Investigation of the Salinity Distribution of the Soil along West Main Canal in Ningxia, China

Juntao Wu1,3, Hefang Jing1,2*, Weihong Wang1, Xiaoxiao Guo1,3 and Xinxia Guo1,3

1 Research Institute of Numerical Computation and Engineering Applications, North Minzu University, Yinchuan, China
2 The Key Laboratory of Intelligent Information and Big Data Processing of Ningxia Province, North Minzu University, Yinchuan, China
3 School of Mathematics and Information Science, North Minzu University, Yinchuan, China
*Email: jinghef@163.com

Abstract. As one of the main irrigation canals in Ningxia, West Main Canal plays a very important role in the irrigation of the land nearby the canal, such as farms, meadows, and tree farms. Because of the long-term use of the Yellow River water for irrigation, the soil salinization in this area become more serious. In this paper, the problem of soil salinization along the West Main Canal in Ningxia is taken as the research object. 82 sample points in the studied area are chosen and a total number of 164 soil samples are measured for the eight main salt ions and pH value. Correlation analysis and principal component analysis are employed to study the distribution of the soil salinity ions and pH value. In addition, two dimensional interpolation is applied to obtain the spatial distribution of the total saltiness. It can be found that Cl−, SO42−, Ca2+, Na+ and HCO3− are the main salt ions and the main soluble salts are NaCl, KCl, CaSO4, Na2SO4 and CaCl2 in the soil of the studied area. The spatial distribution of the total soil salt is mainly in the patterns of north high and south low, far high and near low, up high and down low.

1. Introduction
According to the incomplete statistics of UNESCO and FAO, the area of China affected by soil salinization is 0. 9 ×10^8 hm^2, mainly distributed in Xinjiang, Hetao Plain, Hexi Corridor, Yinchuan Plain, Qaidam Basin, western Northeast Plain, Huang Huai Hai Plain and coastal areas [1]. The research on the mechanism and characteristics of soil salinization has become the key to soil salinization control [2].

In existing soil salinization research, attention has been provided to the following: causes, spatial distribution, saline soil characteristics, dynamic law of water and salt migration, toxicity mechanism of salt ions, assessment methods, monitoring techniques, early warning mechanisms and simulation of soil salinization [3-8]. The soil structure and traits determine the physical and chemical properties of the soil and affect the movement of soil water and salt. Vegetation coverage and hydrological status also affect the salinization process to some extent. Human activities, including land use method, farming and planting and seawater intrusion caused by over exploitation of groundwater, are also significant causes of soil salt accumulation [9-10]. Hence, accurate quantitative analysis of the causes can provide scientific guidance for the formulation of salinization control plans [11].
However, the problem of the soil salt distribution and transportation of Yellow River irrigation area is very complex and the research in this field is not completed and still has long way to go. The West Main Canal is located in the west of Ningxia and the problem of soil salinization is relative more sever. In this paper, series of methods, including Pearson correlation analysis and principal component analysis are employed to analyze the distribution of soil salinity and pH value of the land long West Main Canal.

2. Study Area and Research Method

2.1. Overview of the Study Area
Ningxia Yellow River diversion irrigation area is located in the upstream of the Yellow River, and there are 11 counties or cities and more than 20 large farms, forest farms and pastures in this area. The irrigation area includes Weining irrigation area and Qingtongxia irrigation area, and there are many canal systems including Tanglai Canal, West Main Canal, East Main Canal, Hanyan Canal, Huinong Canal, with a total length of 1540km. This area belongs to continental climate with drought, little rain and strong evaporation, and the average annual evaporation and precipitation are 1100-1650 mm, and 180-210 mm, respectively. The crops are mainly irrigated by irrigation canals from the Yellow River.

The West Main Canal was built in 1959, it belongs Qingtongxia irrigation area. The total length is 113 km, the maximum water diversion discharge is 60m$^3$/s, and the actual irrigation area is more than 700000 mu.

2.2. Sampling Point Setting
Considering the effects of soil salinization, land use and human activities, 82 sampling points were set up along the West Main Canal by using GPS positioning technology, including 10 sampling points in Nanliang farm, 10 sampling points in Nuanquan farm, 10 sampling points in Helan Mountain farm, 12 sampling points in Pingjibao farm, 12 sampling points in Huangyangtan farm and 28 points in other areas, as shown in figure 1. From September to October in 2019, the project team used soil sampler, ring knife and other instruments for sampling with a total of 164 samples.

![Figure 1. Sampling points distribution along West Main Canal.](image-url)
2.3. Research Methods
Based on Ref. [12], the salt contents and its compositions in the soil samples have been measured. The soil samples are naturally dried and, selected by a 1 mm sieve. The soil extracts are prepared according to the ratio of water and soil 5:1. The contents of various salt ions are determined by various methods, in which \( \text{CO}_3^{2-} \) and \( \text{HCO}_3^- \) are determined by double indicator and titration, \( \text{Cl}^- \) by silver nitrate titration, \( \text{SO}_4^{2-} \) by EDTA indirect collateral titration, \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) by EDTA titration. Na\(^+\) and K\(^+\) were determined by flame photometer. The pH value was determined by pH meter. In this paper, all data were analyzed by Excel and SPSS 25, and soil salt distribution map was drawn by ArcGIS 10.2 and MATLAB.

3. Measured Results and Analysis

3.1. Distribution Characteristics of Soil Salt
From September 10-15, 2019, the project team took 164 soil samples at 0-20cm and 20-40cm at 82 points along the West Main Canal by using soil sampler and ring knife and sent them to professional testing institutions for testing. Eight ions, total salt content and pH value of each soil sample were measured. Table 1 shows the measured values of eight ions, total salt content and pH value of 12 representative soil samples. In the first column of table 1, the soil samples beginning with ‘L’ are from Helan Mountain farm, those with ‘N’ are from Nanliang farm, and those with ‘P’ are from Pingjibao farm.

It can be seen from table 1 that all of the pH values of the representative soil samples are greater than 7, indicating that the study area is dominated by alkaline soil. Among the eight ions, the contents of \( \text{CO}_3^{2-} \), \( \text{Mg}^{2+} \) and \( \text{K}^+ \) are less, while the contents of \( \text{HCO}_3^- \), \( \text{SO}_4^{2-} \) and \( \text{Ca}^{2+} \) are larger.

Table 1. Content of eight ions and pH value of representative samples in the study area.

| Point | pH | \( \text{CO}_3^{2-} \)/g/kg | \( \text{HCO}_3^- \)/g/kg | \( \text{Cl}^- \)/g/kg | \( \text{SO}_4^{2-} \)/g/kg | \( \text{Ca}^{2+} \)/g/kg | \( \text{Mg}^{2+} \)/g/kg | \( \text{Na}^+ \)/g/kg | \( \text{K}^+ \)/g/kg | Total salt content /g/kg |
|-------|----|--------------------------|-------------------------|-----------------|-------------------|-----------------|-------------------|-----------------|-----------------|------------------------|
| L-1   | 9.11 | 0.00                     | 0.48                    | 0.21            | 1.13              | 0.36            | 0.08              | 0.14            | 0.03            | 2.44                   |
| L-2   | 8.75 | 0.00                     | 0.25                    | 0.52            | 2.23              | 0.61            | 0.08              | 0.80            | 0.06            | 4.54                   |
| L-3   | 8.74 | 0.00                     | 0.37                    | 0.17            | 0.39              | 0.34            | 0.04              | 0.08            | 0.03            | 1.42                   |
| L-4   | 8.36 | 0.00                     | 0.35                    | 1.94            | 3.55              | 3.24            | 0.06              | 2.53            | 0.12            | 11.80                  |
| L-5   | 8.62 | 0.00                     | 0.37                    | 0.20            | 0.19              | 0.31            | 0.03              | 0.13            | 0.05            | 1.27                   |
| N-1   | 7.94 | 0.07                     | 1.70                    | 0.14            | 2.12              | 0.81            | 0.24              | 0.03            | 0.01            | 5.10                   |
| N-2   | 9.07 | 0.05                     | 4.78                    | 0.13            | 1.83              | 2.12            | 0.60              | 0.08            | 0.05            | 9.63                   |
| N-3   | 9.80 | 0.26                     | 1.82                    | 0.65            | 1.36              | 0.57            | 0.12              | 0.77            | 0.07            | 5.60                   |
| N-4   | 9.04 | 0.00                     | 0.65                    | 0.13            | 0.46              | 0.22            | 0.08              | 0.05            | 0.01            | 1.60                   |
| N-5   | 8.90 | 0.03                     | 0.37                    | 0.16            | 0.13              | 0.25            | 0.11              | 0.03            | 0.01            | 1.09                   |
| P-1   | 8.02 | 0.44                     | 0.10                    | 0.14            | 0.31              | 0.10            | 0.02              | 0.02            | 1.15            | 0.75                   |
| P-2   | 8.90 | 0.02                     | 0.31                    | 0.14            | 0.11              | 0.13            | 0.04              | 0.01            | 0.01            | 0.76                   |

In order to directly reflect the distribution characteristics of soil salt in the study area, the influencing factors, including pH value, eight ions and total salt contents, for all the soil samples were statistically analyzed, and the parameters such as mean value, median, standard deviation, maximum value, minimum value, coefficient of variation, skewness and peak value were calculated, as shown in table 2.
It can be found from table 2 that the average pH value of the soil in the study area is about 8.9, indicating that the soil in the studied area is mainly alkaline. The last column of table 2 is the K-S (Kolmogorov–Smirnov) test, which can be used to detect whether the sample population obeys a certain distribution [13]. In this paper, K-S test is used to determine whether the influencing factors obey the normal distribution. When the test value is greater than 0.05, it is normal distribution, otherwise it is abnormal distribution. Through the K-S test of soil salinity factors and pH value, it can be seen that the test value of soil pH value is 0.057, indicating that the pH value obeys normal distribution. However, all of the test values of other soil salinity factors are less than 0.05, indicating that they do not obey normal distribution.

The variation coefficient reflects the spatial variation intensity of soil salt content. The coefficient of variation of CO$_3$$^-$, Cl$^-$, Ca$^{2+}$, Na$^+$ in the study area is greater than 1, which indicates that the spatial distribution of each factor is uneven and the change rate is large; however, the variation coefficient of soil pH value, HCO$_3^-$, SO$_4^{2-}$, Mg$^{2+}$, K$^+$ and total salt content are less than 1, indicating that the spatial distribution of these factors is relatively even and the rate of change is small.

3.2. Analysis on the Soil Salinization Degree

According to the classification standard of soil salinization degree in China, soil can be divided into five types according to the total salt content, including non-salinized soil, mild salinized soil, moderate salinized soil, severe salinized soil and salinized soil, as shown in table 3.

### Table 2. The statistical characteristics of salt content and pH of soil in the study area.

| Project       | Average value | Median | Standard deviation | Minimum | Maximum | Coefficient of variation | Skewness | Kurtosis | K-S test |
|---------------|---------------|--------|--------------------|---------|---------|--------------------------|----------|----------|----------|
| pH            | 8.917         | 8.930  | 0.281              | 8.085   | 9.800   | 0.032                    | -0.119   | 0.532    | 0.057    |
| CO$_3$$^-$    | 0.032         | 0.026  | 0.061              | 0       | 0.656   | 1.930                    | 7.469    | 72.618   | 0        |
| HCO$_3^-$     | 0.403         | 0.357  | 0.224              | 0.158   | 1.819   | 0.556                    | 4.118    | 21.512   | 0        |
| Cl$^-$        | 0.209         | 0.147  | 0.236              | 0.066   | 1.936   | 1.128                    | 5.632    | 37.461   | 0        |
| SO$_4^{2-}$   | 0.967         | 0.896  | 0.701              | 0.058   | 3.904   | 0.725                    | 1.531    | 3.491    | 0.001    |
| Ca$^{2+}$     | 0.297         | 0.232  | 0.301              | 0.105   | 3.245   | 1.014                    | 7.185    | 64.337   | 0        |
| Mg$^{2+}$     | 0.106         | 0.101  | 0.062              | 0.005   | 0.452   | 0.0590                   | 1.760    | 6.188    | 0        |
| Na$^+$        | 0.159         | 0.073  | 0.316              | 0.011   | 2.533   | 1.985                    | 5.674    | 37.364   | 0        |
| K$^+$         | 0.031         | 0.025  | 0.024              | 0.004   | 0.154   | 0.782                    | 2.457    | 7.339    | 0        |
| Total salt content | 2.204 | 1.873  | 1.423              | 0.739   | 11.797  | 0.646                    | 3.820    | 19.945   | 0        |

According to the standard, 164 samples along the West Main Canal were classified into above five types, as shown in figure 2. The ratio of non-salinized soil to salinized soil is 1:32, and the proportion of salinized soil is about 96.8% in all of the soil samples. Among them, the proportion of mild and moderate salinized soil samples is about 87.1%, and the proportion of severe salinized soil and salinized soil is 9.7%.

### Table 3. Classification standard of soil salinization degree.

| Soil type       | Non salinized soil | Slightly salinized soil | Moderately salinized soil | Heavily salinized soil | Saline soil |
|-----------------|--------------------|-------------------------|---------------------------|-----------------------|-------------|
| Salt content (g/kg) | <1                 | 1~2                     | 2~4                      | 4~10                  | >10         |

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3.3. Correlation Analysis of Soil Salinity Factors
In order to analyze the specific composition in the soil salinity, it is necessary to analyze the correlation of salt ions. Pearson correlation analysis is applied to obtain the internal correlated relationships between each of two different factors, as shown in table 4. It can be found that the total salinity has a very significant positive correlation with Cl\(^{-}\), SO\(_4^{2-}\), Ca\(^{2+}\), Na\(^{+}\), among which Ca\(^{2+}\) has the highest correlation coefficient of 0.882, followed by SO\(_4^{2-}\), with a correlation coefficient of 0.870. In addition, the soil salt ions are also positively correlated. Under the significance level \(\alpha = 0.01\), the correlation coefficient between Na\(^{+}\) and Cl\(^{-}\) is the highest (=0.976), followed by Cl\(^{-}\) and K\(^{+}\) with a correlation coefficient of 0.683. SO\(_4^{2-}\) had a strong correlation with Ca\(^{2+}\), Na\(^{+}\), with correlation coefficients of 0.673 and 0.662, respectively. Therefore, it can be concluded that the order of the main soluble salts are NaCl, KCl, CaSO\(_4\) and Na\(_2\)SO\(_4\) in the studied area.

Table 4. Pearson correlation analysis matrix of soil salinization index in the study area.

|          | pH   | CO\(_3^{2-}\) | HCO\(_3^{-}\) | Cl\(^{-}\) | SO\(_4^{2-}\) | Ca\(^{2+}\) | Mg\(^{2+}\) | Na\(^{+}\) | K\(^{+}\) | Total salt content |
|----------|------|----------------|----------------|------------|--------------|------------|------------|-----------|-----------|-------------------|
| pH       | 1    |                |                |            |              |            |            |           |           |                   |
| CO\(_3^{2-}\) | 0.424** | 1               |                |            |              |            |            |           |           |                   |
| HCO\(_3^{-}\) | 0.126 | 0.368**        | 1              |            |              |            |            |           |           |                   |
| Cl\(^{-}\)   | -0.300** | 0.101          | 0.044          | 1          |              |            |            |           |           |                   |
| SO\(_4^{2-}\) | -0.269** | 0.170*         | 0.210**        | 0.639**    | 1            |            |            |           |           |                   |
| Ca\(^{2+}\)  | -0.275** | 0.253**        | 0.505**        | 0.595**    | 0.673**      | 1          |            |           |           |                   |
| Mg\(^{2+}\)  | 0.107  | 0.519**        | 0.588**        | 0.218**    | 0.513**      | 0.630**    | 1          |            |           |                   |
| Na\(^{+}\)   | -0.209** | 0.167*         | 0.075          | 0.976**    | 0.662**      | 0.622**    | 0.275**    | 1          |           |                   |
| K\(^{+}\)    | -0.083 | 0.376**        | 0.260**        | 0.683**    | 0.517**      | 0.506**    | 0.481**    | 0.694**    | 1          |                   |
| Total salt content | -0.190* | 0.352**        | 0.526**        | 0.743**    | 0.870**      | 0.882**    | 0.694**    | 0.776**    | 0.677**   | 1                 |

\(^a\)Note: In significance level in hypothesis test, ** indicates \(\alpha = 0.01\), and * indicates \(\alpha = 0.05\).  

3.4. Principal Component Analysis of Soil Salinity Factors
In order to further analyze the ion distribution along West Main Canal, principal component analysis method is employed to acquire the leading factors of soil salinity. The principal component analysis has been conducted in following factors: total salt content, pH value, CO\(_3^{2-}\), HCO\(_3^{-}\), Cl\(^{-}\), SO\(_4^{2-}\), Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\), K\(^{+}\), and eigenvalue, contribution rates and load matrices of principal components are
calculate, as shown in tables 5 and 6. It can be seen that the initial eigenvalues of the first three components are greater than 1, so the first three components are chosen as the principal components. The contribution rate of each principal component is 52.1%, 19.8% and 10.7% respectively, and the cumulative contribution rate of the first three principal components is 82.6%, which indicates that the first three principal components can approximately represent the information contained in the original 10 components.

**Table 5.** Eigenvalue and variance contribution rate of principal components of soil salinization.

| Component | Initial eigenvalue | Extract the sum of squares of loads | Sum of squares of rotating loads |
|-----------|--------------------|------------------------------------|--------------------------------|
|           | Total              | Variance percentage /% | Accumulate /% | Total              | Variance percentage /% | Accumulate /% |
| 1         | 5.208              | 52.084                            | 52.084      | 5.208              | 52.084                            | 52.084      |
| 2         | 1.977              | 19.769                            | 71.853      | 1.977              | 19.769                            | 67.103      |
| 3         | 1.075              | 10.749                            | 82.602      | 1.075              | 10.749                            | 82.602      |
| 4         | 0.503              | 5.029                             | 87.632      | 0.503              | 5.029                             | 82.602      |
| 5         | 0.465              | 4.65                              | 92.281      | 0.465              | 4.65                              | 67.103      |
| 6         | 0.354              | 3.54                              | 95.821      | 0.354              | 3.54                              | 82.602      |
| 7         | 0.25               | 2.5                               | 98.321      | 0.25               | 2.5                               | 67.103      |
| 8         | 0.15               | 1.5                               | 99.821      | 0.15               | 1.5                               | 82.602      |
| 9         | 0.018              | 0.179                             | 100         | 0.018              | 0.179                             | 82.602      |
| 10        | -3.69E-16          | -3.69E-15                         | 100         | -3.69E-16          | -3.69E-15                         | 100         |

**Table 6.** Principal component load matrix.

| Index       | Component | 1     | 2     | 3     |
|-------------|-----------|-------|-------|-------|
| pH          | -0.197    | 0.689 | 0.527 |
| CO$_3^{2-}$ | 0.394     | 0.682 | 0.383 |
| HCO$_3^{-}$ | 0.463     | 0.607 | -0.427|
| Cl$^{-}$    | 0.804     | -0.455| 0.293 |
| SO$_4^{2-}$ | 0.824     | -0.175| -0.109|
| Ca$^{2+}$   | 0.863     | 0.025 | -0.312|
| Mg$^{2+}$   | 0.685     | 0.535 | -0.208|
| Na$^+$      | 0.831     | -0.376| 0.328 |
| K$^+$       | 0.777     | -0.014| 0.330 |
| Total salt  | 0.984     | 0.031 | -0.115|

It can be found in table 6 that in the first principal component, total salinity, Ca$^{2+}$, Na$^+$, SO$_4^{2-}$, Cl$^{-}$ have larger positive load values, and their values are 0.984, 0.863, 0.831, 0.824 and 0.804, respectively. Therefore, total salinity, Ca$^{2+}$, Na$^+$, SO$_4^{2-}$, Cl$^{-}$ are closely related to the soil salinization in the West Main Canal. In the second principal component, the loading values of pH, HCO$_3^{-}$ and CO$_3^{2-}$ are relatively larger than other components, indicating that the soil salinization in the West Main Canal is also affected by carbonates and pH value. In the third principal component, the loading value of K$^+$ is also relatively larger, which indicates that K$^+$ is related to the soil salinization in the studied area.
3.5. Spatial Distribution of Soil Total Salinity

Kriging interpolation method is employed to obtain the soil total salinity at 0-20cm and 20-40cm soil layers in the study area, as shown in figure 3.

![Distribution of total salinity](image)

**Figure 3.** Distribution of total salinity.

It can be seen that the total salinity of soil has a trend of high in the north and low in the south. The elevation of the studied area is in a trend of reduction from the south to the north. When the soil is irrigated by the water of the Yellow River, the salinity in the Yellow River water seeps into the soil along the West Main Canal, and part of the salinity can return back into the Yellow River through drainage ditches. However, because the elevation of the north in West Main Canal is low, the salinity seeped in the soil cannot be completely released. The salinity is accumulated in the soil. As a result, the soil salinity is higher in the north and lower in the south.

From the vertical distribution of total salinity, it is generally higher at the surface soil (0-20cm) than that of deeper soil (20-40cm). The reason is that the sampling was carried out in the autumn in 2019, when most of the crops had been harvested, and the water in the soil was strongly evaporated. As a result, the salinity was brought to the soil surface by the water flow.

In order to further reflect the salt distribution characteristics along the West Main Canal, the total salinity of 0-20 cm and 20-40 cm soil layers in the studied area is drawn by 2D interpolation based on the measured data, as shown in figure 4. It can be seen that the soil salinity in the study area is higher in the south and lower in the north along the West Main Canal. Generally speaking, the salinity is lower near the canal and higher far away from the canal. This is because the water of the canal flows into the soil through branch canal system, and the salinity is also brought into the surrounding area at the same time. The elevation near the canal is relatively high, and the elevation of surrounding area is relatively lower. As a result, the water cannot be discharged completely, and the salinity is higher far away from the canal.
4. Conclusions
The soil salinity components along West main canal of Ningxia is measured and analyzed. Series of methods including Pearson correlation analysis, principal component analysis and 2D interpolation, are employed to analyze the characteristics of soil salinity in the studied area. The main conclusions are as follows:

(1) According to the sampling analysis about the data in the autumn of 2019, the proportion of salinized soil along West Main Canal is about 97%, of which the mild and moderate salinized soil occupy about 87%, and the severe salinized soil and salinized soil are about 10%.

(2) The soil in the studied area is mainly alkaline and the alkalinity is strong.

(3) Pearson correlation analysis and the principal component analysis show that Cl\(^{-}\), SO\(_4^{2-}\), Ca\(^{2+}\), Na\(^{+}\), and K\(^{+}\) are the main components of soil salt contents in the study area, and the main forms of soluble salt in the study area are NaCl, KCl, CaSO\(_4\), and Na\(_2\)SO\(_4\).

(4) The distribution of the soil salinity in the studied area are obtained by horizontal interpolation based on the measured data. The results show that the spatial distribution of total soil salinity in the study area present a trend of north large and south small, far away large and nearby small, upper large and down small.

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