Mapping Groundwater Pollution Risk using GIS-based index system of Beihai, Southwestern China

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Abstract:
The protection and preservation of groundwater resources based spatial management has been increasingly important and compulsory in recent China. This study presents an approach for groundwater contamination risk mapping, based on vulnerability index system, contamination load index system, and function value of groundwater. The risk map is a product of probability of contamination and impact, using a spatial analyst tool within Geographical Information System (GIS) to interpolate and manipulate data of those index. This approach was applied on the Beihai City in southwestern China as a case study. The results show that areas of highest contamination risk occur in the southern parts of Beihai City. The majority of public wells are located in an intermediate risk zone and four wells are in a high risk zone. A better understanding of the sources and their binding behaviors of heavy metals may imply the elevated toxic potential from certain metal groups in the aquatic ecosystem, while the analysis of contaminates should be combined with biological evaluations of toxicity at specific sites in future work.

Keywords: Groundwater Risk Mapping, GIS, Vulnerability, Drastic, Contamination source loading, Function Value.

1.INTRODUCTION

Currently, China faces the urban planning issue. As China’s development is on the premise of overall urban environmental planning, the state selects twelve pilot cities of environmental planning, including Beihai City. The major task is to solve the problem of spatial distribution management. In terms of water environment, as Beihai’s drinking source is groundwater, it is important to divide groundwater pollution prevention and control zones. Chinese environmental planning has gained a series of theoretical achievements and some successful experiences over the past 40 years. However it can’t be called as a discipline in particular can’t be regarded as an independent subject due to the absence of the main independent core theory. This paper divides the environmental planning period into three stages, which are the first slow-developing-20 years, the brief but rapid-developing-10 years, as well as the superficial florescent but actually remain-stagnant-10 years. The analysis and characteristics of each stage and the current issues and challenges on environmental planning are discussed here. This paper focuses on the object of study for environmental planning and its “three-way dialectic analysis”, as well as the substantive issues of the category and basic tasks. Based on the theory of ecological civilization, this paper analyses the ideas, goals and tasks of the environmental planning. And thus the paper finally hands out the theory structure and system of environmental planning including the meta-ideology theory, normative theory and functional theory. Due to the experiences that removal and displacement of problems do not necessarily improve public health, Corburn points to precautionary and preventative strategies: “...the precautionary approach demands that preventive and protective actions should be taken even in the face of uncertain science and that the burden of proof of safety rests with those who create risks” (Corburn, 2007). To reconnect the two, Corburn suggests that the precautionary principle and a social justice frame should guide decision making and planning. There are four urban environmental design and planning research areas are
identified: (1) application of environmental services, (2) adaptation of settlements for natural disasters, (3) environmental changes of degraded urban places, and (4) ability of people to link knowledge to action to affect positive change (Steiner, 2014).

GIS and process-based modelling is used to demonstrate overlay/index method and source-pathway-receptor risk chain (Nobre et al., 2007; Baalousha, 2011). Therefore, this paper is to explain and practice a GIS-based index system approach of groundwater contamination risk mapping within a real case, which is a normal coastal city which need further regional plan. The specific targets are (1) to analyze the intrinsic vulnerability of groundwater resource (2) to estimate the sources and contribution of each anthropogenic contamination and their behaviours capability in the underground aquatic ecosystem. (3)to assess groundwater function value (4) attempting to determine the "extent of pollution" by means of the concentration and the capacity of the aquatic ecosystem; (5)mapping the reasonable groundwater pollution prevention and control zones. Finally, detailed analysis of groundwater contamination risk index in the study case is being conducted, in order to quantify the impact of hazard risk and to recommend GPPCZs mapping actions for environmental management. This study successfully analyze the systematic of GPPCZs mapping technology guideline in a coastal city, it is also vital to help make informed decisions concerning the future management strategies of the underground aquatic environment in the regional area.

2. STUDY AREA

The city of Beihai is located in the southern part of Guangxi Zhuang Autonomous Region in southern China and faces the Beibuwan Gulf of the South China Sea (Figure 1). Except the south-western tip and the northeastern part where low hills exist, the area is a low-lying coastal plain ranging in elevation from 8 to 20 m. Rivers are rare and short. The climate of the study area is subtropical humid with a hot summer. The precipitation varies between 849 mm and 2382 mm, with a mean annual value of 1677 mm (Zhou et al., 1997). Rainfall occurs mainly during the wet season from May to October. The subtropical temperature ranges from 2 °C to 37 °C, with a mean annual temperature of 22.6 °C. The tide is an irregular diurnal one, with an extreme spring tide of 3.42 m, lowest neap tide of -2.15 m and mean tide level of 0.36 m. One unconfined aquifer and one confined aquifer can be grouped in the unconsolidated sediments. The water levels in the coastal aquifers follow exactly the tide.

Figure 1. Study area

3. METHODOLOGIES AND RESULTS

In a word, groundwater risk mapping is as a matter of fact to determine boundaries of groundwater pollution impacts. The overlay/index methodology is to aggregate the hydrogeological factors (Groundwater Vulnerability Index), surface contamination sources factors (Sources Loading Index), groundwater current and potential function values factors (Function Value Index), etc. The drinking water sources was also in the consideration.
Then policy maker could consider the administrative demands eventually to determine management components for GPPCZs.

3.1 Groundwater Vulnerability Index

Groundwater vulnerability here is independent of the nature of contaminants and the contamination scenario. The most popular used method for vulnerability assessment is the DRASTIC model, which was developed by the US Environmental Protection Agency to be a standardized system for evaluating groundwater vulnerability to pollution (Aller et al. 1987). DRASTIC model is based on seven hydrogeological parameters: Depth to water table (D), Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Influence of vadose zone (I), and hydraulic Conductivity (C) to assess the intrinsic aquifer vulnerability. Each map is classified and rated, then weighted based on standard DRASTIC weigh system (Aller et al. 1987). The DRASTIC index has the following form:

\[ DI = D_W D_R + R_W R_R + A_W A_R + S_W S_R + T_W T_R + I_W I_R + C_W C_R \]

where DI is the vulnerability index; D, R, A, S, T, I, and C are the 7 parameters, respectively, the subscripts r and w are the corresponding rating and weight associated with each parameter.

- Depth of groundwater (D): It represents one of the most important factors because it determines the thickness of the material through which infiltrating water must travel before reaching the aquifer-saturated zone. In general, the aquifer potential protection increases with its water depth. The borewell and borehole data was collected from Guangxi Water Conservancy Bureau and Land Conservancy Bureau. The unconfined aquifer (2–18 m thick) consists mainly of sand with gravel in the lower part and clayey sand in the upper part of the Beihai Group of the Middle Pleistocene (Q2b). The confined aquifer consists of sand and gravel with clayey sand or lenses of clay of the lower part of the Zhanjiang Group of the Lower Pleistocene (Q1z) and the Shangcun Group (N2sh) and the Huangniuling Group (N1h) of Neogene age. At well Kd4, for example, drilling data indicate that the well penetrates the unconfined aquifer from 2 to 10 m and the confined aquifer from 15.7 to 33.3 m. The average groundwater table is 11.69 m. Across the plains field, home of Chinese and western, bamboo-shack, shallow depth of groundwater, about 2 ~ 3 m, always happy, buried depth is deeper, about 8 ~ 10 m, other parts about 3 ~ 7 m.

- Net Recharge (R): It is the amount of water from precipitation and available artificial sources to migrate down to the groundwater. The net recharge is considered the result of rainfall infiltration (GXO, 2012), irrigation return flow, and absorption wells in the study area. The total net recharge was computed by the Beihai Water Authorities. This method estimates groundwater recharge by analyzing water level fluctuations in observation wells (GWSD, 2012). In general, net recharge of the study area declines gradually from east to west trend as well as the local precipitation.

- Aquifer media (A): The Quaternary and Neogene sediments consist of sand with gravel and scattered lenses of clay or sandy clay. They are determined on the basis of the lithology of the saturated zone. They refer to the consolidated or unconsolidated horizons which serve as an aquifer (such as sand and gravel or limestone). The aquifer medium generally affects the flow system within the aquifer. Information on aquifers of Beihai is typically available in published geologic or hydrologic maps and reports and other exploratory borings (GXLCB, 1986).

- Impact of the vadose zone (I): It is defined as that zone above the water table which is unsaturated. Vadose zone media have been designated by descriptive names, however, each medium represents different groundwater pollution potential. Generally the type of vadose zone media determines the capacity of the material below the typical soil horizon and above the water table to filter contaminants. This zone also controls the path length and routing, thus affecting the time available for attenuation and the quantity of material encountered. The impact of the vadose zone map layer was prepared using the geological formation and the soil map of the Beihai region (GXLCB, 1986). The larger the grain size, the higher the permeability and the lower the ability of the unsaturated zone materials to filter contaminants (Aller et al., 1987). Impervious basement rocks of the study area consist of mudstone with sandstone and granite outcrop in the south-western tip and the north-eastern part of the
study area. The coastal plain is underlain by Quaternary and Neogene unconsolidated sediments with a total thickness of 5 to 350 m.

- Soil type (S): It considers the uppermost part of the vadose zone and it influences the pollution potential. A soil map, for the study area, was obtained by digitizing the existing soil maps covering the region (DSNESS, 2008). Soil of marine sediments in the study area is almost red sandy soil.

- Topography (T): It refers to the slope of the land surface and it is represented by the slope maps (1/50,000 scale) covering the study area (ISDSP, 2010). The north of Beihai is hill whereas the south faces shore of the sea. The topography overall is decreasing from north to south. The maintain mountains are Crown Hill, Daling Head, Cow tail Ridge, Cockfighting, Brews Ridge and Rhinoceros Ridge, the highest hill is cockfighting Ridge of 173.9 meters above sea level, uplift is a concave area in the east - bamboo-shack basin, on the terrain for high ground north of form a, gently sloping to the south coastal plain sector gradually, there are rivers in 93, main stream flow south river bay into the sea from china, 40 km, 84 km. South flow downstream of the river alluvial plain, coastal port. Urban terrain north-south narrow and long things, rhinoceros horn shaped, terrain tilt from north to south. The importance of topography in this context is to control the runoff of pollutants (PRWRC, 2006).

- Hydraulic conductivity (C): It refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient. Hydraulic connections of the study area exist between the aquifers owing to the semiperviousness and termination of the aquitard consisting of the clay in the upper part of the Zhanjiang Group of the Lower Pleistocene (Zhou et al., 2000a). In the unconfined aquifer, groundwater receives recharge from precipitation and seepage from canals and discharges to rivers and to the confined aquifers through leakage. The rate at which the groundwater flows always controls the rate at which a contaminant moves away from the point at which it enters the aquifer (Aller et al., 1987). Hydraulic conductivity here was measured by aquifer pumping tests in wells, by “stimulating” the aquifer through constant pumping, and observing the aquifer “response” or drawdown in observation wells. It is divided into ranges where high values are associated with higher pollution potential. Groundwater in the confined aquifers receives recharge from the unconfined aquifer, flows to the northwest and south, finally discharging into the sea (Zhou et al., 2000b).

All above maps were converted into grid coverage (raster maps). This process was essential in order to perform arithmetic operations within the GIS. Overlapping of the 7 criteria maps, allows obtaining the comprehensive vulnerability index on each cell (raster) of the study area, using the following formula where the relative importance of criterion is: I ≥D>R>A≥C>S>T; a sensitivity analysis was carried out.

Figure 2. Hierarchical graph of buried depth of groundwater Figure 3. Hierarchical graph of precipitation
According to the vulnerability evaluation results as shown in Figure 9, in Beihai City, the middle of the northern part, northwest part, and the eastern part close to Guangdong Province, and other most areas, which are widely distributed, are high- and higher-vulnerability areas. In the centre of southern part, a few areas are middle-vulnerability areas, and most areas of the southern part belong to lower- and low-vulnerability areas.
Figure 9. Hierarchical graph of groundwater vulnerability

Low-vulnerability areas: mainly concentrated in the most part of the southeast and part of the southwest corner of Beihai downtown. In these areas, the buried depth of groundwater is large, and the vadose-zone media with large thickness are mainly clay and loam. Because of the middle-level permeability coefficient, pollutants in these areas are not apt to migrate downward, thereby efficiently preventing groundwater pollution.

Lower-vulnerability areas: mainly concentrated in the south central part of the research area. In these areas, the aquifer has a middle thickness and is mainly composed of silty-fine sand.

Middle-vulnerability areas: mainly concentrated in the middle part, that is, the terrace area. The buried depth of groundwater is between 4 m to 12 m. These areas have middle-level precipitations and permeability coefficients and low vadose-zone thickness and media soil resistance.

Higher-vulnerability areas: mainly concentrated in local places of the northwest and northeast, with the groundwater depth between 2 m to 6 m. The aquifer medium is mainly composed of sand gravel, with a large permeability coefficient.

High-vulnerability areas: mainly concentrated in some places of the north and east, with a large distribution area. In these areas, the buried depth of groundwater is small, approximately 2 m to 4 m. The aquifer medium is mainly composed of sand gravel. The rainfall recharge is large relatively.

3.2 Potential Source Loading Index

Potential contaminant sources were classified in terms of non-point and point sources. The non-point sources were mapped into two categories, including urban and cultivated areas, using information from the LULC map. The distribution of point sources was described in terms of their amount per km², including factories, gasoline service stations, garbage dumps, livestock and poultry farm and sewage treatment works. Relative to gas stations, different ratings were attributed to areas with zero to five stations, indicating a higher probability for BTEX releases in the latter case. The other potential point sources, whenever present, were detected in just one unit per km². This information was collected and recorded with the collaboration of the Maceió municipal government. The methodology is almost the same, which is weights multiple ratings. However, there are three potential sources loading index concern in the rating calculation: Toxic(T), Leachate probability(L), and Leachate quantities(Q).

\[ P_i = T \times L \times Q \]

Every point sources is calculated by the P value. The index has the following form:

\[ PI = \sum W_i \times P_i \]

where PI is the vulnerability index; \( P_i \) is the corresponding rating of different point source, respectively; \( W_i \) is the parameter of weight with each parameter, the subscripts i is the number of the point source. An existing finite difference groundwater flow model (Baalousha 2003) was used as a basis to delineate capture zones of
public drinking water supply wells in the area at different times (1, 2, 5 and 20 years). The advective transport code PMPATH of Processing MODFLOW package was used for this purpose (McDonald and Harbaugh 1988). Particle tracking (Pollock 1989) within the Processing Modflow Package was used to delineate the capture zones of public water wells at different time intervals. Meanwhile, referring to IRIS (Integrated Risk Information System) and HEAST (Health Effects Assessment Summary Tables), potential pollution in areas within capture zones of sources will have a higher impact on public health. Potential sources of pollutants and their possible impact in the sources areas, which is believed to be anthropogenic.

Through the evaluation formula of pollution source load, hierarchical graphs of different pollution source loads in Beihai can be drawn. The pollution source loads in industrial areas and gas stations are extensively distributed and have high risk.

Figure 10. Hierarchical graph of mining groundwater load

Figure 11. Hierarchical graph of industrial source groundwater load

Figure 12. Hierarchical graph of landhill groundwater load
Figure 13. Hierarchical graph of gas station groundwater load

Figure 14. Hierarchical graph of livestock breeding groundwater load

Figure 15. Hierarchical graph of groundwater load of sewage treatment plants

Figure 16. Hierarchical graph of groundwater potential Source Loading
Take a fertilizer plant with the area of 0.1 km² in the mild pollution load area of Beihai City as an example, the waste water contains many types of hazardous substances like SO₂⁻⁴, oxide, lead, arsenic, and phosphorus, and is discharged into the sea along a drainage ditch without seepage control, resulting in severe pollutant seepage along the way. The plant area piles up 2×10⁴ t waste residue all year around, which causes groundwater pollution due to infiltration after rainfall. In groundwater around the fertilizer plant, the content of SO₂⁻⁴ reaches nmol/L, higher than the drinking water standard, with the highest value as 30 times of the standard value. The secondary pollutant is fluorine, which is 2 times higher than the standard value and belongs to industrial pollution.

A section of the middle-level pollution load area, which is located around 2nd Foreign-Trade Warehouse and 1st Winery, as large as 0.2 km², suffers mixed pollution of salt water and sanitary sewage. In the west of Haicheng District, there is a sink with poor seepage-control capability which starts from Dongwei sewage lagoon, passes through the Chinese medicine hospital, winery, aquatic product processor, Salvage Company, foreign-trade refrigeration house, and ends to Dijiao Port. This section centralizes factories and dense residential areas. As sanitary sewage, and washing water of wineries, packinghouses, aquatic product processors, and vegetable markets are splashed locally, and the bottom layer is a loose gravel layer with strong water permeability, sewage and waste water infiltrate easily, causing groundwater pollution. In the water of artesian wells, Cl⁻ is 15 times higher than the standard value, and the water near wineries is 41.2 times higher than the standard value.

### 3.3 Function Value Index

The function value of groundwater is represented by both current water quality and water yield property of groundwater. As they are the same important, their weight values are both 1, similar to the vulnerability and pollution source load index system. The function value of groundwater is obtained based on the weighted summation formula of the GIS spatial analysis platform, and is finally divided into five levels: high, higher, medium, lower, and low.

In response to the requirements of 2012 National Division Technology Outline of Groundwater Function Zones (hereinafter referred to as "Technology Outline") issued by the Ministry of Water Resources, majority provinces and cities of the country have begun the work of dividing function zones of groundwater. Main division conditions of groundwater function zones include: groundwater recharge, water yield property of aquifer and exploitation condition, groundwater quality, type of ecological system and objective and requirements of ecological protection, development and utilization status of groundwater, demand of regional water resource distribution on groundwater development and utilization, national overall deployment for rational development and utilization and protection of groundwater resource, etc. They are nearly the same as the requirements of division of function values. In accordance with the resource optimization and sharing principle of ecological civilization construction, division of groundwater function values will be associated with the exiting results of government, and meanwhile be graded according to relative standards and rules.

![Figure 17. Hierarchical graph of groundwater function division](image)

According to the evaluation results as shown in the figure, the groundwater function zones of Beihai City are generally distributed in concentrated and distributed exploitation areas, that is, susceptible areas of seawater-intrusion geological hazards. They generally have high functionality and will generate large impact on the ecological environment once being polluted. However, as the PH value of water quality is lower than the standard of III-type water, the value of groundwater is affected.
3.4 Risk Mapping Results

According to groundwater pollution risk evaluation results of Beihai as shown in Figure 18, in general, high-risk zones are mainly distributed in some areas of Hepu County, Tieshan Port, and Haicheng District; low-risk zones are mainly distributed in some areas of the middle-east part; and most of the rest belongs to medium- and low-level risk prevention and control zones.

![Figure 18](image-url)

**Figure 18.** Schematic diagram of Beihai groundwater pollution risk evaluation

The risk zones of Beihai are mainly distributed in coastal seawater-intrusion areas and are the most important drinking source of the local place. The drinking sources of Longtan and Hetang also face certain environmental risk, so it is necessary to strengthen construction of groundwater pollution prevention and control measures in new high-risk zones to reduce potential risk of groundwater pollution to the largest extent.

In Beihai City, 79 areas are classified as groundwater source protection areas, in which the first-level protection areas occupy a total land of 2.45 km² and second-level protection areas occupy a land of 232.84 km². According to evaluation results of groundwater pollution status, the quality of groundwater in two places is evaluated as lower than III-type water, with a land of about 14.88 km². The main pollution indicators are nitrite and ammonia nitrogen. One of the two places is located at the rural water supply project of Nankang Town. It is needed to carefully evaluate health risk and restoration risk as soon as possible, so as to control pollution in time.

Except for protection and control areas, all areas of the city are risk prevention and control areas, and are divided into five levels according to risk evaluation results. Each village and town can select new project plan, land use plan, and groundwater resource protection plan according to different regional characteristics. For detailed analysis of evaluation results, see the table below (Table 1).

<table>
<thead>
<tr>
<th>Region</th>
<th>Level</th>
<th>Area (km²)</th>
<th>Percentage to the Evaluation Region (%)</th>
<th>Countermeasures and Suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation zone</td>
<td>1</td>
<td>2.45</td>
<td>0.07%</td>
<td>Prohibit constructing buildings irrelevant to water intake facilities.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Forbid any production activities. Prohibit pumping and stacking industrial residue and urban trash, faeces and other harmful substances, and engaging in husbandry activities. The coverage of physical isolation facilities in level-1 conservation area should be 100%; and the coverage of terrestrial vegetation in level-1 conservation area should be large than 80%. Deploy water quality monitoring wells reasonably to cover the whole monitoring area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Carry out routine index monitoring once per month, and comprehensive water quality analysis once per year.</td>
</tr>
</tbody>
</table>
Ban construction, electroplating, leather, paper-making, pulping, smelting, radioactivity, printing and dyeing, dyeing, and coking enterprises and other ones leading to serious pollution, and order abatement, restructuring, or transfer of existing pollution enterprises within a definite time; restrict husbandry activities, and transfer existing farmland or limit the use of fertilizers; ban mixed exploitation of confined groundwater and phreatic water. Deploy water quality monitoring wells reasonably to cover the whole monitoring area. Carry out routine index monitoring once per month, and comprehensive water quality analysis once per year.

<table>
<thead>
<tr>
<th>Prevention and control zone</th>
<th>Prevalent prevention and control</th>
<th>Control zone</th>
<th>General</th>
<th>Medium prevention and control</th>
<th>Major</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>232.84 %</td>
<td>6.99%</td>
<td>297</td>
<td>8.92%</td>
<td>35.35%</td>
</tr>
<tr>
<td></td>
<td>1,177</td>
<td>35.35%</td>
<td>2,042</td>
<td>1,052</td>
<td>31.60%</td>
<td>31.60%</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>0.99%</td>
<td>33.33%</td>
<td>33</td>
<td>0.99%</td>
<td>0.99%</td>
</tr>
</tbody>
</table>

Control pollution based on pollutant characteristics, enhance monitoring capability, reasonably increase monitoring times and points, clear off pollution sources, and cut off pollution ways. Perform dynamic observation and seriously control usage amount of pesticides and fertilizers used in farmland of agricultural area. Develop the measures of controlling irrigation by using sewage containing heavy metal in mining areas, preferentially perfect auxiliary pipe net of sewage disposal facilities in industrial and other prevention and control areas in cities and towns and industrial areas, speed up the construction of seepage-control facilities, actively promote the construction of sewage disposal and seepage-control facilities for central urban areas, recharge runoff areas, and key pollution areas, enhance the removal efficiency and seepage-control rate of toxic heavy metals and organic pollutants, improve the online monitoring network for groundwater pollution prevention and control, and reinforce environmental supervision for sewage treatment plants and seepage-prevention facilities to ensure safe and stable running of facilities. Put forward a concrete scheme about cleaner production and cyclic utilization of various waste to reduce emissions of pollutants; propose the measures of process, pipe, equipment, and sewage storage, and for disposal of structures to prevent leakage of pollutants, thereby minimizing the environmental risk caused by pollutant leakage.

Prevent pollution from the aspect of antifouling property of groundwater. Preferentially perfect the measures of irrigation control quota of sewage irrigation area and regional permeability adjustment coefficient; strictly implement environmental effect evaluation policy for industrial districts, consider the layout of production equipment, pipe gallery or pipeline, storage and transportation devices, pollutant storage and disposal devices, emergence devices in project implementation and new construction projects, propose a demanding ground seepage-control scheme according to the quality, yields, and emissions of various poisonous and harmful raw and auxiliary materials, intermediate materials, and leakage amount of products, and other types of pollutants; present detailed seepage-control materials and related standards and requirements, and build a seepage-control facility detecting system. Strictly implement environmental effect evaluation policy, and efficiently execute sewage disposal and seepage prevention measures. It is suggested to build new projects in the prevention and control areas with relatively lower prevention and control values and better conditions.

Strengthen comprehensive governance on water sources, renovate, transfer and close major pollution sources (for example, Baishuitang wasteyard) threatening drinking sources, and seriously punish illegal pollutant-emission actions. For the areas and wells suffering severe pollution, observe the rules of natural purification, and closely detect the quality of water supply sources and their peripheral groundwater. Perform renovation evaluation and carry out renovation treatment.
detailed investigation, work out renovation objectives, and recommend the renovation method of monitoring natural attenuation.

<table>
<thead>
<tr>
<th>Beihai</th>
<th>Total</th>
<th>3329.17</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Strictly implement pollution prevention and control for groundwater zones; build a groundwater pollution monitoring system; establish a risk and accident emergency response mechanism.

4. DISCUSSION

The one challenge in groundwater vulnerability mapping is how to attain spatial patterns that are congruent with the capacity of humans for receiving, processing, remembering and transmitting information. One of the main reasons that index assessment systems have become popular is due to their little requirement on field data inputs. The meaning of “low” or “very high” vulnerability has a direct correspondence with a shared perception of the relative susceptibility of a system to a stressor. One way of attaining logical consistency is by using visualization to enable the direct participation of planners, decision makers and stakeholders in the classification of groundwater vulnerability across a region.

All of the above steps could be carried out artificially according to hydrogeologists' experiences.

The overlay/index method can however be deceivingly simple in real-life policymaking in some reasons.

(1) The spatial distribution of groundwater is uneven, and the problem of unreasonable exploitation of groundwater is prominent.

The groundwater of Beihai City that has been exploited is shallow fresh groundwater, so groundwater takes up over 80% of the total water consumption. However, restricted by lithology, landform, and hydrogeological condition, Beihai groundwater is distributed unevenly. The downtown groundwater of Beihai is deep-layer water while the groundwater of Hepu Country is shallow-layer water. In recent years, the water sources in downtown Haicheng District, Hetang Village, and rural area of Hepu County have been exploited excessively. In the dry season, the water source of Hongtan Village, Beihai City has shown the exploitation depression cone, with an area of 13 km². This depression cone disappears with the gradual increase of rainfall in the wet season. Generally speaking, the groundwater level of Beihai is at a relative balance state, but unreasonable exploitation in local offshore sections cause seawater intrusion. Beihai owns three large reservoirs including Hepu Reservoir, Hongchao River Reservoir, and Wangsheng River Reservoir, with good water quality and abundant water source. However, due to lack of auxiliary rural water supply projects, surface water resources have not been fully used. With the development of Beihai economic society and acceleration of urbanization, it is urgent to rationally distribute surface water and groundwater resources, strengthen comprehensive use of water resources, and protect groundwater resources.

The sections suffering groundwater pollution of Beihai are mainly distributed in the west of Haicheng District water source and local sections of Hetang Village water source. The over-standard substances are mostly chloride, 3-nitrogen, manganese, and iron. The PH value of Beihai City exceeds the standard by 90%, which is the highest over-standard rate. The over-standard rate of manganese is 10%, and that of chloride, nitrite, and mercury is 5%. The content of nitrite has the highest over-standard times, that is, 12 times. The over-standard substances of Weizhou Island groundwater are mainly nitrite and manganese, with the over-standard rate as 12.5%.

(2) Groundwater yield grows year by year, and seawater intrusion becomes increasingly severe.

Historically, due to the impact of hydrogeological conditions, the PH value of Beihai groundwater has been highly over-standard. The area with the highest groundwater exploitation degree in Guangxi Province is the Haicheng District water source of Beihai, with the exploitation degree up to 213%, causing serious seawater intrusion; the area with the second highest exploitation degree is Hetang Village water source of Beihai, with the exploitation degree as 127%, also causing seawater intrusion, thereby affecting water quality and yield of groundwater sources. Since the initial stage of the water sources, their yields have been increased year by year.
causing seawater to first intrude offshore areas, and then gradually extend to open-sea areas. As seawater intrusion grows increasingly serious, yields of groundwater decrease year by year. In 1993, the seawater intrusion area reaches the top of 4 km². The Hetang Village water source, adjacent to Northern Guangxi Gulf to the south, showed the phenomenon of seawater intrusion in 1995 as the yield of groundwater was slightly larger than the allowable yield, and the intrusion area reached 1 km² till 2009.

(3) The quality of groundwater declines, and the pressure of environmental protection and modification is heavy.

The groundwater pollution concentration of Beihai City presents a rising trend. As over exploitation of groundwater causes seawater intrusion and a series of hydrogeochemical process between groundwater and the vadose-zone and its wall rock, the quality of groundwater declines. Currently, except that the PH value of groundwater decreases, the main pollution substances are nitrite and ammonia. The groundwater quality is evaluated as below III type. The concentrations of other monitoring indexes increase obviously. For the areas located in Hetang and Yinhai where the groundwater quality is evaluated as below III type, the main pollution substances are nitrite and ammonianitrogen. It is urgent to carry out evaluation on health risk and restoration as soon as possible, and control pollution in time; otherwise, the quality of other water sources will be severely impacted.

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