

Determine the vulnerability of surface water resources in the Rach Gia City, Kien Giang Province using GIS

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Key words: Rach Gia, GIS, AHP, vulnerability, saline intrusion water retention

SUMMARY

The Rach Gia city is located in the west coast of the Mekong Delta. Due to the high salinity intrusion of underground aquifers, surface water is the main source of mining. The water retention consists of reservoirs with around 600,000 m³ and 3.2 km length of a canal. These resources are taken from rivers and canals in the area. However, surface water in the area is contaminated by human activities such as wastewater discharge, waterway traffic,.... Especially in the dry season, when water levels in rivers and canals reaches low and high tides lead to the salinity intrusion infiltrate into rivers, affecting water supplies to water plants. Therefore, necessary to identify the vulnerabilities by pollution on reservoirs and canals. The methodological approach employs a spatial analysis model integrating several previously parameters defined such as slope, land use, drainage network density, runoff, salinity levels. They will be prioritized and weighted and then integrated into a geographic information system (GIS). The results show that drainage network density and land use are majors on causing vulnerability by pollution of surface water resource. Despite the subjectivity involved in the weighing of the analytic hierarchy process (AHP), the study determined levels of vulnerability as well factors that cause pollution. This results will support the protection of surface water resources.

SUMMARY (optional summary in one other language in addition to English, e.g. your own language)

Thành phố Rạch Giá có vị trí ở khu vực ven biển Tây thuộc ĐBSCL. Do các tầng chứa nước ngầm bị nhiễm mặn cao không đạt tiêu chuẩn để khai thác nên nước mặt là nguồn khai thác chủ yếu. Khu vực trữ nước ngọt bao gồm hệ thống hồ chứa có thể tích khoảng 600.000 m³ và kênh dẫn nước Tà Tây có chiều dài 3,2km. Nguồn nước ngọt được dẫn từ các kênh rạch trong khu vực. Tuy nhiên, nước mặt nội vùng của khu vực bị ô nhiễm do các hoạt động như xả nước thải, giao thông thủy,... Đặc biệt vào mùa khô khi mực nước trên các sông, rạch xuống thấp và triều cường dâng cao, xâm nhập mặn tiến sâu vào các dòng sông gây ảnh hưởng tới nguồn nước ngọt cung cấp cho nhà máy nước. Do vậy, để xác định các tác động gây tổn thương do ô nhiễm tới các hồ chứa và kênh dẫn nước, phương pháp tiếp cận sử dụng mô hình phân tích không gian thứ bậc (AHP) với các thông số như độ dốc, hiện trạng sử dụng đất, mật độ mạng lưới dòng chảy, lượng mưa, mức độ nhiễm mặn được gán trọng số ưu tiên sau đó được tích hợp vào GIS. Kết quả cho thấy, mật độ mạng lưới dòng chảy và sử dụng đất là yếu tố chính trong tác động gây tổn thương nguồn nước ngọt. Mặc dù việc gán trọng số cho các

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yếu tố của phương pháp này là chủ quan, nghiên cứu đã xác định mức độ tổn thương cũng như các nhân tố chính gây ra ô nhiễm nguồn nước. Kết quả của nghiên cứu sẽ hỗ trợ trong việc xây dựng các biện pháp bảo vệ nguồn nước mặt sau này.

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1. INTRODUCTION

The Rach Gia City is placed on the west coast of the Mekong Delta. The city has flat and low terrain, with a low west-to-east direction and north to south and high density of river networks. Hau River is the water source of this river networks. With the geological condition of the aquifer, which is highly saline, it is not suitable for exploitation. Thus, the surface water (rivers, reservoirs) is the main sources for water supply of this area. Water retentions consist of Vinh Thong reservoir and small reservoirs nearby with a total of around 600,000 m³ waters and a canal Ta Tay with 3.2 km of length. In recent years, the supply of fresh water in the area has become difficult due to the impact of climate change in the current context of the

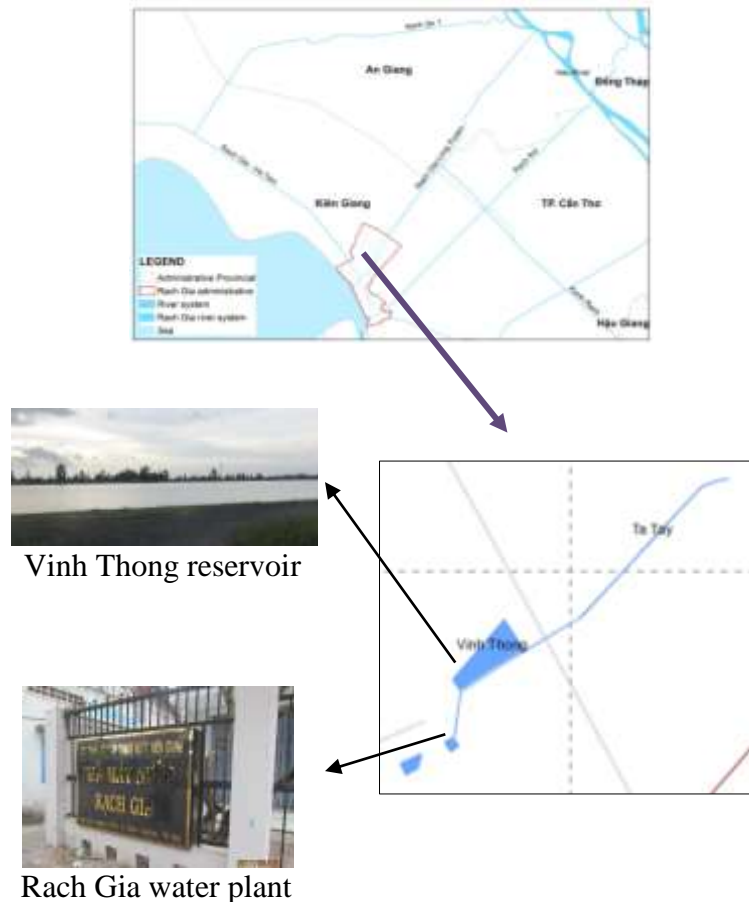


Fig 1. Location of study area

Mekong Delta is generally the increase of saline intrusion. Reservoirs and canals are also suffering from this saline intrusion, especially in the dry season. The transition of agricultural land into the urban and industrial land contributes to the potential for pollution and causes a substantial fall in the quality of surface water. In addition, due to the waterway transport in the area is a dynamic activity and population are mainly concentrated on the banks of the canal leading to vulnerability surface water from pollution.

To mitigate these contamination issues, all measures to ensure surface water quality should be addressed in which identifying water-source damaging factors are important. Geographic information system (GIS) and analytic hierarchy process (AHP) are the primary tools utilized

in natural resource management, surface water resources such as pollution mapping and zoning surface water source (K.A., 2009). This study contributes to the overall welfare of urban water pollution as well as to areas that are vulnerable to pollution in order to better assist the planning and management of surface water.

2. DATA CAPTURE

Data capture is the step of accumulating and classifying different types of spatial and attribute data. The sources of the data are presented in Table 1 displaying factors and the sources of information used in the subject field.

Table 1. List of existing data used

No	Content	Format	Issued by
I	Spatial data		
1	Rach Gia city elevation data in scale 1:10,000	Microstation	Kien Giang province Department of construction
2	Rach Gia existing land use map in 2012	Microstation	Rach Gia City People's Committee
3	Saline intrusion in the Mekong Delta map	Image (*.JPG)	Report of salinity intrusion in Mekong Delta in 2012 _ Southern Institute of Water resources research
4	Soil map	Arcgis (shape file)	Open Development Mekong (ODM)
II	Attribute data		
1	Statistical Year Book of Rach Gia City from 2003 to 2016 Statistical Year Book of Kien Giang province from 2003 to 2016		Kien Giang Statistics Department

The collected data are converted to the ArcGIS data format (shape file), with the goal of synchronizing with national data, VN 2000 coordinate system was used in this study.

3. METHODOLOGICAL APPROACH

Rach Gia is considered a watershed of the Hau River. Land use and water circulation are considered to be factors affecting water pollution. So far, there is no standard method for assessing surface water vulnerability to pollution (Eba A.E.L., 2013). Indeed, the methods are numerous and most relevant are those that integrate topographic, geological, hydrological and land-use data and ensure a realistic determination of the zones influencing the vulnerability of these resources (Schoen R., 2001). Thus, vulnerability assessment accuracy depends essentially on the nature, quantity, and reliability of data used. Its characterization is generally based on the estimation of a certain important parameter number.

The methodology applied to assess the water reservoir vulnerability to pollution were already used in the previous studies (Eba A.E.L., 2013; Schoen R., 2001; K.A., 2009). Thus, with regard to these works, the methodological approach adopted can be summarized in four steps presented in Table 2.

Table 2: Summary of the steps in the methodological approach.

Steps	Methods	Processes
1	Identification of parameters	Choice of used parameters to calculate the pollution vulnerability index
	Thematic mapping	Mapping each parameter at the scale of the studied watershed
	Reclassification of parameters	Each parameter is subdivided into 3 or 4 classes according to the ratings or weights assigned
2	Weighting of parameters	Prioritize the parameters relative to each other by Saaty method
3	Vulnerability assessment	The combination of the different thematic maps by weighting to obtain a final map of the vulnerability index distribution

3.1 Identification of parameters and thematic mapping

3.1.1 Selection of indicators

The assessment of the vulnerability indexes involves several parameters relating to environmental characteristics, land-use, nature of activities, rejections and soil properties. In (Schoen R., 2001) on mapping risk of surface and groundwater contamination caused by plant substances in the Midi-Pyrenees, the selected elements include slope, land use, soil, rainfall, drainage network density. However, for this study area, surveyed in addition to the above factors, the saline intrusion is a great source of water pollution. Thus, salinity levels will be added to the analysis and evaluation.

3.1.2 Rate the level of influence factors

The classification and rating of the elements identified in the assessment of water surface vulnerability are based on the guiding of Schoen, R., et al. (2001). Rankings are classified from 1 to 4 and are indicated according to the degree of vulnerability in the study and the saline intrusion is also rated in this study.

According to the report of the Southern Institute of Water Resources Research on "Prediction of saltwater intrusion in the Mekong Delta", the salinity measured on the river at 0.3 g/l affected the fresh water intake for irrigation and water supply. In fact, the level of salinity intruding measured in the Rach Gia area at the time of dry season ranged from 1g/ l to 4g/l, even when the level of salinity reached more than 10g/l (VAWR, 2016). As a result, this parameter will be set at 4, the highest level of causing water vulnerability.

Table 3: Parameters, classes and ratings of the various parameters.

Parameters	Classes	Ratings
Slope (Sl) (%)	<3	1
	3 - 9	2
	>7	3
Land use (Lu)	Forest	1
	Habitats, public constructions,...	2
	Rice fields	4
	Land for business (restaurants, hotels,...)	3

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	Land of technical infrastructure (landfills...)	3
	Brackish aquaculture	4
Soils media (S)	Soil feralit strongly desaturated	1
	Soil feralit moderately desaturated	2
	Hydromorphic soil	3
Runoff (R) (mm)	<0	1
	0 - 150	2
	> 150	3
Drainage Network Density (D) (km/km ²)	<1.04	1
	1.04 – 1.33	2
	>1.33	3
Saline intrusion levels (g/l)	<0.3	1
	0.3 - 1	3
	>1	4

3.1.3 Thematic mapping

- Slope (SI): normally, this is one of the important factors that affected the vulnerability of water resources, because the steep slopes led to strong stream causes the increased risk of contamination from upstream. However, the slope of this area less than 0.5%, and rated at “1”.

- Soil media (S): this parameter corresponds approximately to the first meter of deposition from the soil surface. According to (Douay D., 2010), soil permeability and bedrock play a role on the rainwaters part which participates in a runoff, but also on transit times to the hydrographic network. Rach Gia has two main soil classes: brackish alluvial soil and nutrient-rich clay, which are of high permeability.

- Land use (Lu): land use contains potential sources of water reservoir pollution. It also plays an important role in the rainwater runoff, retention of suspended solids and pollutant absorption. This city is located near the west coast of Viet Nam so the tourism industry developed, which has led to the strong activities of the restaurant and hotel services. In addition, the technical infrastructure such as the treatment plant, landfill, storage,... is planned on-site city also caused the highly discharge. In this study, two additional land use groups were ranked at high levels: business land and technical infrastructure land. The land use type of this city is reclassified and taken into account the ratings in Table 3.

- Annual Runoff (R):

Flow is the place where pollutants are transported to water sources such as rivers, ponds, lakes, etc. Therefore, the slope and the amount of water on streams are important factors in determining the extent of the damage. Drainage is closely related to precipitation and land penetration. The determination of drainage in this study is based on the calculation of average annual rainfall.

Determination of drainage level based on equation (1) of Thornthwaite:

$$R = r \times P \quad (1)$$

where:

R is drainage (mm)

R is flow coefficient (%)
 P is total annual rainfall (mm)

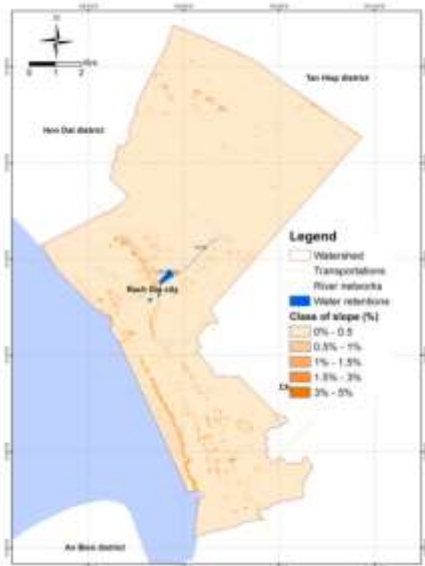


Fig 2. Slope map of study area

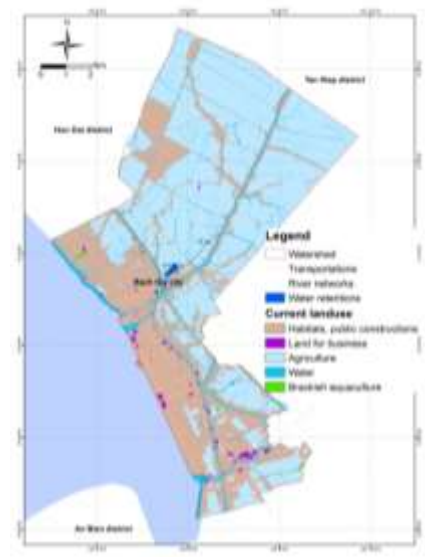


Fig 3. Land use map of study area

Determine the annual rainfall of the area based on the statistical yearbook for 13 years (from 2003 to 2016), rainfall $P = 2136$ mm

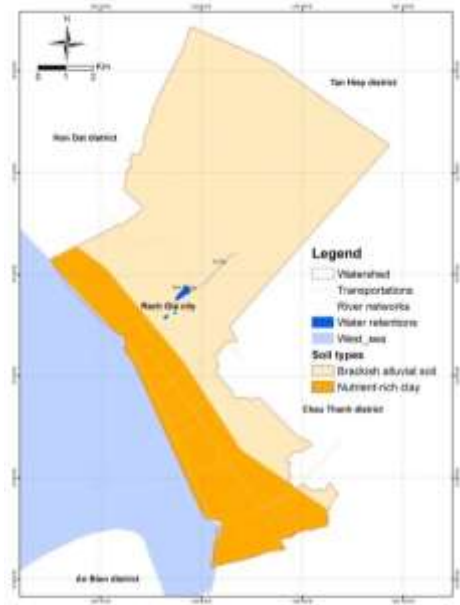


Fig 4. Soil map of study area

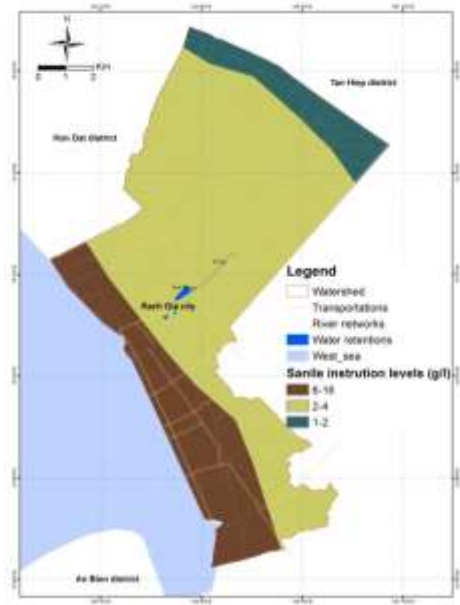


Fig 5. Saline intrusion map of study area

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Calculate the flow coefficient (r) based on Brad Lancaster's method:

$$r = P / (A \times 7.48) \quad (2)$$

where:

- r is the flow factor (%)
- P is annual rainfall
- A is basin area

The coefficient of flow of the region $r = 2.7\%$

Drainage $R = 2.7 \times 2136 = 57.67$ mm. As a result, drainage of the area is within the range of 0-150 (mm). So the rating “2” was assigned to the parameter “R”.

- Drainage Network Density (DD):

Drainage network density is defined as the total length of the hydrographic network per unit area of the watershed. Pollution of surface water resources (lakes, stream, rivers...) is also linked to the hydrographic network density that underlies these resources. With the watershed area around 103.64 km² and the total length of the hydrological network is 298.77 km, result of the drainage network density of this area is around 2.9 km/km².

More by the hydrographic network management unit is dense, vulnerability to pollution of the resource is high. So the drainage network density result of this area is rated at “3”.

- Saline intrusion levels (SI)

Due to climate change, the saline intrusion has occurred in recent years in the coastal areas of the Mekong Delta (Vista, 2016). Due to the decrease of rainfall in the dry season and water flow from upstream on the Mekong River is not abundant caused severe impacts of saltwater intrusion on rivers. The Rach Gia saline intrusion map was derived from the Southern Institute of Water Resources Research. Three saline intrusion classes were then defined from Table 3 to obtain the reclassified saline intrusion map.

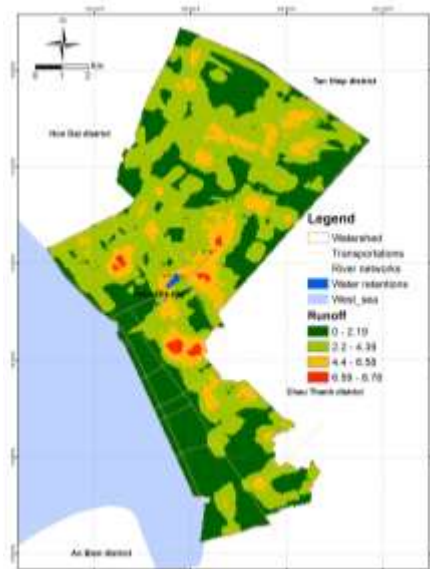


Fig 6. Drainage network density map of study area

3.2 Weights Determination by AHP Method

3.2.1 Elaboration of square matrix

The method used to determine parameter weights is the AHP (Analytic Hierarchy Process) multi-criteria analysis developed by Saaty. This is to compare the relative importance of all the parameters used taken in pairs to setup a reciprocal square matrix. When two parameters have the same importance in the studied phenomenon, the scale of Saaty gives these two parameters the value "1". However, if a parameter is more important than the other then it takes a higher value between 1 and 10 and the other the inverse of this value. This method

allows the production of standardized weights whose sum is equal to "1". Matrix resulting from the pair wise comparison of parameters summarized in Table 4.

Table 4 . Pairwise comparison matrix of the various parameters (original matrix)

STT	Parameters	S	DD	SI	R	Si	Lu	Vp	Cp
1	S	1	1/3	3	1/2	1/5	2	0.5	0.07
2	DD	3	1	5	2	1/3	4	1.6	0.20
3	SI	1/3	1/5	1	1/5	1/8	1/2	0.3	0.04
4	R	2	1/2	4	1	1/4	3	0.8	0.10
5	Si	5	3	8	4	1	7	3.7	0.45
6	Lu	1/2	1/4	2	1/3	1/7	1	1.2	0.14
	Σa_i	11.83	5.28	23.00	8.03	2.05	17.50	8.1	1.00

3.2.2 Verification of logical consistency or consistency ratio (RC) of the matrix

AHP suggests a process to measure the consistency of these comparisons, individual elements are evaluated and the consistency of the evaluation is checked. The coherence is verified through the calculus of coherence rate. If the value of consistency ratio is smaller or equal to 10%, the inconsistency is acceptable. The consistency ratio is determined according to "Equation (3)".

$$RC = \frac{IC}{IA} \quad (3)$$

where:

IC is consistency index

IA is random consistency index

RC is consistency ratio

The consistency ratio value obtained after the calculations is less than 10% (RC = 2.01%).

Therefore the judgments attributed to the parameters can be considered satisfactory.

The results of the parameters are shown in Table 5.

Table 5: Results of calculation of indicators

Parameters	Results
Number of parameters	6
Maximum eigenvalue λ_{max}	6.12
Consistency index IC	0.02
Random consistency index IA	1.24
Consistency ratio RC	0.02

3.2.3 Determination of weights

After verifying the correlation ratio of the matrix is validated, the weighting of each factor is determined based on that standardized matrix. The weighting factor (Cp) of a parameter that can be determined in this study is its intensity in assessing the vulnerability of the reservoir to pollution. Its determination is made through the eigenvectors calculation (Vp), from "Equation (4)". The weighting coefficients are determined from "Equation (5)".

$$V_p = \sqrt[k]{W_1 \times \dots \times W_k} \quad (4)$$

$$C_p = \frac{V_p}{V_p + \dots + V_{pk}} \quad (5)$$

where:

V_p is eigenvector of parameter

V_{pk} represents the different eigenvectors of the parameters

C_p is weighting coefficient

All the results of the different calculations are given in Table 4. In this table, the “saline intrusion levels” parameter has a greater weight (0.45). It will therefore largely influence the water reservoir vulnerability to pollution. The drainage network density parameter (with a weight of 0.2) will also influence this vulnerability assessment.

3.3 Research results

3.3.1 Assessment of Municipal Artificial Lake Vulnerability

Combination of various parameters to map surfaces vulnerability affecting water retention. The approach used to assess the water reservoir vulnerability to pollution in the study area was the weighted sum of the various parameters to obtain vulnerability index map.

In this table, the parameter S_i (salt level) has a weight greater than 0.4. Therefore, this factor will greatly affect the potential for pollution of the reservoir. The magnitudes (flow network density) are also factors that influence the vulnerability assessment.

$$IV = \sum_{i=1}^{i=n} C_{pi} \times R_i \quad (6)$$

where,

IV_g is global vulnerability index

C_{pi} is weighting coefficient of parameter i

R_i is class of parameter i

n is number of parameters

Based on the results above, the calculation of the regional injury index in this study based on

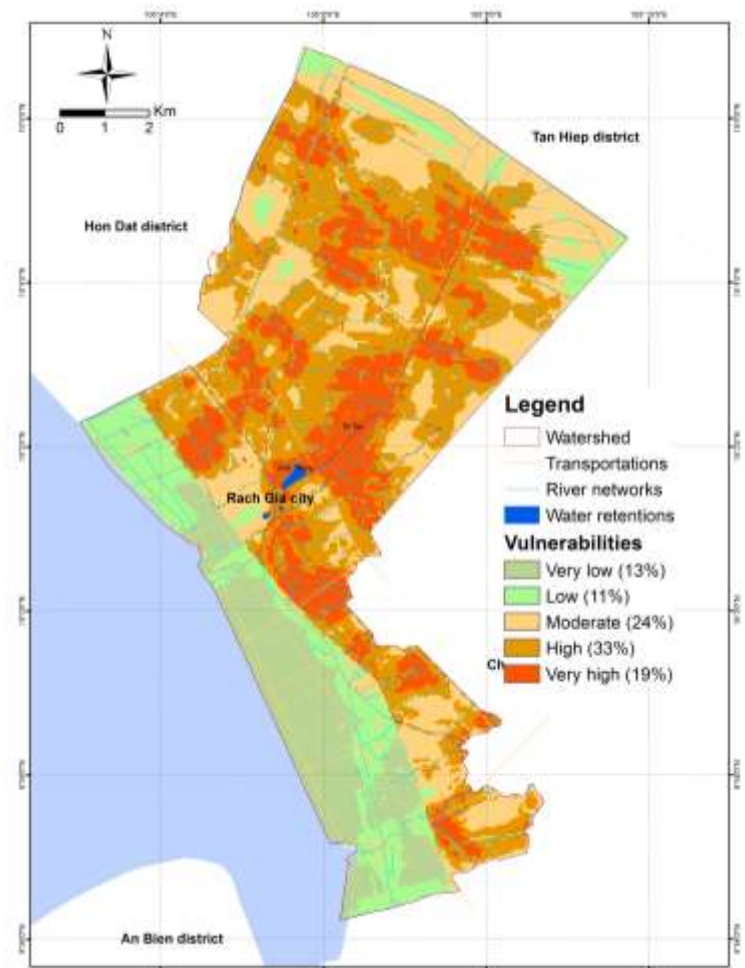


Fig 7. Vulnerability map of Rach Gia's retention water

the above formula will have the following results:

$$IV = 0.07 * S + 0.2*DD + 0.04*SI + 0.1*R + 0.45*Si + 0.14*Lu \quad (7)$$

These indexes represent a measure of the degree of water reservoir contamination risk through the various stresses of its watershed. Finally, a classification of the vulnerability index map according to Table 6 is made to obtain the water reservoir vulnerability map. Thus, vulnerability is more important when the calculated index is high. To determine the intervals of various vulnerability indexes, “equation (8) established by the Ministry of Agriculture, Fisheries and Food of Quebec”, was used to perform the conversion of vulnerability indexes in percentage. This conversion made it possible to better understand the classification expression of vulnerability degrees.

$$IVg (\%) = ((Vgi - Vbmin)/(Vgmax - Vgmin)) * 100 \quad (8)$$

where: IVgis vulnerability index to be identified.

The results of injury index and vulnerability of Rach Gia city are summarized in Table 6:

Table 6: Indicators and vulnerability of levels

No.	Classes of vulnerability indexes	Index intervals	Degrees of vulnerability	Percentage (%)
1	0.87 - 1.29	0% -14%	Very low	13
2	1.29 - 1.8	14%-31%	low	11
3	1.8 - 2.3	31%- 48%	Medium	24
4	2.3 - 2.7	48%-62%	High	33
5	2.7 - 3.8	62%-100%	Very high	19

3.3.2 Map of the factors that affect surface water

A map of surface water sources created by the editing of thematic maps shows five vulnerabilities (very low, low, medium, high, and very high).

The lesion is very low, occupying 13%, concentrated in the western coastal wards and at the source end. This is the place where residential land and public works are located. Although this is a high salinity intrusion area, this is a low-density site (<2.3), so the level of damage to surface water reservoirs due to pollution is not high. The low vulnerability layer (11%) is adjacent to the low-injury area. This area has the key technical infrastructure (landfill and waste treatment ...) that is the source of water pollution. The average vulnerability (24%) is scattered all over the paddy land but low flow density (<2.3). High and high injury sites are concentrated in areas with high flow densities, with the highest rate of injury (33%). Both of these areas belong to the agricultural land, which is a source of surface water pollution. At the same time, the drainage network density was at the highest level. Since this is flat terrain, it does not have much impact on the introduction of pollutants into the lake, so the soil and flow density cause great damage to the surface water.

4. CONCLUSIONS

The geographic approach from the GIS based on assessing the vulnerability of the city's water reservoirs to pollution has shown five (5) vulnerable grades (very low, low, medium, high and very high). This result is corroborated by studies showing that a vulnerable map to pollution

offers the idea of sensitive areas that need special attention when planning land use, as well as Water protection measures such as delineation of protected areas around the reservoir. Protected areas established around the city's artificial lake must allow decision-makers to regulate domestic, industrial and agricultural activities and monitor land use planning and planning to avoid causing pollution. Contemplate this important resource for the regional population. In particular, this could be a reference source in the plan to build more freshwater reservoirs for the city or the management and prevention of pollution.

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BIOGRAPHICAL NOTES

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