MEASURES FOR EFFECTIVE USE OF AGRICULTURAL GROUNDWATER IN JEJU, SOUTH KOREA

HyunJu Park¹, Chag-Ok Kim², Byeong Hun Kim³, Ki-Yeon Park⁴, Cha Youn Jung⁵, JooHyung Son⁶, U-Cheol Lee⁷, HyungGuen Jang⁸

ABSTRACT

The largest island in Korea, Jeju, is an aspilte island, which depends on groundwater for the use of water resources. The majority of economic driving forces in Jeju are tourism and agriculture. Therefore, establishment and use of irrigation system using groundwater is the greatest issue in this region. Since the first success in developing groundwater by the Korea Rural Community Corporation in the 1970s, 96% or more of agricultural water usage in Jeju is supplied through 905 public wells, and the amount is up to approximately 693,900m³/day as of 2015. However, the issue of agriculture water supply is continuously raised due to the change in water balance in this region. In particular, the cyclic and severe droughts in the past and the continuous intrusions of saline groundwater at west coastal area of Jeju have driven the establishment of new water supply system. Thus, the measures for effective groundwater use have been studied since 2013. As a result of this study, “Integrated Agricultural Water Supply System” was designed. Currently, this program completed, pilot projects in 2 zones and is now under operation system check. This program will be implemented for 8 years after such pilot project and the budget for this amounts to $140 million. When this program is completed, it will prevent drought damage permanently and solve the issue of lack of agricultural water, which in turn will increase agricultural yield and lead to the increase of income among farmers. In addition, expected indirect effects include effective preservation of groundwater due to enhanced public groundwater control, improved ability to respond to drought due to supply line linkage. It will become a model case for the effective use of water resources.

Keywords: Public Wells, Seawater Intrusion, Integrated Agricultural Water Supply System.

1. INTRODUCTION

Jeju is located at 126° 08’ 45” ~ 126° 58’ 15” east, 33° 06’ 23” ~ 34° 00’ 00” north, approximately 145km away from Mokpo in the inland of Korea. The area of Jeju
excluding affiliated islands is about 1,828km², taking 1.8% of the entire national area as the largest island of Korea. This island is an aspite, where most of the water resources depend on groundwater. Its major economic driving forces are tourism and agriculture. Therefore, establishment and use of irrigation system using groundwater is the greatest issue in this region.

Since the success of groundwater development in the 1970s, there have been no big problems in the use of water resources until recent times. However, the seawater intrusion in the east and west areas and the shortage of water including drought due to climate change emerged as the greatest issue in this region. Therefore, the development of new water supply system was implemented in a full scale and the “Integrated Agricultural Water Supply System” was designed.

2. GEOGRAPHY AND HYDROGEOLOGY

2.1 Geography

Jeju is located in southwest area of Korea peninsula. The long axis of this island extends 74km in the N70°E direction and the short axis (perpendicular to the long axis) extends 32km in an eclipse shape. The sectional shape is a cone with Mt. Halla as the top. The east-west section as the long axis direction has a very gentle slope (3°~5°), whereas the north-south section has a steeper slope (5°~10°). The slope tends to get steeper from the coastal area to the mountain area.

2.2 Hydrogeology

Jeju is an aspite where the thickness of volcanic edifice is approximately 2,100m (1950m above the sea level, 150m below sea level), consisting of volcanic rocks and sedimentary rocks. The volcanic rocks cover 98% of Jeju area, whereas the sedimentary rocks cover only 2% (23km²).

The chemical composition of volcanic rocks includes a relatively wide range of rocks such as alkali basalt, basalt, trachybasalt, trachyandesite, and trachyte. The sedimentary rocks consist of tuff, marine stratum, stratum between lavas, recent sediments and sand dune deposit.
Figure 2. Volcanic outcrop on surface (left), Volcanic Rocks in underground (right)

The volcanic rocks can be divided into pahoehoe lava and a-a lava depending on their physical characteristics. Pahoehoe lavas are mainly distributed around the coastal lowlands in east and west areas. A-a lavas are distributed in south and north areas as well as Mt. Halla.

According to geological logging results, the pahoehoe lavas distributed in Jeju island has a thin unit thickness ranging from 0.5~5m, characterized by the multi-porosity with well-developed joints and cracks. A-a lavas has the unit thickness ranging from 5~15m, with well-developed vertical joints and cracks and relatively dense center but clinker with good permeability on its top and bottom areas.

Figure 3. Clinker formation in a-a lava

Seogwipo layer as marine stratum is widely distributed at the bottom of the volcanic rocks erupted during the early formation period of Jeju, which plays an important role in determining the shape of groundwater and production characteristics. The underground distribution depth of Seoguipo formation varies largely depending on areas. In the east, it ranges between 110m and 150m under the average sea level, whereas it ranges between 40m and 70m under the average sea level in the west, and between 10m and 80m in the south.
The thickness of unsaturated zone varies across areas. With 100m above the sea level as the reference point, the thickness of unsaturated zone in the east area is approximately 95m~98m, whereas it is 50~60m in the west, 70~80m in the north area and 40~50m in the south area. Therefore, the rainfall penetrating into the underground passes through unsaturated lava sequence to make physical filtering until it reaches groundwater body.

2.3 Shape of Groundwater

The shape of groundwater may be classified into high-level groundwater, basal groundwater, parabasal groundwater and basement groundwater.

2.4 High-Level Groundwater

High-Level Groundwater is the groundwater which moves along the low-permeability layer when the rain falling on the ground surface intrudes through permeable layer under the ground surface and cannot penetrate anymore because of the low-permeability layer such as clay layer or non-permeable rock layer.

It moves at fast linear flow rate along the high-level of Seoguipo formation and therefore shows larger water level variation between raining and dry seasons and greater water level drop by water use, whereas the mean water sampling amount per hole is relatively lower.

Perch groundwater is distributed intermittently within the unsaturated zone as stagnant groundwater at the top of low-permeable layer, which is not hydraulically connected to other aquifers.

3. Basal Groundwater

It is the groundwater where the fresh water exists over the sea water in a lens shape due to the difference in specific gravity between fresh water and seawater: i.e., it exists by the Ghyben-Herzberg laws.

The zoning of a horizontal boundary between basal groundwater body and parabasal groundwater body is done with the hydrological slope distribution of groundwater level and the boundary criteria by non-permeable layer G-H ratio.

3.1 Parabasal Groundwater

It refers to the groundwater body to which G-H principle does not apply because the direct contact between the bottom of the freshwater body and the sea water is blocked by the low-permeable sedimentary layer Seoguipo formation. When it is
located at the top of mean sea level, it is sub-classified into high-level parabasal groundwater, whereas it is sub-classified into bottom parabasal groundwater when it is located at the bottom of mean sea level.

3.2 Basement Groundwater

It is defined as the deep groundwater originated from rainfalls existing within effective pores such as fractured zones and joint developed within the age-unknown U layer (unconsolidated), Daebo granite located at the bottom of a low-permeable sedimentary layer such as Seoguipo formation and a bed rock such as welded tuff. The water quality and the amount of collectible water are affected by the composing minerals of bed rock and the development status of geological structure.

![Figure 5. Shape of groundwater in Jeju](image)

4. USAGE OF WATER RESOURCES AND GROUND WATER

Rainfall of Jeju is 2,061mm/yr and recharge of groundwater is 16.7million m³/yr (45%), and evaporation is up to 12.6million m³/yr. As of 2015, there are 4,851 wells used in Jeju, about 1.45million m³/day used. For Irrigation purposes, 3,316 wells are used for 0.9million m³/day. Among them, there are 905 public wells for 0.6million m³/day supplied to farmland.

5. PROBLEMS IN THE USE OF GROUND WATER

Recently issues in the agricultural water supply are raised continuously due to the change in water balance in this region. The major causes of these issues include the change in rainfall due to climate change, reduced groundwater recharge area due to urban development, increased water demand due to increased tourists and intrusion of saline water at the coastal area due to overuse of saline groundwater in the fish farm.

In fact, cyclic and severe drought, sea water intrusion in the east area and continuous saline water intrusion into the west coastal area since 2009 have a led to serious reduction in crops and serious problems in agricultural land use.

In addition, while there are some water-rich areas with sufficient water supply, there are other water-lack areas with insufficient or no water supply areas. It is difficult to solve this imbalance between these areas with the water user groups. This is a kind of nimbi phenomenon with the concern that if the water in our community is supplied to other regions, there may be a lack of water in our community.
Table 1. Groundwater uses in Jeju (Unit: 10,000 m³/Day)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Total¹</th>
<th>For Living</th>
<th>For Agriculture</th>
<th>For Industry</th>
<th>Mineral Water²</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Holes¹</td>
<td>4,851</td>
<td>1,374</td>
<td>3,316</td>
<td>157</td>
<td>4</td>
</tr>
<tr>
<td>Allowable Amount¹</td>
<td>145.6</td>
<td>55.6</td>
<td>90.0</td>
<td>2.6</td>
<td>0.22</td>
</tr>
<tr>
<td>No. of Holes²</td>
<td>1,243</td>
<td>359</td>
<td>905</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Allowable Amount²</td>
<td>108.4</td>
<td>41.3</td>
<td>69.4</td>
<td>0.2</td>
<td>0.21</td>
</tr>
<tr>
<td>No. of Holes³</td>
<td>3,603</td>
<td>1,013</td>
<td>2,411</td>
<td>155</td>
<td>1</td>
</tr>
<tr>
<td>Allowable Amount³</td>
<td>37.4</td>
<td>14.3</td>
<td>20.7</td>
<td>2.4</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Figure 6. Phenomenon of Seawater Intrusion in West Area of Jeju

Figure 7. Comparison of Water-Rich and Lack Area in Jeju

Proposal of Integrated Agricultural Water Supply System
6. PROGRAM OVERVIEW

This program has already passed the evaluation process of the Ministry of Strategy and Finance, expected to invest total 140 million dollars for 8 years from 2017 to 2024. As a pilot project, local budgets 1.4 million dollars has been already invested in the east area of Jeju, and the system is now completed and under trial run.

Table 2. Program Contents

<table>
<thead>
<tr>
<th>Integrated Water Supply Area (ha)</th>
<th>No. of Districts (No.)</th>
<th>Large Water Storage Tanks (No.)</th>
<th>Connected Pipelines (km)</th>
<th>Auto Water Management System (St.)</th>
<th>Water Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>33,824</td>
<td>37</td>
<td>58</td>
<td>504</td>
<td>1</td>
<td>58</td>
</tr>
</tbody>
</table>

7. CONCEPT OF INTEGRATED WATER SUPPLY SYSTEM

In order to solve the problems in the use of groundwater, the measures to use groundwater effectively have been studied since 2013, and consequently, the “Integrated Agricultural Water Supply System” was designed. Now, this program completed the pilot projects in 2 zones and is under system check.

To examine the program content in detail,

First, the individual water supply system for 905 public wells is adjusted to 37 integrated water supply systems. In addition, it will be analyzed which form of this system will be constructed. The current system is small and independent managed by water use groups so it is difficult to supply water. In addition, the water pressure is low so that it is vulnerable to drought.

On the contrary, the new system will connect the major pipes of existing public wells in close distance with each other to make balances in water supply and increase the efficiency of a water tank with high water pressure.

Second, in order to improve insufficient water supply in each integrated water supply system, well cluster with total 58 holes and 58 large water tank (at least 3,000 m$^3$) will be installed to store water at the middle mountainous area.

Third, the large water tank at one location will connect the pipes with 3~6 existing wells water tank for emergency water supply. In addition, this process will be implemented for all 37 districts.

Fourth, the main pipe of existing wells will be connected with each other in order to respond quickly to the dysfunction of existing public wells due to water depletion, facility failure, and seawater intrusion.

Fifth, “Operation Management System” will be established to observe this “Integrated Water Supply System” at all times and respond quickly to any problem. This automated system is essential for the stable supply and distribution of agricultural water and economic operation and management of facilities. This system is classified into good management, water demand management, observation interpretation and management, facility management and observation monitoring.
8. CLASSIFICATION OF INTEGRATED WATER SUPPLY SYSTEM

There are 3 types in the new system:

First, A-Type (Existing Groundwater Supply Type): It is a zone that does not require new water source development and is easy to integrate water user groups. Construction for this consists of connecting pipes between pressurization device and existing public wells, installation of the large water tank in the middle mountainous zone and connecting new water tank and existing water tank.

Second, B-Type (Combined Water Resources Supply Type): This type mixes groundwater, spring water (artesian) and surface water as the water source.
Extremely few zones will belong to this type. It is only available in the zone where a risk of water quality contamination and artesian well exist.

Third, C-Type (Congregated Groundwater Supply Type): It requires all the processes mentioned in the previous section. However, facility management is relatively easy and the system is most stable. It is proper for the water supply for the middle mountainous areas.

9. CRITERIA FOR SELECTION OF INTEGRATED WATER SUPPLY SYSTEM DRAINAGE AREA

Adjusting 905 existing public wells into 37 integrated water supply system requires the basic principles as follows:

The new system should utilize all water sources including groundwater, artesian well and surface water.

There has to be administrative zoning and the agricultural water use groups should join to form a larger scale unit than at present. In addition, it should consider the balance between water supply and maintenance.

Water resources have to be stable and dependable in order to prepare for climate. It should review current agricultural and irrigation water use.

An accredited public organization should manage the integrated water supply system.

10. CONCLUSIONS

When this program is completed, it will directly prevent drought damage and solve the problem of lack of agricultural water, which in turn leads to the increased agricultural production and increased income among farmers.

For example, the income of 10a for Hanrabong will increase by 120 US$ from 11,950 US$ before program implementation to 12,070 US$ after project completion. And, the water supply farmland among 37,031 ha of target water supply will increase from 28,150ha (water supply rate: 74%) to 33,824ha (water supply rate: 90%). Thus, effective use of agricultural land will be expected.

Besides, expected indirect effects include preservation of groundwater due to enhanced public groundwater control, improved ability to respond to drought because of supply line linkage. It will become model case for the effective use of water resources. And, the end purpose of this program is to move the management and operation system from the water user group for each well to public organization to comprehensively control all wells and increase the efficiency.