Study on Analysis of Risk for Rainwater Collection and Utilization for Rural Safe Drinking Water Project

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Abstract: Firstly, based on the actuality of rainwater collection and utilization project, systematically elaborated rural security drinking water engineering, this paper put forward to the water quantity safety guarantee system and the water quality safety guarantee system; also discusses the basic characteristic of rural security drinking water project for rainwater, the result shows that the collector surface, water storage facilities, water treatment facilities and equipment are to ensure the safety of water quantity and quality. Secondly, this paper analyze the risk source, the risk formation process and its characteristics for water quantity and quality their types, the result shows that the precipitation is the biggest risk and the engineering design standard, the construction quality, the quantity of collecting surface, water requirement and the management of the engineering implementation process are all important factors; the occurrence of water risk have the characteristics of independence, comprehensive, and the water quality risk is the result of various factors. Thirdly, this paper constructs risk evaluation index system for rainwater collection and utilization of rural safe drinking water project by analytic hierarchy process (AHP). Fourthly, based on probability theory and Bayesian theory and methods of risk assessment, water quality risk and comprehensive risk assessment model are constructed. Combining the project design, construction management and actual operation, according to the risk free, low risk, middle risk, high risk and higher risk, a total of 5 levels to set up the comprehensive risk rating standards, in order to control risks for rainwater collection and utilization, improve the reliability of water supply, and preserve water.

1. Introduction

With the implementation of the strategy of national rural safe drinking water, there are a large number of centralized water supply project built to obviously strengthen rural water supply infrastructure and improve water supply guarantee. However, in north China that is the shortage of water resources and the dispersion area where centralized water supply project is difficult to cover, the technology of rainwater collection and utilization can solve the rural domestic water and the situation will remain a longer period. Therefore, this paper will fully explain the basic characteristics for rainwater collection and utilization of rural security drinking water engineering, accurately identify its forming risk source, risk type and risk forming process, scientifically evaluate risk, and determine the level of risk. All of these can effectively control the risk process for the rainwater collection and utilization project, improve water supply reliability of the rainwater collection and utilization of rural water supply, make a scientific project planning, continuous operation and improve the project efficiency.
2. Characteristics of rainwater harvesting (RWH) projects for safe drinking water in rural area

2.1. Composition of Engineering
RWH projects for safe drinking water proposes in rural areas consist of catchment area, storage facility, water supply pipeline, pressurized water supply facilities as well as water treatment facilities and equipment, such as sediment basin and purifier. Among them, the collecting surface and water storage facilities are mainly used for ensuring water supply, and belong to the category of water quantity safety; The water treatment facilities and equipment is mainly used for ensuring the water quality to meet the standard, and belong to the category of water quality safety. In addition, water supply pipeline and pressurized water supply facilities belong to the affiliated facilities, therefore, water quantity and quality are not be affected greatly due to RWH projects with the advantages of small-scale and convenient management.

2.2. Basic Characteristics
On the one hand, the implementation of RWH projects cannot be separated from natural precipitation, namely, only the certain natural precipitation can ensure RWH projects to play its proper role. On the other hand, the demand of water supply should be meet by the water quantity and quality simultaneously, so as to realize the water supply guarantee. In the whole RWH system, the water sources of RWH projects should be consisted by catchment area and natural precipitation together from the water quantity safety view, which will play a decisive role in ensuring water quantity safety during the water supply period; Water storage facilities just like a regulating reservoir, which is an important means in ensuring adequate supply of water quantity by day; From the water quality safety view, the water treatment facilities and equipment just like water purification workshop in water supply plant, which is a combination of each water treatment technology at initial, middle and late stage, meanwhile, it is also a synthesis and integration in improve water quality, and play the decisive role. Thus, a certain amount of natural precipitation should be as premise, the enough catchment area as necessary grantee, the moderate scale of water storage facilities plays a key role, and effective water treatment facilities and equipment is the guarantee of RWH projects for safe drinking water in rural areas.

3. Basic Characteristic of RWH Projects for Safe Drinking Water in Rural Areas

3.1. Discrimination of Risk Source
In view of the basic characteristics of RWH for safe drinking water projects in rural areas, the implemented risk of the project mainly lies in links of resource endowment, engineering guarantee, operation and management and so on.

First of all, the randomness and uneven seasonal distribution of natural precipitation is the biggest risk in the implementation of RWH projects. As previously mentioned, the precipitation as the water source of RWH projects, therefore, the precipitation events decreased by extreme drought will inevitably become the maximum risk of the implementation of RWH projects for rural safe drinking water, however, the uneven seasonal distribution is significantly increase the difficulty of RWH. Secondly, it is also the mainly risk affected RWH, such as the design standard for engineering, construction quality, the quantity of catchment area and storage facilities, and the effectiveness of water treatment facilities. The quality of the project decides on the design standard, and then affects the service life, rainwater collection efficiency and effect of seepage control, thus indirectly affecting the amount of water available for the project; the number of the facilities directly determined how much rainwater runoff can be collected, stored and utilized in planned projects; the quality of rainwater depend on the effective and durability of water treatment facilities. Thirdly, the process management, such as engineering planning, draw up scheme, operation and management, etc., also plays a decisive role in water supply and quality guarantee of RWH projects. The project planning mainly determine component and structure of the system and to solve the problem of top-level design.
The programming mainly determine the supporting technology and the implementation mode, and to solve problems at special implementation and operation level. The operation management oriented towards operation, management and maintenance, and the key to solve the guarantee problems.

### 3.2. Identification of Risk Categories

The basic demand of safe drinking water in rural areas is to realize the double security of water quantity and quality. Therefore, the risk of RWH projects for safe drinking water in rural areas mainly include two aspects, one is water quantity shortage resulting in decrease of reliability and amount of water supply, the other is the poor water quality lead to its cannot meet the objective of safe water consumption. First of all, in terms of RWH projects, the main reason caused by water quantity scarcity involve of less precipitation, inadequate of catchment area and storage volume, low-standard engineering construction, improper operation and management and so on. If the reducing of reliability of any links will directly cause the decrease of availability and reliability of water supply of RWH projects for rural safe drinking water without exception, thereby resulting in the risk of water quantity. Secondly, RWH for safe drinking water projects in rural area are designed and adopted by the three-stage rainwater quality sedimentation and filter treated facilities and equipment facing the status quo, namely, coarse filter before storage, sedimentation after storage, and fine filter before use, which will play a very important role in ensuring water quality for living use propose. At the same time, the effectiveness of cohesion and treatment among three-stages treatment facilities will likely become main inducement resulting in the risk of water quality, as well as long-term operation of facilities cause the decrease of treatment capacity, partial function loss.

### 3.3. Formation Process of Risk

Although the risk is a probabilistic event, it is often the result of the combination of right man in harmony with right heaven and right earth. Therefore, the risk should be analysis by resource endowment, engineering guarantee, process management and so on. Furthermore, because the features of all links of risk source can became an independently disaster, the individual occurrence of any link will inevitably lead to the potential risk during engineering operation period.

#### 3.3.1. Water Quantity Risk

First of all, the implementation of RWH projects should be given a certain amount of natural precipitation as guarantee. Known from Technical code for rainwater collection, storage and utilization (GB/T 50596-2010), 250mm of the average annual precipitation is the lower limit for the implementation of RWH projects. The reliability of domestic water supply is 90 percent, a Red-line should be set up by these requirements to decrease the risk of RWH and improve the reliability of water supply at technical level. But even like this, the randomness of natural precipitation caused the reducing precipitation in some year, which brought the risk of water quantity is still exist. Secondly, catchment area and storage facilities play an irreplaceable role in ensuring water supply as important component of RWH system., Whichever the calculation method is adopted by the typical year or long-series one, the specific requirements would be put forward for the scale and quantity at theoretical level during the planning and design period while the risk of water supply caused by inadequate facilities still exist due to limited factors of site condition, geological condition, funds guarantee, etc. Thirdly, good engineering design standards and engineering construction quality are the important guarantee in improving rainwater collection efficiency and seepage control capacity of storage facilities, as well as extending the service life of engineering. On the contrary, if the construction standards of engineering are low with quality problems, the risk may be caused by insufficient water supply. Fourthly, the standard and effective construction and operation of engineering are very important in ensuring the sustainable utilization and high efficient operation of RWH projects. On the contrary, absence of management inevitably brings immeasurable risks for the implementation of projects. It should be pointed out that the occurrence of water quantity risk is with features of independence and comprehensive from the view of water quantity component of RWH projects. At the same time, the occurrence of water quantity risk is the result of the comprehensive
action of the above-mentioned factors, which is not only be transmitted, but also reduced among risk factors, meanwhile, with dual risks features of additivity and no additivity.

3.3.2 Water Quality Risk The water quality is one of the important indexes of safe water supply in rural areas. the three-stage treatment facilities and equipment of water quality of RWH projects for safe drinking water in rural areas, which can effectively remove the debris, sediment, bacteria and other harmful substances from stored runoff in ensuring the quality of water supply meet the demand of safe drinking water. However, the accumulated effects will co-lead to the occurrence of water quality risk, such as the structure type of facilities, the effectiveness of treatment process, the durability and timeliness of facilities, raw water quality beyond the design standard, the cohesion level between facilities and equipment, as well as absence of management and operation. Thus the occurrence of water quality risk became a results of multiple factors complex and comprehensive action with complex and integration features, such as facilities, equipment, management and other related factors.

4. Risk Assessment Index of RWH Projects for Safe Drinking Water in Rural Areas
The risk assessment index of RWH projects for safe drinking water in rural areas is an important means and used to measure and analysis of regional RWH projects for rural safe drinking water, and the index system should be comprehensive, integration and accurate to reflect the characteristics of natural precipitation at regional level, and develop comprehensive assessment of the risk of RWH for rural safe drinking water from multiple perspectives and all-round view. In combination with the above mentioned contexts of the discrimination of risk source, the identification of risk categories and analysis of risk formation process, according to the requirements of rural safe drinking water to quantity and quality, based on three aspects causing the occurrence of the risk, namely, resources endowment, engineering guarantee and operation management, the seven evaluated indexes have been selected for water quantity, plays a decisive role in water supply of rainfall, catchment area and storage volume, as well as play a significant restrictive effects upon the engineering design standards, construction quality, management system and construction and management; the five evaluated indexes have been selected by sediment basin, flocculant, purifiers and facilities maintenance. The overall evaluation index system of risk for safe drinking water will be set up by three layer, namely the target layer (A), criterion layer (B) and index layer (C) according to the influence to some extent of different evaluation indexes to quantity and quality, formulation process and mechanism of action. The overall evaluation index system for rural safe drinking water and the component of system are shown in Fig. 1 and Table 1.

| Objective layer A | Criterion layer B | Index C | Index description |
|-------------------|-------------------|---------|-------------------|
| Resources endowment | Precipitation risk C1 | The degree of deviation of the actual precipitation relative to the design reliability one |
| Engineering guarantee | Catchment area risk C2 | The degree of deviation of the actual catchment area relative to the design one |
| Water quantity risk | Storage volume risk C3 | The degree of deviation of the actual volume of storage facilities relative to the design one |
| Operation management | Design criterion risk C4 | The responsiveness of the engineering design standard to criterion determine the engineering standards |
| | Construction quality risk C5 | The response of engineering construction to the quality requirement of engineering design |
| | Management system risk C6 | Integration of engineering construction and management operation system |
| | Operation and management | The effectiveness of engineering operation and management |
5. Risk Assessment Model of RWH Projects for Safe Drinking Water in Rural Areas

5.1. Water Quantity Risk Assessment Model
The forming factors of RWH projects for safe drinking water in rural areas, among control factors of precipitation, catchment area and storage volume, bastardize of any factors will directly cause the occurrence of the risk. However, the occurrence of risk is complex, it is not only transfer, but also can reduce. The risk brought by the water sources, such as precipitation and catchment area, can be superimposed while the risk brought by storage volume and between the overall factors of water sources are not superimposed. In the management of risk of design criterion, construction quality and operation maintenance, etc., the risk can be passed and reduced. Moreover, the two kinds of risk, namely, the above mentioned the forming and management of water quantity can be occurred simultaneously and superimposed, the occurrence of former has non-negative effects. Therefore, the risk assessment mathematical model of RWH projects for safe drinking water in rural areas can be expressed in formula (1) according to probability theory.

$$ R = \max \left\{ \max \left( \left( R_{mp} + R_{ms} - R_{mp} \cdot R_{ms} \right) \cdot R_{mv} \right) \cdot \left( 1 - R_{mg} \right) + R_{mg} \right\} $$

Where: $R_{mp}$ --the degree of water quantity risk.
$R_{mp}$ -- the degree of precipitation risk;

$R_{ms}$ -- the degree of catchment area;

$R_{mv}$ -- the degree of storage facilities risk;

$R_{mg}$ -- the degree of management risk.

Precipitation, catchment area, storage volume and the degree of management risk can be calculated and determined by the equation (2), (3), (4) and (5).

\[
R_{mp} = 1 - \frac{P}{P}
\]

\[
R_{ms} = 1 - \frac{S}{S}
\]

\[
R_{mv} = 1 - \frac{V}{V}
\]

\[
R_{mg} = \sum R_{mg} \cdot K_{mg}
\]

where: $P$ -- the actual precipitation in year $i$ of project area, mm;

$P$ -- the design precipitation for the planning engineering, mm;

$S$ -- catchment area which has been built actually, m$^2$;

$S$ -- catchment area for engineering planning, m$^2$;

$V$ -- storage volume which has been built actually, m$^3$;

$V$ -- storage volume of facilities for engineering planning, m$^3$;

$R_{mg}$ -- the degree of risk in No. $i$ management measures;

$K_{mg}$ -- weight of class $i$ management measures;

Other signs are the same as before.

Among them, the risk degree of management measures should be determined according to the formulation process of risk and the degree of influence. The proportion of risk factors in the whole of risk should be determined by the expert grading method. The specific risk and weight of water management risk are shown in table 2.

| Management measures          | Weight of risk | The degree of risk and evaluation standard |
|-----------------------------|----------------|------------------------------------------|
|                             |                | 0  | 0~0.1 | 0.1~0.2 | 0.2~0.3 |
| Design criterion            | 0.2            | Higher | High | Fair | Low |
| Engineering quality         | 0.3            | Very good | Good | Fair | Poor |
| Management system           | 0.2            | Very perfect | Perfect | Fair | Nil |
| Operation and maintenance   | 0.3            | Very good | Good | Fair | Poor |
5.2. Water Quality Risk Assessment Model

Water quality plays a decisive role on safe drinking water in rural areas. As above mentioned, the water quality risk is a result of common action in facilities, equipment structure type, treatment effect and service life, and different risk elements have different functions and effects in the forming process of risk. Therefore, the mathematical model of the water quality risk of safe drinking water in rural areas can be expressed by formula (6):

\[ R_z = R_l \cdot K_l + R_b \cdot K_b + R_j \cdot K_j + R_q \cdot K_q + R_g \cdot K_g \]  

(6)

Where: \( R_z \) -- the degree of water quality risk; 
\( R_l \cdot K_l \) -- the degree of risk and weight in length of sediment basin; 
\( R_b \cdot K_b \) -- the degree of risk and weight in width of sediment basin; 
\( R_j \cdot K_j \) -- the degree of risk and weight in flocculant; 
\( R_q \cdot K_q \) -- the degree of risk and weight in water purifier; 
\( R_g \cdot K_g \) -- the degree of risk and weight in facilities maintenance.

Among them, the length of sediment basin and the degree of width risk can be calculated and determined by formula (7) and (8), and the risk degree of flocculant, water purifier and facility maintenance are quantified according to the qualitative evaluation results. Flocculant, purifier, assessment standard of facility maintenance risk and weight of facilities maintenance risk are shown in Table 3.

\[ R_l = \begin{cases} 
1 - \frac{L_s}{L} & (L_s < L) \\
0 & (L_s \geq L)
\end{cases} \]  

(7)

\[ R_b = \begin{cases} 
1 - \frac{B_s}{B} & (B_s < B) \\
0 & (B_s \geq B)
\end{cases} \]  

(8)

In formula: \( L_s \) -- the actual length of sediment basin; 
\( L \) -- design length of sediment basin; 
\( B_s \) -- the actual width of sediment basin; 
\( B \) -- design width of sediment basin

| Management measures         | Weight of risk | The degree of risk and evaluation standard |
|-----------------------------|----------------|-------------------------------------------|
|                             | 0              | 0.0~0.1                                   |
|                             | 0.1~0.3        |                                           |
|                             | 0.3~0.5        |                                           |

| Length of sediment basin    | 0.15           | ---                                       |
| Width of sediment basin     | 0.15           | ---                                       |
| Flocculant                  | 0.2            | with, use in very good                    |
| Purifier                    | 0.2            | with, use in fair service life            |
|                             |                | Nil or use in poor                        |

Table 3 evaluation standard and weight of water quantity risk
5.3. Risk Comprehensive Assessment Model
The integrated risk of rainwater collection and utilization of safe drinking water in rural areas is the result of the joint action of water quantity risk and water quality risk. However, the particularity of rainwater collection and utilization project to determine the order for different risk of this project. Water quantity risk has occurred firstly, and then water quality risk occurred. Especially when water quantity risk occurred then the water quality risk can occurred where the water quantity risk has not occurred. Therefore, according to the theory of probability addition, the integrated risk assessment model of rainwater collection and utilization of rural safe drinking water is available in formula (9):

$$ R = R_m + R_z - R_m \cdot R_z $$

(9)

5.4. Comprehensive Risk Assessment Standard
Basis for rainwater collection and utilization of rural safe drinking water project risk evaluation results, according to the risk-free, low risk, medium risk, high risk and extremely high risk, a total of 5 set the risk level, specific evaluation criteria are shown in table 4.

Table 4 RWH of rural safe drinking water project comprehensive risk assessment standard

| Risk degree | 0   | 0~0.1 | 0.1~0.2 | 0.2~0.3 | >0.3 |
|-------------|-----|-------|---------|---------|------|
| Risk level  | Risk-free | Low risk | Medium risk | High risk | Extremely high risk |

6. Conclusion
Rainwater collection and utilization of rural safe drinking water project risk is to be made up of water quantity and water quality risk. The risk is the results of the combined action among the resources endowment, security engineering, operation, management and so on. However, they are very important to analyze the risk factors and the formation process, establish a risk evaluation index system and evaluation model, put forward the risk evaluation methods, scientifically evaluate risk and determine the risk level. They can play very important role in controlling risks for the effective process of rainwater collection and utilization project, improving the reliability of water supply, implementation safeguard water supply, ensuring the sustainable utilization of the rainwater collection and utilization project, and supporting the economic and social sustainable development.

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