basins by (Ali, 2007) including Halabja- Khurmal and Said Sadiq sub-basins. Approximately 57% of the studied area is an arable area due to its suitability for agriculture (Statistical Dectorate, 2014).

GEOLGY AND HYDROGEOLOGICAL SETTING

Different geological formations were exposed to the basin, these formations consists of limestone, dolomitic limestone and conglomerate which have an effective role in the vulnerability system in the basin. Alluvial (Quaternary) deposits are the most important unit in the area in terms of hydrogeological characteristics and water supply. The thickness of these deposits as observed by (Abdullah et al, 2015 a) of about nearly 300 m.

Hydrogeologically, different groundwater aquifers exist in the area based on its geological origin, table (1). The mountain series, which surround the basin of the northeast and southeast, are characterized by high depth of groundwater, while toward the center and the southeastern part, the groundwater level has a relatively lower depth. A groundwater movement is usually from high elevated areas at the north, northeast, south and southeast towards southwest or generally toward the reservoir of Derbandikhan Dam.

Table 1. Result of index ratio for all applied models.
Aquifer type | Geological formation | Thickness (m) |
--- | --- | --- |
Intergranular | Alluvials | >300 |
Fissured | Balambo, Kometan | 250 |
Fissured-Karstic | Avroman, Jurassic fn. | ~200 |
Aquiferdard | Tanjero | ~2000 |

**METHODOLOGY**

Two different models have been applied with the aid of GIS technique in order to map groundwater vulnerability in the study area. The first applied model is VLDA, predominantly it reflects lithology of vadose zone (V), pattern of land use (L), groundwater depth (D), and aquifer characteristics (A), (Zhou et al, 2012). In addition, reliable weight can be assigned to each of the four indexes depending on its impact on groundwater vulnerability.

The vulnerability comprehensive assessment index (DI) is the sum of the above-mentioned weighted four indexes, as computed conforming to the following formula:

\[
DI = \sum_{j=1}^{4} (WijRij) \quad (1) \quad (Zhou \ et \ al, \ 2012)
\]

Where DI is the comprehensive assessment index, Wij is the weight of the jth comprehensive assessment index of the ith subsystem, Rij is the value of the jth assessment index of the ith subsystem; 4 is the quantity of indexes.

The lower the DI signifier to the lower vulnerability of the groundwater system and the superior the stability will be. To assess the groundwater vulnerability, the new corresponding weights in HSB were proposed using sensitivity analysis method (Abdullah 2015 b). Based on the result of sensitivity analysis, the proposed weights used for VLDA model measured as 8.2, 4.8, 5.2 and 4.8, and after normalization, the weight is 0.357, 0.209, 0.226 and 0.209, respectively, (Abdullah 2016 a).

The second applied model is COP; its contraction comes from the three initials of parameters namely flow Concentration (C), Overly layers (O) and Precipitation (P), (Vias et al, 2006). The hypothetical basis of this strategy, as indicated by the European Approach (Daly et al, 2002) and (Goldscneider and Popescu, 2004), it is to evaluate the ordinary protection for groundwater (O variable) controlled by the properties of overly soils and the unsaturated zone, and also to measure how this assurance can be adjusted by diffuse, infiltration (C factor) and the climatic conditions (P Factor – precipitation). The COP-Index map was computed from equation 2, (Abdullah et al., 2016 b):

\[
COP \ \text{Index Map} = C*O*P \quad \cdots \cdots \cdots \ \text{(2)} \quad (Vias \ et \ al, 2006)
\]

**RESULTS AND DISCUSSION**

Subsequent to the weighted scores were achieved for all parameters in each model, the GIS technique was used to combine all layers. The vulnerability result based on VLDA model, illustrates that a total of four ranges of vulnerability indexes had been distinguished ranging from low on very high, with vulnerability indexes (2.133 - 4, >4 - 6, >6 - 8 and > 8), figure (2). The area of low and very high vulnerability zones to occupy 2% and 1% of the whole study area respectively. The High vulnerability classes covered most of the mountains area that surrounding the area and the central part of HSB. This vulnerability zone covered an area of 53% of whole area. Furthermore, medium vulnerability zones to cover an area of 44% of all studied area and positioned southeast and northwest. Both high and moderate classes that occupied most of the studied basins refer to the exhaustive human activities, good water yield property and lithological composition of existed aquifers.
Four categories of vulnerability ranging from very low to high be achieved according to the COP model, figure (3). High vulnerability areas covering an area of 60% of the entire HSB, geologically includes the fissure zone and minor carbonate karstic rocks. While the low vulnerability class comes in second place and occupies 37% of the entire region, this region is predominantly characterized by alluvial sediments. The area with moderate and very low vulnerable groups covers only 2% and 1% of the total area, respectively.

VALIDATION OF THE RESULT

Validation of vulnerability maps for these two models became mandatory because of considerable variation in vulnerability classes illustrated with all applied models. Therefore nitrate concentration analysis as a pollution indicator has been selected. In the exacting study case, the nitrate differences between two following seasons (dry and wet) were analyzed from (30) watering wells. The result exemplifies considerable variations in nitrate concentration on dry to wet seasons, figure (4). Based on this verification, it can be confirmed that aquifers in the HSB are able to receive contaminants because of its suitability in geological and hydrogeological conditions. On the basis of this verification, the degree and distribution of the acquired vulnerability using a VLDA model is more logical than that of the COP model. With increased concentration of nitrates the levels of vulnerability also increased, because the land use patterns are considered to be one of the most effective factors of VLDA model and this parameter dose not included in the COP model.
CONCLUSION

Two different approaches have been applied to assess the potential groundwater vulnerability of HSB namely VLDA and COP models. The value of the VLDA indexes ranged from (2.133-9.16), and the value of the COP indexes ranged between (0.79-6.2). The high index value of the VLDA models means a higher category of vulnerability, while the value of the lower indicator of the COP model means a higher degree of vulnerability.

The vulnerability classes are clarified in the table (2), all models to clarify four vulnerability classes. COP model comprises (very low to high), while VLDA model embraces (low to very high) vulnerability classes. The noteworthy variation has been observed from all applied models, therefore the results required to be validated. Nitrate as a pollution indicator from agricultural processes can be supportive to distinguish the evolution and changes of groundwater quality. The result illustrates significant variations in nitrate concentration on dry to wet seasons. So it can be confirmed that groundwater in HSB is capable of receiving the pollutant. Based on this confirmation, figure (4) reveals that the degree and distribution of level of vulnerability obtained using the VLDA method is more sensible than that achieved from COP method.

Table 2. Type of aquifers in the study basin.

| Vulnerability class | VLDA rate % | COP rate % |
|---------------------|-------------|------------|
| Very low            | 0           | 1          |
| Low                 | 2           | 37         |
| Medium              | 44          | 2          |
| High                | 53          | 60         |
| V. High             | 1           | 0          |

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