The Analysis on the Inversion of the Seawater Intrusion Based on RS
—a Case Study of Longkou City

Jianrong Cao\textsuperscript{1a,b,c,d} Hongjun Yu\textsuperscript{c} Xingyong Xu\textsuperscript{c} Yi Gao\textsuperscript{b,d} Changhui Zhou\textsuperscript{a}

\textsuperscript{a}College of Environment and Planning, Liaocheng University, Liaocheng 251059
\textsuperscript{b}South China Sea Institute of Oceanology, Chinese Academy of Sciences Guangzhou 510301
\textsuperscript{c}the First Institute of Oceanography, SOA Tsingdao 266061
\textsuperscript{d}Yantai Institute of Coastal Zone Research for Sustainable Development Chinese Academy of Sciences, Yantai 264003

Abstract

Hydrosphere movement in coastal zone performs as salty and fresh water mutual function. The Longkou city coastal zone which moves in the humanity under the intervention, has initiated the large-scale sea water intrusion, and therefore was especially under severe circumstances since 1980s. Until the end of 1980s and the beginning of the 90's, the sea water intrusion zone has formed the belt which spread fast from several hundred meters to several thousand meters along the coastal zone of Longkou city. Taking the landsat TM images in 2000 as data sources, first we applied the principal components transformation and analysis to analyze the six TM wave bands, and then use the histogram equalizing to deal with them. We use the two-value approach to be possible to remove the villages and small towns, the path, the pond (fishpond), the vegetables greenhouses, the rivers, the sand very conveniently. We take wave band as the research band, TM3, TM4 and TM5, which passed through correlation coefficient confirmation. Using the principal components analysis method to determine vegetation degree of coverage, the bare land index and the green index, the humidity analyzed in turn as four factors of the sea water intrusion. Inversion model of sea water intrusion is build up with the four factors. Finally a case study on the Longkou city, the analysis is obtained that the results have a very good correlation with the field measurements, and in accordance with the extent of the intrusion is divided into four categories.

Key words: RS; Principal Component Analysis; Longkou City; Seawater Intrusion; Inversion Model; Categories

1. Preface

Coastal Zone of Longkou city is located in the northern part of Shandong Peninsula, the geographical coordinates: 120 ° 12'42" E to 120 ° 35'42" E, 37 ° 31'54" N to 37 ° 45'53" N, an area of about 187km\textsuperscript{2}. Mainly of the coast is sandy coast. According to the causes, it can be divided into two sections: the northern coast and the gulf coast of Longkou city.

Because of the influence of humane activities, the coastal zone of Longkou city has occurred large-scale seawater intrusion, which is a very prominent case for Chinese coastal hydro-geological environment. The coastal plain in Longkou city has been found in 1970s for the first time. There's a seawater intrusion zone along the coast in the 1990s, which is several hundred meters wide and several kilometers long (Zhenye, 1999). Large area of seawater intrusion in coastal zone has changed the hydro-geological characteristics, and resulted in an extremely fragile coastal zone of a series of changes. The most obvious sign of coastal changes was the rapid lowering of surface vegetation coverage.

2. Data professing

\footnote{Email: caojianong@lcu.edu.cn; phone+86 0635 8539 939; Supported by Chinese offshore investigation and Assessment (Grant No. 908-01-BC17, 908-01-ZH2, 908-02-03-05).}
2.1 Data acquisition and analysis

Bureau of Water Resources of Longkou city has set up more than 100 groundwater observation holes in the seawater intrusion zone since 1985, in summer and winter in each year water samples have been collected and analyzed in laboratory so as to obtaining a large number of valuable information. Through analysis, they have mastered the causes, the development process and distribution characteristics of the seawater intrusion. Based on the previous work, in August 2000 with the use of GRE-1500 Fifth portable spectrometer, we have tested the vegetation spectral characteristics, spectral characteristics of bare land observed as the center of 30 × 30 quadrats measuring. The relationship and analysis between the calculation of vegetation and the bare land have been found. The results were comparatively analyzed through remote sensing data of vegetation index and the index of bare land. On the one hand, we verified the accuracy of the both calculations; on the other hand, the purpose was to provide a basis of calculating the degree of vegetation. At the same time, through the retrospective it not only tracked the evolution of seawater intrusion, but processed and analyzed the remote sensing survey data and remote sensing data over the same period so as to obtain very valuable acquaintance. It indicated that remote sensing technology in monitoring the dynamics of seawater intrusion had a certain useable value. We also applied TM remote sensing data and image in 2000 to the relevant research.

2.2 The Simplified image

The complexity of the geographical space in coastal zone is bound to lead to the complexity of remote sensing images, not all the characteristics of each type of remote sensing images are favorable to the inversion calculation of seawater intrusion. We have to determine which factors can directly reflect the seawater intrusion of the imaging characteristics of ecological factors. Then we can establish a model inversion (Carder K.L, 1985; Bruun.P, 1954). In order to improve the accuracy of image inversion we should try to minimize the interference image information, that is, the type of noise interference. The influences of seawater intrusion inversion of noise are: roads, villages, reservoirs (fishpond), greenhouses, rivers and so on. These image features associated with the seawater intrusion are extremely small. The amount of information should be reduced as much as possible, thus it can ensure that the amount of very information coincides with the information after the deduction of information and seawater intrusion.

Taking the land sat TM images in 2000 as an example; first we applied the principal components transformation and analysis to analyze the six TM wave bands. Through this transform the first host component element grey level are situated between 48.379 and 496.422; the second host component element grey level is situated between 183.51 and 23.44; the third host component element grey level is situated between -249.02 and 4.8281. Because the visual effect of the image is not well, we should use the histogram equalizing to deal with them. Through the processing various components of the remote sensing image grey level is located the range of 0~255, the remote sensing image visual quality obtains the very big enhancement. Then via counting spectrum characteristics in the villages and small towns, the road, the pond (fishpond), vegetable greenhouses, rivers, sand, we find the first host component remote sensing image in six kinds of the images’ pixel value quite is large and the smallest images’ pixel value is 180. the others smaller than 180, therefore, in the first host component we set the threshold value T=180, and use the two-value approach to be possible to remove the villages and small towns, the path, the pond very conveniently (fishpond), the vegetables greenhouses, the rivers, the sand, and this processing applies to the other components or various wave bands, which will remove the majority types of noise affecting the sea water invasion inversion computation, thus simplify the remote sensing image complexity, and most of the remainder of the remote sensing information is closely related to the intrusion of sea water. We take wave band as the research band, TM3, TM4 and TM5, which passed through correlation coefficient confirmation.
3. The inversion calculation of the seawater intrusion

Analyzing the ground objects spectral data, remote sensing gray value (DN) data, and the observation of groundwater data, we could find that there's a certain degree of correlation among them. In addition to a small number of observation points, the correlation coefficients are between 0.625 ~ 0.718. The degree of relevance has something to do with the area size, the depth of groundwater and seawater intrusion intensity. On the whole, the nearer to the coast, the stronger the correlation is; the shallower salt water depth, the stronger the correlation is, and the stronger seawater intrusion intensity, the stronger the correlation is.

After further analysis of seawater intrusion intensity and the spectral response of remote sensing images we found: Remote sensing data of different bands reflecting the effects of seawater intrusion are very different. The results show that the band TM3, TM4 and TM5 have the relatively good effects. The correlations are beyond 0.65. The band TM1 has the worst effect, the correlations have no more than 0.50. If we take measures to make a necessary processing to the every period of remote sensing image, it may further improve the relevance of both enhance the inversion accuracy. Next taking TM image for example, the means of image Combination algorithms came into inversion intensity of the seawater intrusion.

3.1 Calculation of vegetation coverage

Seawater intrusion is bound to lead to relatively high salt in soil, seriously to a large number of serious cases of plants. The exposed surface will reduce soil moisture and then reduce the biomass as to the growth of vegetation, thus it will lead to reduced vegetation coverage. Therefore, the intrusion of sea water is closely related to vegetation coverage. Multi-spectral remote sensing data of TM contains a wealth of plants growth, the exposed surface and ground water conditions information. The ratio of gray value (DN) of band TM4 and TM3 is an important indicator of green biomass. It is called Vegetation Index and expressed as

\[ V' = \frac{(TM4 - TM3)}{(TM4 + TM3)} \]

Due to strong reflection of red light, Vegetation on the near-infrared has a relatively low reflectance, therefore, the normal difference vegetation remote sensing images of the band TM4-TM3 where vegetation is bound to the gray value greater than zero, that is, DN> 0. So the above-mentioned vegetation index can be improved by:

\[ V = 0 \quad \text{when} \quad TM4-TM3 < 0 \quad (2) \]

\[ V = [TM4 - (256 - TM3) - (TM4 - TM3) + 1]^{1/3} \quad \text{when} \quad TM4-TM3 > 0 \quad (3) \]

In order to further reduce the non-vegetation factors, Formula 2 and Formula 3 directly enhanced the sensitivity of he vegetation on the seawater invasion in fact. However, the vegetation does not mean pure spectra of the reflectance spectrum of vegetation, which can also be tested through the ground to be verified. It should be vegetation, soil brightness, and the shadow of a mixture of factors, and is still a mixed pixel that can not be a true characterization of vegetation coverage. In order to improve the accuracy of vegetation index, we can use pixel decomposition method of linear mixed-pixel decomposition.

According to the linear sub-pixel decomposition operator itself, spectral client component can not be more than the number of pixels involved in decomposition of the linear spectrum band (TM contains 6 bands, SPOT contains 4 bands). As the image has been simplified through on-site investigation, we have chosen three types of geographic things, namely,
vegetation (crops, fruit trees, forests, etc.) as the End member. Based on actual field observations, as far as possible, we choose the right pure pixel training as End member pixel, taking into account the homogeneity of image features and algorithms consumption, choosing a window size of $3 \times 3$. The ENVI image processing software which deals with linear spectral decomposition will result in three kinds of land-cover types of the abundance of images, in which the abundance of vegetation cover gray-scale image pixel based on the size of the percentage.

The vegetation cover of the abundance of images value $N_v$ and their corresponding vegetation index $V$ have been analyzed, the Correlation coefficient between them reaches 0.897, linear regression equation is:

$$ V = 104.82N_v + 0.842 \tag{4} $$

In the formula, $V$ for the abundance of vegetation by the image of vegetation index corrected.

### 3.2 Calculation of index of bare land

Seawater intrusion is also related to the bare land index and it is written by $B$,

$$ B = \frac{(TM4 + TM1) - (TM4 + TM1)}{(TM4 + TM3) + (TM4 + TM1)} \tag{5} $$

With the same $V$, $B$ is still a mixed pixel. We need pixel decomposition technique technology to improve bare land index. The bare land index will has the same algorithm that Vegetation coverage to calculate the bare land index by analyzing the abundance of bare land images pixel value of the abundance of bare land index $B$ for correlation analysis. The Correlation coefficient between them reaches 0.853, so we establish the linear regression equation is:

$$ B = 109.82N_v + 0.895 \tag{6} $$

In the formula, $B$ is the revised bare land index.

Strictly speaking, the vegetation coverage index and the index of bare land should be equal to 1. As the decomposition of linear mixed abundance after the image of the shadow of the pixel value (DN) is very small, basically it can not be considered, which means that the vegetation coverage index and the index of bare land result in two-dimensional space and they should be approximate linear relationship. Figure 1a and Figure 1b, respectively stand for before and after decomposition of the vegetation index with the index consisting of bare land scatter two-dimensional space. It shows that the mixed-pixel decomposition, a revised vegetation index and a bare land index, stands for the truer growth conditions of vegetation.

### 3.3 Calculations of the green degree and the humidity component

In order to improve the accuracy of inversion, we must make a certain number of constraints. As for TM data (in addition to the other six thermal infrared bands), K-T transformation is the access to the second component, which is important indicators reflecting in the quality of plant growth, written by $G$. The third component is the index reflecting the ground water condition, which is called humidity component and written by $H$, Both of them have some relationship.
3.4 Establishment of the inversion model

Using the numerical analysis to the seawater intrusion areas by TM images, the main statistical analysis of TM band 6 for the original gray value and the transformation to the V, B, G, and H show the distribution scope of data and changes law. We find that relations between the extent of seawater intrusion and TM the existence of remote sensing image-band are as follows (Table 1):

<table>
<thead>
<tr>
<th>Severe invasion</th>
<th>B &gt; G</th>
<th>TM5 &gt; TM7 &gt; TM1 &gt; TM3 &gt; TM2 &gt; TM4</th>
<th>H = G = 0</th>
<th>V ≤ 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate invasion</td>
<td>B ≥ G</td>
<td>TM5 &gt; TM7 &gt; TM3 &gt; TM2 &gt; TM4</td>
<td>H &gt; G &gt; 0</td>
<td>V ≤ 1</td>
</tr>
<tr>
<td>Mild invasion</td>
<td>B &lt; G</td>
<td>TM5 &gt; TM1 &gt; TM7 &gt; TM3 &gt; TM2 &gt; TM4</td>
<td>H &gt; G &gt; 0</td>
<td>V ≥ 1</td>
</tr>
<tr>
<td>No invasion</td>
<td>B &lt; G</td>
<td>TM4 &gt; TM5 &gt; TM1 &gt; TM2 &gt; TM3 &gt; TM7</td>
<td>H &gt; G &gt; 0</td>
<td>V ≥ 1</td>
</tr>
</tbody>
</table>

Based on the above relationship, we establish seawater intrusion inversion model and the specific process is:

Let grant the characterization of the extent of seawater intrusion by letter D, The bigger is the D value, the more seriously extent of seawater intrusion is. It can be found: D ↑, B ↑, G ↓, TM4 ↓, H < G ↓, V ↓, TM5 - TM3 ↑. Thus D is proportional to B/GB/V, 1/TM4, 1/H-G, TM3-TM5, the model is:

$$D = \frac{B}{G} \times \frac{1}{V} \times \frac{1}{TM4} \times \frac{1}{H - G} \times \frac{1}{TM3 - TM5}$$  \hspace{1cm} (7)

Clearly the range of D is between 0 and 1. When the value is close to 0, the invasion is very small; when the value is close to 1, the invasion is very severe; when the value is between 0 and 1, the seawater invasion degree is between the two above-mentioned. Therefore the formula 7 can be changed by as follows:
The improved formula will be:

\[
D = \frac{1}{e^{G/H}} \times \frac{1}{e^{V/B}} \times \frac{1}{e^{TM4/H}} \times \frac{1}{e^{TM5}} \in [0,1]
\]

(8)

The improved formula will be:

\[
D = \frac{1}{e^{G/H}} \times \frac{1}{e^{V/B}} \times \frac{1}{e^{TM4/H}} \times \frac{1}{e^{TM5}} \in [0,1]
\]

(9)

As can be seen from the above formula for seawater intrusion, whether serious or not, the contrast between the relations is the same condition. But the extent of seawater intrusion in fact is different from each other that rise and fall of the relationship between changes in the overall trend does not run slightly different circumstances. Therefore, a number of weighting coefficients can be added:

\[
D = \frac{1}{a^{G/H}} \times \frac{1}{b^{V/B}} \times \frac{1}{c^{TM4/H}} \times \frac{1}{d^{TM5}} \in [0,1]
\]

(10)

Based on the concrete data a, b, c, d and e, according to the established equation from a number of selected areas, in the end coefficient can be calculated through the several adjustments: a=13.472; b=7.652; c=10.729; d=4.677; e=11.536.

4 Analysis of the results

The inversion results (D value) and the seawater intrusion in the same period surveyed by the Water Supplies Department in Longkou city the level of observation (chloride ion concentration), can be done with accurate analysis. Thus we can draw the different the corresponding D value, V value and B value which reflect the extent of seawater intrusion as well as the original images corresponding to image features (Table 2).

<table>
<thead>
<tr>
<th>Grade</th>
<th>D value</th>
<th>V value</th>
<th>B value</th>
<th>Landscape and the image features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe invasion</td>
<td>≤0.30</td>
<td>≤0.45</td>
<td>≥0.55</td>
<td>Large white spots, vegetation growth was seriously inhibited</td>
</tr>
<tr>
<td>Moderate invasion</td>
<td>0.30 ~ 0.60</td>
<td>0.45 ~ 0.60</td>
<td>0.40 ~ 0.55</td>
<td>Ground broken, white spots apparent relatively spare vegetation</td>
</tr>
<tr>
<td>Mild invasion</td>
<td>0.60 ~ 0.90</td>
<td>0.60 ~ 0.75</td>
<td>0.25 ~ 0.40</td>
<td>Occasional white spots, no significant changes in vegetation cover</td>
</tr>
<tr>
<td>No invasion</td>
<td>≥0.90</td>
<td>≥0.75</td>
<td>≥0.25</td>
<td>Normal vegetation growth, uniform color</td>
</tr>
</tbody>
</table>

Adopting D value as the abscissa and the measured chloride data in the same period as longitudinal coordinates, the scatter figure are as follows:
The expression of the relevant indicators \( R^2 \) in the figure is:

\[
R^2 = \frac{\sum (C_i - D_i)^2}{\sum (C_i - \bar{C})^2}
\]  

(11)

\( C_i \) is the measured value in formula 11, \( \bar{C} \) is the average value of the measured samples, \( D_i \) is the value of the image spectrum via inversion calculation.

After statistical calculating a correlation coefficient of \( C_i \sim D_i \) is 0.884, thus it can be obtained from the image information which reflects the extent of seawater intrusion through image combination processing.

References