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DETERMINE THE VULNERABILITY OF URBAN SURFACE WATER RESOURCES IN RACH GIA CITY, VIETNAM USING GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT: Rach Gia city is located on the west coast of Mekong Delta, Vietnam. Due to the high salinity intrusion of underground aquifers, urban surface water is the main source of mining. 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, urban surface water in the area is contaminated by human activities such as wastewater discharge and waterway traffic. Furthermore, in dry seasons when water levels in rivers and canals reach low salinity intrusion infiltrate into rivers, affecting water supplies. Therefore, it is necessary to identify the vulnerabilities of pollution on reservoirs and canals. This study employs a spatial analysis model integrating several previously defined parameters such as slope, land use, drainage network density, runoff and salinity levels. They will be prioritized and weighted and then integrated into a geographic information system (GIS). Results indicated drainage network density and land use are majors to cause vulnerability of pollution on an urban surface water resource. Despite the subjectivity involved in the weighing of analytic hierarchy process (AHP), the study determined vulnerability levels as well as factors that cause pollution. These results will support to protect urban surface water resources.

Keywords: AHP, GIS, Rach Gia, Saline, Vietnam, Vulnerability

1. INTRODUCTION

Rach Gia city is placed on the west coast of Mekong Delta, Vietnam. 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 the 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 Ta Tay canal with 3.2 km of length [1]. 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 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 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 [2].

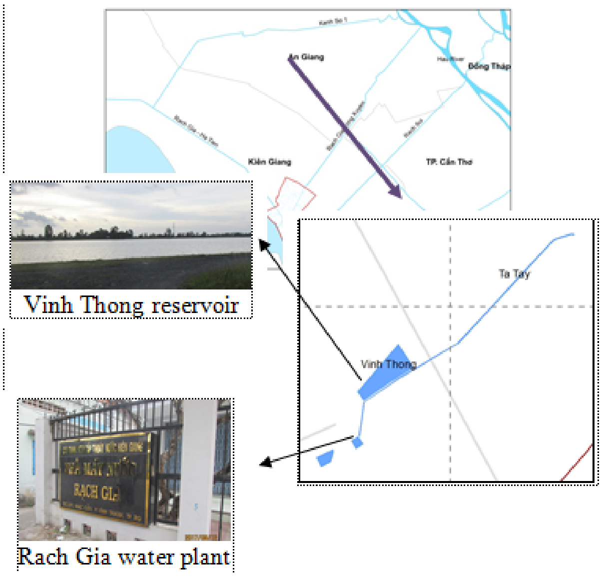

Fig. 1 Location of the study area

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) [3,4,5] and analytic hierarchy process (AHP) [6,7] are the primary tools utilized in natural resource management, surface water resources such as pollution mapping and zoning surface water source [8]. 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.

The collected data are converted to the ArcGIS data format (shape file). The goal is to synchronize with the national data coordination system that is used in this study.

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 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 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 2003-2016 Statistical Year Book of Vietnam 2003 - 2016		Kien Giang Statistics Department

3. RESEARCH METHODOLOGY

Rach Gia city is considered a watershed of 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 [9]. Indeed, numerous methods and most relevant ones 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 [10]. 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 [8,9,10]. Thus, with regard to these works, the methodological approach adopted can be summarized in four steps (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 thematicmaps by weighting to obtain a final map of the vulnerability index distribution

4. DATA ANALYSIS

4.1 Identification of Parameters and Thematic Mapping

4.1.1 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. On mapping risk of surface and groundwater contamination caused by plant substances in the Midi-Pyrenees [10], 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.

4.1.2 Rate the Level of Influence Factors

The classification and rating of the elements identified in the assessment of water surface vulnerability are based on guiding [10]. 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", [11] 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 [12] (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 businesses	3
	Land of technical infrastructure	3
	Brackish aquaculture	4
Soils media (S)	Soil fertility strongly desaturated	1
	Soil fertility moderately desaturated	2
	Hydromorphic soil	3
Runoff (R) (mm)	<0	1
	0 - 150	2
	> 150	3
Drainage Network Density (km/km²)	<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

4.1.3 Thematic Mapping

- Slope (Sl): 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 [13] (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:

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

where:

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

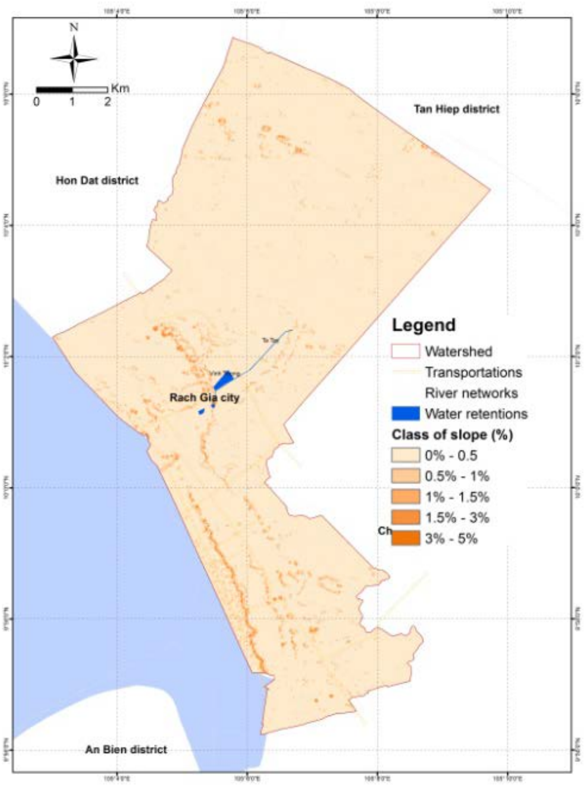

Fig. 2 Slope map of the study area

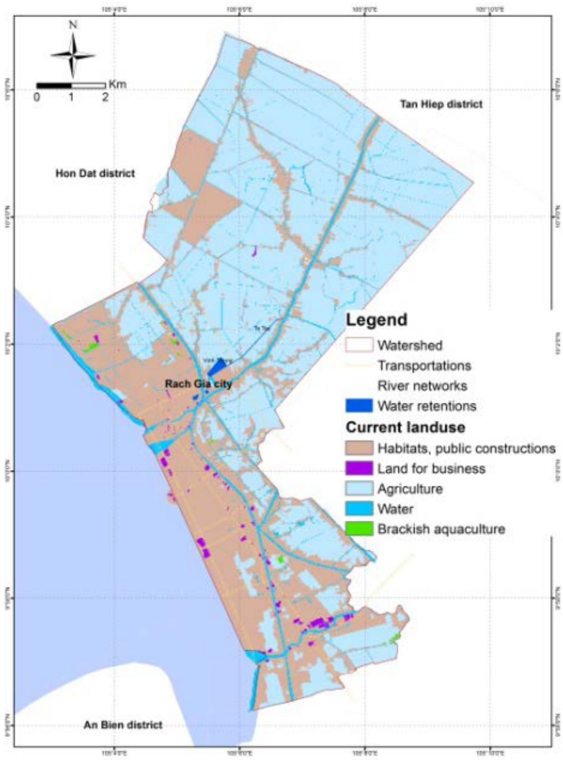

Fig. 3 Land use map of the study area

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

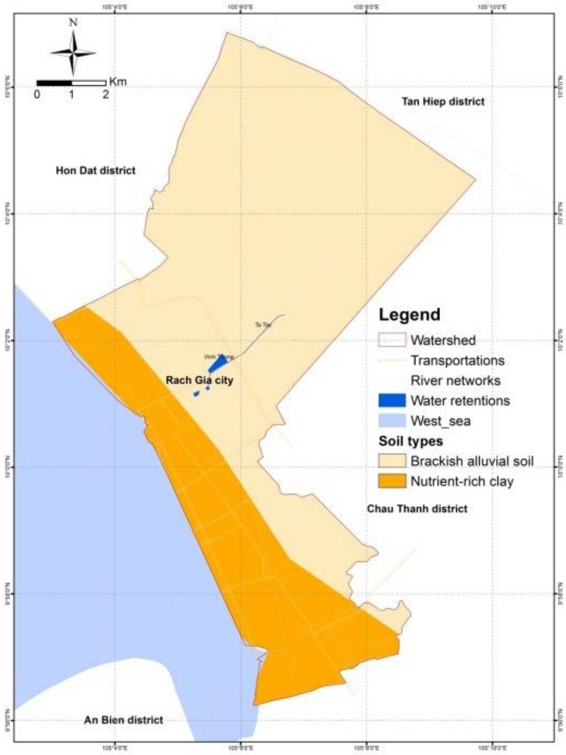

Fig. 4 Soil map of the study area

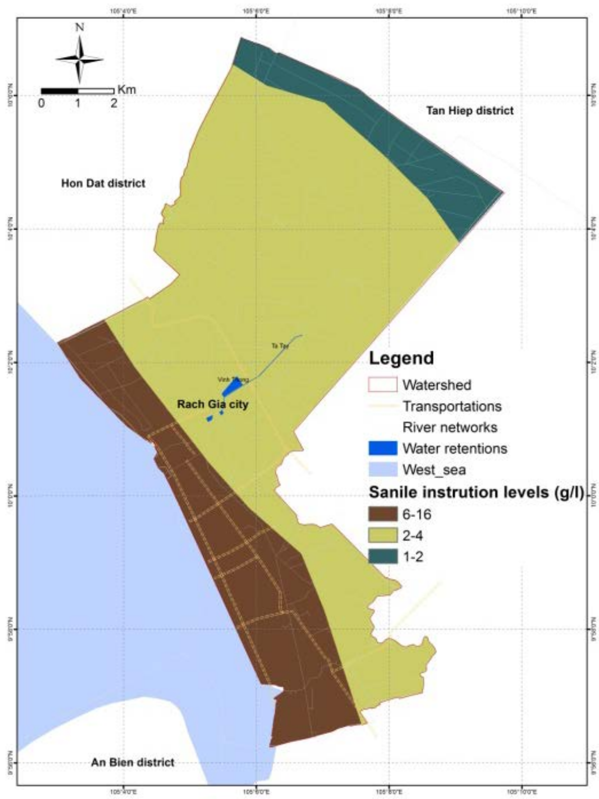

Fig. 5 Saline intrusion map of the study area

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

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

where:

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

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

Drainage R = 2.7 * 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”.

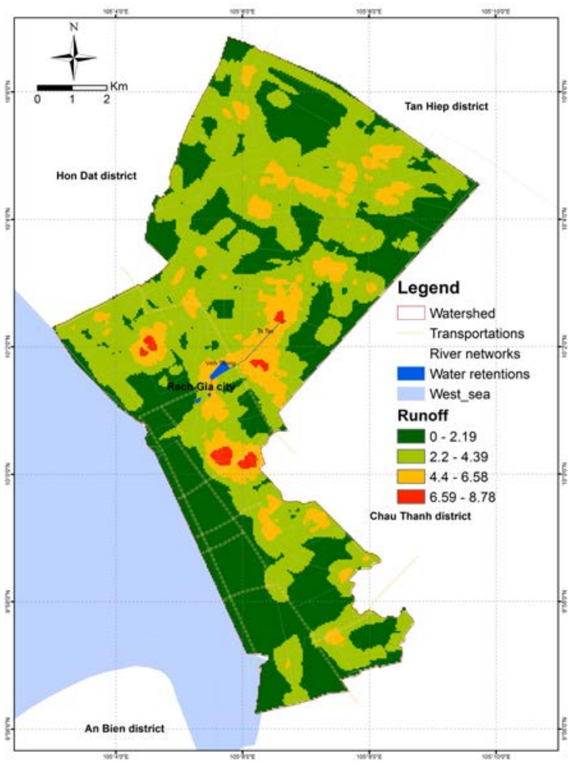

Fig. 6 Drainage network density map of the study area

- Saline intrusion levels (Sl): Due to climate change, the saline intrusion has occurred in recent years in the coastal areas of the Mekong Delta [14] (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.

4.2 Weights Determination by AHP Method

4.2.1 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)

Parameters	S	DD	Sl	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. Sl	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

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 the 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 the consistency index

IA is random consistency index

RC is the 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

4.2.2 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)".

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

$$Cp = \frac{Vp}{Vp + \cdots + Vpk} \quad (5)$$

where:

Vp is an eigenvector of parameter
Vpk represents the different eigenvectors of the parameters
Cp is a 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.

4.3 Research Results

4.3.1 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 Si (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 vulnerability assessment.

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

where,

IVg is global vulnerability index
Cpi is a weighting coefficient of parameter i
Ri is class of parameter i
n is a number of parameters

Based on the results above, the calculation of the regional injury index in this study based on the above formula will have the following results:

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

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 Energy and Water, Benin" [15], 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.

Results of injury index and vulnerability of Rach Gia city are summarized in Fig.7 and Table 6:

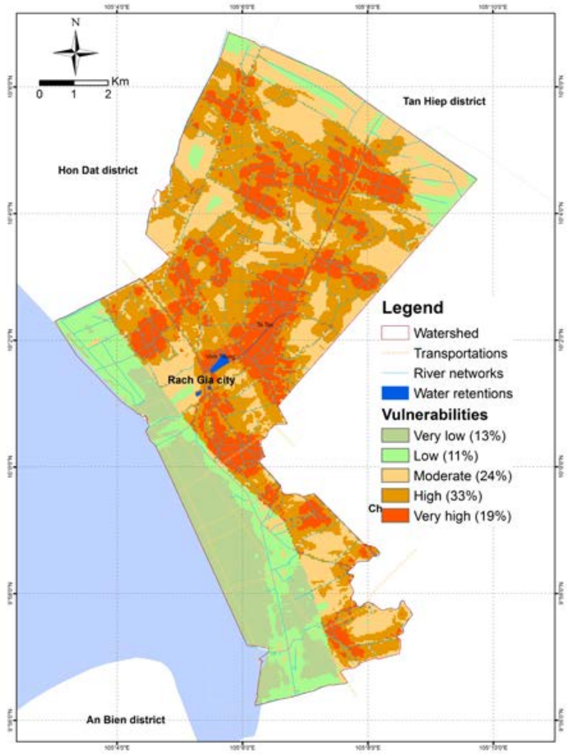

Fig. 7 Vulnerability map of Rach Gia's retention water

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

4.3.2 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

5. CONCLUSION

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.

6. REFERENCES

[1] Cuong C.V., and Son H. N. Using Shoreline Video Assessment for Coastal Planning and Restoration in the Context of Climate Change in Kien Giang, Vietnam. Ocean Science Journal, Vol 6, 2015, pp.15-18.

[2] Kien N.C., and Hung V. L. Evaluated Saline Intrusion West South Coastline of Vietnam. Journal of Marine Science and Technology Vietnam, Vol 14, 2014, pp.56-63.

[3] Al-Abadi A.M., Al-Shamma'a. A.M., Aljabbari M.H., A GIS-Based Drastic Model for Assessing Intrinsic Groundwater Vulnerability in Northeastern Missan Governorate, Southern Iraq, Journal of Applied Water Science, Vol 7(1), 2017, pp.89-101.

[4] Al-Adamat R., Modeling Surface Water Susceptibility to Pollution Using GIS. Journal of Geographic Information System, Vol 9(3), 2017, pp.293-308.

[5] Ratanopad S., K. W., Using GIS and map data for the analysis of the expansion of salinized soils, 2006, Symposium of ISPRS Commission IV. Goa.

[6] Saaty T., A Scaling Method for Priorities in Hierarchical Structures. Journal of Mathematical Psychology, 2015, Vol 15(3), 2015, pp.234-281.

[7] Saaty T., How to Make a Decision: The Analytic Hierarchy Process. European Journal of Operational Research, Vol 48(1), 1990, pp. 9-26.

[8] Anoh K.A., Vulnerability Assessment Specific to Agricultural Inputs of Groundwater in the Region Bonoua, 2009, Master Thesis at University of Cocody, Cote d'Ivoire .

[9] Eba A.E.L., Kouamé K.J., Jourda J.P., Aké G.E., Bachir S.M., Anoh K.A., Kouakou D.S., Demarcation of Surface Water Protection Perimeters by Using GIS: Case of Gagnoa Reservoir in West Central of Côte d'Ivoire. International Journal of Scientific & Engineering Research, Vol 4(4), 2013, pp.1311-1320.

[10] Schoen R., C. A., Mapping the Hazard of Pollution of Surface and Groundwater by Plant Substances in the MidiPyrenees, 2001, Manual 46p.BRGM /RP-51456-FR.

[11] Nam .T. T., Flow in the dry season in Mekong Delta, 2008, Vietnam Resource and Environment Institute.

[12] VAWR., Report Saline Intrusion at the River Mouth in the Coastal Area of the Mekong Delta and Propose Solutions to Prevent Drought, 2016, Vietnam Academy for Water Resources.

[13] Douay D., L. E. (2010). Délimitation des Aires d'Alimentation des captages prioritaires du bassin Adour Garonne, 2010, Vol 28, Méthodologie de cartographie de la vulnérabilité intrinsèque des captages d'eau superficielle, pp. 24-31.

[14] Vista., Saline Intrusion into Mekong Delta: Causes, Impacts and Response, 2016, Vietnam Ministry of Science and Technology.

[15] Achidi J.B., Establishment of a Protection System of the Catchment Areas of Drinking Water. Methodological Guide for Use by Municipalities of the Republic of Benin, 2010, Ministry of Energy and Water, Benin.