Study on the evaluation method of operation performance for rural domestic wastewater treatment facilities

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Abstract: Rural domestic wastewater treatment has become one of the key and main battlefields of China's sewage treatment industry, the operation performance of rural domestic wastewater treatment facilities is directly related to the realization of rural environment comprehensive renovation and rural revitalization strategic planning objectives. This paper expounds the present situation and existing problems of the operation of rural domestic wastewater treatment facilities in China, and the necessity of carrying out the research on the operation performance of rural domestic wastewater treatment facilities, and rural domestic wastewater treatment facilities Operation Evaluation Index System Construction, evaluation index calculation method, scoring standards and evaluation methods. It is expected to promote the operation reliability and effectiveness of rural domestic wastewater treatment facilities in China through the use of evaluation methods of the operation effectiveness of rural domestic wastewater treatment facilities.

1. The current operation and problems analysis of domestic wastewater treatment facilities for rural area in our country

1.1. Current situation
At present, the object of wastewater treatment in our country is the wastewater in cities, towns and villages. The wastewater in cities and towns includes residents’ wastewater and industrial wastewater in cities and towns. In which, the residents’ wastewater in cities and towns comes from the daily life of communities, hospitals and public places; industrial wastewater mainly comes from industrial enterprises. As for wastewater in rural areas, there are 2,500 thousand natural villages in our country now with 670 million people. The daily weight of domestic wastewater can be more than 30,000 thousand tons. Most of the domestic wastewater is discharged to natural environment without treatment. Quite a few systemic villages have no wastewater treatment facility and the rate of wastewater treatment is lower than 10%. At present, there are three methods of wastewater treatment in rural areas: regional centralized treatment, nearby centralized treatment and household centralized treatment. Regional centralized treatment aims at the villages which are close to cities and towns. The wastewater of villages is collected and transported through pipelines to the wastewater treatment plant in city or town. Nearby centralized treatment is to collect wastewater of households through pipelines for centralized treatment in wastewater treatment station of village. Household centralized treatment is to use small wastewater treatment equipment or natural ecological treatment method to treat or apply the wastewater of single or several households around the houses.
1.2. The current problems

During “the 12th Five-Year Plan” and “the 13th Five-Year Plan”, rural wastewater treatment facilities in large batch have been constructed rapidly in our country. Owing to relatively rapid speed of construction, some treatment plants have problems of design and construction quality which shall be solved and reformed gradually in subsequent operation. Besides, owing to the existing problem “emphasize construction but neglect operation”, the overall operation quality of wastewater treatment facilities is lower than that in developed countries. Effluent quality can be improved and energy consumption can be decreased greatly by optimizing existing facilities. Referring to the actual rural domestic wastewater treatment in our country, there are some problems listed below: Firstly, scientific choice and decision is deficient for treatment methods and technical systems. The types of rural domestic wastewater are complex; regional differentiation is great; the scale of domestic wastewater is small and the discharge is dispersive. It is especially important to choose proper treatment method and technical system. However, because of deficient scientific decisions, it is subjective and random now to choose technique and technological process. In this case, it is difficult to guarantee good effect of treatment. Secondly, the good and bad quality of equipment is intermingled. The effect of facility running is not good enough and the mechanism of guarantee and supervision needs to be improved. At present, the wastewater treatment techniques and types of equipment used in rural areas are multiple but the quality of equipment is irregular. Owing to deficient evaluation on the performance of treatment system and facilities, their running effect cannot be guaranteed effectively. As for some rural domestic wastewater treatment facilities established, it is difficult to make them work continuously or the working efficiency is low; long-term effective guarantee mechanism and supervision mechanism are deficient. Thirdly, the standards relevant to domestic wastewater treatment in rural areas are greatly deficient. Up to now, there is no uniform standard for wastewater discharge in rural areas yet. Some places take the discharge standard of wastewater treatment plant in towns and cities for reference; some places use stricter discharge standard. In September 2018, Ministry of Ecology and Environment of the People’s Republic of China and Ministry of Housing and Urban-Rural Development of the People’s Republic of China jointly issued Notice for Accelerating Establishment of the Standard of Rural Domestic Wastewater Treatment and Discharge. The Notice requires to determine control indexes and discharge limits in classification referring to different position conditions, population density in villages, scale of wastewater, target area of discharge and the demand of human settlement environment in rural areas in principles of area and grade partition, combination of strictness and loose, priority of recycle, emphasis on actual effect and convenience of supervision and management. It requires all the places specified to complete the establishment of rural domestic wastewater treatment and discharge standard before the end of June 2019. Apart from the deficiency of discharge standards, the product standards of rural domestic wastewater treatment equipment, performance detection standards and the standards of facility running effect evaluation are deficient.

Especially in the aspect of wastewater treatment facility operation and management, there are industrial standards CJJ/T 228 Standard of the Operation Quality Assessment for Municipal Wastewater Treatment Plan and HJ2038 -2014 Technical Specification for Management of Municipal Wastewater Treatment Plant Operation which involve the operation and management of rural domestic wastewater treatment facilities. Besides, in 2019, to accelerate improvement of rural human settlement environment and regularize the construction, operation, maintenance and management of rural domestic wastewater treatment projects, Ministry of Housing and Urban-Rural Development of the People’s Republic of China organized new construction, expanded construction and reconstruction of domestic wastewater treatment project aiming at administrative villages, natural villages and dispersive peasant households, toilet reconstruction and toilet wastewater treatment project for dispersive peasant households. It researched and issued GB/T 51347-2019 Technical Standard for Domestic Wastewater Treatment Engineering of Rural Areas. In 2019, Central Rural Work Leading Group of Chinese Communist Party, Ministry of Agriculture and Rural Affairs of the People’s Republic of China, Ministry of Ecology and Environment of the People’s Republic of China, Ministry of Housing and Urban-Rural Development of the People’s Republic of China, Ministry of Water Resources of the People’s Republic of China,
Ministry of Science and Technology of the People’s Republic of China, National Development and Reform Commission, Ministry of Finance of the People’s Republic of China, China Banking and Insurance Regulatory Commission etc. jointly issued Instructions for Pushing Forward Rural Domestic Wastewater Treatment that requires “to accelerate establishment and revision of standards, summarize establishment and revision of standards, build and improve the standard and system of rural domestic wastewater treatment, accelerate research on and establishment of the standard of rural domestic wastewater treatment, normalize the design, construction, maintenance etc. of wastewater treatment facilities, make suitable technical rules or standards for local rural domestic wastewater treatment and strengthen technical guide.” The research on the methods of evaluating the effect of rural domestic wastewater treatment facilities can help to transform research achievements to be relevant evaluation standards. In this way, the standards and system of rural domestic wastewater treatment in our country can be further improved.

2. The necessity of research on the methods of evaluating the effect of rural domestic wastewater treatment facilities

During the periods of “the 12th Five-Year Plan” and “the 13th Five-Year Plan”, the party and nation pay high attention to the treatment of rural domestic wastewater. A series of significant environmental protection policies, plans and guidance documents relevant to rural wastewater treatment have been issued.

2.1. To meet the requirements of plans and policies relevant to environmental protection

In March 2016, The 13th Five-Year Plan for National Economy and Social Development was issued to require: “to take actions of constructing ecological civilization model villages & towns and improving rural human settlement environment.” In November 2016, the State Council issued Ecological Environment Protection Plan in “the 13th Five-Year Plan” to require: “to accelerate comprehensive treatment of agricultural and rural environment, push forward uniform planning, construction and management of rural wastewater treatment in whole counties and actively accelerate extension of wastewater facility and service in towns and cities to villages.” In December 2016, the State Council issued Notice of Energy Conservation and Emission Reduction Work Program in “the 13th Five-Year Plan” to require: “to strengthen rural domestic pollution source discharge control, use multiple methods of cities’ and towns’ pipeline extension, centralized treatment and disperse treatment and accelerate treatment of rural domestic wastewater; by 2020, all counties and key towns in the whole country should have the ability of wastewater treatment and the wastewater treatment rate of counties should reach about 85%.” In December 2016, Development Plan for Energy Saving and Environmental Protection in “the 13th Five-Year Plan” was issued to require: “to popularize small water treatment technologies with low cost and micro power, popularize livestock & birds cultivation surface source pollution control technologies and push forward the disperse treatment of domestic wastewater in small towns and villages and the wastewater in construction places and production places.”

2.2. Support improvement of rural environment and put rural revitalization plan into practice

General Office of the Central Committee and General Office of the State Council issued Three-Year Action Plan for Improvement of Rural Human Settlement Environment in February 2018. It requires: “in accordance with the different rural position conditions, population density of villages and scale of wastewater, use the construction pattern and treatment process of combining pollution abatement with resource utilization, combining engineering measures with ecological measures and combining centralized treatment with disperse treatment based on local conditions; the wastewater treatment technologies with low cost, low energy consumption, easy maintenance and high efficiency shall be popularized actively.” In May 2018, the State Council issued National Strategic Plan of Rural Revitalization (2018-2022). It requires “to improve rural human settlement environment continuously, take special actions of improving rural environment and improve rural domestic wastewater treatment
step by step; the cities and towns try to extend wastewater treatment facilities and pipelines to surrounding villages; wastewater treatment facility shall be constructed for the villages with high density of population which are far away from town and city; household wastewater treatment facility shall be popularized to the villages with small population.” In June 2018, the State Council issued The Requirements of Strengthening Ecological Environment Protection Comprehensively and well Controlling Pollutions. It requires: “to well treat agricultural and rural pollutions, take actions to improve rural human settlement environment continuously aiming at construction of beautiful and livable villages, improve environment of all administrative villages of the country; by 2020, rural human settlement environment will be improved obviously; villages will be clean, tidy and orderly.” Law on the Prevention and Control of Water Pollution of the People’s Republic of China and Law on Environmental Protection Tax of the People’s Republic of China revised in 2018 have been implemented. “The action plan of water pollution prevention” has been put forward. “The 19th National Congress of the Communist Party of China” further arranges ecological civilization construction and requires to protect the blue sky, clear water and clean land. Agricultural and rural pollution treatment has been listed to be one of the seven landmark significant campaigns.

All related places and departments have been implementing the requirements of the CPC Central Committee and actively pushing forward the treatment of rural domestic wastewater. That has got certain effect and played important functions for improving rural ecological environment, improving peasants’ living quality and pushing forward agricultural and rural modernization. In this case, the research on method of evaluating the effect of rural domestic wastewater treatment facilities can offer effective technical means for implementing national policies and plans of environmental protection; the high quality and effectiveness of rural domestic wastewater treatment facilities can be guaranteed.

3. The research on method of evaluating the effect of rural domestic wastewater treatment facilities

3.1. The bases and basic principles of evaluation
Rural domestic wastewater means “the wastewater produced in daily life of rural residents, including the wastewater in toilet, bathroom, kitchen etc.”; rural domestic wastewater treatment facility means “the equipment and structures for treating rural domestic wastewater”. The evaluation on the effect of rural domestic wastewater treatment facility shall be based on the laws, regulations and standards of environmental protection. Based on the premise of reaching national, local and professional standards and requirements, it is scientific, objective, just and fair evaluation on the operation effect of rural domestic wastewater treatment facility. Five aspects will be considered for comprehensive evaluation: rationality of system design, effect of environment treatment, economical efficiency of environment treatment, stability of environment treatment, secondary pollution. In detail, it involves high facility use ratio, up-to-standard discharge or utilization and prominent environment improvement, low operation cost, energy resource consumption, the complete, safe, reliable and stable operation and management system, improvement of water environment with high degree of people’s satisfaction and no complaint.

3.2. Build evaluation index system
Evaluation index system shall be built for the operation effect of rural domestic wastewater treatment facility with the scale of no more than 500m³/d. The evaluation index system for the effect of rural domestic wastewater treatment facility contains 5 evaluation indexes at grade 1 and 11 detailed evaluation indexes at grade 2. The total score of evaluation is 100, including 20 scores of facility operation status, 30 scores of environmental benefit, 20 scores of energy resource consumption, 20 scores of operation and management and 10 scores of public satisfaction. The total score of each grade-1 index and the score of each grade-2 index are shown in Table 1.
Table 1. Evaluation on the effect of rural domestic wastewater treatment facilities

| No. | Name of grade-1 index                  | Total score of grade-1 index | Name of grade-2 index                          | Score of grade-2 index |
|-----|----------------------------------------|------------------------------|-----------------------------------------------|------------------------|
| 1   | Facility operation status              | 20                           | The operation ratio of facilities and equipment | 10                     |
|     |                                        |                              | Average hydraulic loading rate                 | 10                     |
| 2   | Environmental benefit                 | 30                           | Rate of reaching effluent quality standard     | 30                     |
|     |                                        |                              | Power consumption for unit wastewater treatment | 10                     |
| 3   | Energy resource consumption            | 20                           | Chemical consumption for unit wastewater treatment | 10                     |
|     |                                        |                              | Operation and management system                | 5                      |
|     |                                        |                              | Operation maintenance record                   | 6                      |
|     |                                        |                              | Environment and labels                         | 3                      |
|     |                                        |                              | Safety management                              | 6                      |
| 4   | Operation and management               | 20                           | The times of effective complaints              | 6                      |
|     |                                        |                              | The rate of complaint disposal                  | 4                      |
| 5   | Public satisfaction                    | 10                           |                                               | 100                    |

In the above table, “facility operation status” means the degree of effectively utilizing rural domestic wastewater treatment facilities, including two grade-2 indexes: the operation ratio of facilities and equipment and average hydraulic loading rate. It reflects the multipurpose utilization efficiency of rural wastewater treatment plant (station). The operation ratio is a basic index. High operation ratio is the premise of evaluating operation quality. Average hydraulic loading rate is also an important index that evaluates the utilization efficiency of wastewater treatment facilities. Only sustainable and adequate wastewater treatment indicates good status of facility operation. “Environmental benefit” means the effect of removing pollutants (such as CODcr, SS, ammonia nitrogen, total nitrogen, total phosphorus etc.) in the work process of rural domestic wastewater treatment facilities. It mainly evaluates one grade-2 index: the rate of reaching standard of water quality. It is the main goal of operating rural wastewater treatment plant (station) and a key index of standard evaluation. “Energy resource consumption” means the consumption level of phosphorus removal chemical and electric power in the work process of rural domestic wastewater treatment facilities. It contains two grade-2 indexes: power consumption for unit wastewater treatment and chemical consumption for unit wastewater treatment. The energy resource consumption accounts for the largest proportion of cost in the operation of wastewater treatment facilities. The level of consumption reflects the level of operation and management. The main equipment in rural wastewater treatment plant (station) is small integrated wastewater treatment equipment. Conventional operation and low power consumption are required. Therefore, power consumption for unit wastewater treatment is used as one of the main evaluation indexes of the effect of rural wastewater treatment plant (station). Chemical consumption for unit wastewater treatment encourages the optimization of phosphorus removal process. The rural wastewater treatment technologies are multiple; water COD is greatly different and the methods of disinfection are multiple. To evaluate different technologies, the index only involves the effective quantity of chemical used for phosphorus removal. “Operation and management” means the management and maintenance of rural wastewater facilities operation, containing four grade-2 indexes: operation and management system, operation maintenance record, environment and labels and safety management. It is an important index that reflects the normalization of the operation and management of rural wastewater treatment plant (station) and it is the important aspect that reflects the normalization and elaboration of operation. “Public satisfaction” means the degree of satisfaction of surrounding people towards the secondary
pollution in the work process of rural domestic wastewater treatment facilities. It contains two grade-2 indexes: the times of effective complaints and the rate of complaint disposal. The index reflects the degree of secondary pollution and its influence on the living environment and life of peasants.

3.3. The calculation method and scoring standard of evaluation indexes

Both qualitative evaluation and quantitative evaluation are used to evaluate the effect of rural domestic wastewater treatment facilities. “Operation and management” is a qualitative index and calculation formula is not needed. Different scores and weights can be given to the four grade-2 indexes according to their respective importance degree. The calculation method for other quantitative evaluation indexes is given below.

3.3.1. The operation ratio of facilities. Facility operation ratio is the proportion of effective operation days of rural domestic wastewater treatment facilities in all calendar days of evaluation period. The effective operation days of rural domestic wastewater treatment facilities are the days that daily hydraulic loading rate is larger than 30%. The calculation formula of facility operation rate is:

\[ F_{11} = \frac{D_{wo}}{t} \times 100\% \]  

In which:
- \( F_{11} \) — facility operation rate (%);
- \( D_{wo} \) — effective operation days of rural domestic wastewater treatment facilities in evaluation period (d);
- \( t \) — the number of calendar days in the evaluation period (d).

3.3.2. Average hydraulic loading rate. Average hydraulic loading rate is the proportion of actual volume of water treated by rural domestic wastewater treatment facility in the scale of design in evaluation period. The calculation formula is:

\[ F_{12} = \sum_{i=1}^{t} \frac{Q_{dai}}{Q_{dd}} \times t \times 100\% \]  

In which:
- \( F_{12} \) — average hydraulic loading rate (%);
- \( Q_{dai} \) — actual daily volume of wastewater treated in evaluation period (m³/d);
- \( Q_{dd} \) — daily volume of wastewater treated in design (m³/d).

3.3.3. Environmental benefit. The rate of reaching effluent quality standard is the proportion of the times of effluent quality from rural domestic wastewater treatment facility that meets the reaching standard in the total times of being inspected casually in the evaluation period. The calculation formula is:

\[ F_{21} = \frac{t_1}{t_2} \times 100\% \]  

In which:
- \( F_{21} \) — the rate of reaching effluent quality standard (%);
- \( t_1 \) — the times of reaching effluent quality standard in evaluation period (time);
- \( t_2 \) — the total times of casual inspection in evaluation period (time).

3.3.4. Power consumption for unit wastewater treatment. Power consumption for unit wastewater treatment is the average electric quantity consumed for wastewater treatment facility treating unit wastewater in evaluation period. The calculation formula is:
$$F_{31} = \sum_{i=1}^{tt} (E_{\text{ma}i}) / \sum_{i=1}^{tt} (Q_{dai})$$

In which:
- $F_{31}$ —— quantity of electric power consumed for treating unit wastewater (kW•h /m$^3$);
- $E_{\text{ma}}$ —— actual total monthly consumption of electric power (kW•h);
- $tt$ —— the number of calendar months in evaluation period.

### 3.3.5. Chemical consumption for unit wastewater treatment.

Chemical consumption for unit wastewater treatment is the compound average of flocculant (effective content) consumed for wastewater treatment facility treating unit wastewater in evaluation period. The calculation formula is:

$$F_{32} = \frac{1000 \times \sum_{i=1}^{tt} (PM_{dai})}{\sum_{i=1}^{tt} (Q_{dai})}$$

In which:
- $F_{32}$ —— weight of chemical consumed for treating unit wastewater (mg/L);
- $PM_{da}$ —— actual total monthly weight of flocculant (effective content) consumed (kg).

### 3.3.6. Public satisfaction.

The times of effective complaints of the public is the times of effective complaints of the public in the work process of rural domestic wastewater treatment facilities. The rate of complaint disposal is the proportion of effective complaints disposed in all effective complaints after receiving valid public complaints. The calculation formula is:

$$S_1 = \frac{M}{N} \times 100\%$$

In which:
- $S_1$ ——the rate of complaint disposal (%);
- $M$ ——the times of complaint disposal;
- $N$ ——the times of effective complaint in evaluation period.

### 3.4. Basic conditions of evaluation, data acquisition and total score of evaluation

As for the basic conditions of evaluation, standard regulates that: the effect of rural domestic wastewater treatment facility shall be evaluated after the facility passes acceptance check of environmental protection; the object evaluated shall have no relatively serious safety liability accident, no significant potential safety hazard, no punishment given by production supervision department, no direct or indirect responsibility for environmental pollution accident and no punishment given by environmental protection supervision department in the evaluation period.

As for data acquisition, the standard regulates that: the operation data used for evaluation shall be acquired by qualified measuring instruments and normalized measurement methods; the measuring instruments shall accord with corresponding quality standards or norms; in addition, they shall be calibrated periodically by the institute with measurement calibration qualification; the method of water quality detection shall meet the requirements in GB 18918; water sampling shall meet the requirements in GB 12999. All necessary materials and statistical data in the evaluation period shall be collected, including design documents, equipment materials, original records of facility operation, the data of operation & control center database, online monitoring and data, data of manual sampling for analysis, repair records of treatment facilities, basic information of chemicals (name, consumption and cost, purchase and transport, safety management system), operation time, cost of management and maintenance, environmental detection information, materials of acceptance check, management system etc. The mode of evaluation is determined by the evaluation unit, such as casual inspection, regular inspection, mass inspection etc.
As for the total score of evaluation, the treatment scale 5m³/d is the demarcation point of evaluation. If the scale > 5m³/d, the total score of evaluation is got from the five grade-1 evaluation indexes; if the scale ≤ 5m³/d, only three grade-1 indexes: environmental benefit, operation & management and public satisfaction are evaluated to calculate the total score of evaluation.

3.5. Grading in evaluation

The grade of effect of rural wastewater treatment facility can be “excellent”, “very good”, “good”, “OK” or “unqualified”. The score and grade of the effect of rural wastewater treatment facility shall meet the requirements in Table 2.

| Total score of evaluation | Grading in evaluation |
|---------------------------|-----------------------|
| F ≥ 90                    | Excellent             |
| 80 ≤ F < 90              | Very good             |
| 70 ≤ F < 80              | Good                  |
| 60 ≤ F < 70              | OK                    |
| F < 60                   | Unqualified           |

4. Conclusion

Rural domestic wastewater treatment is important work for implementing rural revitalization strategy and improving rural human settlement environment. Relevant evaluation techniques and methods are needed urgently to normalize and lead the industry of rural domestic wastewater treatment facility operation service. In the principle of strict evaluation, scientific and applicable evaluation index system is built for the method of evaluating rural domestic wastewater treatment facility operation. For evaluation indexes, reasonable weight allocation is established; the data acquisition method, calculation method and scoring standard with better operability are specified. By using the evaluation method in the future, the current problem - “emphasize construction but neglect operation” of rural domestic wastewater treatment facilities in our country will be solved effectively. It will give scientific technical method support for improving facility operation quality continuously.

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A researcher of resources and environment branch of China National Institute of Standardization, a member of National Standardization Technology Commission of Environmental Protection (SAC/TC275) and National Standardization Technology Commission of Environmental Management (SAC/TC207). He works on standardization research and important technical standards establishment in the fields of environmental protection, environmental management, comprehensive utilization of resources etc. in long term. He once hosted or participated in more than 20 national key scientific research programs during “the 11th Five-Year Plan” and “the 12th Five-Year Plan”. And he has hosted or participated in the establishment of more than 60 national standards in the fields of environmental protection, environmental management, and comprehensive utilization of resources etc.

References:
[1] GB/T 34605-2017 Technical requirements of operation performance assessment for coal-fired flue gas desulfurization installation.
[2] GB/T 34340-2017 Technical requirements of operation performance assessment for coal-fired flue gas denitrification installation.
[3] GB/T 34607-2017 Technical requirements of operation performance assessment of the desulfurization equipment and dust collector for sintering flue gas from iron and steel industry.
[4] Huang Jin, Lin Ling, Gao Xiang etc. Research on operational performance assessment index system of desulfurization, denitrification and dust elimination equipment of key industry, Standard Science, 2016, NO.4:24-29.
[5] Huang Jin, Research on the standards system of new environmental service industry in China, China Standardization, 2018, NO.7:47-52.