GIS based aquifer vulnerability assessment in Hangzhou-Jiaxing-Huzhou plain, China.

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Abstract

Hangzhou-Jiaxing-Huzhou plain is among the regions which faces the shortage of water due to its increasing population, industrialization, agriculture and domestic use; hence there is high dependence on ground water. In China, the exploitation of aquifers has been historically undertaken without proper concern for environmental impacts or even the concept of sustainable yield. In order to maintain basin aquifer as a source of water for the area, it is necessary to find out whether certain locations in this ground water basin are susceptible to receive and transmit pollution, this is why the main objective of this research is to find out the ground water vulnerable zones using Geographical Information System (GIS) model in Hangzhou-Jiaxing-Huzhou plain. GIS was used to create ground water vulnerability map by overlaying hydro-geological data. The input of the model was provided by the following seven data layers: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. This study showed that Hangzhou-Jiaxing-Huzhou area is grouped into three categories: Highvulnerable zone with 27.4% of the total area, moderate vulnerable zone which occupy the greatpart of that area 60.5% and low vulnerable zone with 12.1%. This research suggests first theprioritization of high vulnerable areas in order to prevent further pollution to already pollutedareas; next the frequent monitoring of vulnerable zones to monitor the changing level ofpollutants; and finally suggests that this model can be an effective tool for local authorities whoare responsible for managing ground water resources in that area.

Key words: Hangzhou-Jiaxing-Huzhou plain, Ground water vulnerability, GIS, DRASTIC model, shallow aquifer

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Introduction

Ground water is water located beneath the ground surface in soil pore spaces and in the fractures of lithologic formations (Enger et al, 2006). Other than ocean water (97.2%) and frozen water (2.1%), ground water (0.6%) accounts for a significant volume of the Earth's water (Fetter 1994). Ground water accounts 20.58% of fresh water (Enger et al, 2006) and if only water is considered,94 percent is ground water. Ground water is an important source of water due to its large volume and its low vulnerability to pollution when compared to surface waters (USEPA, 1985).

Many regions all over the globe are entirely depending on ground water resources for the various uses (Babiker et al., 2004). That high dependence on ground water coupled with industrial and demographic expansion resulted in increasing pressures on available ground water resources in terms of quantity and quality and contribute significantly to ground water deterioration and pollution. In China, due to high population growth, economic development and industrialization, greater amounts of domestic and industrial effluents are discharged and demands proper management of all natural resources, including ever-increasing water, Hangzhou-Jiaxing-Huzhou plain is among the regions which are more affected, hence there is a requirement of ground water vulnerability studies in that region; this is why the author of this paper has chosen to work on this topic of GIS based aquifer vulnerability assessment in Hangzhou-Jiaxing-Huzhou plain, China which had the general objective of finding out the ground water vulnerable zones using Geographical Information System (GIS) model and specific objectives: to Develop DRASTIC model using ArcGIS by overlaying the following hydro-geological data layers: Depth to water table, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity; to develop a rapid assessment model to guide identification of priority areas for protection in order to direct regulatory, monitoring and policy development efforts to those areas where they are most needed for the protection of ground water quality; to differentiate between areas that need protection from potential contaminating activities, and those where such activities would constitute a minor threat to the ground water.

Materials and Methods

Study area description

Hangzhou-Jiaxing-Huzhou Plain is located between the Yangtze and Qiantang Rivers in northern Zhejiang Province, south of Shanghai City and Jiangshu Province. The total area of the plain is about 6,490 km^2(fig.1).

It is among the regions where economic development and population growth are most rapid in China. Geological and hydrogeological surveys reveal a multi-layered aquifer system beneath the plain, which includes Holocene phreatic water layers and Pleistocene confined aquifers and it is highly affected by ground subsidence (Changjiang et al., 2006).

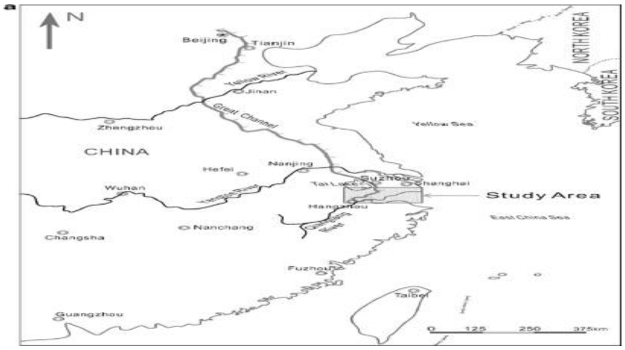

Figure1: Location of the Hangzhou-Jiaxing-Huzhou plain in Eastern China

Methodology used

DRASTIC is a method developed in the United State of America as the result of a cooperative agreement between the National Ground Water Association (NGWA) and US Environmental Protection Agency (EPA) in 1985 to evaluate the potential for ground water contamination in any hydrogeologic setting (Aller et al. 1985).

DRASTIC is an acronym for depth to water (D); net recharge (R); aquifer media (A); soil media (S); topography (T); impact of vadose zone media (I); and aquifer hydraulic conductivity (C). The original DRASTIC method is based on three components (weight, range and rating) that are expressed numerically. Every parameter in the model has a fixed weight indicating the relative influence of the parameter in transporting contaminants to the ground water. The weights range from five (most significant) to one (least significant). The range component divides each DRASTIC feature into several classes, or significant media types, which may affect the potential for pollution (Ehteshami et al, 1991). The rating assigns each class a value, based on a scale of one (least contamination potential) to ten (high contamination potential). The parameter ratings are variable, which allow the user to calibrate the model to suit a given region (Dixon, 2005, Bukowski et al, 2006). The final vulnerability map is based on the DRASTIC index (D_i) which is computed as the weighted sum overlay of the seven layers. The higher the DRASTIC index is, the greater the ground water contamination potential (Merchant, 1994, Fritch et al., 2000, Al-Zabet 2002, Atiqur, 2007, Ahmad et al, 2007).

The final DRASTIC index is calculatedusing the following formula:

DRASTIC Index = DrDw + RrRw +ArAw + SrSw + TrTw + IrIw + CrCw…… (1)

Where ‘r’ = the rating assigned to a particular cell for each of the hydrologic factors

‘w’ = weight assigned to each parameter

Based on the resulting DRASTIC indices,a greater value means higher susceptibility to contamination compared to a lower DRASTIC index. According to the US EPA (1985), aquifers with a DRASTIC index greater than 150 are considered to be highly vulnerable. Tables containing ranges, weights used for all parameters are in the following table.

Table 1: Assigned weights for hydrogeologic settings

Setting	Weight
Depth to water	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of vadose zone	5
Hydraulic Conductivity of Aquifer	3

Source: Aller et al., 1987

Depth to the water: The depth to the water table was obtained by subtracting the groundwater level from the elevation wells, the elevation of the wells and the mean water level table was provided for the last 10 years by Department of Geology and Mineral Resources in Zhejiang

Province. The point data were contoured by interpolating and divided into three categories i.e. <5 m, 5–10 m, and >10 m. Thereafter it was converted into grid to make it raster data for GIS operation.

Net recharge: the primary source of ground water is precipitation, canal seepage and irrigation seepage that infiltrate through the unsaturated zone to the water table. Recharge map was constructed using the following equation:

N R= (R- ET)

Where N R refers to Net Recharge, R to Rainfall and ET to Evapo-transpiration.

Aquifer media: Aquifer media refers tothe consolidated or unconsolidated rock that servesas an aquifer. It is the potential area for water storage, the contaminant attenuation of aquifer depends on the amount and sorting of fine grains, higher the grain size, lower the attenuation capacity of aquifer media and consequently the greater the pollution potential. An aquifer media map was prepared using lithologic data from Department of Geology and Mineral Resources in Zhejiang Province·

Soil media: Soil media refers to that uppermost portion of the vadose zone characterized by significant biological activity. Soil has a significant impact on the amount of recharge that will infiltrate into the ground and hence on the ability of a contaminant to move vertically into the vadose zone. The soil grain size and macro-pores which are controlled by the amount of clay which is present in soil affect mainly the soil pollution potential of any place. This means that the presence of fine grain size materials and the percentage of organic matter within the soil cover can decrease intrinsic permeability, and retard or prevent contaminant migration via physico-chemical processes. Soil data were obtained from Department of Geology and Mineral Resources in Zhejiang Province.

Topography: topography refers to theslope variability of land surface. It helps to controlthe likelihood that a pollutant will run off or remainon the surface in one area long enough to infiltrate.It is a controlling factor for pollutant runoff or infiltration. Inherent to this component is soil development as an input to contaminant attenuation. At 0 to 2 percent slope, the greatest potential exists for pollutant infiltration whereas with more than 18 percent slope, little potential exists for infiltration. However, contamination to surface water increases along with a greater probability of erosion (Aller et al., 1987).

Steep terrain will help to control runoff of pollutants and their infiltration into the ground water, hence the less vulnerability to ground water contamination; while areas with low slope tend to retain water for longer period of time which allows a greater infiltration or recharge of water and a greater potential for contaminant migration. In this research, slope percentages have been grouped into 3 classes less than 5, between 5 and 10 and greater than 10.

Impact of vadose zone: the vadose zone is defined as that zone above the water table which is unsaturated or discontinuously saturated. The type of vadose zone media determines the attenuation characteristics of the material below the typical soil horizon and above the water table. The vadose zone has a high impact on watermovement if it is composed with permeablematerial; i.e. the impact of vadose zone implies thatless permeable confining layers improve ground water protection. The determination of Impact of vadose zone followed the guidelines of Piscopo (2001) using the following equation I = D + S, where I is impact of vadose zone, D depth to water and S soil. It has been used also by Pathak, (2008). He combined lithologic data with depth to water where Depth to water less than 10m is given rating 5, groundwater level between 10m and 30m; is given the rating 2 and greater than 30m the rating 1. For lithologic data, high permissible soil, rating is 5, Medium to low permissible soil, rating is 3 and Low permissible soil, rating is 1.

Hydraulic conductivity: Refers to the aquifer's ability to transmit water; an aquifer with high conductivity is more vulnerable to contamination because contaminants can move easily through the aquifer. Hydraulic conductivity values were obtained from published hydrologic reports of Zhejiang Province and have been classified in 3 classes, less than 100, between 100-200 and greater than 200.

Results and discussion

Maps of seven layers used are presented from fig 2 to fig 8 and groundwater vulnerable zones are shown on the fig 9 and fig 10.

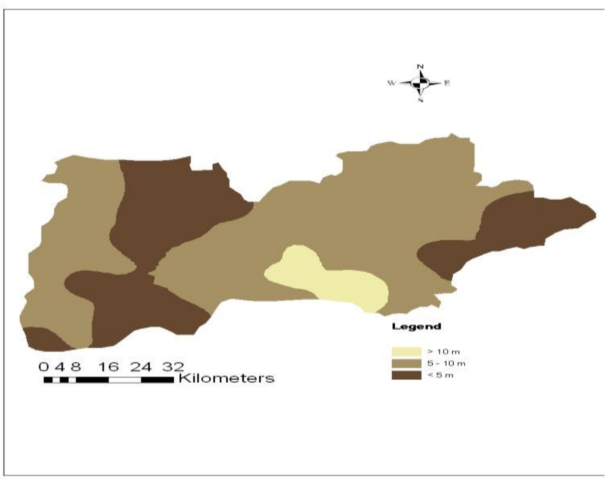

Figure 2: Depth to water of Hangzhou-Jiaxing-Huzhou

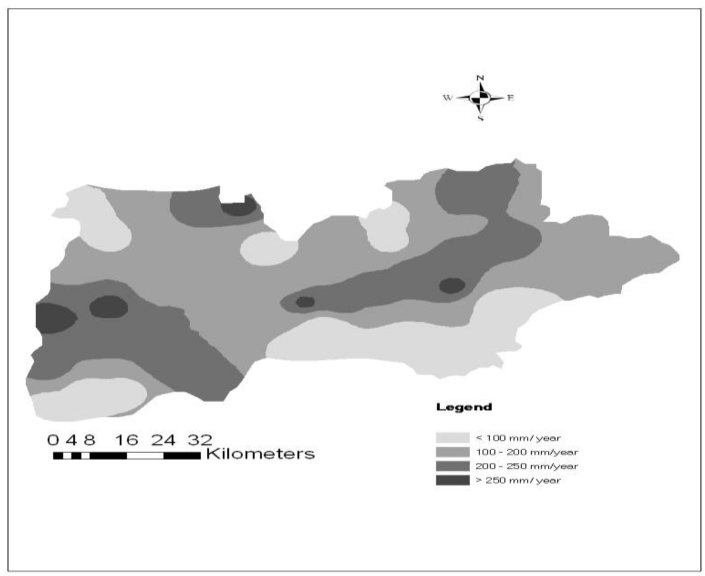

Figure 3: Net Recharge of Hangzhou-Jiaxing-Huzhou

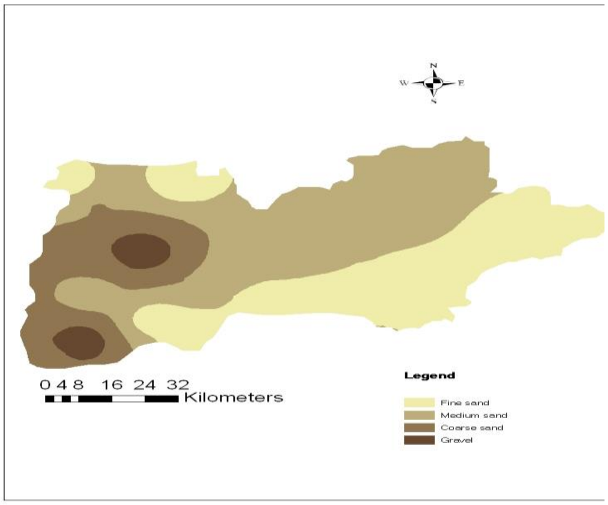

Figure 4: Aquifer media of Hangzhou-Jiaxing-Huzhou

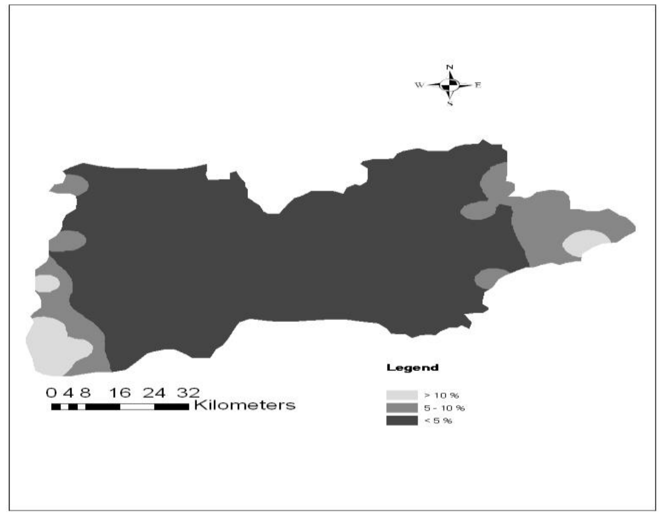

Figure 6: Topography of Hangzhou-Jiaxing-Huzhou

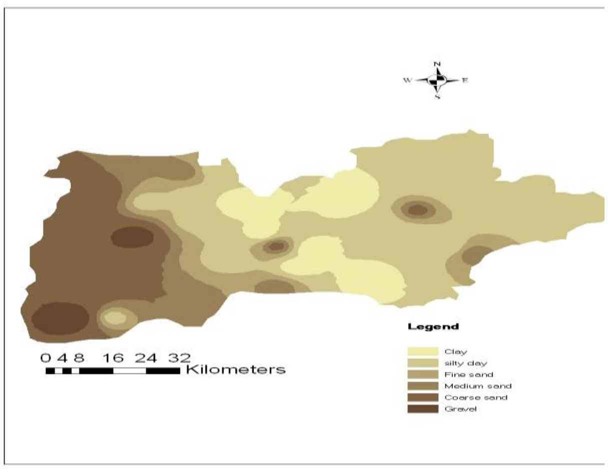

Figure 5: Soil Media of Hangzhou-Jiaxing-Huzhou

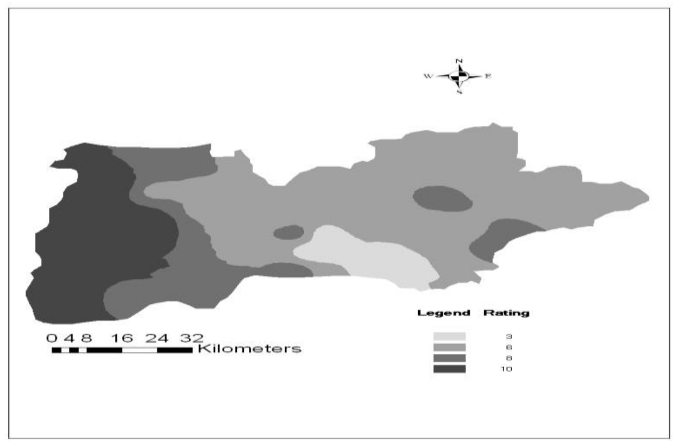

Figure 7: Impact of Vadose Zone of Hangzhou-Jiaxing-Huzhou

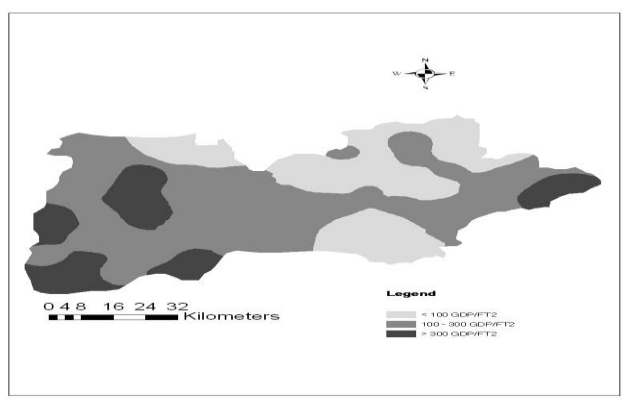

Figure 8: Hydraulic Conductivity of Hangzhou-Jiaxing-Huzhou

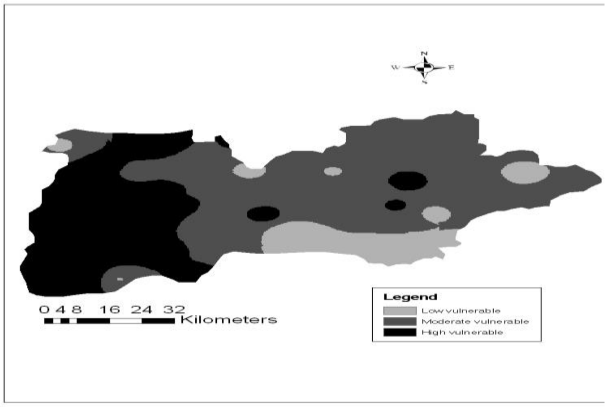

Figure 9: Ground water Vulnerable Zones of Hangzhou-Jiaxing-Huzhou

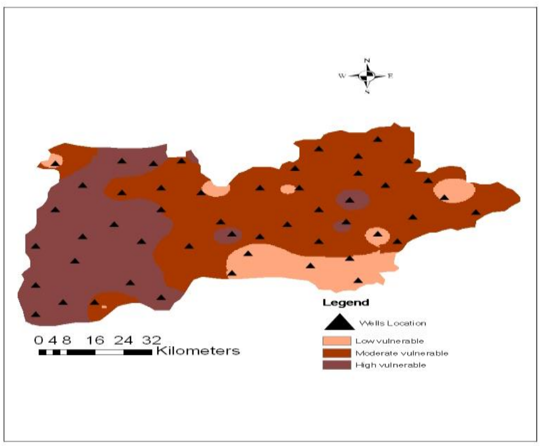

Figure 10: Ground water Vulnerable Zones with wells location in Hangzhou-Jiaxing-Huzhou

Depth to water

It represents the depth from ground to water table. It determines the depth through which a contaminant must travel before reaching the water table in an aquifer (Baalousha 2006). Shallower water table is more vulnerable to pollution. Fig 2 describes the depth to water of Hangzhou-Jiaxing-Huzhou plain.

According to fig.2, the depth to water table in Hangzhou-Jiaxing-Huzhou plain is shallow in almost the total area where 67.5% is between 5 and 10 m, 27% is in less than 5m and only 5.5% is in greater than 10m.. This shows high risk of ground water contamination in this plain when we consider that factor which was the first to be given high weight of 5.

Net Recharge

It represents the amount of water that penetrates the ground surface and reaches the water table; it facilitates the transport of contaminant vertically to the water table and horizontally within the aquifer.

Hangzhou-Jiaxing-Huzhou plain is moderately recharged in its major party, and it was given a weight of 4. This is due to its climate with plenty rainfall as shown on the figure 3 where 11.3% of the area receives less than 100mm per year of rainfall, the biggest part i.e. 50.7% gets annually between 100 and 200 mm of rainfall, 35. % of the area gets between 200 and 250mm per year and only 3% obtains more than 250mm of rainfall per year as shown by fig 3.

Aquifer media

It is the potential area for water storage. High permeability allows more water and therefore more contaminants to enter the aquifer. Fig 4 gives details on the aquifer of Hangzhou-Jiaxing-Huzhou plain. In Hangzhou-Jiaxing-Huzhou plain, the aquifer iscomposed primarily by fine sand with 42.3%,medium sand with 44.88%, coarse sand with 10.6%and gravel 2.3%. For more details see fig 4.

Soil Media

Soil media is the uppermost and weathered part of the ground characterized by significant biological activity; soil cover characteristics influence the surface and downward movement of water and contaminants. The thickness of soils determines the length of time contaminants reside within the media, the longer the contact time, the more opportunity for interaction with biological and physical elements that can potentially degrade pollutants or dissolve contaminants. More the finer particles present less is the vulnerability of the soil to pollution

Soil media affects the transport of the contaminant and water from the soil surface to the aquifer, but it can also provide better habitats for microorganisms which can potentially biodegrade the contaminant. The soil in Hangzhou-Jiaxing-Huzhou is composed by different types of soils where some prevent the pollutant migration like clay with 10.2%, silty clay with 42%, those which are moderate like fine sand with 9.2%, medium sand with 7.5% and others like coarse sand with 26.4% and gravel with 4.7% increase the risk of contamination (fig 5).

Topography

Topography refers to the slope variabilityof land surface. It helps to control the likelihoodthat a pollutant will run off or remain on the surfacein one area long enough to infiltrate. With a low slope, the contaminant is less likely to become run-off and therefore more likely to infiltrate the aquifer while areas with steep slopes, having large amount of run-off and smaller amount of infiltration, are less vulnerable to groundwater contamination.

With a low slope, the contaminant is less likely to become run-off and therefore more likely to infiltrate the aquifer， as shown on the fig.6 almost the Hangzhou-Jiaxing-Huzhou area is characterized by the low slope where 87.9 % has the slope which is less than 5%, 8.7% of the area has slope between 5 and 10% and only 3.4% has the slope which is greater than 10%.

Impact of Vadose zone

Vadose zone is unsaturated or discontinuously saturated horizon above the water table, its influence on aquifer pollution potential is similar to that of soil cover, depending on its permeability, and on the attenuation characteristics of the media. If the vadose zone is highly permeable then this will lead to a high vulnerability.

Vadose zone in Hangzhou-Jiaxing-Huzhou moderately favors the pollution potential in its main part which covers 63.6% of the total area while the area with low permeability vadose zone occupies 8.4%, but the area in east of Hangzhou-Jiaxing-Huzhou seems to be highly permeable to pollution and covers about 15.8% and the between medium and high permeability is about 12.2% (fig.7).

Hydraulic Conductivity

It refers to the ability of the aquifer formation to transmit water; therefore it determines the flow rate of contaminant through the aquifer. The greater the hydraulic conductivity the further contaminants will travel and potentially contaminate greater volume of groundwater

The hydraulic conductivity is variable and relatively small in Hangzhou-Jiaxing-Huzhou plain as shown on the figure 8, where 59.1% of the total area has the hydraulic conductivity between 100 and 200, and 28.3% has hydraulic conductivity which is less than 100 while only 12.6% has hydraulic conductivity which is greater than 300 as presents fig.8.

Vulnerable zones

Table 2: Area under different ground water pollution vulnerability degrees in Hangzhou-Jiaxing-Huzhou

DRASTIC Index value	Area (sq km)	Area (in %)	Vulnerability zones
66-120	785.29	12.1	Low

120-160	3926.45	60.5	Moderate
160-185	1778.26	27.4	High
Total	6490	100	

Table 3: DRASTIC index vulnerability

DRASTIC index value	Corresponding vulnerability level
More than 199	Very high
Between 160 and 199	High
Between 120 and 159	Moderate
Lower than 120	Low

. Source: Aller et al., 1987

Based on the results presented in the table 2 using the table 3 as standard and sensitivity maps fig.9 and 10, of the total of 6490 square kilometers, an area of 785.29 square kilometer, i.e. 12.1% is in the low vulnerable zone with a DRASTIC index range between 66 to 120, about 3926.45 square kilometers which make 60.5%, are in the moderately vulnerable zone with a DRASTIC index ranging between 120 and 160. It means that more than half of the Hangzhou-Jiaxing-Huzhou ground water is at moderate risk in terms of pollution potential; this is mainly the result of moderate net recharge and less-porousness lithology of that area. About 1778.26 square kilometer, which makes 27.4%, are in the high vulnerability zone with a DRASTIC index ranging between 160 to 185, which is mainly due to shallow depth to water table, impact of vadose zone with permissible soils in west part of the study area and low slope in the whole study area in general.

Vulnerability maps have proved popular tools and are now a common feature of groundwater and environmental management throughout the world Connell and Daele, (2003), also groundwater vulnerability maps are effective for identifying locations warranting more detailed groundwater pollution and vulnerability investigations Thapinta and Hudak, (2003). In recent years, DRASTIC method is highly used to create those maps. It is a well-established method that is often applied in the United States (e.g. Rupert 2001; Merchant 1994; Loague and Corwin 1998; Wade et al. 1998; Stark et al. 1999; Fritch et al. 2000) and Canada (Murat et al. 2004). This method also has been used in Europe (e.g. Stigter et al. 2006; Vias et al. 2005), South America (Tovar and Rodriguez 2004; Herlinger and Viero 2006), Australia (Piscopo 2001), New Zealand (McLay et al. 2001), Asia (Al-Adamat et al. 2003; El-Naqa 2004; Thirumalaivasan et al. 2003; Atiqur 2007; Kim and Hamm1999), and Africa (Lynch et al. 1997; Ibe et al. 2001), etc.

Hence the results of this research are efficient and will help water managers in this plain to improve the way they are managing it.

Conclusion

In this study, the GIS based aquifer vulnerability map of Hangzhou-Jiaxing-Huzhou plain has been developed using the DRASTIC method which reflects an aquifer's inherent capacity to become contaminated.

In this plain, the vulnerable zones were classified into three zones namely Low, Moderate and High vulnerable zones. It was found that 27.4% of the total study area is under high vulnerable zone, which is mainly as a result of shallow depth to water table, impact of vadose zone with permissible soils in west part ofthe study area and low slope in the whole study areain general. It was also found that the major part, 60.5% of thetotal area is under the moderate vulnerable zonewhich is mainly the result of moderate net rechargein the major part of the plain and less permeable lithology in the main part of the study area. In the Hngzhou - Jiaxing-Huzhou, this research showed that about 12.1% is under low vulnerability.

Our study suggests the prioritization of high vulnerable areas in order to prevent the further pollution to already more polluted areas. There is also a need for further studies in the Hangzhou-Jiaxing-Huzhou plain which can incorporate other factors, such as ground water movement, pollutants properties, sources of pollution for better future ground water use and planning.

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