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Improvement of water quality and operational management of small water supply systems in rural area, South Korea

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ABSTRACT

Supplying clean and safe drinking water evenly to residents is the basic responsibility of the national water management policy to realize water welfare in any country. This study investigated 1,526 samples of small water supply systems in 12 cities and counties in Chungcheongnam-do Province, South Korea to come up with measures to improve water quality and operation management of small water supply systems, a major source of water in rural areas. The results revealed that in total, 1,183 samples (77.5%) out of 1,526 samples supplied in 12 cities and counties were suitable for the current drinking water standard of Korea. However, 343 samples (22.5%) were found to be inadequate for water quality. The main non-conformities item of water quality in the facilities were found to be 34.1% of microorganisms; general bacteria, total coliforms, due to some characteristics of the rural area, 17.2% of nitrate caused by a livestock and excrement facilities, 7.9% of fluorine and 5.5% of turbidity, and 2 items or more redundant facilities were found to be 18.7% of unsuitable samples. This indicates that geological strata, facility management insufficiency, and poor disinfection control conditions in areas where small water supply systems are installed are the main factors in determining the quality of water. By doing this, we intend to enhance the effectiveness of the sustainable water management policy for the realization of equal water welfare in the country and provide important ideas for the fundamental improvement and operation management of small water supply systems currently operating in rural areas.

INTRODUCTION

Water, essential to human survival, is the source of human development and all life activities and health, and is a natural resource that forms the basis of human cultural development. Everyone has the right to use water equally. Nevertheless, equal water use rights are regional disproportionate and unequal. Some areas have dams or rivers and are rich in water available, while others suffer from water shortages due to unfavorable natural conditions. Of course, even though water is plentiful, the expertise of water treatment facilities and management to use it as drinking water varies greatly from region to region (Je-sang, 2013).

Equally supplying clean and safe drinking water is the basic responsibility of any country. The management of drinking water sources, which directly affect the lives, health and daily lives of residents, is a top priority water management policy (Kim et al., 2004; Wheon-hwa et al., 2013). Moreover, the gap between water use and

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management by region due to global climate change is becoming extreme, which requires the maintenance of a healthy aquatic ecosystem in the country and region, and the securing and management of water autonomy in terms of residents' environmental and health. However, water use rights, a social common resource that all Koreans have the right to use equally, are disproportionate and unequal due to the gap in the management of water supply facilities between regions (Jin-ho, 2007; Ministry of Environment, 2016; Sung-ryul, 2011).

South Korea had a 99.1% water supply rate as of the end of 2018 thanks to its wide-area and provincial water supply projects to secure better water quality and quantity based on steady investment from the 1970s (Ministry of Environment, 2016). Rural areas still have a lower water supply rate than urban areas. The water supply rate in Chungcheongnam-do Province is 93.1%, far below the national average of 99.1% and the lowest among cities and provinces in the country (Ministry of Environment, 2017). Accordingly, residents in rural area still do not receive enough water supply benefits and use small water facilities or wells, and some small water facilities are exposed to contamination because of aging facilities and poor management, which are feared to cause harm to residents' health (Chang-shin, 2008; Korean Association of Water and Sewage Waterworks, 2005).

In areas where small-scale water supply facilities are managed by villagers with little expertise and where water is not disinfected on time, or where water is used by water sources such as valleys and rivers, the facilities that prevent or block the inflow of livestock waste water from nearby farms are considered to be the cause of exposure to contamination (Bereskie et al., 2017). As a result, fundamental and systematic water quality improvement and effective facility management have not been performed by operating and managing the facility by partially supplementing the facility or replacing some facilities without a detailed investigation of actual water quality assessment and diagnosis of facility operation (Korea Environment Corporation, 2014). Given the reality of the rural villages where environmental contamination is increasing, enhancing water safety for village water supply and small water supply facilities, which are being used for water supply in most rural areas, is an urgent task in terms of water environment management and environmental health (Yong-chul, 2007; Ministry of Environment, 2010).

Small water supply systems are divided into village water supply and small water supply facilities. "Village water supply" means a general tap water supply system that supplies whole water to more than 100 or 2,500 water supplies under the Presidential Decree. It is a general water facility designated by the head of a local government with a daily supply of less than 20 m^3 and less than 500 m^3 or a similar size. On the other hand, "small water supply facility" refers to a water supply facility with less than 100 water supply zones jointly installed and managed by residents or with a daily supply of less than 20 m^3 (Ministry of Environment, 2016; Ministry of Environment, 2018).

The nation's metropolitan or provincial water supply facilities are generally equipped with safe water supply facilities (Wheon-hwa et al., 2013; Korea Environment Corporation, 2014; Hyun-je et al., 2016). However, the village water supply system, which uses underground or valley water as its source as its main water supply facility in rural areas, is a blind spot for water contamination and facility management, requiring improvement through accurate diagnosis of the water quality and operation management of the facilities (Sang-min, 2009). The improvement of safety concerning the quality of water and facilities of the village water supply is seen as an urgent diagnosis and improvement task considering that the contamination of various chemicals used in agriculture, including air pollution, and drinking water sources caused by agricultural materials and livestock waste water, is one of the factors threatening a healthy living environment and safe life (Ministry of Health, Labor and Welfare, 2009a; Percival et al., 2004; USEPA, 2003; WHO, 2008). Most of the drinking water used in rural areas of Korea was shallow wells or government wells before 1970s (Ministry of Environment, 2016; Ministry of Environment, 2018). The well was installed inside the house, and was supplied with unsanitary drinking water to old facilities that are likely to be contaminated by adjacent toilets, livestock slaughter facilities, and sewage. In order to improve the reality of drinking water of villages in rural area, the government established a small water supply systems in the rural areas, which was 20 houses or higher, from 1970 to 1987, and used it as a major source of water to supply safe drinking water. Since then, the small water supply system has been supplying hygienic drinking water to farming and fishing villages, improving the residential and residential environment and enhancing residents' health and cultural life. Currently, the construction and management services of local water supply facilities are wholly delegated to the head of local governments (Sung-ryul, 2011; Jeong-hak and Kwang-hyun, 2007; Ministry of Agriculture, Food and Rural Affairs, 2018; Hamouda et al., 2018; Park and Gyeong-mi, 2012).

It is also true that small water supply systems have greatly contributed to improving the living environment and improving the health and cultural life of rural residents by supplying hygienic and abundant quality water to residents in rural areas (Hyun-je et al., 2016). Recently, there has been a need for improvement due to frequent facility failures, aging of existing facilities, the inter-supply concerns by winter solstice, the suspension of water supply by shortage of water supply in the season, insufficient facility management, and inadequate water

Table 1. Operating conditions of Induced Coupling Plasma and Ion Chromatograph instrument in the study.

ICP/MS (PerkinElmer NexION 300D)		Ion Chromatograph (Dionex ICS-2100)	
Variable	**Operating conditions**	**Ion type**	**Anion**
Plasma gas(Ar) flow rate	18.0 L/min	Column	Ionpac AS 18 × 250 mm
ICP RF Power	1.3 kW		
Auxiliary gas(Ar) rate	1.2 mL/min	Detector	Conductivity detector
Nebulizer gas(Ar) flow	0.95 L/min		
Scan Mode	Peak Hopping	Suppressor	ASRS 300 ~ 4 mm
Mass range	8~240 amu		
Dwell time per AMU	50 ms	Eluent	KOH
Replicates	3 times	Flow rate	1.0 mL/min
GC/MS (PerkinElmer)		**GC (Agilent 7890A)**	
Variable	**Operating conditions**	**Variable**	**Operating conditions**
Carrier gas(He) flow rate	1.0 L/min	Carrier gas(N2) flow rate	1.0 L/min
Column	Elite-5 MS (30m×0.25ID×0.25μm)	Column	CP selected 624CB (60m×0.25IDx1.4μm)
Partition ratio	10 : 1	Detector	FID
Oven Temp.	36°C(7min)-20°C /min-200°C(0min)	Oven Temp.	40°C (2min)-4°C/min- 100°C (2min)-12°C /min- 225°C (2min)
Injection Temp.	250°C	Injection Temp.	230°C

quality caused by unsanitary water sources (WHO, 2008; Leclert et al., 2016). Problems such as safe water prevention from contamination of small water supply systems, which are the main sources of water in rural areas, and operational problems such as the cost burden for residents, and other matters concerning the proper management of facilities are to be solved quickly (Park and Gyeong-mi, 2012; Ministry of Health, Labor and Welfare, 2009b; Vide Souza and Costa da Silva, 2014).

The scope of this study is to investigate problems in water quality and operation management through a survey of village water supply and small water supply facilities installed and operated in 12 cities and counties in Chungcheongnam-do for three years from 2016 to 2018 and to prepare a system for safer water supply and water management by exploring ways to improve the operation of small water facilities currently installed and operated in rural areas. By doing this, we intend to evaluate the effectiveness of its water welfare service environmental policies and propose fundamental measures to improve water quality. And it aims to promote the rational operation and management of small water facilities to realize universal water welfare where all Koreans can use healthy water safely anywhere.

MATERIALS AND METHODS

Samples

1,526 samples are collected from small water supply systems operated in 12 cities and counties in Chungcheongnam-do Province during three years from 2016 to 2018.

Experimental method

The water quality analysis of 1,526 samples in the study was conducted 58 items according to the Korean Drinking Water Quality Test Standard (Ministry of Environment, National Institute of Environmental Research, 2015). Facilities that were found to be unsuitable were evaluated for nonconforming factors by conducting a precision water quality analysis. Heavy metal components were analyzed using inductive coupled plasma mass spectrometry (ICP/MS), ionic substances were analyzed by ion chromatograph (ICS 2100), and volatile organic compounds and disinfection missiles by gas chromatograph (GC). The analysis conditions for the instruments used in this study are shown in Table 1.

Statistical analysis and geological investigation

The water quality analysis data were compiled using the SPSS/PC statistical program to statistically treat distribution by region between components, and the comparison of average values was conducted between ANOVA test and t-test (Wheon-hwa et al., 2013; Hyun-je et al., 2016; Water Journal, 2016). The correlation

Table 2. The present condition of water-intake source in Chungcheongnam-do area (Unit: Number of facility).

Classification	Total	Ground water	Valley water	Spring water	Surface water	Underground water	Others
Total	1,837	1,674	79	74	8	1	1
Village water system	877	840	11	26	0	0	0
Small-scale water system	862	737	68	48	8	1	0
Exclusive water system	98	97	0	0	0	0	1

***Sources:** 2017 Korean water supply statistics (Ministry of Environment, 2017).

Table 3. The completion year of small supply water facilities in Chungcheongnam-do area (Unit: Number of facility).

Classification	Total	Under 10 year ('08~)	10 ~ 20 year ('98~'07)	20 ~ 30 year ('88~'97)	Above 30 year (~'87)	Non-identified
Total	1,837	397	669	184	556	31
Village water system	877	164	404	80	214	15
Small-scale water system	862	215	231	58	342	16
Exclusive water system	98	18	34	46	0	0

***Sources:** 2017 Korean water supply statistics (Ministry of Environment, 2017).

analysis between components was conducted using Pearson correlation coefficient (r), a universal measure, and the causes of nonconforming substances exceeding the current drinking water quality standards were investigated and evaluated as a result of the water quality survey. In addition, the geological survey was used the 1:50,000 geological map (https://mgeo.kigam.re.kr/map.jsp?mode=geology_50k) operated by the Korea Institute of Geoscience and Mineral Resources to examine the geographical and environmental characteristics and the detection components of rural areas.

RESULTS AND DISCUSSION

Current status of facilities

Water-intake source

The status of water-intake used for small water supply systems in the Chungcheongnam-do area is shown in Table 2.

Installation status of facilities

The small water supply systems provide major drinking and living water for about 2.52 million rural residents, 5.2% of the total population, while the nation's village water supply and small water supply systems are 18.5%, which is more than 20 years old, and 42.5%, which is more than 30 years old. Therefore, 61% of the facilities are aging, so it is urgent for the facility to be opened. Chungcheongnam-do Province has fewer aged facilities than the our country; 58.0% of facilities older than 20 years, 10.0% of facilities older than 20 years, and 30.3% of facilities older than 30 years in Table 3 (Ministry of Environment, 2017).

If you look at the operation management status of small water supply systems, the operation management of the facilities is basically an issue of inadequate operation management due to lack of expertise of village unit facilities managers, in addition to the problem of budget support for the improvement of the facilities. Because the characteristics of rural areas where small water facilities are installed, absence of standardized systematic management of industrial facilities and frequent equipment failures caused by facility retirement are the problems of operation management (Chang-shin, 2008; Bereskie et al., 2017).

Result of water quality analysis for small water supply systems

Water quality analysis result of underground water

As a result of this study, the current Korean drinking water quality standards for nonconforming water components are shown in Table 4. The water quality analysis results of small water supply systems as shown

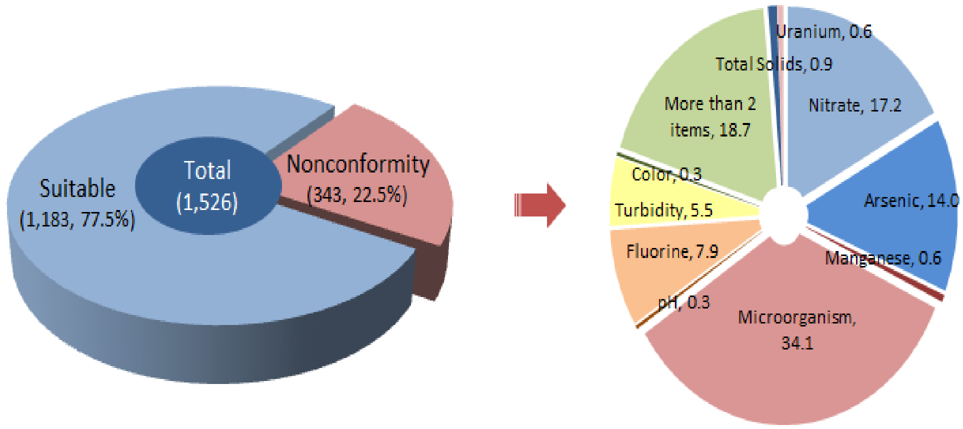

Figure 1. Analytical results of water quality of the small supply water system for 12 cities and counties in Chungcheongnam-do Province.

Table 4. Korean drinking water quality standards for some inappropriate items (Ministry of Environment, National Institute of Environmental Research, 2015) (Unit : mg/L).

Item	Microorganism		Fluoride	Arsenic	Nitrate Nitrogen	Copper	Color
	General bacteria	Total coliforms					
KDWS	100CFU/mL	N.D/100mL	1.5	0.01	10.0	1.0	5 do
Item	Total Solids	Manganese	Turbidity	Hardness	Chloride	Sulfate	$KMnO_4$ consumed
KDWS	500	0.3	0.5 NTU	1,000	250	200	10

***KDWS,** Korean Drinking Water Quality Standard; **CFU,** colony forming Unit, **N.D,** not detected; **NTU,** nephelometric turbidity unit.

in Figure 1.

As shown in Figure 1, of the 1,526 samples studied, 1,183 samples (77.5 %) were suitable for the current Korean drinking water quality standard (Ministry of Environment, National Institute of Environmental Research, 2015), but the 343 samples (22.5%) were unsuitable. The main nonconformities items with poor water quality were found to be 34.1% of microorganisms, general bacteria and total coliforms, due to characteristics of rural areas, 17.2% of nitrate caused by a livestock and excreta facilities, 14.0% of arsenic caused by the geological stratum of the area, 7.9% of fluoride and 5.5% of turbidity, and 18.7% of nonconforming facilities with two or more items. This was similar to the study (Ministry of Environment, 2010; Kyung-seok et al., 2010; Kanf and Yang, 2010) conducted in Korea, which found that contamination by microorganisms is 44.1% and that by nitrate is 13.7%. Since nitrate, a frequent nonconforming component of water quality in rural area, is mainly affected by the nearby livestock or fecal pollution facilities where the water supply facilities are located, thorough disinfection and prevention of potential contaminants by nearby pollution-causing facilities are required. In particular, special management supervision and attention to livestock wastewater discharged from livestock feeders is required in areas where many livestock farms are located, as it is caused by excretion, living sewage, livestock wastewater, and nitrogenous fertilizer consumption used in agriculture.

Correlation between water constituents and distribution of major nonconformities

Table 5 shows the statistical analysis of the correlation between the water components detected in the water quality analysis in this study. Of the 58 items analyzed, the correlation between items was greatest between total solids and chlorine ion (r=0.848) and the hardness (r=0.798) among the 13 items significant in statistical data evaluation, while the color and turbidity (r=0.679) and hardness (r=0.631) were higher than the other components. In addition, the positive relationship between evaporation residues and sulfate ion, manganese and chlorine ion, hardness and sulfate ion can be checked.

The concentration distribution ratio for the seven items with the highest detection rate excluding microorganisms

Table 5. Correlation coefficient between items of water quality nonconformity in this study.

Item	Micro-organism	F	As	NO_3-N	Cu	Color	Total solids	Mn	Turbidity	Hardness	Cl^-	SO_4^{2-}	$KMnO_4$ consumed
Micro-organism	1												
F	-0.031	1											
As	-0.008	-0.020	1										
NO_3-N	-0.032	-0.179	-0.089	1									
Cu	-0.010	-0.030	-0.018	0.309	1								
Color	0.110	-0.037	-0.021	0.002	-0.002	1							
Total solids	-0.010	-0.114	0.072	0.283	0.080	0.012	1						
Mn	-0.016	-0.033	-0.016	-0.020	-0.006	0.061	0.352	1					
Turbidity	0.022	-0.052	-0.028	0.000	0.023	0.679	-0.007	0.066	1				
Hardness	-0.043	-0.071	0.098	0.219	0.061	-0.006	0.798	0.199	-0.021	1			
Cl^-	-0.018	-0.058	0.028	0.101	0.006	0.058	0.848	0.458	0.040	0.631	1		
SO_4^{2-}	-0.035	-0.023	0.093	0.052	0.015	-0.022	0.494	0.164	0.010	0.461	0.307	1	
$KMnO_4$ consumed	0.032	-0.090	-0.010	0.011	0.072	0.191	0.185	0.105	0.073	0.156	0.215	0.130	1

among nonconforming water items, calculated as 100% of the current drinking water quality standard for each item, and compared the mean detection concentration and distribution as shown Figure 2.

According to the analysis of distribution, the average detection concentration of turbidity and nitrate is high and the concentration distribution is large. For turbidity, the variation in detection concentration is high, and for arsenic, fluoride, and manganese, the average detection concentration does not often exceed the Korean drinking water quality standard (Ministry of Environment, National Institute of Environmental Research, 2015), the distribution range is specific due to the effect of the corresponding the geological stratum. For total solids, the average detection concentration was high, however, the concentration range significantly exceeded the drinking water quality standard was not large. In other areas, it can be expected that water content that is not detected at all has a significant effect on water quality, depending on the specific geological distribution and local environmental factors in the area.

Figure 3 shows the distribution of 4 items; hardness, chloride, sulfate, and total solids, that are statistically more correlated, regardless of region based on the current Korean drinking water standard calculated at 100%. It is shown that the regional detection distribution of the major nonconforming items is consistently proportional to each other, as shown at the top of Figure 4. The concentration distribution of the 4 items in the Boryeong and Dangjin areas bordering the bottom schematic coastal areas was characteristically higher than that in the other nine regions in Chungcheongnam-do Province. This is judged to have been the result of the effects of local environmental characteristics on the water quality of groundwater.

The relationship between hardness and evaporation residues and ionic materials; chloride, nitrate, fluorine, sulfateas shown Figure 4 is unusually high in Boryeong and Dangjin area. Looking at the relationship between components that showed a high correlation overall, hardness and total solids were significantly higher in positive correlation between 0.75 and 0.95, in 11 cities and counties except Gongju area, and the correlation between chlorideand sulfate ion was relatively low.

Problems of operation management of small water supply systems

Residents in rural areas are not benefiting from the nation's water welfare policies compared to urban dwellers. As a result, universal water

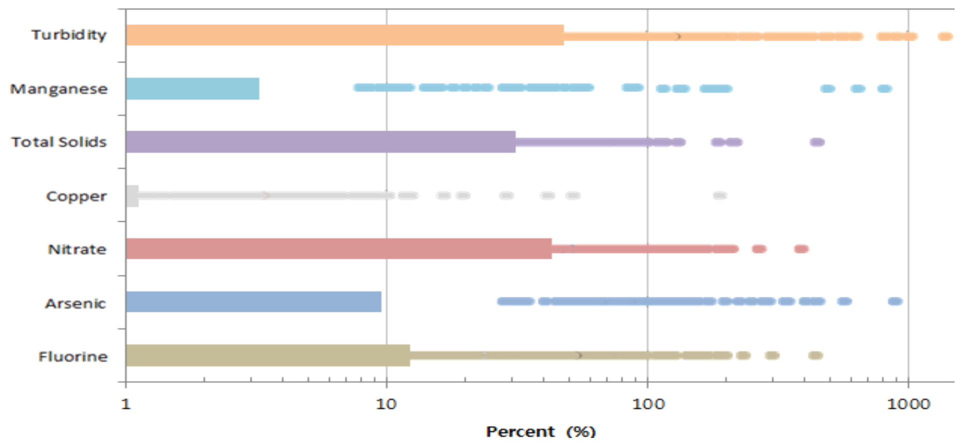

Figure 2. Distribution diagram of the detected concentrations for seven water qualityinadequate items.

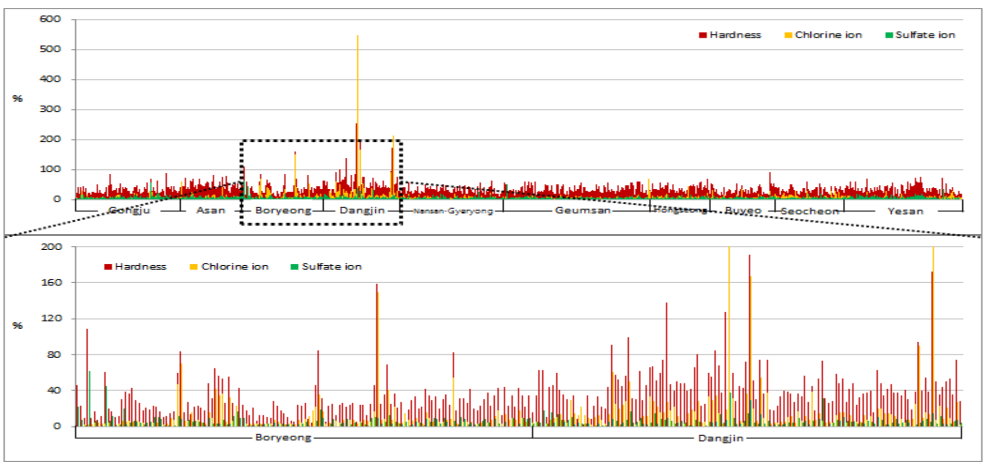

Figure 3. Distribution diagram of the detected concentration on three inadequate items; hardness, chloride, and sulfate.

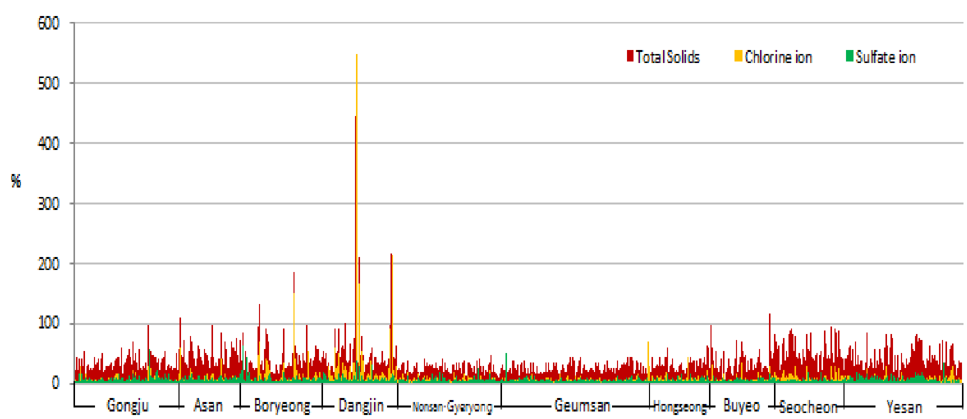

Figure 4. Distribution diagram of the detected concentration on other three inadequate items; total solids, chloride, and sulfate.

Figure 5. The present conditions of management for the intake water source and facility pipe.

welfare policies are being shaken and residents' distrust is growing. Legally, since the head of local governments is responsible for the operation and management of small water supply systems, the limitation of regional budgets for the improvement of aged and defective facilities is the biggest obstacle to facility improvement. Local governments can support the retrofit and repair of aging facilities within the budget, and operating costs are in accordance with the principle of user burden (Young-il, 2013).

Local governments may provide part of their operating expenses, but the level of support is insignificant because of poor local finances. A national management system, not selective support for underground water, is urgently needed. Moreover, the rural areas have increased water pollution caused by various chemicals used in agriculture and farming materials, wastewater discharged from livestock wastewater facilities, posing a threat to sound residential conditions and safe living. Improving water quality safety for small water supply systems, mostly installed in rural areas, is an important environmental policy of the country and is very urgent in terms of residents' environmental and health management. Recently, there is a growing need to improve facilities due to frequent facility failures caused from aging of facilities, lack of water supply according to constant drought, unsanitary management, and inadequate water supply by contaminated water sources etc. (Hyun-je et al., 2016; ITU, 2014). With thorough water quality supervision and reasonable management of operations, an equal universal water welfare policy is required for anyone of the people to use healthy water with confidence wherever they are.

Deterioration of facilities and contamination of drinking water sources

The problem with the facility is that most of the water tanks, which collect water from the water source, are constructed from concrete, often undergoes severe internal corrosion due to long-term use or secondary contamination caused by not performing regular cleaning. Disinfectant dispensing facilities for prevention of infectious diseases are often a cause of problems due to lack of expertise of managers and awareness in rural communities, and insufficient use of facilities. In particular, when introducing installation or improvement of a facility, the specific economic cost-evaluation matrix for proper maintenance and rational use of the facility must be reviewed and implemented based on the recognition and consent of the residents who are the parties to use it (Sung-ryul, 2011).

Figure 5 illustrates the inadequate use of aged facility equipment for other purposes rather than its intended purpose. Since the economic costs incurred by residents using small water supply systems are major factors, such as not only water quality, but also utilization population and supply quantity of underground water, the capacity and water quality of the facilities must be clearly investigated to ensure substantial improvement of the facilities only when technologies, costs and affordable levels of the residents' economy are considered.

Small water supply systems in Chungcheongnam-do Province rely on underground water for 90% of intake water capacity, which can make it difficult to secure sufficient quantity of underground water sources in the future and cause contamination of underground water by

Table 6. The management subject of small water supply system.

Section	Village water system	Small-scale water system
Subject	Chief exclusive in local governments	Village headman or delegate of the consumer conference
Financial charge	Local government	User (part support from local government)

pesticide and fertilizer spraying, livestock wastewater, and excretion of excrement as some underground water pipes are located near agricultural or livestock farms. If valley water is used as a water resource, it is difficult to secure stable amount because the flow rate changes according to seasons and it is easily exposed to pollutants. Meanwhile, the securing of water containers due to drought in different regions according to climate change is an urgent task of water management policy. In terms of facilities, 40.3% of the facilities are over 20 years old, making it urgent for projects to shut down or improve substandard facilities (Ministry of Environment, 2017). In addition, since most small water supply systems provide daily water only through the disinfection process without water purification of facilities, it is difficult to actively cope with deterioration of water quality in the intake water source.

Insufficient management of operations

Lack of operational management personnel and budget for facilities is a fatal factor in the proper operation management of small water supply systems. The management subject of a small water supply systems are 45% of the operation of local governments, 34% of the consignment management, 21% of the villagers' representatives or residents' councils, according to the managing body (Sang-min, 2009). However, the facility installation is promoted as a rural agricultural and living water development project in accordance with the Farm and Fishing Village Maintenance Act (Ministry of Environment, 2018; Ministry of Health, Labor and Welfare, 2009a). Meanwhile, the facility improvement project is handled by the water supply-related department.

Therefore, the responsibilities and efficiency of operation management are low due to different departments for facility improvement and installation. Accordingly, there are only one or two employees in charge of the facilities in local governments, and due to their frequent personnel changes, normal management is not being carried out. Thus, the efficiency of consigned operation management in some local governments is also shown to be low. Although the responsibility for the operation and management of small water supply systems is legally delegated to the head of local governments, many of the facilities subject to management and scattered because of the characteristics of rural areas, village representatives are designated and managed by consignors in some areas. The administrative authorities manage the facilities carry out water quality inspection, custodian education, and disinfectant support work. In many facilities, water tanks, one of the major facilities, are located mainly in mountains or highlands and are operating under severe facility obsolescence (Sang-min, 2009).

The state and local governments are obliged to provide necessary technology and financial support for the hygiene control of the town's water supply system. The head of a local government is obliged to operate and manage small water supply facilities in the jurisdiction according to the ordinance of the respective local governments (Jeong-hak and Kwang-hyun, 2007). Therefore, the Act stipulates that the facility should be investigated for contamination of the water source, shortage of water, leakage, or damage caused by accident, and that the facility should be upgraded and repaired first, and that the costs required for facility improvement and repair and operation should be borne by the user as shown Table 6.

In some areas, it is a matter of operation management that consignors designate and manage village representatives, but the operation of facilities are not properly managed because of the lack of expertise of managers in each unit village. Systematic management is needed to maintain safe water quality. In the event of a facility failure by poor management, normal water supply and facility maintenance are not properly managed on account of low immediate response capability. Since small water facilities are social public goods that cannot be assessed through economic gains and losses, they are public domain that needs national investment and improvement to improve their operational management.

The budget issue must be addressed above all to improve the fundamental management of small water supply systems. Also, continued training of the management personnel is required to improve operational management expertise (Ministry of Agriculture, Food and Rural Affairs, 2018). In addition, since small water facilities are scattered in rural areas, there are limitations in the operation of personnel for remote analysis. Therefore, it is necessary to establish an integrated management system for three to five cities and counties, to switch to a system where specialized management personnel oversee operation management, and to strengthen supervision of the facility management body for efficient rational management.

Incorrect water quality management

A small water supply systems have been exposed directly to pollutants caused from prolonged drought-caused shortage and poor underground water irrigation protection facilities because of the increasing impact of climate change, In the case of facilities that use water in valley or river-bed water as water source, the water source of nearby livestock facilities is highly susceptible to contaminants from discharging water, agricultural land and wildlife waste due to the large seasonal variation in quantity and the lack of protection in the rainy season. The inadequate water quality of small water facilities is increasing because of the management of water quality by village unit managers who have low expertise. As a result, it is exposed to contamination as there are no facilities that prevent or block the inflow of livestock wastewater from nearby farms. In addition, it is not uncommon for inadequate water supply and utilization to exceed the water quality standards, regardless of the type of operation of the facility management body.

A proposal for improving water quality and the optimal management of small water supply systems in Korea

It is the government's role and responsibility to address inequality in water supply and create basic systems and conditions to provide clean and safe drinking water. Small water supply systems are, in essence, a major source of drinking water for poor and backward local residents who do not have public water supply. Management of drinking water sources, which directly affect the lives, health and daily lives of residents, is a priority water environment policy. Specific policy approaches and implementation programs for substantial water quality improvement and proper facility operation for small water supply systems should be established.

Since the underground water quality of small water supply systems, which are used as a major source of drinking water in rural areas without a wide area or local water supply, is often caused by local non-point contamination sources rather than by point contamination sources, it is judged that water management through a non-point contamination and water circulation status evaluation system is essential by calculating the reduction amounts of non-point contamination sources according to the national water pollution control guideline and setting of each region comprehensive measures shall be developed to reduce the non-point emission loads by water systems or basin to ensure actual effective water quality control.

Specialization of operations management through the establishment of regional base integrated management system

In terms of water welfare equity and efficiency, small water facilities in rural areas lying in blind spots should be unified into a wide area and local water supply management system for unified management, water welfare administrative services in reliable, practical rural areas should be provided through the Continuous Performance Implementation (CPI) Strategy (Bereskie et al., 2017; Leclert et al., 2016) by the entrusted operation management system of specialized agencies with adequate technical skills to improve backward and aging facilities and improve water quality. With this study, the management of water quality can be strengthened by specialization of operation management, improvement of facilities and enhanced analysis management, reform of water intake and drainage management, and upgrade of awareness among the residents of use. Some local governments may seek to make up for the deficiencies of private consignment management in place and to be able to devise an efficient way to execute the budget. Based on the number of facilities and distribution status by region, a hub management system that integrates three to five cities and counties into one block can be operated to promote productive operation management. In particular, intensive control of substances that exceed drinking water quality standards by region-specific contaminants and geological background is required, and efforts to eliminate and treat contaminants through the development and dissemination of local custom underground water treatment technology (Kyung-seok et al., 2010). In addition, state budget support should be expanded for proper water quality maintenance and operation management.

Improving the public water quality analysis system and strengthening supervision of management

The central government is obliged to provide necessary technology and financial support for the proper management of small water supply systems, while the heads of local governments are responsible for the operation and management of water supply facilities in their jurisdictions. Small water supply systems are essential public facilities that cannot be evaluated by economic efficiency. Sound management of drinking water sources directly related to the daily lives of residents in rural areas is a water environment policy that should come first. Accordingly, implementation programs should be established for practical facility improvements and efficient budget support measures. In 2008, the central government recommended consignment management of facilities by local governments in accordance with its plan to allow small water supply systems to be entrusted to specialized agencies, but it still represents an operation with poor water quality and expertise (Park and Gyeong-mi, 2012; Vide Souza and Costa da Silva, 2014).

Therefore, management supervision should be strengthened so that the current 13 items on a quarterly basis for small water supply systems and the national water quality analysis institutions, not the private ones, will be required to conduct water quality tests on all items at least once every two years and announce the results. This eliminates anxiety about the safety of drinking water for residents due to aging facilities, neglect of management, water contamination, and guarantees the reliability of the state's water welfare administrative service, and cannot expect normal operation of the facilities under the current management system, which has a low level of understanding of water facilities and is not specialized. Securing the people's health and environmental rights through rational water management is possible on the basis that water is a public resource.

Maintaining adequate water quality and improving operation management for small water facilities cannot be realized with the finances of poor local governments. The entrusted management of some local governments, which had been expected to enhance efficiency and accountability of facility management, has also resulted in undermining the public nature of water welfare because of lack of institutions. Sustainable water welfare policies that are oriented toward the future should be implemented through specialization of operations through integrated regional base management system and strengthened supervision of public water quality analysis management.

Conclusions

The water quality analysis result of 1,526 sampleson small water supply systems in Chungcheongnam-do Province of South Korea, 343 samples, 22.5%, are shown to be inadequate for water quality. The main nonconformities with poor water quality were found to be 34.1% of microorganisms, 17.2% of nitrate, 14.0% of arsenic, 7.9% of fluoride, 5.5% of turbidity, and 18.7% of nonconforming with two or more items. It means that geological strata, management status, and disinfection control conditions of the small water supply systems in operation were the main factors in determining the suitability of the water quality.

The nonconforming rate of water by region was higher in Seocheon area (44.2%), Buyeo area (42.2%), Cheonan area (37.4%), and lower in Yesan area (33.2%), Boryeong area (4.5%), Gongju area (7.3%) and Dangjin area (8.1%) in order. Water quality and facility management were relatively good in the city compared to the county area. The impact on water quality depended largely on geological strata, local environmental impacts, degree of aging of equipment due tothe age limit of installation, the facility management body, and the recognition.

Consequently, for the optimal operation of small water supply systems, which are the main water supply facilities in rural areas, the improvement of old facilities will have to be made first. Administrative budget support of the facility management entity is needed for the improvement of aging facilities. To ensure proper management of small water supply systems, it is deemed necessary to strengthen effective operation by introducing an integrated management system for three to five cities and counties in consideration of the current management of facilities scattered in rural areas. Moreover, areas where aging facilities and water contamination are serious are required to improve the fundamental water quality through the transition to a wide-area or a local water supply system or alternative water development.

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