Comparative study of soil erosion along the Middle Route of South-to-North Water Transfer Project based on RUSLE model

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Abstract. In order to probe the impact of the construction of the Middle Route of the South-to-North Water Transfer Project on soil erosion in its buffer area and to offer support on decision which improve the surrounding soil and water environment, this paper conducts a comparative study on soil erosion in 2010 and 2015 based on the RUSLE model. The results show that: 1) the soil erosion modulus in 2010 and 2015 are both at the level of micro-erosion; 2) the effect of project on erosion becomes apparent in 200-500m buffer zone of the main canal, and the most severe buffer zone is in 200-300m; 3) with the increase of buffer distance, the soil erosion modulus in 2015 fluctuates as similarly as that does in 2010.

1. Introduction
As a typical water conservancy project, the Middle Route of South-to-North Water Transfer Project is a strategic project aiming to optimize the allocation of water resources across regions and to alleviate the shortage of water in the Huang-Huai-Hai Plain, but the construction has an impact on the environment. Soil erosion is an important factor of land degradation and ecological environment deterioration[1]. At present, most researches on soil erosion focused on administrative regions or river basins, while few researches were relevant to projects-affected areas. Thus, a comparative study of soil erosion in 2010 and 2015 is carried out to clarify the effect on the surrounding soil erosion, and to provide a strategic basis as to improve the surrounding soil and water environment.

2. Study Area
The Middle Route of the South-to-North Water Transfer Project originates from Danjiangkou Reservoir, travels to north along the Beijing-Guangzhou railway, and reaches Beijing and Tianjin via the North China Plain. The main canal exceeds 1400 kilometers, and the water supply area reaches 155,000 square kilometers, which solves the water problems along the route. The main canal spans Henan, Hebei, Beijing and Tianjin provinces (municipalities directly under the central government). The terrain, climate, biological zone and soil along the main canal are rich and diverse.

The project came into play in 2014, so this paper explores the soil erosion in 2010 and 2015. Besides, as the buffer zone along the main canal is the area strongly affected by project, this paper selects the 1000m buffer zone along the main canal as the research area.
3. Empirical Analysis

The universal soil erosion model (RUSLE) is the most widely used empirical model to calculate soil erosion modulus and to evaluate soil erosion quantitatively[2]. The formula is as follows:

\[ SI = R \times K \times L \times S \times P \times C \]  

(1)

Where, \( SI \) is the annual average soil erosion modulus; \( R, K, L, S, P \) and \( C \) are rainfall erosion factor, soil erosion factor, slope length factor, slope factor, soil and water conservation measures factor and vegetation cover factor respectively.

However, for the factors of the universal model, many scholars proposed different research methods or optimized them. Based on the results of previous studies, this paper determines the calculation methods of the factors to reach the soil erosion modulus in 2010 and 2015. The methods are more sophisticated and more applicable to the geographical environment of the study area.

3.1. Rainfall erosion factor

Rainfall erosion factors such as rainfall intensity, rainfall and raindrop size and velocity affect the amount of soil erosion[3]. Since most of the study area is located in the North China, based on the daily rainfall data of 31 sites including the study area are downloaded from the NOAA website, Su's research results of rainfall erosivity factor are used to calculate the factor, and the formula is as follows:

\[ R = 105.44 \left( \frac{P_{6-9}}{P} \right)^{1.2} \]  

(2)

Where, \( R \) is the rainfall erosion factor; \( P_{6-9} \) is the total rainfall from June to September of that year. \( P \) is the current year's rainfall.

3.2. Soil erosion factor

Soil erosion factor characterizes the degree of soil erosion[5]. This study uses EPIC model to calculate \( K \) value, and the formula is as follows:

\[ K = \left( 0.2 + 0.3e^{-0.0256S_d(1-S_i/100)} \right) \times \left( \frac{S_i}{C_i+S_i} \right)^{0.3} \times \left[ 1.0 - \frac{0.25C}{C+e^{3.72-2.95C}} \right] \times \left[ 1.0 - \frac{0.75SN}{SN+e^{-5.51+22.95N}} \right] \]  

(3)

Where, \( S_d, S_i \) and \( C_l \) represent the content of sand, silt and clay respectively. \( SN = 1 - S_d/100 \); \( C \) represents soil organic carbon content, which can be obtained by dividing the organic matter content by 1.724. The data used for this factor are downloaded from the Resource and Environment Data Cloud Platform and the National Earth System Science Data Center.

3.3. Slope length factor

Soil erosion increases with the increase of slope length. This study applies Mccool's method of calculating slope length, and the formula is as follows:

\[ L = \left( \frac{\lambda}{22.13} \right)^\alpha \]  

(4)

\[ \alpha = \beta / (\beta + 1) \]  

(5)

\[ \beta = (\sin \theta / 0.0896) / (3.0 \sin \theta^{0.8} + 0.56) \]  

(6)

Where, \( \lambda \) is the cumulative grid slope length; \( \alpha \) is slope length factor index; \( \beta \) is the slope length index; \( \theta \) is a slope.

When calculating the grid slope length of this factor, this study introduces the interruption factor as the critical point from erosion to deposition[7]. The cumulative grid slope length is solved through the process of filling in the depression, calculating the flow direction of grid unit, identifying local elevation points, calculating the non-cumulative slope length of grid unit, and calculating the cumulative slope length of grid unit.
3.4. Slope factor
The amount of soil erosion increases nonlinearly with the increase of slope, and the mode of soil erosion gradually develops towards the direction of landslide and collapse[8]. This study calculate the slope factor just as Hu does[9], and the formula is as follows:

\[
S = \begin{cases} 
10.8 \times \sin \theta + 0.03, & \theta < 5^\circ \\
16.8 \times \sin \theta - 0.5, & 5 \leq \theta \leq 10^\circ \\
21.92 \times \sin \theta - 0.96, & \theta > 10^\circ 
\end{cases}
\] (7)

Where, \(S\) is the slope factor; \(\theta\) is a slope. Data were obtained from the national satellite remote sensing application center.

3.5. Soil and water conservation factor
Soil and water conservation measures are a series of measures including engineering and plant, which aim to reduce soil erosion. The range of soil and water conservation measure factor \(P\) is between 0 and 1. 0 represents the area without soil erosion, and 1 represents the area without any soil and water conservation measures. Based on previous achievements, this study summarizes soil and water conservation factors of different land cover types, as shown in Table 1. Land cover types use the MODIS products in 2010 and 2015.

| Types                  | \(P\) | Types                  | \(P\) | Types                  | \(P\) |
|------------------------|-------|------------------------|-------|------------------------|-------|
| Water Bodies /Snow and Ice | 0     | Woody Savannas         | 1     | Cropland - Natural Vegetation Mosaic | 0.25  |
| Permanent Wetlands     | 1     | Savannas               | 1     | Croplands              | 0.15  |
| Deciduous Broadleaf Forest   | 1     | Closed Shrublands      | 1     | Urban Areas            | 0     |
| Mixed Forests          | 1     | Grasslands             | 1     | Unclassified area      | 1     |

3.6. Vegetation cover and management factors
Vegetation can weaken and intercept runoff, improve soil erosion resistance and soil properties, and increase precipitation infiltration[10]. This study uses Cai’s[11] method to study soil erosion amount, and the formula is as follows:

\[
C = \begin{cases} 
1, & c = 0 \\
0.6508 - 0.3436 \log c, & 0 < c < 78.3% \\
0, & c \geq 78.3% 
\end{cases}
\] (8)

Where, \(C\) is the vegetation and management factor; \(c\) is vegetation coverage, represented by NDVI in MODIS vegetation coverage product.

In the light of the formula 2 to formula 8, the values of each factor can be calculated. Based on them, the soil erosion modulus can be obtained by formula 1. The soil erosion modulus in 2010 and 2015 are shown in Figure 1.
4. Results

According to the “Standards for classification and gradation of soil erosion (SL190-2007)”, this paper classifies the soil erosion modulus in 2010 and 2015, and they are both at the level of micro-erosion, which means the soil erosion are both slight in 2010 and 2015. With the increase of buffer distance, the soil erosion modulus in 2015 fluctuates similarly as that does in 2010. The farther away from the main canal, the soil erosion modulus in 2010 is always higher than that in 2015, which indicates that the change of environment will improve the soil erosion situation on the basis of little impact of the project.

We calculate the average soil erosion modulus of each 100m buffer zone in the range of 1000m, and make the following conclusions. In 2015, due to the existence of canal protection vegetation and environmental effect, the soil erosion modulus is lower than that in 2010 in the 0-100m buffer zone. By refining the buffer zone, it is found that the effect of project on erosion becomes apparent in 200-500m buffer zone. In 200-300m buffer zones, the soil erosion modulus in 2015 surpassed that in 2010. And the difference between 2015 and 2010 is significantly higher than that in other zones, which means the zone is the most severely affected by project. In the 300-400m buffer zone, the soil erosion modulus in 2015 is always slightly higher than that in 2010. In 400-500m buffer zone, the soil erosion modulus in 2010 and 2015 are basically the same. Outside the 500m buffer zone, as the distance from the main canal increases, the soil erosion modulus in 2010 is once again higher than that in 2015, which means the project effect is weakened. The average soil erosion modulus in each buffer zone are shown in Figure 2-(a).
We also calculated the average soil erosion modulus within several distances from the main canal, and draw some conclusions as below. Within 300m, the soil erosion increases first and then decreases in 2010, while in 2015, the modulus of soil erosion continues to rise, which shows the latter has been effected by project compared with the former. The soil erosion modulus in 2010 and 2015 are almost equal within 400m. The same is true within 500m, which says the environmental effects and project construction impact are balanced within 400m and 500m. Within 600m, the soil erosion modulus in 2010 is once again higher than that in 2015, and it is extended with a stable difference after that, which indicates that the effect of the project falls into a decline with the increase of the distance from the main canal. The average soil erosion modulus within several distances from the main canal are shown in Figure 2-(b).

5. Conclusion
This paper explores the effect of water conservancy project construction on soil erosion. We take the Middle Route of South-to-North Water Transfer Project as an example and research the impact of the project construction on the buffer area based on RUSLE model. The results show that the soil erosion modulus in 2015 is lower than 2010 in the 0-100m buffer zone; the effect of project on soil erosion becomes obvious in 200-500m buffer zone, and the most severe zone is 200-300m buffer zone; with the increase of distance, the soil erosion modulus in 2015 fluctuates as similarly as that does in 2010 and the effect of the project fades.

Although the comparative results of soil erosion in 2010 and 2015 is summarized, the overall soil erosion modulus does not change too much. It may be that the influence caused by the project is not fully reflected in the initial stage of operation. In the follow-up study, we should expand the regional scope and time span to analyze the impact of water conservancy projects on soil erosion.

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References
[1] Liang, J.F., Wei, X.C., Ma, S.L., Yan, H., Xia, C.H. (2019) Research on Soil Erosion in Sansui County, Guizhou Province Based on RUSLE Model. Pearl River., 40(08):13-18.
[2] Hu, X.P., Zeng, C., Qian, Q.H., Wang, Q., Li, Y.B. (2019) Using RUSLE Model to Analyze Temporal and Spatial Characteristics of Soil Erosion in Tongren Area From 1987 to 2015. Journal of Ecology and Rural Environment., (02):158-166.
[3] Feng, Z.X., Qiao, G.J. (2012) Analysis on Soil Erosion Influenced by Rainfall Process. South-to-North Water Transfers and Water Science & Technology., 10(A02):137-138.
[4] Su, X.J. (2018) Study on the Formula of Rainfall Erosion Factor R Applicable to North China. Soil and Water Conservation Science and Technology in Shanxi., (4):17-19.
[5] Zhu, M.Y., Tan, S.D., Zhang, Q.F. (2014) Characteristics of soil Erodibility in the South-to-North Water Transfer Project(Middle Route), China. Resources and Environment in the Yangtze Basin., 23(08):1161-1165.

[6] Mccool, D.K., Foster, G.R., Mutchler, C.K., Meyer, L.D. (1989) Revised Slope Length Factor for the Universal Soil Loss Equation. Transactions of the ASAE., 32(5):1571-1576.

[7] Cao, L.X., Fu, S.H. (2007) A Comparison of Methods for Computing Slope Length Based on DEM. Bulletin of Soil and Water Conservation., 27(5):58-62.

[8] Chen, M.H., Zhou, F.J., Huang, Y.H., Lu, C.L., Lin, F.X. (1995) Effect of Slope Gradient and Slope Length on Soil Erosion. Journal of Soil and Water Conservation., 009(001):31-36.

[9] Hu, S.Y. (2018) Research on spatial-temporal changes of eco-environment quality in Hubei province. Wuhan University.,75.

[10] Han, P., Li, X.X. (2008) Study on Soil Erosion and Vegetation Effect on Soil Conservation in the Yellow River Basin. Journal of Basic Science and Engineering., (02):181-190.