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Evaluation of small-scale farmland water conservancy construction mode in China

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Abstract: This study aims to evaluate the construction mode of small-scale farmland water conservancy using secondary data from the China statistical yearbook (2000–2019), which was simply and statistically computed. To put it briefly, the simple linear regression model was used to analyse the number of small-scale reservoirs and irrigated areas relative to their capacities and effectiveness. The results showed that the number of small-scale reservoirs increased by 122.2 units of their capacity and the number of small-scale irrigated areas increased by 6.8 units of their effectiveness. The present study introduces the simple linear regression model and accounts for how the number of the small-scale reservoirs and irrigated areas has increased (the total number of reservoirs was 83,260 in 2000 and 98,822 in 2018) relative to their capacity and effectiveness, respectively. Of course, the capacity of water harvesting and the effectiveness of irrigated areas have shown a linear increase over time. Between 2000 and 2019, the capacity increased from 3842 to 7117 for large-scale reservoirs, from 746 to 126 for medium-scale reservoirs, and from 594 to 710 for small-scale reservoirs and their ranges were 3.2, 380, and 116, respectively. Furthermore, the findings of this evaluation provide insights for making decisions on water conservancy interventions.

Keywords: simple linear regression model, small-scale farmland water conservancy facilities, small-scale reservoir, small-scale irrigation, water conservation

INTRODUCTION

The practice of water conservation in reservoirs and various structures has a long history, especially on small-scale farms in water-scarce regions of China. The systems date from 202 BC–330 AD and they offer opportunities to fight against agricultural drought and mitigate the food crisis situation [QIN *et al.* 2012]. Even though the early water conservancy was simple and primitive in its construction, the facilities existed at the level of small farms and were operated by farmers. The significant steps in the construction of modern facilities were introduced in 1949 with the establishment of the People's Republic of China [WANG *et al.* 2015]. Furthermore, it was stepped up at the time of the reform and opening-up policy in 1978 [GUO 1995], which focused on diversifying and intensifying the water conservancy programs by integrating valuable components such as small-sized irrigation areas and drainage projects, drought-resistant water projects in irrigation areas, and small-scale reservoirs: ponds, reservoirs, water cells, and wells with a particular significance to agricultural development, prosperous rural economy, and farmers' incomes.

Water conservancy has many potential uses in agricultural development and includes small-scale reservoirs and irrigation, which has been actively engaged in the construction and operation of the property as it contributes to water-saving in agriculture [ZHANG 2012]. Additional steps were taken to achieve sustainable water use in agriculture and to ensure improvement in food security [FISHMAN 2015], which supported the gradual shift from traditional to modern agriculture [LU *et al.* 2021] but also addressed the terrifying food insecurity [LIU *et al.* 2020]. Moreover, more attention was given to integrating proper land use with different water conservancy frameworks [LIU *et al.* 2014] by focusing on improving the efficiency of agricultural water use [FISHMAN 2015], improving water administration practices, and developing water resources [GEERTS, RAES 2009; LIU *et al.* 2013]. These advanced engagements are accelerating a vigorous water conservancy programme, including reservoirs and irrigation structures that split into various sizes and systems [LIU *et al.* 2013]. One type of the small size farmland water conservancy is called small-scale farmland water conservancy facilities, which require repairs and measures to improve their efficiency as they are aging [WANQI 2016].

Although, for instance, small-scale reservoirs have low efficiency; they can deaccelerate the flow velocity of water and eventually increase hydraulic lifetime [MAECK *et al.* 2013], an important bar of water conservation and hydropower expansion [JIA 2016] and developing water conservation. Furthermore, it is part of the goal set in 2017 to reach farmland water conservancy of $53.3 \cdot 10^6$ ha [MoLRNDRC 2017; SEARS *et al.* 2018]. Farmland water conservancy is an indispensable requirement in modern agriculture [WANG *et al.* 2011]. As a result, the Chinese government has placed a high priority on reforms and top-up policies, classifying water conservancy facilities at different levels such as small, medium, and large-scale. It is challenging with unprecedented drastic land-cover alterations, while little attention is given to rural crises, flooding, and drought [SHIJIN *et al.* 2021]. Therefore, the construction of farmland water conservancy is the tool for upgrading modern agriculture, developing a socio-economic foundation, and sustaining ecological conditions. For example, LIU *et al.* [2017] found that small-scale farmland water conservancy facilities increased the demand for irrigation water. The small size reservoirs and irrigation are part of small-scale farmland water conservancy facilities and are effectively articulating the basis for the other types [PU *et al.* 2019]. Even so, small-scale farmland water conservancies usually feature obsolete facilities, in poor state of repair, whose efficiency significantly decreases due to the lack of investment, maintenance, and management [WANG 2017].

Evaluating small-scale farmland water conservancy representing the small amount of water-soil conservation services and the conservation capacities such as water harvesting rate (the amount of water harvesting divided by the amount of water resources) and soil conservation rate (i.e., the amount of soil conservation divided by the amount of potential soil loss), should be explained in landscape management [LIU *et al.* 2021]. One way to evaluate small-scale farmland water conservancy is by categorising small-scale irrigation and harvesting water in a small reservoir or dam [YANG *et al.* 2021]. On the other hand, we have evaluated the parts of small-scale farmland water conservancy facilities that transfer water through irrigation from the reservoirs. Meanwhile, this study introduces a simple methodology based on the linear regression model to evaluate the capacity of small-scale reservoirs and the effectiveness of small-scale irrigated areas and compute the number of small-scale water storage and irrigated areas.

The main objective of this study was to apply and demonstrate the mode of small-scale farmland water conservancy for the evaluation of reservoirs and irrigated areas. In this study, we intend to apply the simple statistical method and simple linear regression model in the small-scale farmland water conservancy construction mode to address the following questions:

1) Was there a change in the capacity of small-scale reservoirs and the effectiveness of small-scale irrigation?

2) Does the simple linear regression model explain it better than the simple statistical method?

Based on these questions, data from the China statistical yearbook [China Statistics Press 2019; 2020] were used for evaluating the mode of the small-scale farmland water conservancy at the national level. We examine and analyse the data and interpret the results to provide insights for supporting evidence-based decision-making and practice.

MATERIALS AND METHODS

DATA SOURCES

Different sets of data, including the number of reservoirs, the capacity of reservoirs, the water-saving irrigated areas, the number of irrigated areas, and the effectiveness of irrigated areas, were calibrated to evaluate farmland water conservancy facilities which originated from the China statistical yearbook [China Statistics Press 2019; 2020]. Effective irrigation means using water efficiently to irrigate many different plantings. Consequently, effective irrigation means the agricultural process of applying manageable amounts of water to land to assist in the production of crops. In addition, water-saving irrigation saves more water than conventional irrigation, which can even lead to an increase in crop yields. Therefore, water-saving irrigation is one of the methods of reducing water consumption, such as improving irrigation efficiency and using conservation tillage practices. According to the China statistical yearbook, the capacity of water harvesting, and effectiveness of irrigated areas were classified and applied water at the level of large-, medium-, and small-scale irrigated areas of (>33,000 ha), (20,000–33,000 ha), and (667–20,000 ha), respectively [China Statistics Press 2019; 2020]. These classifications are used, above all, for clarifying the data processing of small-scale farmland water conservancy and have a relative advantage over medium and large scales. In addition, they lead to a simple statistical method that is used for evaluating small-scale farmland water conservancy facilities. However, this method has its drawbacks, and the evaluation capacity was very low. It has either been short-term or not been used in the parametric system to measure small-scale farmland water conservancy and resulted from the capacity of the reservoirs and the effectiveness of irrigated areas. Unlike the former, the present study employed a simple linear regression model to evaluate small-scale farmland water conservancies that specifically measured the number of small-scale reservoirs and irrigations in terms of their capacity and effectiveness, respectively.

DATA ANALYSIS

The only simple statistical method was computed to highlight the contrast between farmland water conservancy facilities but was not econometrically analysed. Meanwhile, the simple linear regression model explored small-scale reservoirs and irrigated areas specifically and econometrically in terms of their capacity and effectiveness. It can also comprehensively define the small-scale farmland water conservancy construction mode in small-scale reservoirs and irrigated areas.

For the simple linear regression model, we used the number of small-scale reservoirs and their capacity as dependent and independent variables, respectively. In addition, the number of small-scale irrigated areas was used as a dependent variable and its effectiveness was considered an independent variable.

These variables were applied in the linear regression model and were derived from the basic mathematical equation.

The modelling application of ordinary least squares (OLS) linear regression allows one to predict the value of the response variable for varying inputs of the predictor variable given the slope and intercept coefficients of the line of best fit. Therefore, we used the following simple linear regression model that fit our data:

$$y = \beta_0 + \beta_1 x + \varepsilon \quad (1)$$

where: y = a dependent variable, β_0 = a constant (an intercept point), β_1 = a coefficient (slope) of an independent variable, x = an independent variable, ε = an error.

To evaluate small-scale farmland water conservancy facilities, we used two types of variables as control variables. These are the capacity of reservoirs and the effectiveness of irrigated areas. The first type of variable is the capacity of small-scale reservoirs. The second one is the effectiveness of small-scale irrigated areas. According to the Cobb-Douglas function, we used the proportion of input-output correlation analysis, which means that if the number of inputs is high, it can generate sufficiently high outputs. Meanwhile, the effectiveness of irrigation projects mainly increased due to a large number of inputs and resources. We used the panel for the period 2000–2019 from the China statistical yearbook, which were classified as follows: 2000–2005, 2006–2010, 2011–2015, 2016–2017, and 2018–2019 but not only consecutive six observations [China Statistics Press 2019; 2020].

RESULTS

THE SMALL-SCALE FARMLAND WATER CONSERVANCY IN SIMPLE STATISTICAL METHOD

According to [Zhou *et al.* 2021], the serious problems of effectiveness and capacity have been realised in small-scale farmland water conservancy, and many engineering facilities were thus constructed to develop and support water conservancy. In our study, the simple statistical method was applied to evaluate small-scale farmland water conservancy relative to the medium, and large-scale farmland water conservancy in the periods considered. From this, we obtained the overall capacity and effectiveness of small-scale farmland water conservancy facilities, which are displayed in the Figures and Tables below.

Table 1 summarises the number of reservoirs in different years. The number of reservoirs showed an increasing trend in farmland water conservancy facilities in the period 2000–2019. Importantly, the increment in the number of small-scale reservoirs was greater than in the number of medium-scale and large-scale farmland water conservancy facilities. In addition, the capacity of reservoirs tended to increase with each year (Fig. 1). Between 2000 and 2019, the capacity of reservoirs increased from 3842 to 7117 for large scale reservoirs, from 746 to 1126 for medium-scale reservoirs and from 594 to 710 for small-scale reservoirs and their ranges were 3.2, 380, and 116, respectively.

Table 2 presents the results of the analysis using the simple statistical method to show the trend of water-saving irrigation. The water-saving irrigated areas showed an increasing trend from the year 2000 to 2019. The water-saving irrigated area (in 10,000 ha) increased from 16.4 mln ha to 37.1 mln ha (9.8 to 22.2%).

Table 1. The number of reservoirs

Year	Number in			Total number of reservoirs
	large-scale area	medium-scale area	small-scale area	
2000	420	2,704	80,136	83,260
2005	470	2,934	81,704	85,108
2010	552	3,269	84,052	87,873
2015	707	3,844	93,437	97,988
2017	732	3,934	94,129	98,795
2018	736	3,954	94,132	98,822
2019	744	3,978	93,390	98,112

Note: large-scale >33,000 ha, medium-scale 20,000–33,000 ha, and small-scale 667–20,000 ha.
Source: own study based on data from China statistical yearbook [China Statistics Press 2019; 2020].

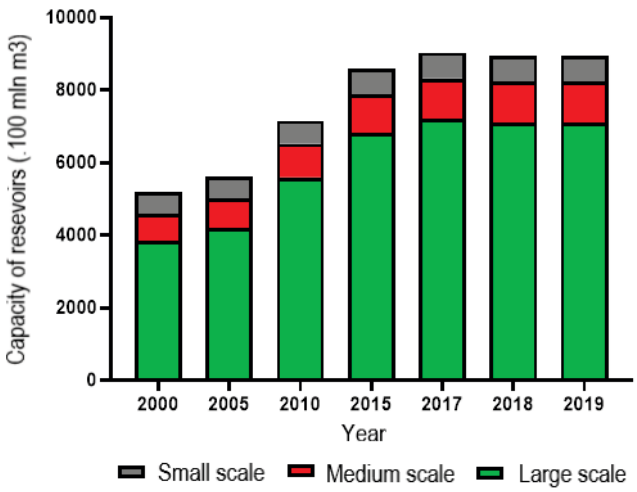

Fig. 1. The capacity in different reservoirs from years 2000–2019; note as in Tab. 1; source: own study based on data from China statistical yearbook [China Statistics Press 2019; 2020]

Table 2. Water-saving irrigated areas

Year	Water-saving irrigated area	
	mln ha	%
2000	16.4	9.8
2005	21.3	12.8
2010	27.3	16.4
2015	31.1	18.6
2017	34.3	20.6
2018	36.1	21.6
2019	37.1	22.2

Note as in Tab. 1.
Source: own study based on data from China statistical yearbook [China Statistics Press 2019; 2020].

Table 3 summarises the number of irrigated areas in the period 2000–2019. The large-scale irrigated areas increased from 1 to 1.8 (11.5 to 19.9%) in years 2000 to 2019. The medium-scale irrigated areas increased from 1.4 to 2.9 (10.2 to 20.8%) in years 2000 to 2019. The small-scale irrigated areas increased from 54.4 to 74.2 (14.1 to 19.2%) in years 2000 to 2019. At the end of 2018/2019, the percentages of large, medium, and small-scale irrigated areas reached 2.2, 3.4, and 94.4%, respectively.

Table 3. Number of irrigated areas over million hectares

Year	Number of areas in		
	large-scale	medium-scale	small-scale
2000	101	141	5441
2005	117	170	5573
2010	131	218	5446
2015	176	280	7417
2017	178	281	7380
2018	175	286	7420
2019	176	284	7424
%	2.2	3.4	94.4

Note as in Tab. 1.
Source: own study based on data from China statistical yearbook [China Statistics Press 2019; 2020].

Table 4 indicates the effectiveness of irrigated areas from 2000 to 2019. Between 2000 and 2019, small-scale irrigated areas increased from 13.2 to 15.5 million ha (according to Table 4 caption) (84.8%) medium-scale irrigated areas increased from 3.4 to 5.4 million ha (63.7%) and large-scale irrigated areas increased from 7.9 to 12.6 million ha (63.5%). The present results have addressed mainly the small-scale farmland water conservancy rather than both medium and large. It was contributed to indicate the ways to find the specific evaluation of small-scale farmland water conservancy construction mode. Therefore, the present research is a novel and conscious evaluation of small-scale farmland water conservancy construction, and aims to find more specific components of it, as this has not yet been addressed in practice [Liu *et al.* 2019]. Therefore, our results have been showing evidence for the small-scale farmland water conservancy construction.

Table 4. Effective irrigated area (million ha)

Year	Large-scale	Medium-scale	Small-scale
2000	7.9	3.4	13.2
2005	10.2	4.1	12.1
2010	10.9	4.7	13.8
2015	12.0	5.7	14.6
2017	12.5	5.4	15.4
2018	12.4	5.4	15.5
2019	12.6	5.4	15.5
% Increment	63.5	63.7	84.8

Note as in Tab. 1.
Source: own study based on data from China statistical yearbook [China Statistics Press 2019; 2020].

SMALL-SCALE RESERVOIRS AND IRRIGATED AREAS

To assess the econometric advantages of small-scale farmland water conservancy facilities, regression analysis was performed using a simple linear regression model that calculated the capacity of small-scale reservoirs and the effectiveness of small-scale irrigated areas while considering their numbers.

The regression analysis results between the number of reservoirs and the capacity of reservoirs are shown in (Tab. 5–7). The constant and coefficient of the capacity of small-scale reservoirs amount to 7407.90, and 122.2, respectively. The number of small-scale reservoirs increased, meanwhile the capacity of small-scale reservoirs also increased linearly, which suggested a positive linear relationship. Figure 2 illustrates the estimated number of small-scale reservoirs. For every unit of

Table 5. The computed values of independent and dependent under constant and capacity of reservoir, respectively; model 1: OLS, using observations 1–6, dependent variable: number of reservoirs

Independent variables	Coefficient	Standard error	*t*-ratio	*P*-value
Constant	7,407.90	4,287.80	1.728	0.1591
Capacity of reservoir	122.2	6.48991	18.83	<0.0001***

Source: own study.

Table 6. The mean dependent variables and R^2 values of the reservoirs

Parameter	Value	Parameter	Value
Mean dependent variables	87,931.83	*SD* dependent variables	6,660.013
Sum squared residuals	2,473,361	*SE* of regression	786.3462
R^2	0.988848	Adjusted R^2	0.986060
F (1, 4)	354.6679	*P*-value (*F*)	0.000047
Log-likelihood	−47.30162	Airlike criterion	98.60324
Schwartz criterion	98.18676	Hannan-Quinn	96.93603

Source: own study.

Table 7. The number of the reservoirs under fitted and residual values

Number of the reservoirs	Fitted	Residual
80,136	80,007.8	128.226
81,704	80,985.5	718.450
84,052	85,385.5	−1,333.54
93,438	93,085.5	352.472
94,129	93,941.1	187.918
94,132	94,185.5	−53.5257

Note: model estimation range: 1–6; standard error of residuals = 786.346.
Source: own study.

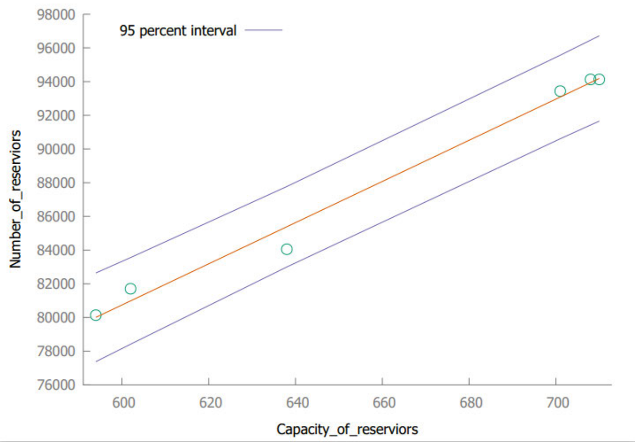

Fig. 2. Estimation and actual values of regression analysis of the number of reservoirs; source: own study based on data from China statistical yearbook [China Statistics Press 2019; 2020]

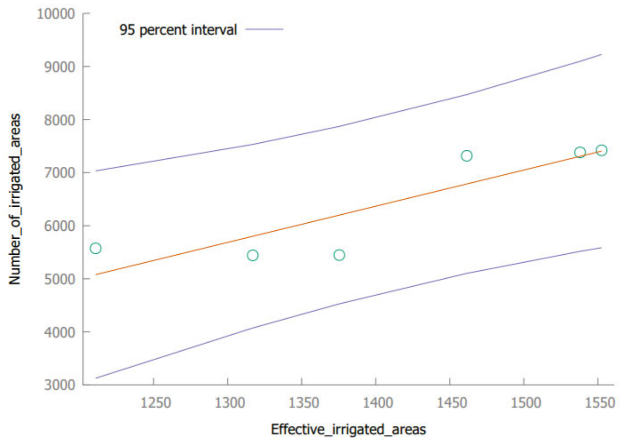

Fig. 3. Estimation and actual values of regression analysis of the number of irrigated areas in (million ha); own study based on data from China statistical yearbook [China Statistics Press 2019; 2020]

capacity, the small-scale reservoirs have been estimated to grow by 122.2 units. The constant and coefficient of effectiveness of small-scale irrigated areas were −3168.8 and 6.8, respectively (Tab. 8). In addition, the results indicated that the number of small-scale irrigated areas increased by 6.81 units of the effectiveness of the irrigated areas. The number of small-scale irrigated areas increased linearly even though the point of it was intercepted at −3168.8, which meant the number of small-scale irrigated areas increased less than effectiveness. In a simple linear regression estimated and actual values of the number of irrigated areas were dispersed from the effectiveness (Fig. 3). The effectiveness of irrigated areas size was 0.8, which indicated it was safe as the $R > 0.7$ (Tab. 9). Therefore, the number of small-scale reservoirs increased significantly by 122.2 units of the capacity, and the number of small-scale irrigated areas increased by 6.8 units of its effectiveness in small-scale farmland water

Table 8. The computed values of independent and dependent variables (?) under constant and effective irrigated area, respectively; model 1: OLS, using observations 1–6; dependent variable: number of irrigated areas

Independent variables	Coefficient	Std. Error	*t*-ratio	*P*-value
Constant	−3168.8	2631.12	−1.204	0.2948
Effective irrigated area	6.8	1.86016	3.662	0.0216**

Source: own study.

Table 9. The mean dependent variables and R^2 values of the effective irrigated areas

Mean dependent variables	6429.500	*SD* dependent variables	1034.427
Sum squared residuals	1229416	*SE* of regression	554.3951
R^2	0.770211	Adjusted R^2	0.712764
F (1, 4)	13.40727	*P*-value (F)	0.021550
Log-likelihood	−45.20450	Akaike criterion	94.40900
Schwarz criterion	93.99252	Hannan-Quinn	92.74179

Source: own study.

conservancy facilities. These findings were supported by [Zhang 2012], who stated that more inclusive facilities are operating the capacity of medium-scale and large-scale farmland water conservancy engineering facilities. But our study results did not consider the medium and large-scale farmland water conservancies or their management.

However, the farmland water conservancy data was analysed by simple statistical methods and continuous measurements on each category were taken during this period. The reason for this is that the simple statistical method was used for the linear regression model. The model has clearly measured the small-scale farmland water conservancies, which included small reservoirs and irrigated areas; there is a linear regression of the number of small reservoirs and irrigated areas. This means that the smallest size reservoirs and irrigated areas are clearly defining the small-scale farmland water conservancies. Therefore, the simple linear regression model is more appropriate for evaluating specific small reservoirs and irrigated areas rather than the simple statistical method. Therefore, the linear regression model has formulated value, and solved biased estimation of the capacity of reservoirs and effectiveness of irrigated areas and economic conditions carried to each subsequent time period.

CONCLUSIONS

Using the China statistical yearbook data for the years 2000–2019, we evaluated the number and capacity of small-scale reservoirs and the effectiveness of the small-scale irrigated areas using a linear regression model. We have achieved the constructive capacity of small-scale reservoirs and effectiveness of irrigated areas. This paper addressed the question of whether small-scale farmland water conservancy construction has occurred in Chinese rural areas, what its mode was, and whether this had an impact on construction quality. We found that: 1) small-scale farmland water conservancies are widespread in rural China; 2) the effectiveness of small-scale irrigated areas was found linearly productive; 3) the number of small-scale reservoirs has the marginal effect of a unit of the capacity; 4) the number and effectiveness of small-scale irrigated areas increased linearly.

Moreover, the number of small-size farming, water conservation and irrigation facilities are distributed on a larger area of the country than medium and large-scale ones. Yet, they are conventional, obsolete facilities, in a poor state of repair, and are operated by farmers. The present research has explored the gap between them and led to important intervention insights for future modifications. In general, our study contributed to the literature and provided a number of evaluation insights. First, our work explores the literature on soil and water conservation and the construction status of small-scale farmland water conservancy facilities. Specifically, the existing literature clarifies the status of small farms and the water protection system that has been operated by rural farmers and improved some obsolete facilities. Secondly, we have implemented both the simple statistical calculation and a linear regression model to evaluate China's small farmland water conservancies construction mode from 2000 to 2019 that supplement the literature on small farms and water conservation.

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