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RESEARCH PAPER

A Gis-based drastic model for assessing groundwater vulnerability in the coastal plain of Collo, Northeastern Algeria

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Abstract

A DRASTIC-model method based on a geographic information system (GIS) was used to study groundwater vulnerability in coastal plain of Collo in North east Algeria. The aquifer is the main source of water supply in the area and is showing signs of contamination due to the existence of pollution sources. The main objective of this paper is to find out the groundwater vulnerable zones. DRASTIC model is based on the seven data layers that provide the input to the modeling. It corresponds to the initials of seven layers i.e. Depth of water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. The results show that the central and northern part of the study area is classified as a high and very highly vulnerable zone which recorded higher nitrate values. The southern and western part of study area is classifed as a medium and low vulnerable zone. The study suggests that this model can be an effective tool for local authorities who are responsible for managing groundwater resources.

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Introduction

In Algeria, the average drinking water consumption per individual will reach 185 liters/day by 2025, against 170 liters currently, and 90 liters in the year 1990 (MRE, 1996). The growth of the demand for water is multiplied by four in 40 years, in particular in the north of the country. That is to say: 13% of the national surface, where six Algerians out of ten live in more than 550 urban centers. This situation has made the durable access to water resources a major concern; especially with the climate change, the fall of pluviometer for three decades, and the expected urban and demographic growth which are likely to worsen the hydrous situation of stress. While groundwater water constitutes a significant portion of water resources in Algeria, conservation and protection of these water resources remain of central importance to Algeria.

Groundwater resource protection requires knowledge of groundwater to pollution vulnerability and any vulnerability information is essential to facilitate groundwater planning and management. The concept of ground waters vulnerability to contamination was first introduced by Albinet and Margat in 1970. The term vulnerability would then be defined as an intrinsic property of a groundwater system that depends on the sensitivity of the material in permitting the degradation of the saturated zone by pollutant substances originated from human activities (Hirata, R *et al.* 2002).

Therefore, several methods have been developed to evaluate groundwater vulnerability. The methods can be divided into three main categories: process based-methods, statistical methods, and overlay and index methods (Vrba and Zaporozec, 1994; Tesoriero *et al.*, 1998; Gogu and Dassargues, 2000; Goldscheider, 2002; Zwahlen, 2003). Choosing an appropriate method will depend on many factors such as the scale of the study area, data availability, and desired results (Al-Hanbali *et al.*, 2006).

The DRASTIC model is one of the most reliable models of aquifer vulnerability assessment developed by the United States Environmental Protection Agency (USEPA 1985) for demarcating the vulnerable zone by overlaying different types of semi-quantitative geospatial layers (Aller *et al.*, 1987). One of main drawbacks of DRASTIC is its subjectivity in rating and weighting the model parameters. Doubts have been expressed in the selection of proportionate rates and weights with regard to the local hydrogeological setting of each area (Panagopoulos *et al.*, 2006). This model has been widely used in many countries because the inputs required for its application are generally available or easy to obtain.

The Collo aquifer, which is located in the noth east of Algeria provides a source of water for domestic, industrial and agricultural use. High nitrate levels exceeding the 13 mg/l concentration (the human affected value) (Babiker *et al.*, 2004) have been encountered in groundwater of the Collo aquifer (Chabour, 2004; Boulabeiz, 2006). While some concentrations have already exceeded the maximum acceptance level (44mg/l). The dominant source of the nitrate contamination has been identified as agricultural land use with some possibility of urban sources.

The aim of this research is to assess the groundwater vulnerability to pollution in the coastal plain of Collo systematically threatened by the urban development and the polluting activities which are associated there, and developing management options to help the establishment of protection zones of groundwater. A study of groundwater vulnerability to pollution of the aquifer has been performed by applying the DRASTIC parametric method in GIS environment allowing the acquisition, storage, analysis and display of geographic data.

It is based on seven parameters to be determined as input for computing the DRASTIC index number, which reflects the pollution potential for the aquifer (Aller *et al.*, 1987). The verification of the validity of the vulnerability's card obtained is based on the measurement data of nitrates in the water was carried out in this study.

Materials and methods

Study area

The Collo basin is located 2 km SE of the city of Collo, Skikda (Fig. 1). The study area consists of an alluvial fill that extends over an area of 9 square kilometres. Having a more or less triangular form, the area of interest is bounded on the east and west by a hills set. Further north, the Collo plain is bordered by the Mediterranean Sea (Bay of Collo) over a length of 6 Km. The climate of the region is typically Mediterranean. The average annual rainfall varies between 760 and 1000 mm and the average annual temperature is about 18°C (ANRH, 1970–2014). Surface drainage is provided mainly by the Guebli Wadi which crosses the plain from south towards north.

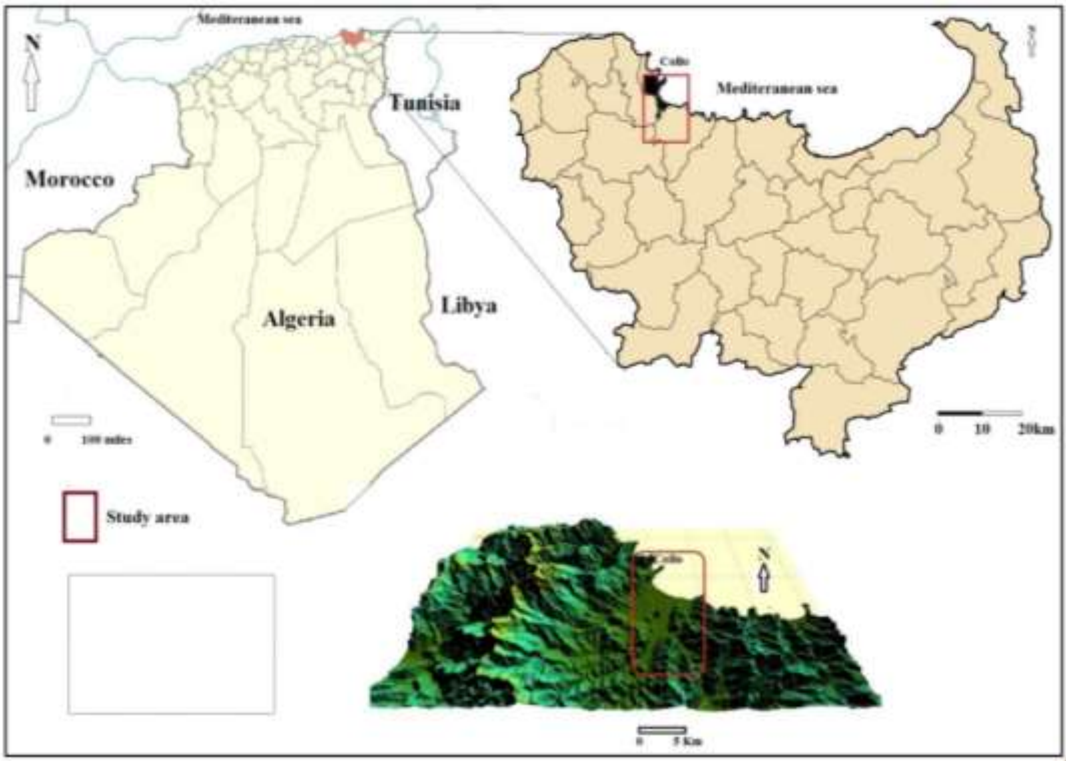

Fig. 1. Location map of the study area.

Due to intensive tectonic activities, the geology of the Collo region is very complex. Yet, the geological frame of the basin is relatively simple as shown in (Fig. 2).

The basin is mainly underlain by an alluvial deposit surrounded on the west and east by igneous and metamorphic rocks, respectively. Quaternary deposits cover almost the entire plain and are mostly represented by alluvial fills. . It includes different types of sediments that were deposited on a predominately shallow platform and range in age from Miocene to quaternary (Table. 1).

Available data (CGG, 1965; Minmeliovodkhoz, 1965) indicate that the reservoir depth increases considerably from about 5 to 10m to the south, and more than 30 m to the east of the plain. This group of sediments consists of silty and sandy materials. The northern portion of the aquifer is mostly 15 to 20m deep with respect to mean sea level is hydro geologically the most important. This zone is essentially made up of gravel and pebbles, coarse sands, and fine sands from the bottom up. The impermeable substratum of the aquifer consists of the marlous formation of Mio-Pliocene age.

Table 1. succession of geological horizons of the study area.

Age	Lithology
Quaternary	Alluvialdeposits:silt, sand andgravel
Pliocene	blue marl, limestonealgae.
Miocene	alternatingsandstoneandmarl

Fig. 2. Geological map of the study area (adapted from Negrousta, 1970).

DRASTIC model overview

The methodology utilised the DRASTIC model in GIS environment to generate intrinsic groundwater vulnerability. The DRASTIC model was developed by the US Environmental Protection Agency (EPA) and was designed to be a standardised system for evaluating the groundwater vulnerability for a variety of land areas (Aller *et al*., 1987). (Aller *et al*., 1987).

The acronym DRASTIC stands for the seven parameters used in the model which are: depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity (Table 2). Each factor or parameter is assigned a subjective rating between 1 and 10 based on functional curves. This rating is then scaled by a weighting factor ranging between 1 and 5, and the weighted ratings are summed to obtain the DRASTIC index. The DRASTIC index has the following form:

$$VI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

Where: D, R, A, S, T, I, C was defined earlier, r rating for the study area being evaluated and w the importance weight for the parameter. The different hydro geologic datasets were arranged in a geo-spatial database using ArcGIS 10.1 for handling the DRASTIC parameters in a GIS environment (Fig. 3). The different data and maps are digitised and projected into UTM Nord Sahara Zone 32N. The seven DRASTIC layers are prepared as raster grids of cell size 25 x 25m.

Table 2. DRASTIC parameters and data sources.

Factor	Description	Relative weight	Data sources	Mode of processing
Depth to water D	Increasing depth to water increases the migration pathway for surface contamination to reach the aquifer, thus reducing vulnerability.	5	monitoring of 30 shallow wells (Nov 2015)	Interpolation
Net recharge R	Higher rates of recharge promote vertical migration through the vadose zone, thus increasing vulnerability	4	Precipitation, Evapotranspiration (ANRH, 2014)	Interpolation
Aquifer media A	Aquifer materials with physical properties that make the aquifer more likely to be permeable result in increased vulnerability	3	Well, logs, geological map (Minmeliovodkhoz, 1968, CGG, 1965)	Interpolation
Soil media S	Soils with higher drainage capacity increase the potential for contaminants to enter the vadose zone, this increasing vulnerability	2	Soil maps (agricultural map of the Collo, 1:10000)	Digitalisation
Topography T	Areas with steeper topographic slope result in more runoff generated, thus reducing vulnerability	1	satellite data SRTM (earthexplorer.usgs.gov)	Interpolation
Impact of vadose zone I	Vadose zone materials with lower permeability may impede infiltration of contaminants, thus reducing vulnerability	5	Analysis of waterlogs and geological maps	Interpolation
Hydraulic Conductivity C	Higher hydraulic conductivity values may allow contaminants to move quickly through the aquifer and spread, thus increasing vulnerability	3	Pumping tests (Belloulou L, 1986)	Interpolation

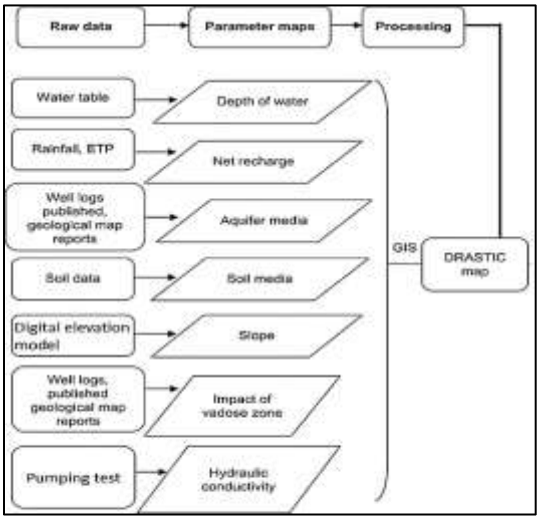

Fig. 3. Flow chart of methodology for validation test of groundwater vulnerability using the DRASTIC model in GIS.

Results and discussion

Drastic Model Parameters

Depth to Groundwater (D)

The water level map of the Collo plain was based on data from the depth of water (static level) recorded in 30 shallow wells evenly distributed over the study area (November 2015). As shown in (Fig. 4), the depth to the groundwater table in the study area is normally less than 6 m decreasing gradually from north to south. This makes the northern part of the Heights more susceptible to contamination according to DRASTIC assumptions. The rating scores ranges between 7 and 9 where the highest scores were assigned to the far northern part of the area (depth to water < 4.5m).

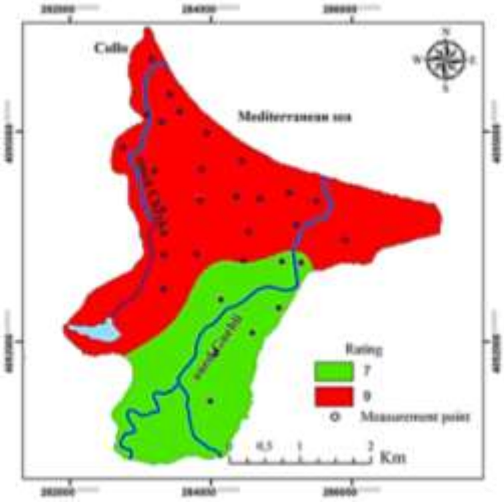

Fig. 4. Depth to water (D) of the study area.

Net recharge (R)

The method used to develop the map of the net recharge of groundwater of Collo aquifer is that of Williams and Kissel (1991). Net recharge, R, is calculated according to this method with the following equations corresponding to different hydrologic soil groups A, B, C and D (Viessmann *et al.*, 1977):

$R = (P - 10.28)2 / (P + 15.43)$ → hydrologic group A.$R = (P - 15.05)2 / (P + 22.57)$ → hydrologic group B.

$R = (P - 19.53)2 / (P + 29.29)$ → hydrologic group C.$R = (P - 22.67)2 / (P + 34.00)$ → hydrologic group D.

The net recharge to the groundwater aquifer is mainly controlled by the type of land use/cover on the surface. Based on this method, the average net recharge value at the plain varies from less than 45,46 mm/year on west to more than 215,9 mm/year to the north of study area which was assigned high rating scores (8). Finally, the obtained net recharge values were used to develop the recharge rating map as shown as (Fig. 5).

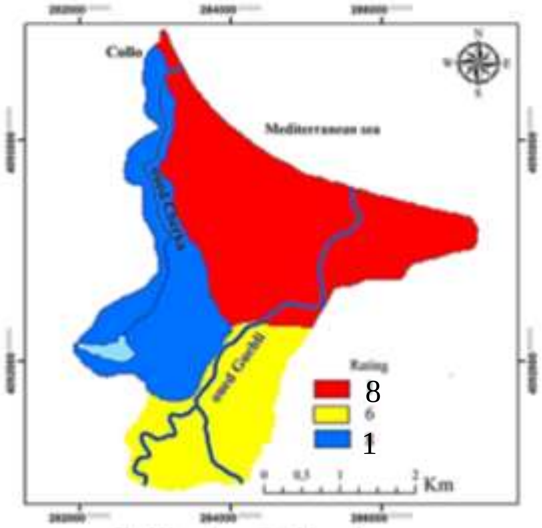

Fig. 5. Net recharge (R) of the study area.

Aquifer media (A)

Aquifer media have been identified from the borehole data and geological section obtained from previous study (CGG, 1965, Minmeliovodkhoz, 1968, Boulabeiz, 2006). The aquifer media was classified as: sand and gravel in the northern part of the study area, sandy on the southern part and sandy loam in the eastern and western part. Indeed, aquifer media ratings vary from 4 to 9, as shown in (Fig. 6).

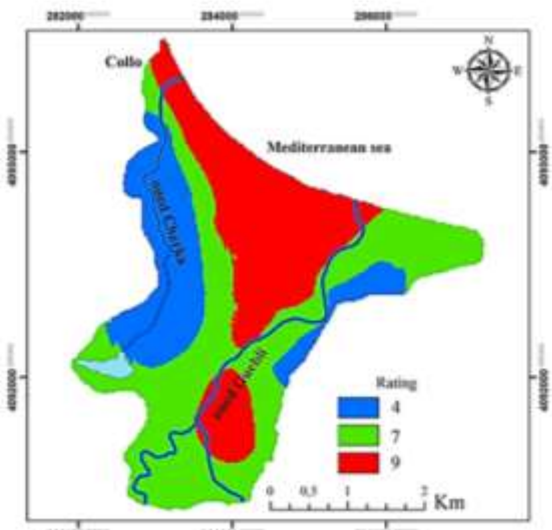

Fig. 6. Aquifer media (A) of the study area.

Soil Media (S)

The soil media parameter was characterised based on the agricultural map of the Collo plain in vector format (1:10000). The soil media parameter map is shown in (Fig. 7). ratings vary from 1 to 9. The highest rate (9) was assigned to mineral soil in the northern part of the study area.

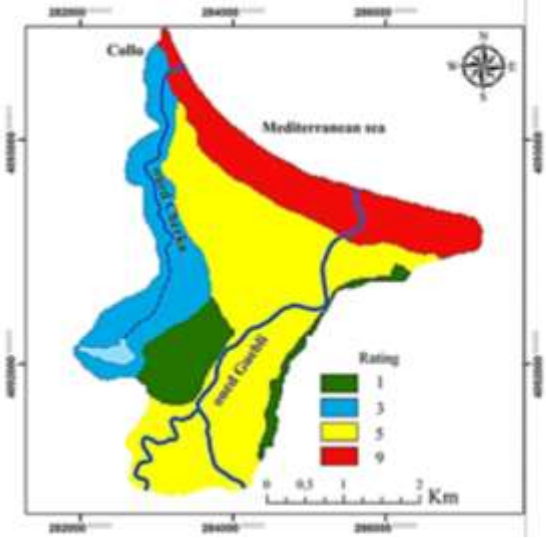

Fig. 7. Aquifer media (S) of the study area.

Topography (T)

Slope was calculated in GIS using the 25m digital elevation model (DEM), and classified according to the original DRASTIC rankings. The resulting topography parameter map is shown in (Fig 8). The topography of the Collo basin is for the most part a flat plain, slope being generally low (0–6%).

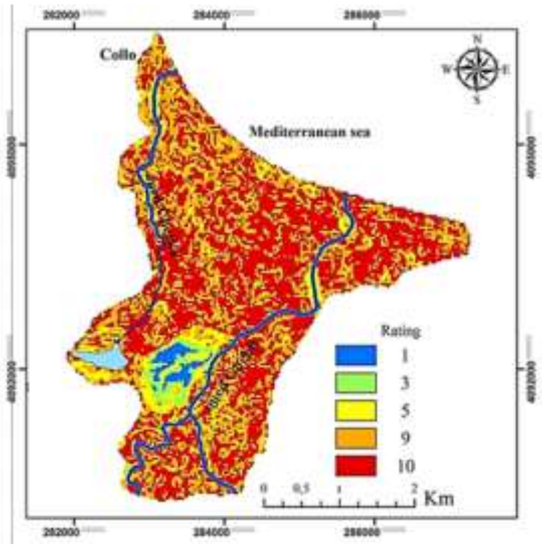

Fig. 8. Topography (T) of the study area.

Impact of the Vadose Zone (I)

The vadose zone materials were characterised based on the surficial geology maps (Minmeliovodkhoz, 1968) and hydro geological cross section (Boulabeiz M, 2006). In the study area the vadose zone is composed of unconsolidated, fine and coarse-grained size materials. Theratings vary between 3 for confining layers to 8 for sand (Fig. 9).

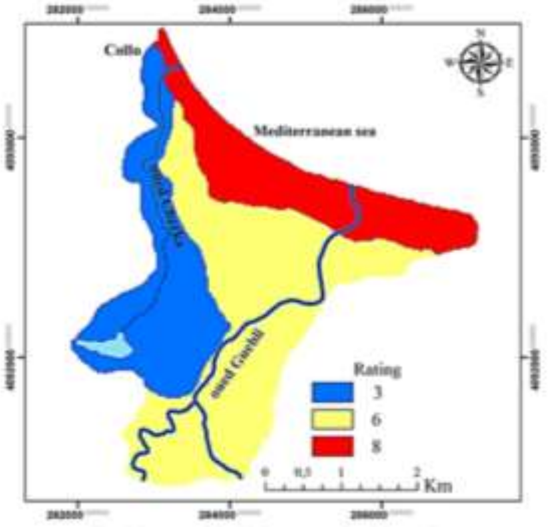

Fig. 9. Impact of the vadose zone (I)of the study area.

Hydraulic Conductivity (C)

The hydraulic conductivity values were calculated from the pumping tests (*Belloulou*, 1986). The highest values of hydraulic conductivity are observed in the northern part of the study area ($>9{,}5.10^{-4}$m/s), therefore, was assigned the maximum rating score of

10. The rest of the aquifer has a relatively lower conductivity hence was assigned low rating values ranging from 2 to 6. as shown in (Fig. 10).

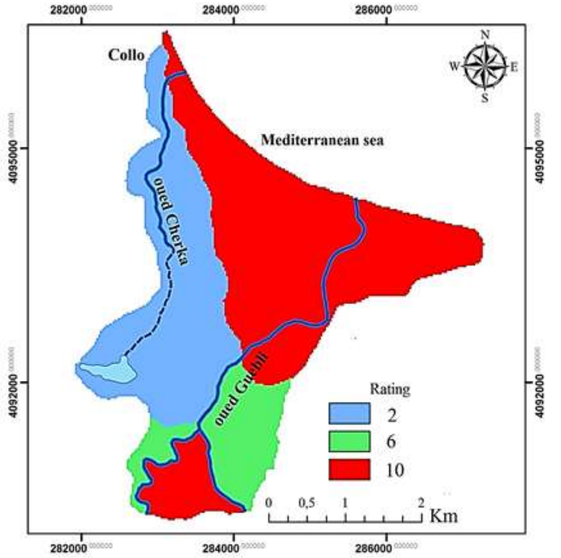

Fig. 10. Hydraulic conductivity (C)of the study area.

Computing DRASTIC Vulnerability Index

The maps for each parameter were weighted and added in GIS environment (Arc Gis 10.1) by using the seven hydro-geological data layers to result in an intrinsic vulnerability.

Map of the shallow subsurface for the study area Areas of higher vulnerability are shown in red with areas of lower vulnerability in green. The DRASTIC scores obtained from the model vary from 84 to 202 as shown in (Fig. 11).

This range has been divided into four equal classes: 84–120 (low vulnerability) Covering 26.48% of the study area, it is located in to the western part of the plain. 121–160(moderate vulnerability):

Covering 30.18% of the study area and located mainly in the south. This is due to the combination of deep water table, less-porous vadose and aquifermedia.161–200 (High vulnerability) Covering 31.2% of the study area and occupying.

The centre and northeast of the plain. 201–202 (Very high vulnerability) in the northern part of the plain covering 11.83% of the study area. Higher vulnerability is the result of generally shallow water tables combined with high recharge rates.

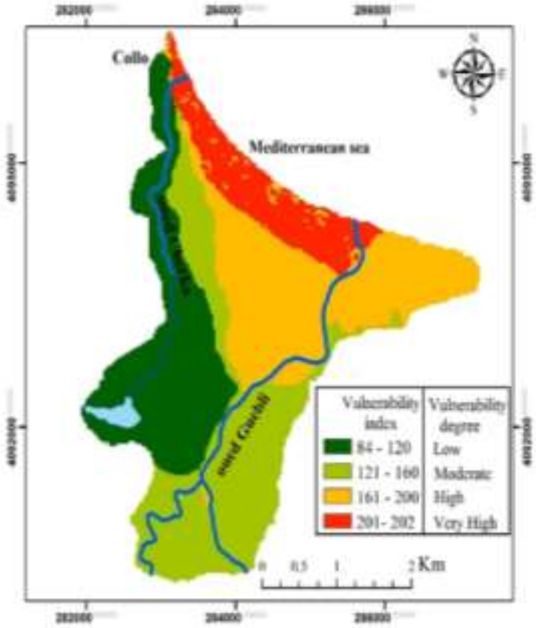

Fig. 11. Groundwater vulnerability maps of the Collo aquifer according to the DRASTIC model.

Validation of Drastic Model

For validation of the vulnerability assessment, 30 groundwater samples were collected (during November 2015) from different vulnerability zones of the study area for estimation of concentration of nitrates.

Then, ArcGIS 10.1 was applied to interpolate the nitrate concentration used to generate the nitrate pollution map. The nitrate concentration map (Fig. 12) shows a gradual increase in concentration of nitrates from south to the north of the study area.

Accordingly, the most polluted areas couldbe observed in the northern part of the study area, where vulnerability classes are « High » and « very high ». However, the lowest values corresponded to the southern and western part of the study area, that had « moderate » and « low » vulnerability.

The analysis indicates that there is a certain degree of similarity between nitrate contamination distributions of shallow groundwater, and groundwater vulnerability map of Collo plain.

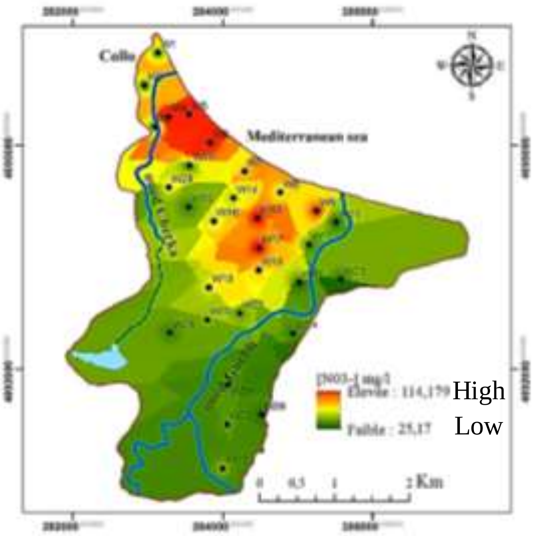

Fig. 12. Spatial distribution nitrate in groundwater of Collo aquifer (Nov 2015).

Conclusion

In order to assess the aquifer vulnerability for contamination potential in Collo aquifer, the combined use of the DRASTIC and geographical information system (GIS) demonstrated as an effective method for groundwater pollution risk assessment. DRASTIC index value was evaluated 84 to 202 for the study area. The areas, which are under the high vulnerable pollution are mainly in the northern and central parts, where the physical factors like depth to the groundwater and hydraulic conductivity are very well supporting the chances of getting shallow aquifer water polluted. The DRASTIC model was tested using nitrate concentration data from the aquifer. High nitrate concentrations coincide with the high pollution risk area. This can confirm the precision of the model. This study is a valuable tool for local authorities for managing groundwater resources, monitoring this problem closely and to act accordingly.

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