Path analysis of water use efficiency in water diversion and irrigation areas in the lower Yellow River

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Abstract. The evaluation of water use efficiency is a comprehensive and continuous evaluation of irrigation water use efficiency in an irrigation district. The relationship between the main impact factors can effectively improve the accuracy and rationality of the results. Based on the data from 2005 to 2014 in the Yellow River irrigation area of the lower reaches of the Yellow River, this paper determined the direct effect, indirect effect, determination coefficient of the eight quantitative impact factors, as well as the difference of total contribution to R², through the mathematical method of path analysis. Through the calculation data and analysis, it is found that the completion rate of supporting facilities is the most important influencing factor for the water use efficiency of the water diversion and irrigation areas in the lower Yellow River. The completion rate of supporting facilities also plays a role in the investment of water-saving projects, channel length and channel lining rate, which plays a significant role of water diversion and irrigation areas in the lower Yellow River. and the least influential factor is precipitation. The above studies have identified the existing problems and weak links in the process of water resources management in the Yellow River Diverssion Irrigation Area, providing technical support for the scientific planning and sustainable development of the Yellow River Diverssion Irrigation Area in the next step.

1. Introduction
Water is the source of life, the key to production and the basis of ecology [1]. The average annual water shortage in China reaches more than 50 billion m³, and the contradiction between supply and demand of water resources is very significant [2]. At present, the effective utilization coefficient of irrigation water in China is only 0.50, which is significantly different from the world advanced level of 0.7 ~ 0.8 [3]. The No. 1 document of the CPC Central Committee and the State Council in 2011 clearly pointed out that: By 2020, the effective utilization coefficient of national irrigation water should be raised to above 0.55, the control red line of water use efficiency should be firmly established, and the waste of water resources should be resolutely curbed. Water saving should be regarded as a long-term and arduous task, running through the whole process of national economic development and people's production and life [4]. Therefore, it is a long-term strategic task for China to vigorously save water.
resources and continuously improve the efficiency of agricultural water use, so as to effectively guarantee the irrigation effect in the irrigated areas. In 1921, S. Right proposed the calculation method of Path Coefficient for the first time. Path Analysis is a multivariate statistical Analysis method that studies the mutual relationship between direct and indirect effects of variables, and the interaction mode and degree of independent variables on dependent variables. Through the results of path analysis, the direct and indirect effects of independent variables on dependent variables can be found, the independent variables caused by the strong correlation between independent variables can be determined, and the unnecessary independent variables can be removed through the index sensitivity analysis, so as to establish the best and simple regression equation [5-6]. Path analysis has been used in the field of agricultural breeding and cultivation since the 1950s. Then, Ming Daoxu introduced in detail the principle and calculation method of path analysis, mathematical derivation process, correlation analysis and test among traits through cases [5-6]. At present, for the application of path analysis, there are many research results from different cases and perspectives, but few results related to the water use efficiency and comprehensive completeness of the water diversion and irrigation areas in the lower Yellow River. Previous research has made of Yellow River irrigation water use efficiency in some basis, this paper established by the method of path analysis of direct and indirect utility significant impact factors, and to determine the relationship among these factors. Thus, the utilization effect of water resources can be improved, the most stringent water resources management system can be implemented better, and the development of irrigation areas can be served better.

2. Case study and calculation method

2.1. Basic information of the study area

The total land area of Sanyizhai water diversion and irrigation areas in the lower Yellow River in Henan Province is 4 344.2 km², and the total cultivated land area is 270,000 hm²[7]. At present, the water diversion capacity of the irrigation area is about 150 m³/s, and the effective irrigation area involves 9 counties (districts) in Kaifeng and Shangqiu: Xiangfu District, Lankao County, Qi County, Minquan County, Ningling County, Suiyang District, Liangyuan District, Sui County and Yucheng County, etc. [8]. In order to facilitate the division and management, Lankao County is mainly divided into Lankao South District and Lankao North District by taking the Lankao Main Canal as the boundary when dividing the two administrative areas. Minquan County is mainly bordered by the old Yellow River route, which is divided into the southern and northern districts of Minquan. The rest of the administrative region is divided into a separate district according to the administrative region, that is, Kaifeng County, Qi County, Sui County, Ningling District, Shangqiu City, Yucheng District.

2.2. Path analysis calculation steps

Path coefficient is a statistic representing the influence relationship between related variables. It is a variable standardized partial regression coefficient without unit. It is the correlation coefficient with direction between independent variable and dependent variable. Path coefficient is the partial regression coefficient after the standardization of variables, and its mathematical model is the multiple linear regression model after the standardization of partial regression coefficient [9-10]. In order to make the results accurate and easy to understand, the relevant matrix algorithm [6] and mathematical model [11] are used in this paper to carry out the related calculation of path analysis. For an interrelated system, if there are \( n \) independent variables \( x_i \) \((i = 1,2,...)\) and one dependent variable \( y \), and the regression equation is

\[
y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n \tag{1}
\]

According to the simple correlation coefficient \( r_{xy} \) \((i,j \leq n)\) between the respective variables and the simple correlation coefficient \( r_{xy} \) \((i \leq n)\) between the respective variables and the dependent variable, through mathematical transformation of Equation (1), the normal matrix equation is established as
By solving the matrix equation (2), the path coefficient \( P_{yxi} \) can be obtained, which represents the direct path coefficient of the independent variable \( x_i \) on the dependent variable \( y \), and is the direct action effect of \( x_i \) on \( y \). \( r_{xixj} \) represents the indirect path coefficient of independent variable \( x_i \) on dependent variable \( y \) through \( x_j \), and is the indirect effect of \( x_i \) on dependent variable \( y \) through \( x_j \). The path coefficient \( P_{yxe} \) of the remaining term is expressed as

\[
P_{yxe} = \sqrt{1 - (r_{xy}P_{yxe} + r_{xyp}P_{xy} + \cdots + r_{xyp}P_{yxe})}
\]

If the path coefficient \( P_{yxe} \) of the remaining items is small, it indicates that the main factors affecting the dependent variables have been found out. If the value of \( P_{yxe} \) is large, it indicates that the test error is large or more important independent variables are not taken into account [9].

\[
d_{y} = b_{y} \frac{\sigma_{e}^2}{\sigma_{y}^2} = p_{y}^2 (i = 1, 2, \cdots, m)
\]

\[
d_{y} = 2p_{x}p_{y} r_{x} (i, j = 1, 2, \cdots, m, i < j)
\]

\[
d_{y} = 1 - \left( \sum_{i=1}^{n} d_{x} + \sum_{j=1}^{m} d_{y} \right)
\]

3. Path analysis of water use efficiency in water diversion and irrigation areas in the lower Yellow River

3.1. Selection of impact factors

According to the previous research results [12], the water use efficiency of Sanyizhai Irrigation Area in Henan Province was evaluated on the basis of 11 index data from 2005 to 2014, including 9 quantitative indicators and 2 qualitative indicators, and the fuzzy optimization evaluation with multiple weights was carried out. Path analysis was based on the years as the calculating unit, select ten samples of 2005-2014, and considering repeatability and computation between the various evaluation index, excluding two qualitative indicators and a quantitative index, select the following eight factors affecting the sizing analysis: engineering factors of supporting facilities of the pipe, actual diverted, channel length, channel lining rate, actual irrigation area; Precipitation and groundwater resource modulus in natural factors; management factors in water-saving project investment. Because three different weights were used for fuzzy optimization evaluation of water use efficiency in the irrigation area, the average value of the three evaluation results was determined as the dependent variable. Through the calculation and screening of path analysis of water use efficiency in the Water diversion and irrigation areas in the lower Yellow River, the analysis indexes used include the correlation coefficient \( r_{ij} \), path coefficient \( P_{yxi} \), determination coefficient \( d_{y} \) and the total contribution to the reliability degree of regression equation \( R^2 \), etc.

3.2. Path analysis of water use efficiency

In the path analysis of water use efficiency in Sanyizhai Water diversion and irrigation areas in the lower Yellow River, 8 influencing factors were selected: Facilities intact rate \( (X_i) \), the actual diverted
(X2), channel length (X3), channel lining rate (X4), the actual irrigation area (X5), precipitation (X6), modulus (X7) of groundwater resources, water saving engineering investment (X8), the dependent variable for processing after the water level of efficiency evaluation of characteristic value Y1, according to the size coefficient and correlation coefficient (as shown in Table 1), get the water diversion and irrigation areas in the lower Yellow River water use efficiency and eight sizing chart, impact factor and error due to the limited sheet only marked with the correlation coefficient of impact factor X1, as shown in Figure 1.

![Figure 1. Path relation diagram of 8 influencing factors on water use efficiency in Water diversion and irrigation areas in the lower Yellow River](image_url)

### Table 1. Correlation coefficient $r$ between efficiency and influencing factors in the Water diversion and irrigation areas in the lower Yellow River

| Factor | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | Y1 |
|--------|----|----|----|----|----|----|----|----|----|
| X1     | 1.0000 | 0.9188 | 0.8424 | 0.8917 | 0.6086 | -0.2798 | 0.3248 | 0.8898 | 1.0000 |
| X2     | 0.9188 | 1.0000 | 0.9361 | 0.8418 | 0.5344 | -0.0936 | 0.4664 | 0.6657 | 0.9188 |
| X3     | 0.8424 | 0.9361 | 1.0000 | 0.6555 | 0.6913 | -0.0095 | 0.4313 | 0.5332 | 0.8424 |
| X4     | 0.8917 | 0.8418 | 0.6555 | 1.0000 | 0.2826 | -0.2587 | 0.4846 | 0.7099 | 0.8917 |
| X5     | 0.6086 | 0.5344 | 0.6913 | 0.2826 | 1.0000 | -0.2183 | -0.1819 | 0.4924 | 0.6086 |
| X6     | -0.2798 | -0.0936 | -0.0095 | -0.2587 | -0.2183 | 1.0000 | 0.5431 | -0.5403 | -0.2798 |
| X7     | 0.3248 | 0.4664 | 0.4313 | 0.4846 | -0.1819 | 0.5431 | 1.0000 | 0.0220 | 0.3248 |
| X8     | 0.8898 | 0.6657 | 0.5332 | 0.7909 | 0.4924 | -0.5403 | 0.0220 | 1.0000 | 0.8898 |

After the equation (2) is converted into a normal matrix equation, the normal equations of 8 influencing factors $X_i$ and $Y_1$ on the path coefficient $P_{y1i}$ are solved, and the direct and indirect effects of each influencing factor on the water use efficiency in the water diversion and irrigation areas in the lower Yellow River are calculated. The results are shown in Table 2. The formula (4) - (7) to calculate the impact factors and according to the absolute value of the coefficient of decision between size sorting, analysis of eight independent variables in regression equations to estimate reliability $R^2$ total.
contributions, will be the biggest decision before 6 and error coefficient of sorting, $R^2$ total contributions of each independent variable of the previous seven factors as shown in Table 3.

Table 2. The influence factors direct and indirect effects on the water use efficiency in the Water diversion and irrigation areas in the lower Yellow River

| Independent variable | Correlation coefficient $r_{x_i}$ | Direct effect $P_{x_i}$ | Indirect effect (By the following independent variables) Total $X_i$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ |
|----------------------|-----------------------------------|------------------------|------------------------------------------|-------|-------|-------|-------|-------|-------|
| $X_1$                | 0.8375                            | -0.9698                | 0.9532                                   | 0.3480 | -0.4148 | 0.4057 | 0.1691 | 0.0340 | -0.0867 | 0.4979 |
| $X_2$                | 0.7855                            | 0.3787                 | 0.3607                                   | -0.8911 | 0.4609 | 0.3830 | 0.1485 | 0.0114 | -0.1245 | 0.3725 |
| $X_3$                | 0.7664                            | 0.4924                 | 0.2123                                   | -0.8169 | 0.3545 | 0.2983 | 0.1921 | 0.0012 | -0.1151 | 0.2984 |
| $X_4$                | 0.6616                            | 0.4550                 | 0.2000                                   | -0.8647 | 0.3188 | 0.3228 | 0.0785 | 0.0314 | -0.1294 | 0.4426 |
| $X_5$                | 0.7502                            | 0.2779                 | 0.4318                                   | -0.5902 | 0.2024 | 0.3404 | 0.1286 | 0.0265 | 0.0486 | 0.2756 |
| $X_6$                | -0.6057                           | -0.1214                | -0.3945                                  | 0.2713 | 0.0354 | 0.0047 | -0.1177 | -0.0607 | -0.1450 | -0.3024 |
| $X_7$                | -0.1024                           | -0.2670                | 0.1903                                   | -0.3150 | 0.1766 | 0.2123 | 0.2205 | -0.0506 | -0.0659 | 0.0123 |
| $X_8$                | 0.7786                            | 0.5596                 | 0.2081                                   | -0.8629 | 0.2521 | 0.2625 | 0.3599 | 0.1369 | 0.0656 | -0.0059 |

Table 3. Determining coefficient of influence factors on water use efficiency and ranking of total contribution to $R^2$ of Water diversion and irrigation areas in the lower Yellow River

| Rank | Factor | Determination coefficient $d_{yix}$ | Independent variable | Total contribution to $R^2$ |
|------|--------|-------------------------------------|----------------------|--------------------------|
| 1    | $d_{y1x8}$ | -0.9658                          | $X_1$                | -0.8121                  |
| 2    | $d_{y3x1}$ | 0.9404                           | $X_8$                | 0.4357                   |
| 3    | $d_{y1x3}$ | -0.8045                          | $X_3$                | 0.3774                   |
| 4    | $d_{y1x4}$ | -0.7869                          | $X_4$                | 0.3010                   |
| 5    | $d_{y1x2}$ | -0.6750                          | $X_2$                | 0.2975                   |
| 6    | $d_{y4x8}$ | 0.4028                           | $X_5$                | 0.2085                   |
| Error term | $d_{ye}$ | 0.0021                           | $X_6$                | 0.0736                   |

4. Conclusion
For the evaluation of water use efficiency in water diversion and irrigation areas in the lower Yellow River, the integrity rate of supporting facilities is the most important influencing factor. The integrity rate of supporting facilities also has internal effects with water-saving project investment, channel length and channel lining rate, and has a significant effect on water use efficiency in water diversion and irrigation areas in the lower Yellow River, and the least influencing factor is precipitation. Therefore, in order to improve the water use efficiency of water diversion and irrigation areas in the lower Yellow River, we should focus on improving the completion rate of supporting facilities, the investment in water-saving projects, and the improvement of channel length and lining rate.

Sizing calculation, through the above of the lower reaches of Yellow River irrigation area water use efficiency of impact factor to conduct a comprehensive analysis of error term performance of water use efficiency of direct effects, indirect effects are minimal, instructions for irrigation water use efficiency, influential factors on the evaluation of all considered, evaluate the smaller error and the calculation results more accurate. Compared with other methods such as correlation coefficient and regression analysis, path analysis has obvious advantages in accurately calculating the direct and indirect effects of dependent variables on dependent variables. Thus, it can effectively improve the utilization effect of water resources in the irrigated area and better serve the future high-quality development of the irrigated area.
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