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第 **5** 屆亞洲區域研討會論文發表

The Innovation of Irrigation Water Quality Evaluation Program in Taiwan

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60th International Executive Council Meeting &

5th Asian Regional Conference, 6-11 December 2009, New Delhi, India

THE INNOVATION OF IRRIGATION WATER QUALITY EVALUATION PROGRAM IN TAIWAN

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ABSTRACT : *The aim of irrigation is to supply water to crops at right times with adequate quantities and appropriate qualities. Thus, the quantity and quality of water for irrigation use are of equal importance. Availability of irrigation water resources now a days is increasingly constrained, as a result of climate change, population growth, and industrial and commercial developments. Therefore, the need of quality management for the limited available irrigation water supply is increasingly urgent. In Taiwan, presently more than 2,500 monitoring points have been set up on various irrigation canals, for examining and recording the water quality conditions, such as temperature, acidity, and electrical conductivity once in every other month. The monitored results of the irrigation water quality for a specific irrigation association or system are then compiled and analyzed to calculate the qualified ratios of its irrigation water, or the ratios of amounts of water that meet the water quality criteria for irrigation to the total amount of irrigation water supplied in a certain period. Conventionally, the qualified ratio is calculated by means of the "Monitoring Point-Frequency Method" (MPF method). However, in this method is not taken into comprehensive consideration of the different background characteristics of the monitoring points, such as affected irrigation areas, irrigated water amounts, cropping patterns, etc. As such, neither the substantial present conditions of water quality nor the canals with inferior water quality can be factually reflected from the statistic data obtained from the MPF method. Consequently, the subsequent water quality management cannot be implemented systematically and effectively. Thus, the performances of water quality improvement measures achieved are usually incompatible to the relevant resources inputs ever made.*

In order to solve the shortcoming of the MPF method, in this study was proposed the "Weighted Irrigation Canal-Area Method" (WICA method), by taking into account the characteristics of irrigation areas in the monitored results. This method was applied to calculate the ratio of irrigation water in each canal fulfilling the water quality criteria, by integrating the irrigation area of the canal as a weight factor into the method. In the study was also developed a four-tier framework of "irrigation association - irrigation system - canal - monitoring point" for better realizing the water quality conditions in each canal. Furthermore, the irrigation water quality was classified into four grades; namely, good, qualified, unqualified, severely polluted for each canal, which was certainly helpful to the relevant irrigation associations to take appropriate management measures upon the actual water quality conditions of the irrigation canal rated.

The irrigation water quality evaluation mechanism developed from this study has been approved by the competent authority and then implemented in Taiwan area since early 2009. In this paper it is not only systematically introduced various measures used in this evaluation mechanism, but also summarized *its preliminary achievements as of to date.*

Keywords: *Irrigation, Water Quality, Evaluation, Investigation*

1. INTRODUCTION

Agriculture is the fundamental industry of a nation's economy and the cornerstone of the social stability. In the course of the development of economy in each country, it always plays an important and indispensable role. As water is the essential element of agricultural production, to supply adequate quality and quantity of water at appropriate time is the main purpose of developing and building the irrigation and water conservancy systems worldwide. At the early times, like most of other countries, the water resources in Taiwan rarely faced the menace of pollution, which quality generally met the requirements of irrigation usage. The key factors of the then irrigation management were focused on the volumes and the distributions of water. However, as a result of the economic growth and population concentration in urban areas, the demands of both domestic and industrial water consumptions have both been increasing year by year. As such, under the limited water resources availability, the agricultural water resources have become increasingly constrained. Meanwhile, the pollutants discharged from various purposed water uses were massively drained into rivers, streams and irrigation canals, which have seriously damaged the water quality for irrigation and the crop production farmlands. Since there are no substitutes for water and land resources in the great nature, therefore according to the projection of the experts in UN, should the proactive management of the planet's resources be still neglected, the crisis of the insufficient water resources will get worsen continually under the impact of the climate change in this 21st century. Therefore, besides fulfilling the adequate water supply in volumes in the future water management, it is a sure trend to invest more resources to enhance the monitoring and maintenance of water quality. It is also one of the most essential works in the national policy for development of food safety or safe agriculture in each country.

There are two fundamental principles in the irrigation water quality management. Firstly, the substantial maintenance of the good quality water in canal; and secondly, systematic investigations and improvements of problematic water quality in canals. Therefore, the key factors of levels of performances of the water quality management are whether the related management are capable of surely grasping the water quality conditions in various canals, and meanwhile duly taking appropriate management actions. Since 1979, the ministerial level Council of Agriculture (COA) Taiwan has promoted in whole scale the maintenance work on irrigation water quality. Under the guidance of the COA , the irrigation associations in various districts of Taiwan have set up the water quality monitoring points on the irrigation canals, and examined and recorded the water quality conditions once every two months. And the monitored data have been analyzed to evaluate the qualified ratios of the irrigation water quality or the ratios of water quantities fulfilling the irrigation water quality criteria, thereby to indicate any irrigation association's or canal's averaged water quality situations. However, because of the negligence of the background impacts from the monitoring points in the conventional statistic method, the assessed results could hardly reflect the actual water quality conditions in respective irrigation canals. And due to the insufficient reliable data on the resources inputs, it has made the follow-up improvement measures in the canal water quality management difficult to achieve the predetermined targets. To improve such a situation, in this study was reviewed the shortcomings of the existing statistic methods for evaluating the qualified ratios of irrigation water, and proposed the modified framework and methodology for the statistic analysis. Besides, the water quality classification system for the canals was developed in this study. This system will facilitate the establishment of a reasonable and systematical evaluation mechanism, in which is integrated with all the elements related to irrigation water quality management, beginning from monitoring, statistical analysis of data, till the follow-up investigations and resources allocations in the water quality improvement.

2. REVIEW AND MODIFICATION OF THE QUALIFIED RATIO STATISTIC METHODS OF THE IRRIGATION WATER

Currently, the irrigation water quality monitoring and management system is adopted by the local irrigation associations as the core tool for the management of the irrigation water quality in Taiwan. Under this system, the COA provides guidance to the local irrigation associations on building up the irrigation water quality monitoring network, in which each irrigation association's headquarters is designated as the Head Monitoring Station; each of its Administrative Offices as the District Monitoring Station, and each of its Working Stations as the Local Monitoring Station. In sum, there are 15 head monitoring stations, 13 district monitoring stations, and 276 local monitoring stations, which manage a total of 2,558 irrigation water quality monitoring points in Taiwan, as of December 2008. The irrigation water quality conditions sampled and tested once every two months. And subsequently the resulted data are analyzed to obtain the qualified ratios by means of the "Monitoring Point-Frequency Method" (MPF method).

The MPF method is applied to calculate the ratios of the monitoring points-frequencies of qualified water to the total monitoring points-frequencies of an irrigation association or canal (Equation 1). Although its calculation method is easy and quick, yet it has not taken into account the background characteristics of each water sampling point, such as affected irrigation area, variations of irrigation water volumes and cropping patterns, to include in the equation the appropriate weights of these factors. Therefore the derived results from this method cannot present the realistic irrigation water quality conditions, neither can detect in which canals the flows are of poor quality.

$$\begin{array}{c}\textit{Qualified Ratio of} \\ \textit{Irrigation Water Quality}\ (\%)\end{array} = \frac{\textit{Qualified Monitoring Points} - \textit{Frequency}}{\textit{Total Monitoring Points} - \textit{Frequency}} \times 100\% \qquad ......1$$

To solve the shortcoming in the MPF method, the "Weighted Irrigation Area Method" (WIA method) was developed in 2006, trying to express the characteristics of the monitoring points with the weighted indexes in the computed results. In view that the irrigation water amounts usually more fluctuate with the external environmental factor, e.g., no irrigation due to farm fallowing, so, on the basis of the assumption that the irrigation water quantities are proportional to the irrigation areas, in order to fix the weighted index at every monitoring point for simplifying the calculation, for the WIA method the affected irrigation area of each monitoring point was chosen as the "weighted index". Thus, the ratio of irrigation water quality having met the required is expressed as follows:

$$\begin{array}{c}\textit{Qualified Ratio of} \\ \textit{Irrigation Water Quality}(\%)\end{array} = \frac{\begin{array}{c}\textit{Total Affected Irrigation Area of All} \\ \textit{Qualified Testing Po}\text{int}-\textit{Frequency}\end{array}}{\begin{array}{c}\textit{Total Affected Irrogation Area of} \\ \textit{Total Testing Po}\text{int}-\textit{Frequency}\end{array}} \times 100\%$$

……2

After a series of the field examinations of the calculated results, it showed that the results from the WIA method were much closer to the actual irrigation water quality conditions, and hence more conformed with the essence of irrigation water monitoring. Comparing the results from the WIA and MPF methods, the following two major differences were observed. Firstly, the irrelevant monitoring data of the monitoring points on drainage ditches which water has no impact on the irrigated crops, have been totally excluded from the qualified ratio calculations in the WIA method. Secondly, if there were more than one monitoring point on the same irrigation canal, which water had been polluted, its weight in the overall calculated results could be relatively reduced by the weight calculation mechanism of the WIA method.

However, because the aforementioned method is based on the affected areas of the monitoring points, in application of the WIA method in the irrigation associations, the following two dilemmas were encountered. The first was that the irrigation associations each had not yet mastered at the database management, hence some of the irrigation associations had been short of the relevant information on the affected area of each monitoring point for reference. The second was the difficulty to define the actual area boundary affected by each monitoring point. Even though some of the irrigation associations have built up their own database of concern, yet the different standards defining the affected areas between the irrigation associations or between the working stations have caused the need of clarification of the accuracy of these data. On the other hand, the reasons that the WIA method could not entirely replace the MPF method were that the former method still adopted the single monitoring point as the basic unit in its calculation, and its results still could not meet the objective of showing the canals where the poor quality flows exists.

Therefore, during this study work the WIA method was further modified, on the basis of adopting the affected irrigation area as the weight factor, by adopting the irrigation canals as the basic calculation units for evaluating the overall irrigation water quality conditions. The so modified method was termed as "Weighted Irrigation Canal-Area Method" (WICA method).

The principle of the WICA method is: to divide each irrigation canal system into several calculation units, and delineate the irrigation area of each canal. Subsequently based on the monitored water quality data of canals, by means of the arithmetic average method, the comprehensive evaluation index of each canal's water quality is calculated (see Equation 3). Then, with the introducing of the concept of the WIA method, the water qualified ratios of an canal system can be obtained (see Equation

4). Finally, the overall irrigation water qualified ratio of an irrigation association is calculated from the weighted mean value of the ratios of its irrigation canal systems (see Equation 5).

$$\begin{matrix}\textit{Comprehensive Evaluation Index of} \\ \textit{Water Quality in a Canal}\end{matrix} = \frac{\begin{matrix}\textit{Numbers of Monitoring Points with Water} \\ \textit{the Canal having beeing within the Quality} \\ \textit{Control Limit}\end{matrix}}{\begin{matrix}\textit{Total Numbers of Monitoring Points} \\ \textit{on the Canal}\end{matrix}} \times 100\% \quad \ldots\ldots 3$$

$$\begin{matrix}\textit{Qualified Ratio of} \\ \textit{Water Qualityof a System } (\%)\end{matrix} = \frac{\sum \begin{matrix}(\textit{Irrigation Area perf Canals} \times \textit{Comprehensive} \\ \textit{Evaluation Index of Water Quality per Canal})\end{matrix}}{\sum(\textit{Irrigation Area per Canal})} \times 100\% \quad \ldots\ldots 4$$

$$\begin{matrix}\textit{Qualified Ratio of} \\ \textit{Irrigation Water Quality } (\%)\end{matrix} = \frac{\sum \begin{matrix}(\textit{The Irrigation Area of per System} \\ \times \textit{ Qualified Ratio of Water Quality per System})\end{matrix}}{\sum(\textit{Irrigation Area of per System})} \times 100\% \quad \ldots\ldots 5$$

An example is given here for illustrating the aforementioned methods. Assuming the irrigation water sources of an irrigation association are from two separate rivers, River A and River B (Fig.1). When this irrigation association is to assess the qualified ratios of irrigation water, the calculations will be preliminarily respectively made to the River A and the River B irrigation systems. There are four main canals in River A system; namely, A_1 (200 ha), A_2 (50 ha), A_3 (100 ha) and A_4 (150 ha). The irrigation areas noted in the brackets can be well identified from the irrigation plan formulated by the association. When applying the "Weighted Irrigation Canal-Area Method" to assess the qualified ratios of irrigation water, the first step is to obtain the average qualified ratio of each monitoring point on each canal by use of the arithmetic mean approach. This is meant that the water quality comprehensive evaluation index is used to indicate the water quality condition of the canal. For instance, if there are 5 monitoring points on Canal A_3, and the water quality in 2 of the 5 points do not yet meet the irrigation water quality standards, then, the water quality comprehensive evaluation index of the canal is 0.6 (= 3 / 5). The adoption of the arithmetic mean makes the computation work less time–consuming, so that the concerned irrigation association staff do not need to count the affected irrigation area of each monitoring point as well as the total of all the points. It is expected that the conservative mean value will reduce the errors in identifications of affected irrigation areas. On the other hand, it can significantly simplify the calculation procedure, which is regarded as the optimum compromise between the calculation accuracy and efficiency.

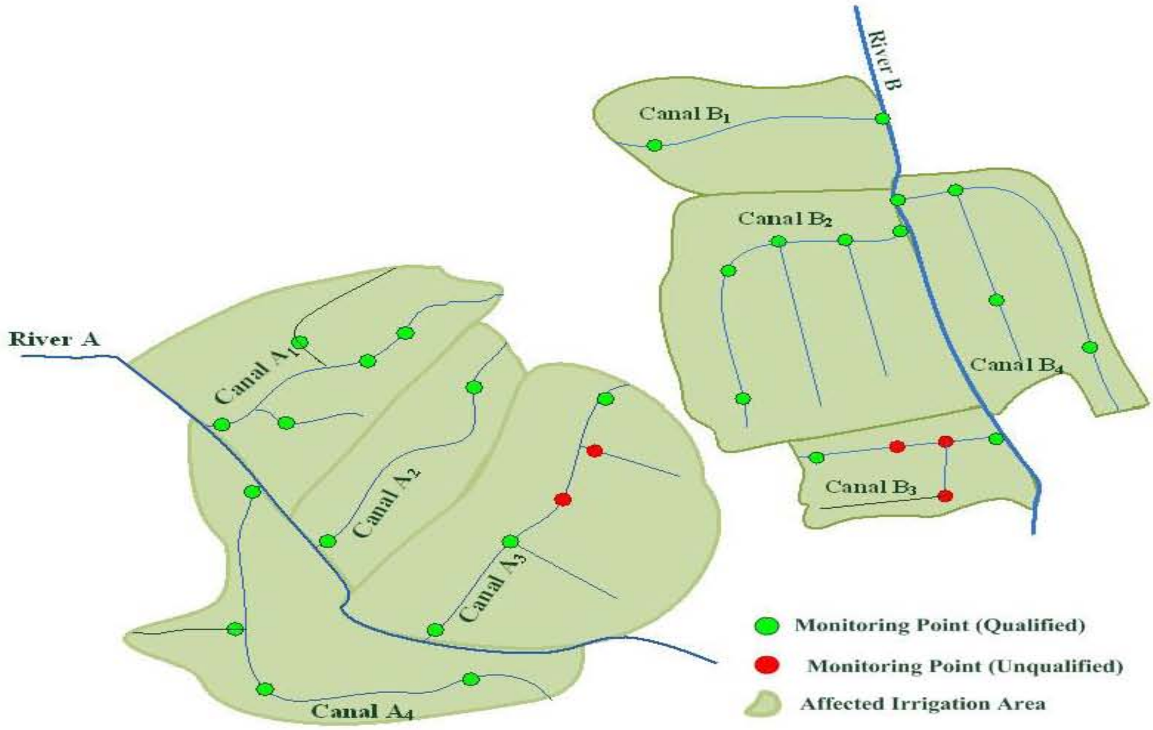

Fig. 1 Calculation of Qualified Ratios of Irrigation Water Quality: Using the Virtual Irrigation Canals and Monitoring Points Layout

Following the same approach as above, assuming the water quality comprehensive index of Canals A_1, A_2、 A_3 and A_4 are 1 (= 5/5), 1 (= 2/2)、 0.6 (= 3/5) and 1(= 4/4) respectively, the qualified ratio of water quality of the system River A can be obtained with Equation 4.

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$$\begin{aligned} &\textit{System River A`s Water Quality Qualified Ratio (\%)} = \frac{\sum \left(\begin{array}{l}\textit{The Irrigation Area per Canal} \times \textit{Water Quality} \\ \textit{Comprehensive Evaluation Index per Canal}\end{array}\right)}{\sum (\textit{Irrigation Area per Canal})} \times 100\% \\ &= \frac{\sum (200 \times 1 + 50 \times 1 + 100 \times 0.6 + 150 \times 1)}{\sum (200 + 50 + 100 + 150)} \times 100\% \\ &= 92\% \end{aligned}$$

To highlight the rational of the calculated qualified ratio data of the WICA method for the canals with polluted water, in the irrigation system River B is deliberately assumed the water in Canal B_3 (50 ha) is polluted, and the water qualities in 3 of the 5 monitoring points of the canal have been found inconformity to the quality control limits, hence the calculated water quality comprehensive evaluation index of the canal is 0.4 (= 2/5). However, the water quality in the rest of the 3 canals are all qualified, as mentioned previously (2/2, 5/5 and 4/4). Based on their irrigation areas: B_1 = 100 ha, B_2 = 200 ha and B_4 = 50 ha, then, the qualified ratio of water quality of the System River B can be obtained by Equation 4.

$$\begin{array}{c} System\ River\ B`s \\ Water\ Quality\ Qualified\ Ratio\ (\%) \end{array} = \frac{\sum(100\times1+200\times1+50\times0.4+150\times1)}{\sum(100+200+50+150)}\times100\%$$

$$= 94\%$$

And the overall qualified ratio of the irrigation water quality of the irrigation association can be obtained by means of Equation 5.

$$\begin{array}{c} Qualified\ Ratio\ of \\ Irrigation\ Water\ Quality\ (\%) \end{array} = \frac{\sum\begin{pmatrix} The\ Irrigation\ Area\ per\ System \\ \times\ Qualified\ Ratio\ of\ Water\ Quality\ per\ System \end{pmatrix}}{\sum(Irrigation\ Area\ per\ System)}\times100\%$$

$$= \frac{\sum(500\times92\%+500\times94\%)}{\sum(500+500)}\times100\% = 93\%$$

From the calculation process, there are two aspects can be reasoned to verify that the calculated results from the WICA method will be more rational and conform to the actual water quality conditions than those from the MPF method.

(1) The irrigation canal systems of the River A and River B have been respectively set up 16 water quality monitoring points, and water quality at 2 and 3 monitoring points on respective systems are unqualified according to monitored results. If using the original “Monitoring Point-Frequency Method” as the computation basis, because the River A irrigation system has less monitoring points with unqualified water, theoretically, the qualified ratio of the water quality in River A irrigation system should be higher than that of the River B system. However, the qualified ratio of the River B system, by calculating with the “Weighted Irrigation Canal-Area Method”, is 94 % as compared to the corresponding ratio of the River A system, which is 92%. The key of the difference lies at the 3 monitoring points with unqualified water quality are all located on the Canal B_3, which irrigation area is the smallest (50 ha) among the canals of System River B. In contrast, the impact factor caused by the unqualified water quality of Canal A_3 with the largest irrigation area (100 ha) among the canals in the System River A. Obviously, the latter exerts greater impact to the overall irrigation water quality of the irrigation canal or system. Hence the “Weighted Irrigation Canal-Area Method” can more accurately reflect its impact weight in the results of computations.

(2) Moreover, from the viewpoint of the overall irrigation water qualified ratios of the irrigation association, the qualified ratio calculated with the WICA method is 93 %. However, with the estimation of the MPF method, as the water quality in 5 of the 32 monitoring points of the association are not qualified, the qualified ratio therefore dramatically declines to 84.3 %. By probing in detail the monitoring points of the unqualified water quality which are all situated on Canals A_3 and B_3, with the total irrigated area of 150 ha which accounts for 15 % of total 1,000 ha irrigation area of the association. Therefore, the

reasonable overall irrigation water quality qualified ratio should be greater than 85 %. It indicates that even if the irrigation water quality of the abovementioned two canals are both unqualified according to the standards of water quality, the qualified ratio of the irrigation water quality should not be lower than 85 %. Comparing the computation result of these two methods, the qualified ratio calculated from the MPF method, 84.3%, apparently does not conform to the actual irrigation water quality condition of this association. But the result obtained from the WICA method, 93 %, not only falls into the reasonable range but also can provides information for the management to grasp the actual canals/irrigation systems where the water quality is beyond the existing standards prescribed. So its application in the subsequent value-added analysis is even better than the MPF method.

For the purpose of implementing the WICA method in computations of the routine water quality monitoring results, it is necessary to establish the four-tier framework of "Irrigation Association – Irrigation System – Canal – Monitoring Point". The most important fundamental task in the framework is to establish the relationships between the monitoring points, individual canals and the irrigation canal system concerned.

Because for all the irrigation associations the complex levels of the irrigation canal systems vary and the completeness of related database established for relevant canals are in different degrees, too. These situations have caused greater difficulties in creating the statistic framework. The team of this study had conducted face to face communications with concerned staff in charge in the associations, to request for their assistance in clarifying the relationships mentioned previously. Furthermore, by keeping the fundamental statistic principles without change, micro modifications in the statistic method were made in this study, which were necessary for accommodating the varying environmental background situations of the associations' irrigation canal systems. Such situations included background water quality, supplementary water sources, irrigation practices, and their direct connections with irrigation water quality. The effort aimed to allow the modified statistical methods to calculate the water quality qualified ratios thereby rationally indicate the actual irrigation water quality conditions in each association.

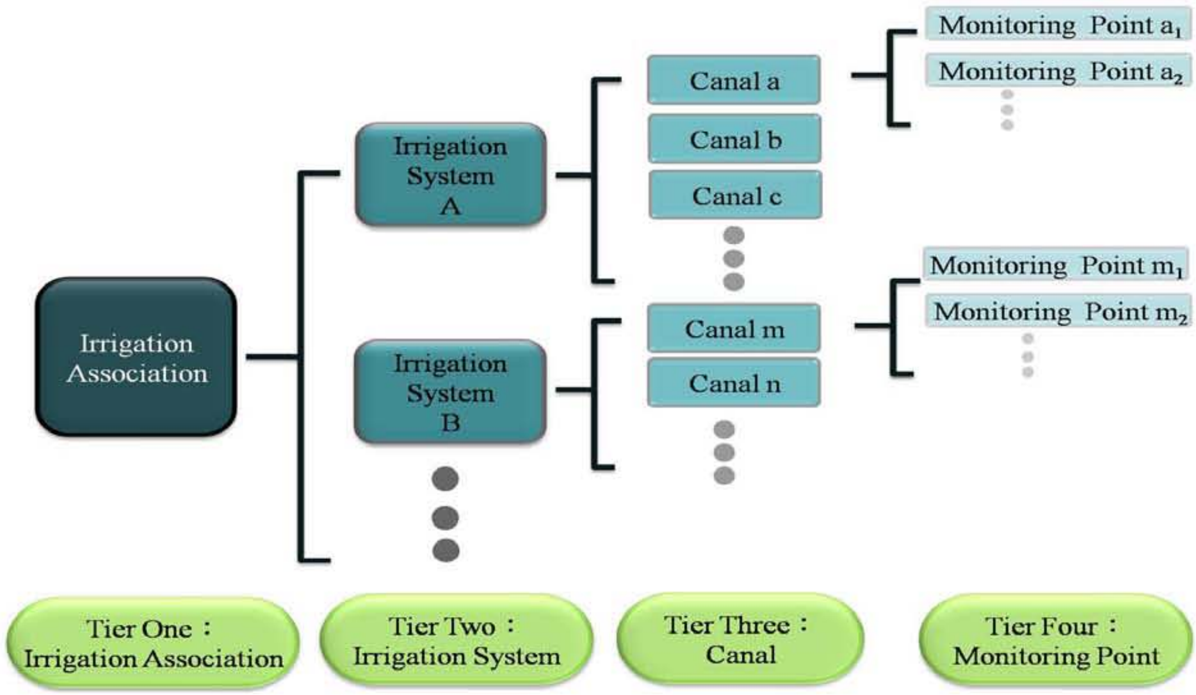

Fig. 2 Statistical Framework for the Preliminary Qualified Ratios of Irrigation Water Quality at the Monitoring Points

Within the re-established statistic framework for qualified ratios of irrigation water quality (Fig.2), the monitored irrigation water quality results not only indicates the beginning and end tiers; that is, the qualified ratios of water quality of the irrigation association as a whole and the individual monitoring points. They also include the adjacent canals and the irrigation canal systems connecting these canals. Therefore, under the new statistic framework, the irrigation water quality conditions of each irrigation association will be demonstrated by 4 tiers of qualified ratios as illustrated in Fig. 3.

3. ESTABLISHMENT OF CLASSIFICATION SYSTEM OF WATER QUALITIES IN CANALS

The new irrigation water quality evaluation framework mentioned above is much helpful for the practices of systematic evaluations of current water quality conditions and also the classifications as well as zoning works on regional water quality situations (Figure 3). In regard of the once every 2-month regular preliminary and repeated irrigation water quality monitored data analyses, since the new statistic framework is incorporated with the irrigation canal systems, the causes and ranges of water pollutions can be fully realized. On the other hand, the analyzed results can also provide the irrigation associations with practical information on the locations and ranges required for taking follow-up actions to strengthen the irrigation water quality monitoring and management.

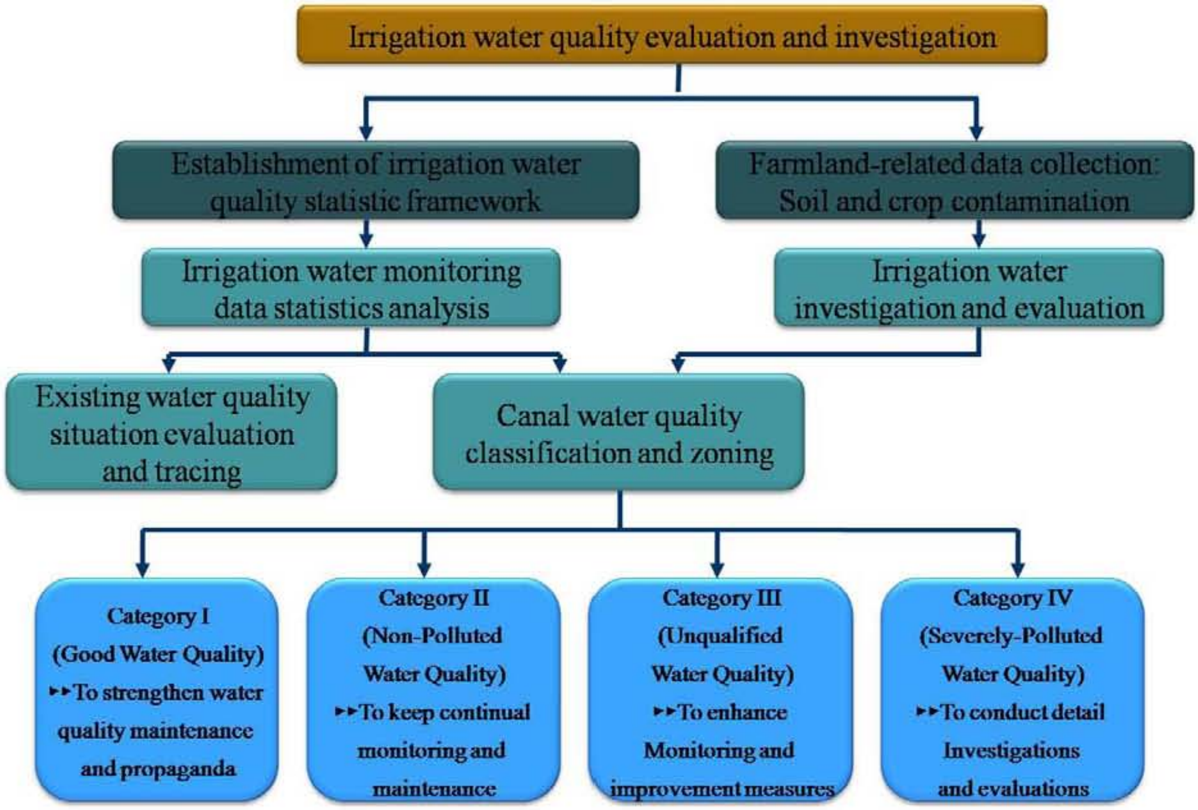

Fig. 3 Framework of Irrigation Water Quality Evaluation and Investigation Activities

Moreover, the purpose of classifying and zoning the regional water quality situations is to further implement a systematic and integrated evaluation of the water quality in canals and irrigation areas. Based on the evaluation results, the allocations and usages of the management resources for the irrigation water quality management are expected to be carried out more efficiently, so as to reach the goal of the optimal performance of the management. As mentioned previously, under this new statistic framework, the irrigation associations can well realize the water quality situations of each canal. So in the study the historical monitoring records of the water quality of the past 3 years were compiled to serve as the inputs for the evaluation comparison basis. The evaluation of each canal's water quality condition was made in two stages.

3.1 First Stage : Classification of Water Quality in Canals

The working stations were conventionally taken as the basic units for water quality classification and regional evaluation. In comparison, with the establishment of the new evaluation statistic framework, the classification of irrigation water quality should be oriented to the irrigation canals as the evaluation units. Such a practice would be more fit to the basic concept of water quality management on the watershed basis. In the first stage planning conducted during this study, the last 3 years' preliminary water quality tested data at the monitoring points were used for evaluation purpose (mainly the electrical conductivity, EC). The SPSS analysis method was adopted to draw the Box- Whisker diagram. Then, the monitored mean values within the 95% confidence interval were calculated which was termed as the water quality characteristic value of canals (the characteristic value). The characteristic values were used as the basis for classification of the canal water quality. Afterwards, supplements with the frequency conditions of the unqualified water quality occurrences were made to carry out the double condition screening. The canal water quality conditions were classified into 4 categories, as defined below:

Category I - Characteristic Values 250 μS/cm; good water quality canals, recommended for demonstration purpose.

Category II - 250μS/cm < Characteristic Values 750 μS/cm, or Characteristic Values 250μS/cm but the numbers of tested values > 250 μS/cm are over 1/3 of the total tested numbers; such canals' water quality to be continually monitored and maintained by the associations concerned.

Category III - 750μS/cm < Characteristic Values 2,250 μS/cm, or 250 μS/cm < Characteristic Values 750 μS/cm but the numbers of tested values > 750 μS/cm are over 1/3 of the total tested numbers; canals' water quality to be strengthened the monitoring and improvement.

Category IV - Electrical conductivity values > 2,250 μS/cm,or 750μS/cm < Characteristic values 2,250 μS/cm but the numbers of tested values > 2,250 μS/cm are over 1/3 of the total tested numbers; canals' water severely polluted; intensive investigation and monitoring and evaluation to be carried out to find out the main pollutants and the possible pollutant sources.

The categories of evaluated water quality of the canals of each association were plotted with different colors on the concerned range affected. This was to help relevant staff of each irrigation association realize the water quality conditions and the locations of the canals with poor water quality.

3.2 Second Stage : Classification of Severeness of Pollution

The main purpose of the classification work conducted in the second stage is to comprehend the pollutants in the polluted canals, and to use them for references for the follow-up actions to carry out the detailed investigations in and improvement measure planning for the polluted canals.

In this stage the re-inspected canal water quality test data during the last 3 years were used as the references (Table 1). Like in the 1st stage, the SPSS was adopted as the analysis method to draw the Box-Whisker diagram to find out the distribution range of the monitored mean values within the 95% confidence interval. Next, the canals' water quality rated as Categories 3 and 4 in Stage 1 were taken for further assessing the main pollution types and degrees of severeness.

However, the irrigation associations' polluted canal re-inspection operations have not been so satisfactory as the preliminary inspection operations. Accordingly two measures were propose in order to avoid the influence to the classification assessment of water quality from the shortage of relevant re-inspected data of some of the canals, In the beginning, from the irrigation systems the canals which had been rated as Categories 3 and 4 in the preceding stage and had not been conducted any re-inspections during the last 3 years were listed. Then, the lists were submitted to the COA for delivering to relevant irrigation associations to implement the water quality re-inspection work on the listed canals. Meanwhile this study team also compiled the data on the monitored farmland soils and crops from both relevant authorities. To the polluted farmlands observed from such data, the team also conducted investigation and supplementary monitoring of water quality in the related canals. Then the categories of water quality of these canals and the severenes levels of canal water pollutions were rated based on the assessment results.

Table 1: Evaluation Criteria for Classification of Water Pollution

Pollution Degree	**Class 1**	**Class 2**	**Class 3**	**Class 4**
Nitrogen (Organic contamination) mg/L	≦1.0	>1.0~≦3.0	>3.0	
Chloride mg/L		≦175	>175-≦350	>350
Sulfate mg/L		≦200	>200-≦600	>600
RSC (alkaline contamination) meq/L		≦1.25	>1.25-≦2.50	>2.50
SAR (Sodium-Na contamination) (meq/L)$^{1/2}$		S1	S2	S3
Copper (heavy metal) mg/L		≦0.1	0.1<Conc.≦0.2	>0.2
Lead (heavy metal) mg/L		≦0.05	0.05<Conc.≦0.1	>0.1
Nickel (heavy metal) mg/L		≦0.1	0.1<Conc.≦0.2	>0.2
Zinc (heavy metal) mg/L		≦1.0	1.0<Conc.≦2.0	>2.0
Cadmium (heavy metal) mg/L		≦0.005	0.005<Conc.≦0.01	>0.01
Chromium (heavy metal) mg/L		≦0.05	0.05<Conc.≦0.01	>0.1

SAR(Sodium-Na contamination) Assessment Standard : Based on the EC and SAR standards prescribed in the American Agriculture Irrigation Water Quality (1995)

Additionally, the COA of Taiwan Government has been entrusting a technical specialist team to choose every year 5 irrigation areas or canals, based on the pollution characteristics in each irrigation association jurisdiction, to demonstrate the technologies for polluted farmland recovery. The factors for choosing the demonstration locations include the seriously contaminated farmland soils and or corps, areas concentrated with small to middle sized pollutant-discharging factories or livestock farms, irrigation areas downstream from the large-scale industrial or science parks, irrigation areas using the re-recycled water, and water quality having been polluted yet the sources of pollution unclear.

4. INITIAL ACHIEVEMENTS

4.1 Revision of the Qualified Ratios of Irrigation Water Quality

The statistic framework of qualified ratios of irrigation water quality of the irrigation associations in Taiwan area (excluding the two associations in Taipei City) has been basically completed after the assistance of the investigation and confirmation were made by the irrigation associations. Under the new 4-tier statistic framework, in the present 15 irrigation associations, there are 137 irrigation canal systems, 1,174 canals, and 2,558 irrigation water quality monitoring points. Because the independence of the canals and whether the water quality may affect each other of the canals were adopted for the basis of separating the canals in framework, therefore the distribution ranges of the affected irrigation areas between the canals were rather large. There are 85 major canals with the affected irrigation areas respectively more than 1,000 ha, mainly located in Yunlin, Changhua and Chianan Irrigation Associations' jurisdiction areas.On the other hand, there are 682 canals with the affected irrigation areas respectively less than 100 ha. The numbers of the independent but small canals are over half of the total, mostly spread around the Peikee, Yilan, Pingtung and Miaoli Irrigation Associations.

Based on the preliminary tested data of irrigation water quality for the two cropping seasons in 2009, the statistic results from the WICA and the MPF methods were compared, from which the following phenomena were noted:

(a) With regard to the overall average qualified ratios of irrigation water quality of the 15 irrigation associations, there is no major difference between these 2 statistic methods; that is, within 2 %. But after comparing the two methods' statistic results of each irrigation association, it was noted that most of the qualified ratios of irrigation water quality of the respective irrigation associations did not show significant changes. There were 9 and 11 irrigation associations which statistic disparities of water quality tested in the two monitoring periods were respectively under 2 %. On the other hand, there were 5 and 3 irrigation associations which qualified ratios in respective monitoring periods rose 3 % due to the change of statistics method. However, there were 2 and 1 irrigation associations which qualified ratios in respective periods lowered 3% because of the same reason mentioned above.

(b) After conducting detailed analyses of the relations between the rising/lowering of qualified ratios of the irrigation water quality and the statistic methods used, it showed that the factor lied at the installation locations of the monitoring points. The irrigation water monitoring points presently are set up by the irrigation associations in line with the principles set out in the "Irrigation Water Quality Monitoring Work Specifications". The monitoring points locations selection principles as set out in the Specifications include irrigation water sources, junctions of the primary, secondary and sub-secondary canals, and where the water quality conditions in need of intensive monitoring. In general, most of the irrigation associations' monitoring points scatter rather evenly on the major canals, and the canals' affected irrigation areas covered by the monitoring points are relatively average. Therefore, in calculations of the qualified ratios of the irrigation water quality, whether the weights are given weights, the statistic results reflected only minor difference.

(c) On the other hand, part of the irrigation associations, like Chianan and Changhua, concentrated the monitoring points on the canals usually with poor water quality or being prone to pollution, because of the constraints of their resources available for water quality management,. Under such a circumstance, the average affected irrigation areas of the monitoring points with unqualified water quality were smaller than those of the other monitoring points. The use of the WICA method highlighted such kind of phenomenon, in which the weights were given to the affected irrigation areas to transform the differentials in the background conditions. As a result, the statistic values of the qualified ratios of irrigation water quality were notably boosted, which were close to the actual quality conditions of the irrigation water supplied by the respective irrigation associations.

4.2 Promotion of Classification of Water Quality of Canals

According to the foregoing classification method for the water quality, 995 out of 1,174 canals (84.8 %) were assessed as Category I. And 62 canals assessed as Category II, which were mainly located in Nantou, Yilan and Taitung Irrigation Associations. Canals in which water qualities were rated as Category III and IV were respectively 89 and 28 numbers. These were mainly scattered around the irrigation areas where water sources were scarce and had to rely on recycled water or return flows as suppletion. They were mostly located at the irrigation associations in the southwestern Taiwan.

In Taiwan, the major cause of the irrigation water to become unqualified has been that the river water sources have had been polluted in various degrees. And the pollutions have been mostly from the discharges of wastewater not yet adequately treated or concentrated in some sections of rivers, by various industries surrounding the irrigation areas, Therefore, when further analyzing the pollutants, it was found out that such pollutants were highly related to the businesses of these industries which discharged their wastewater into the canals. The canals of the irrigation associations in southern Taiwan were mainly polluted by the wastewater from livestock farms. The pollutants mainly contained high electric conductivity, and ammonia and organic nitrogen elements. However, the canals of the irrigation associations in the middle and northern Taiwan were mainly polluted by the industrial wastewater which contained mainly all kinds of heavy metallic matters.

After realizing the overall water quality conditions of the canals, this study will proceed to conduct the detailed and meticulous investigation and evaluation of the water quality of 129 canals. The scope work will mainly include synthesis of the pollution types, degrees of impact, and also investigation and assessment of the urgency of the improvement needs, and then sort out the priority order of improvement works to be recommended. Afterwards, the systematic planning work will be implemented for about 5 years. In 2009, the investigation work in 25 priority canals has been in progress. It is expected to complete the relevant investigation reports at the end of the year.

5. CONCLUSIONS

Under the impacts of the climate change the topics of water resource management has regained widespread attention by people. Besides supplying the water in appropriate quantities, the water use management concepts should also be emphasized on the strengthening of monitoring and management of water quality.

The authority of agriculture in Taiwan has started since 30 years ago to guide and assist the irrigation associations in monitoring periodically the water quality in their canals. Because the irrigation associations are yet to establish the reasonable and systematic evaluation investigation mechanism to the monitored data collected from their irrigation canals, even though the agricultural authority has ever subsidized plenty of resources to the associations in the maintenance and improvement of the canal water qualities, still they have been difficult achieve the most beneficial results from the subsidies. To improve this phenomenon, in this study has been proposed the "Weighted Irrigation Canal-Area Method" to take into account the affected irrigation area of monitoring points in calculating the weighted monitoring results of the water quality. Further, based on the essence of watershed management, the four-tier statistic framework of "irrigation association-irrigation system-canal-monitoring point" was developed, to facilitate the concerned irrigation water quality management entities to wholly grasp the overall water quality conditions in the canals.

From the results of the statistic framework developed in this study which was applied in early 2009, it was evident that the new statistic method of evaluation could provide the actual conditions of the canal water quality, while the previous Monitoring Point-Frequency Method could not do so. Such function could assist the irrigation associations in confirmation of the specific targets of canal water quality management. In addition, through the weighted assessment of the affected irrigation areas to modify the qualified ratios of canal irrigation water quality, it could effectively adjust the unrealistic results due to the concentrated set-up of monitoring points on only some of the canals.

This study is playing an important role in the innovation work of irrigation water quality evaluation investigation mechanism in Taiwan. And meanwhile it provides the systematic planning and suggestion on the polluted canals' water quality investigations and also improvement of the allocations of water quality management resources. With the establishment of the statistic framework, this study team could wholly grasp the pollutant matters and the severeness of pollution in each canal. Incorporating with the consideration of the affected areas and the urgency of the investigation work, the sequence of promotion of the painstaking and rigorous investigations then could be confirmed. Thus the follow-up investigation and improvement works can be set into action. As such, the events of repeatedly inputs of water quality management resources would be significantly avoided, as to effectively promote the achievements of the maintenance and the improvement works on the irrigation water quality in Taiwan, which would be the substantial contribution of this study.

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